Terrestrial carbon loss from degraded peatland in Bengkalis Island, Indonesia

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1. Background

Peatland covered with swamp forest naturally acts as a carbon sink. In 1955, the northern coast of Bengkalis Island was protected by mangrove forest. Typically, it has a function as a natural barrier against coastal erosion. Currently, the condition of this area has been severely eroded. Field observation has revealed that the driving factors of coastal erosion are not only caused by the disappearance of mangrove, but also accelerated by peat failure process which occurred near the coastal cliff. The unique coastal erosion process that occurs in Bengkalis contributes significantly to the carbon loss from terrestrial ecosystem into marine environment. The study site is reflecting the condition of degraded tropical peatland especially caused by exploitation of natural peat swamp forest by human activity.

2. Method

2.1. Study area

Bengkalis Island is located 8 km off the coast of Sumatra along the west side of the Malacca Strait as shown in Fig. 1. The island is almost flat and has maximum surface elevation of approximately 10-15 m. The total land area is roughly 900 km^2, of which more than 70% of its area is covered by peat more than 1 m thick. The research area was focused on the north western section of Bengkalis Island.

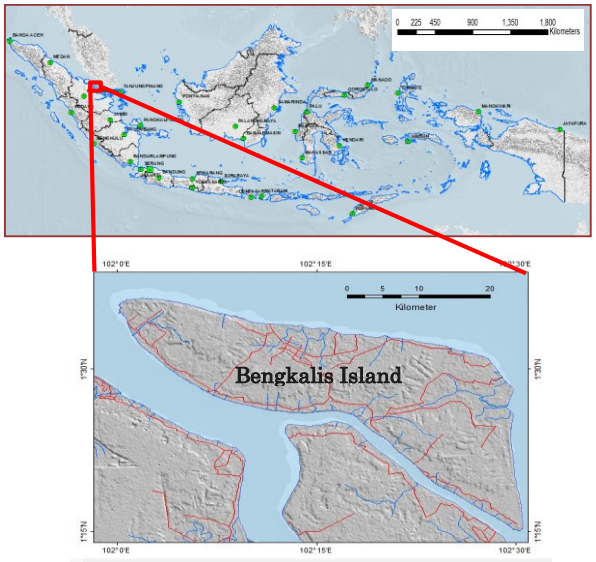

Fig 1. The location of study area

2.2. Coastline extraction

In order to cover the study area with a time series of high-resolution satellite images, altogether 4 satellite scenes from ALOS PRISM sensor and SPOT 6 sensors were used. ALOS PRISM images were recorded on March 24, 2010, and March 27, 2011, while the SPOT 6 images were captured on January 27, 2013, and September 18, 2013. We used SPOT 6 image recorded on September 18, 2013 as a master image for geometric correction. In order to preserve the original pixel value, nearest neighbor was applied for resampling the pixel value following affine method that used to rectify the image. 5 ground control points obtained from in-situ measurement by using static GPS were used for rectifying the master image, producing a RMSE of 0.97 m. The other 3 images were rectified based on master image by employing image to image rectification, producing RMSE less than 1.85 m.

The morphology of the northern coast of Bengkalis is mostly cliff-shaped coastline. Coastlines were drawn at the coastal cliff and mostly associated with vegetation cover. The coastline map derived by different method for each type of satellite data. For SPOT 6 multispectral imagery, we analyzed the NDVI which used as a guideline to digitize the coastline. Meanwhile, the coastline detection from ALOS PRISM panchromatic data is identified by visual interpretation method. The main approach is to distinguish the boundary between vegetation and non-vegetation and also identifying coastal cliff. In order to evaluate the level of severity at various location, 3

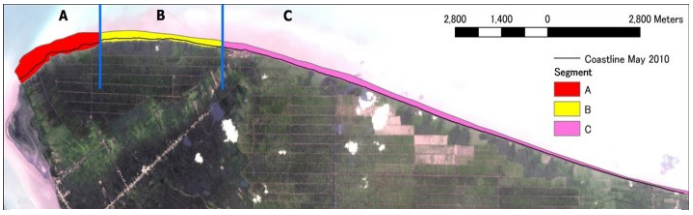

Fig 2. Long term coastline change in 3 segment

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segments were proposed based on coast facing direction as shown in Fig. 2.

2.3. Topographic Map

The height points were extracted on the open area in ASTER DSM. Based on these points we interpolate by using nearest neighbor method to derived topographic map. The topographic transect was measured using RTK GPS to validate the topographic map. The difference between RTK GPS and topographical map is 0.883 meter in average. The topographical and coastline change map are used to calculate the erosion volume V. It was estimated by clipping the area extent of erosion on topographical map and extracting the volume of designated area (red polygon) as shown in Fig. 3.

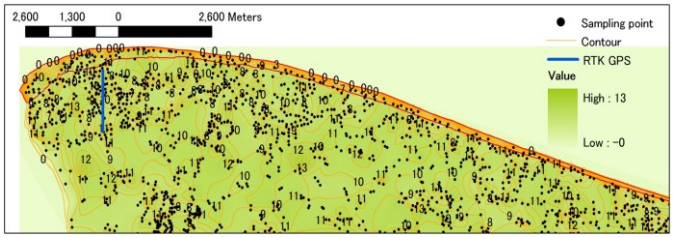

Fig 3. Topographic map derived from ASTER DEM

2.4. Carbon loss

Theoretically, carbon loss M_T is a linear function of erosion volume V, carbon content α and dry density ρ_d and describe by the following equation:

$$M_T = \rho_d \alpha V \quad (1)$$

Dry density and carbon content were analysed from samples which were taken during field survey. Carbon content values were derived indirectly based on the analysis of soil organic matter. Loss on ignition method was used to obtain the value of soil organic matter then subsequently applied Van Bemmelen's factor (0.57) to derive the carbon content.

3. Result and Discussion

Coastal Erosion varies alongside the northern coast of Bengkalis Island, which tends to be less intense on the eastward. Based on the erosion pattern that appeared on high resolution images, we are able to identify a specific feature near the coastline that correspond to peat failure process. These peat failure areas were characterized by the specific feature in the form of multiple concave lines in front of the other. These areas are also associated with the material deposition on the tidal flat that resulted from the failure material. The peat failure process usually occurred locally but it caused a massive setback. The coastal erosion is segmented into three area based on coastline facing direction as shown in Fig. 2. In both short term (2010-2013) and long term (2000-2013) analysis as shown in Table 1, the most intense coastal setback occurred at Segment A where the coastline is facing northwest direction with the annual setback is 54.67 m during 2000 - 2013. While Segment B is facing north direction with annual setback relatively constant during short term and long term period. The vertical distribution of dry density was measured in 3 sample sites and the result is shown in Fig. 4. The profile provides important information about the peat soil properties which strongly affect the value of carbon loss. The result is clearly shown that in the upper layer (< 1 meter depth) the dry density is higher than the value of lower layer (>1 meter depth) because of compaction. The upper layer of eroded volume contribute up to 31 % of carbon loss although it only contributes 18 % from its total volume as shown in table 2.

Table. 1. Erosion rate and set back rate at each segment in 2010 – 2013 (short term) and 2000 – 2013 (long term)

Period	segment	Erosion			
		Area (ha)	Rate (ha/yr)	Set back (m)	Rate (m/yr)
Short term	A	28.377	8.108	98.8	28.23
	B	21.361	6.103	56.84	16.24
	C	45.124	12.892	30.95	8.84
Long term	A	128.3	9.622	728.89	54.67
	B	83.32	6.249	222.35	16.68
	C	214.57	16.093	139.38	10.45

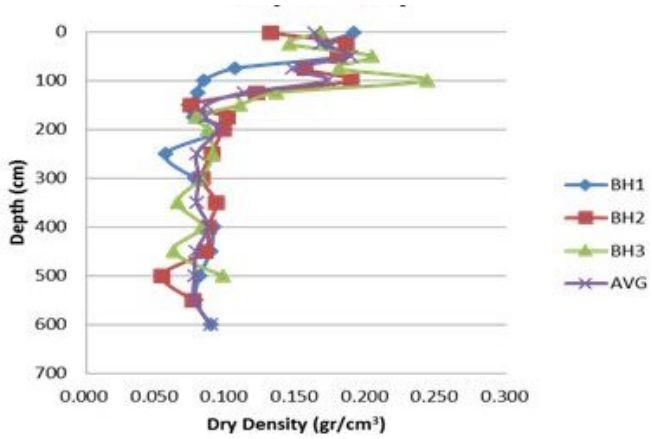

Fig 4. Vertical distribution of dry density in the palm oil plantation in Bengkalis Island

Table. 2. Calculated results of the terrestrial carbon loss

Peat Depth (m)	Volume (Mm^3)	Dry Density (kg/m^3)	Organic carbon (%)	Carbon loss (Mt)
≤ 1	3.38	168	57.63	0.33
> 1	15.1	85	57.63	0.74
Total	18.48			1.07

4. Conclusion

By combining remote sensing data and peat properties, we can obtain useful information about the carbon loss. The main challenge is deriving precise topographic map to calculate erosion volume. Ideally, we should employ detailed topographic map. In the long term period, the results reveal that total erosion extent is 426 ha in the past 13 years between 2000 and 2013, representing peat volume loss of 18.48 x 106 m3 which correspondent to total organic carbon release of 1.07 x 10^6 ton.