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Effect of River Organic Carbon Input in Mangrove Sediment

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Abstract: Mangrove is a coastal ecosystem that absorbs and stores carbon as organic carbon in sediment. The high value of organic carbon in mangrove sediment is influenced by one factor: organic input from the river. This study aims to analyze the effect of the river's total organic carbon (TOC) on TOC stored in mangrove sediment. The samples used were water samples analyzed by the TOC analysis method and sediment samples taken at a depth of 20 cm and analyzed by the combustion method using a C-N analyzer and measuring oceanographic parameters at the research location. The results showed that TOC in the Bakau Kecil River was higher (79 mg/L) compared to TOC in the Bakau Besar River (66.36 mg/L). This is based on the finding of the highest TOC in the Bakau Kecil River mangrove sediment compared to Bakau Besar, with values of 840.14 tons C/ha and 698.86 tons C/ha, respectively. However, regression analysis showed a negative relationship between TOC in mangrove sediment and TOC in waters. If TOC in the river increases, then TOC in sediment tends to decrease. In addition, oceanographic parameters that affect TOC are tides. When TOC rises, TOC is more significant than when TOC recedes.

Keywords: Mangrove; River; Total organic carbon; West Kalimantan

Introduction

Mangrove forests are coastal ecosystems that are very important in maintaining environmental balance in coastal areas (Salahuddin et al., 2024; Runtuboi et al., 2024). Mangroves are important coastal ecosystems in supporting biodiversity, providing ecosystem services, and mitigating climate change (Sedyaaw et al., 2024; Junianto et al., 2023). The mangrove ecosystem in Indonesia is vital in the global carbon cycle because it has an area of 22.6% of the world's mangrove area, or the highest in the world (Giri et al., 2011; Rumanta et al., 2023). One of the main functions of mangroves is as an absorber and storage of carbon in the form of organic carbon in sediments (Cuenca-Ocay, 2024). This ability makes mangroves one of the balancing ecosystems in the global carbon cycle (Anu et al., 2024; Purwanto, 2024). However, the existence of mangroves is also greatly influenced by external organic carbon inputs, including from aquatic ecosystems such as surrounding rivers (Lovelock et al., 2024).

Mangroves are a group of plants that can live in tidal areas (Sadeer & Mahomoodally, 2022; Retnoningsih & Rahayu, 2024). Mangrove environments are often found in river estuaries bordering the sea (Hamzah & Harijati, 2023). Mangroves grow well in coastal areas with large river estuaries and muddy substrates (Yatno et al., 2019; Lismarita et al., 2022). However, in coastal areas without river estuaries, mangrove forest growth is less than optimal (Rifdan et al., 2023). Rivers carry various sources of organic carbon, both natural and anthropogenic, originating from upstream activities such as soil erosion, biomass decomposition, and human activities. The organic carbon input from rivers can interact with mangrove sediments through sedimentation, deposition, and nutrient enrichment processes. The relationship between river organic carbon and organic carbon in

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mangrove sediments is important to understand, especially in tropical areas with high productivity levels.

Several studies have been conducted on the total organic carbon stock of sediment in mangrove ecosystems. Tue et al. (2012) stated mangrove roots can trap more fine sediment from river flow and tidal water in areas with similar tidal current dynamics. In addition, Murdiyarso et al. (2015) revealed that the carbon condition in sediment can also be affected by the ebb and flow of water. A similar study was conducted by Liu et al. (2020), who reported that rivers in mainland China transported around 9.63 TgC of organic carbon from rivers to coastal areas.

Mempawah District, especially Bakau Besar and Bakau Kecil Villages, has a strategic mangrove ecosystem and great potential to support organic carbon storage. However, information on the interaction of organic carbon from rivers with mangrove sediments in this area is still minimal. Related research tends to focus on the biological aspects of mangroves. In contrast, studies on the dynamic relationship between river organic carbon and mangrove sediment organic carbon are rare, especially in West Kalimantan.

This study aims to fill this gap by analyzing the effect of river-borne organic carbon on organic carbon stored in mangrove sediments. This study will reveal how river carbon input affects carbon storage in mangroves and how these dynamics may differ based on location characteristics, such as Bakau Besar and Bakau Kecil Villages. The findings of this study are expected to provide new insights for sustainable management of mangrove ecosystems, especially in the context of climate change mitigation and coastal ecosystem conservation.

Method

Study Sites

This research was conducted in Bakau Besar and Bakau Kecil Villages, Mempawah Regency, West Kalimantan, as seen in Figure 1. Bakau Besar Village (Location 1) and Bakau Kecil (Location 2) were divided into 4 research stations. The division includes 2 research stations in Bakau Besar Village (St 1 and St 2) and 2 research stations in Bakau Kecil Village (St 3 and St 4). Both locations are natural mangrove areas. At the research location, a river is located in the middle, separating St. 1 and St. 2 in Bakau Besar Village and St. 3 and St. 4 in Bakau Kecil Village. This river is part of the Kapuas River, West Kalimantan.

Sampling and Oceanographic Parameter

Data collection involved measuring physical parameters, water quality, and mangrove density, along with sampling river water and sediment. Physical measurements included currents, wave height, discharge, and tides, with tide data sourced from BIG's predictions and currents measured using the current kite method. Mangrove observations were conducted at low tide, and density, species, and individual counts were assessed following the CIFOR protocol at each research station. Sampling at both places was carried out with three repetitions.

Sediment sampling was carried out using polyvinyl chloride (PVC) pipes placed in the centre of the circle plot points. The sediment samples were taken at a depth of 20 cm because this layer captures the primary layer where organic carbon accumulates and is affected by the sediment transport process driven by the tides (Alongi, 2012). After the sediment was taken, the sediment was wrapped using alumunium foil and plastic clips and then put into a cool box with a temperature of 4 °C during the trip to the laboratory to maintain the quality and integrity of the sample.

Water sampling was carried out in the river on the surface layer during high and low tide, with 1 sampling at high tide and 1 water sampling at low tide. 500 ml of water was taken using a sample bottle. Furthermore, the water was filtered using a vacuum pump and a GF/F filter with a pore size of 0.7 µm and a diameter of 47 mm. Before use, the filter was burned for 3 hours at a temperature of 400 °C to ensure cleanliness (Parsons et al., 1984). After filtration, the filter was wrapped in aluminum foil and plastic clips and then stored in a cool box filled with blue ice to maintain sample quality (Nuraya et al., 2019).

Laboratory Analysis

Laboratory analysis was conducted to measure the parameters of sediment organic carbon and organic carbon contained in water samples. Sediment organic carbon was measured using the combustion method at a temperature of 900 °C using a C-N analyzer (Kauffman & Donato, 2012), while organic carbon contained in water was measured using the TOC analysis method. For the sediment fraction, analysis was carried out using the pipette method, plotted, and classified according to the Wentworth standard.

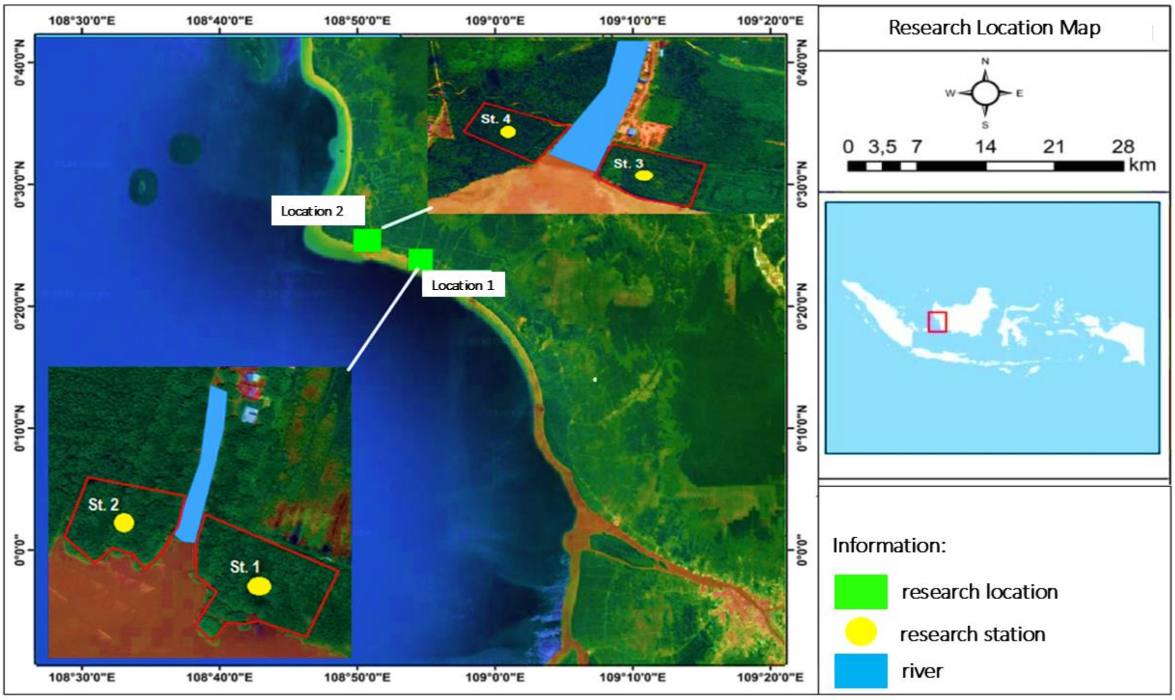

Figure 1. Research location map

Current Velocity

Current measurements are carried out using the drifting buoy method during tidal conditions. Drifting buoys are released into rivers, and the movement of buoys left to follow the current is tracked. Current speed calculations were performed using the following equation (equation 1) :

$$v = \frac{s}{t} \quad (1)$$

where:

v = current speed (m/s)
s = length of rope (m)
t = the time it takes for the rope to become taut (s).

Organic Carbon Stock

The sediment organic carbon stock calculation is the amount of organic content found at each sediment depth, calculated using equation 2 (Kauffman et al., 2011) :

$$OC_S = BD \times C \times D \quad (2)$$

where:

BD = bulk density (gram/cm^3)
C = percentage of organic carbon produced from the laboratory (%)
D = sediment depth interval (cm).

The research flow can be seen in flowchart shown in Figure 2.

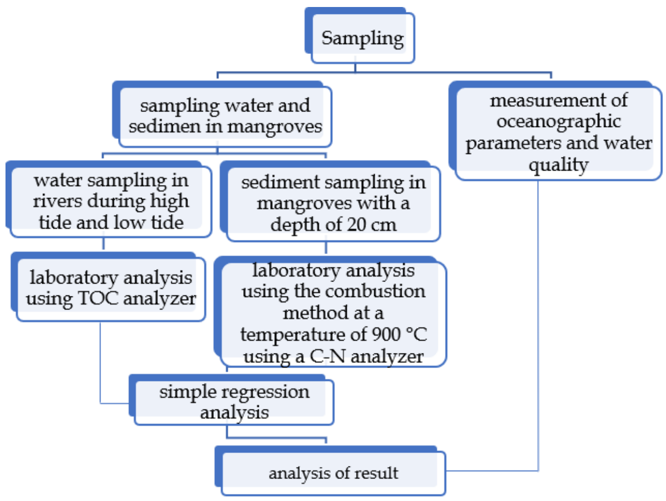

Figure 2. research flowchart

Result and Discussion

Water Quality Condition

The condition of water quality is measured through physical and chemical parameters to see the quality of the water and whether the water quality is good or bad. The parameters measured are temperature, salinity, pH, current, brightness, TDS (Total Dissolved Solid), and tides. Parameter measurements occur in river around the mangroves during high and low tide conditions. The acquisition of high and low tide data is taken from BIG (Geospatial Information Agency) data, where the high and low tide conditions can be seen in Figure 3.

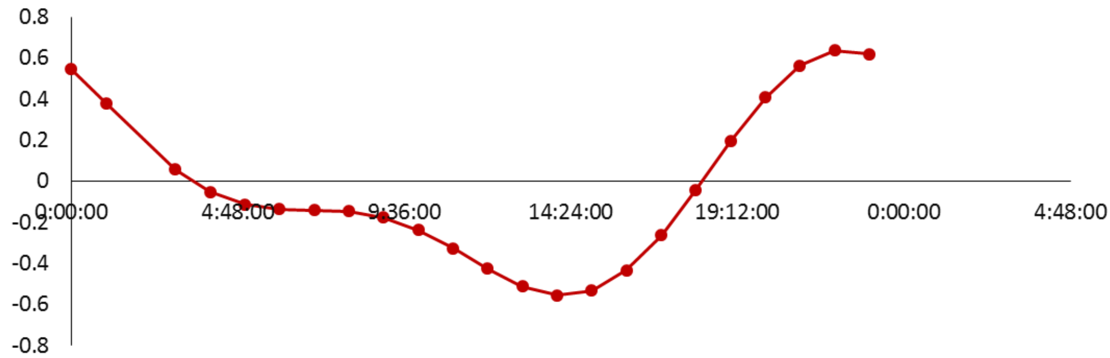

Figure 3. Tide condition at the research location from BIG data

Based on observations in Figure 3, the low tide at around 14.00 WIB, followed by high tide conditions that begin to occur at 19.00 WIB. The type of tides at the research location is diurnal, where the peak of high and low tides occur only once a day. This is in line with research conducted by Nuriman (2015). Therefore, measurements of physical and chemical parameters and water sampling are carried out by adjusting to high and low tide conditions. This is important because the content of material carried from the sea to the river differs between high and low tide.

Table 1 shows the parameters observed at each research location, including temperature, salinity, pH, current, TDS, and brightness. The values at each location were different during high and low tide conditions.

The water temperature in the river at both locations ranged from 28.5 - 32.5 °C. During low tide, the highest temperature was found at the Bakau Besar location. This is because the sampling was conducted towards noon when the weather conditions were very bright. The water temperature increases in the morning because solar radiation begins to heat the surface layer of the water. Bright weather conditions accelerate energy absorption, so the water temperature rises faster (Davis & Fitzgerald, 2004). High tide conditions are carried out in the afternoon towards night when the water temperature decreases because solar radiation is significantly reduced, and the environment begins to release stored heat into the atmosphere.

For salinity parameters, the location of Bakau Besar differs during low and high tide conditions. During high tide conditions, both the river mouth and the river body are included in the salinity category of 20 - 25 PSU compared to low tide with a salinity value of 0, or it can be interpreted that the river water is classified as fresh at low tide. This is because the river experiences greater mixing (due to the influence of rock weathering sources and soil erosion), while the salinity conditions are higher during high tide. It is suspected that water from the sea, classified as high salinity, is entering and flowing into the river (Lotfinasabasl et al., 2018). Differences in salinity can affect the carbon value contained in these waters. High salinity can indicate a decrease in carbon.

The pH value ranges from 5.7 to 7.6; these results are based on research conducted by Eddiwan & Hendrizal (2024), who found pH results of 6.1 to 6.8, stating that this value still supports the growth of mangrove trees. The pH value tends to be lower at low than high tide. At low tide, the pH at both locations is lower because it is dominated by river water rich in organic matter from the mainland, which can produce organic acids. Conversely, seawater that enters at high tide has a higher pH because of its alkaline mineral content (Carpenter & Capone, 2008).

Current and TDS parameters also show variations. The current value is higher at low tide in Bakau Kecil (0.7 m/s) than at high tide (0.4 m/s), which may be caused by the dominant water movement out of the river. The TDS value is higher at low tide conditions in Bakau Kecil, which indicates a greater concentration of dissolved material from land. In contrast, TDS is lower at high tide conditions due to seawater mixing. Water clarity is higher at low tide in Mangrove Kecil (17.5 cm), caused by greater shallowness and sedimentation at high tide.

Sediment Type

The types of sediments found at the research site can be seen in Figure 4. The types of sediments obtained consisted of 3 types: sand, silt, and clay. The results of sediment type analysis at the research location showed that silt sediment dominated the composition at the four research stations (St. 1 to St. 4), with a percentage of 80 - 92%. In contrast, clay sediment ranged from 8 - 19%. Silt sediment types dominate mangrove forests and, together with clay sediment types, contribute 95% of the particles on the surface of mangrove sediments (Lotfinasabasl et al., 2018). The high silt content is caused by mangrove roots, which can store more sediment particles in the sediment (Banerjee et al., 2018).

Table 1. Physical and chemical parameter data

Location	condition	temperature (°C)	salinity (PSU)	pH	current (m/s)	TDS (mg/l)	brightness (cm)
Bakau *Kecil*	low tide	29	0	5.70	0.70	766	17.50
	high tide	28.50	0	5.91	0.40	716	11
Bakau *Besar*	low tide	32.50	0	6.32	0.10	286	10.75
	high tide	28.80	25	7.60	0.40	340	15

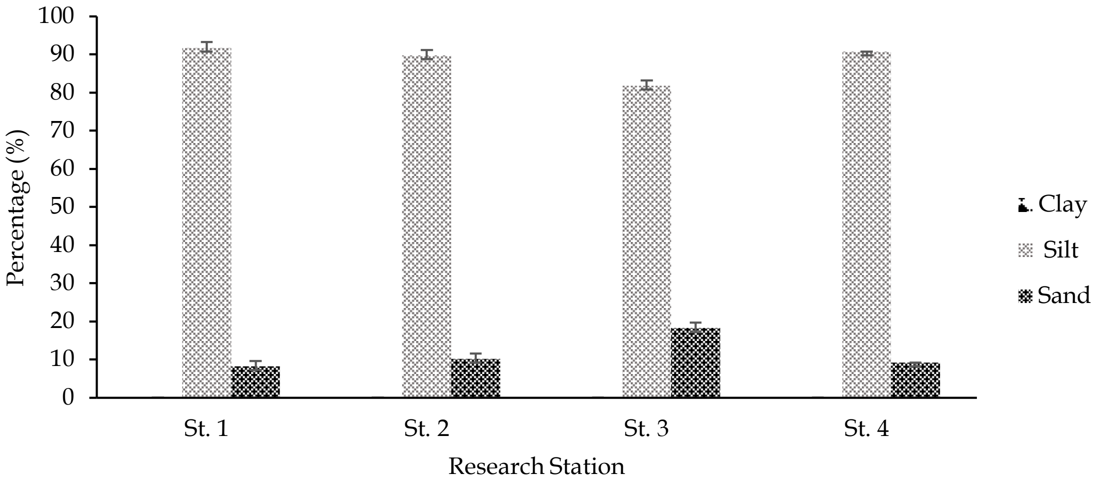

Figure 4. Sediment type

The dominance of silt at all stations indicates that the study area is in an environment with low hydrodynamic energy, such as estuaries, lagoons, or protected waters. Silt sediments tend to settle in areas with calm water flow, where fine particles can be distributed and deposited dominantly. This finding is consistent with previous studies, which state that sediment distribution is greatly influenced by current dynamics, sediment supply, and local environmental geomorphology (Hakim et al., 2015; Soesilo, 2017).

The results show that the location of Bakau Kecil at Station 4 has the highest silt sediment type compared to large mangroves, while clay sediment types in Bakau Besar area are less than in Bakau Kecil location. This difference can cause differences in sediment carbon values. This is because the smaller the size of the sediment, the greater the carbon contained in the sediment. Small-sized sediment types have more organic carbon values (Cameron et al., 2019).

Stock Organic Carbon Sediment Mangrove

Total sediment carbon is stored in sediment (Indriani et al., 2017). Total carbon in sediment comes from fallen mangrove litter and river flow (Kusumaningtyas et al., 2019). The study results showed that the total organic carbon in sediment at both research locations ranged from 510 - 840.13 tons C/ha. The location of Bakau Besar was the highest at St. 2 which is 840.14 tons C/ha, while for the Bakau Kecil location, the highest organic carbon stock is at St. 4, which is 698.86 tons C/ha (see Figure 5). Furthermore, the lowest organic carbon stock in sediment was at St. 3, at the Small Mangrove location at 660.2 tons C/ha. This is thought to be caused by the station's location and the type and size of sediment grains that dominate. The type of sediment that dominates at the research location (Figure 4) is the type of silt and clay sediment, which is the smallest in size (<0.004 mm). Small sediment types have higher organic carbon values (Cameron et al., 2019). Sediment texture greatly affects carbon storage capacity. For example, St. 2, dominated by fine sediment (silt and clay), can absorb organic carbon due to its larger surface area. Conversely, locations with low carbon stocks, such as St. 3, likely have a dominant proportion of sand, which is less efficient in storing organic carbon.

The interaction between these factors explains the differences in organic carbon stocks at each location. St. 2, which shows the highest carbon stock, most likely has environmental conditions more conducive to carbon accumulation in terms of hydrodynamics, sediment texture, and chemical parameters. In contrast, St. 3, with the lowest carbon stock, reflects the influence of a combination of oceanographic factors (strong currents) and physical parameters (dominant sand) less conducive to carbon accumulation.

These results support the findings of several previous studies, which state that sediment organic carbon stocks are highly dependent on a combination of sediment texture factors, organic inputs, oceanographic dynamics, and environmental physical-chemical conditions (Kristensen et al., 2008; Donato et al., 2011; Alongi, 2012). The research results are similar to those of previous studies. This study obtained a value of 620.9 tons of C/ha for the Kubu Raya area of West Kalimantan (Murdiyarso et al., 2015). The total flow of organic carbon comes from many sources, one of which is input from rivers (David et al., 2018).

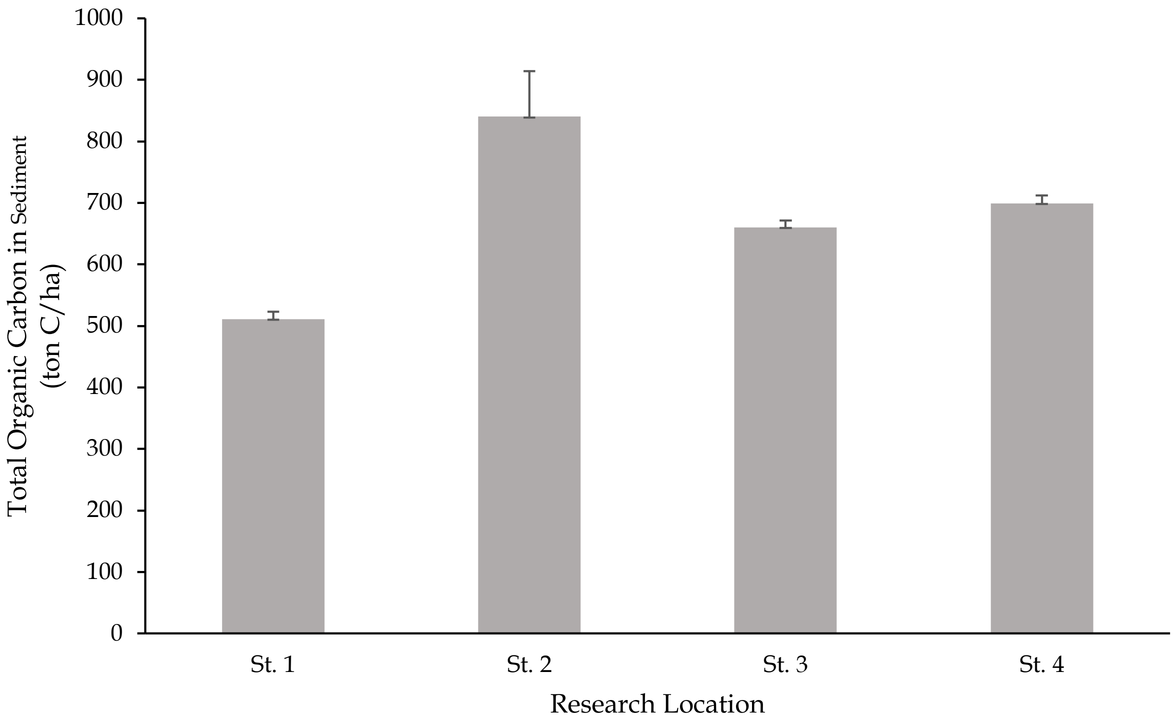

Figure 5. Total organic carbon in sediment (ton C/ha)

Effect of river organic carbon input

Total organic carbon is the amount of carbon in a dissolved form bound in water. The total organic carbon in this study was taken at high and low tide, where water samples were taken near the mangrove forest, which was the study's sample. The results of the research on total organic carbon in the river can be seen in Table 2. The results show that the total organic carbon in the Bakau Kecil River is greater than in the Bakau Besar River during high and low tide conditions. At high tide, the total organic carbon in the Bakau Kecil River is 79 mg/L, while the Bakau Besar River is 66.36 mg/L. At low tide, the total organic carbon in Bakau Kecil River is 18.96 mg/L, while in Bakau Besar River, it is 20.54 mg/L. This is because, there are more residential areas in the Bakau Kecil Rivers, while the Bakau Besar Rivers are a bit far from residential areas. When the tide is high, the water flowing from the sea meets the river water discharge, causing mixing around the river mouth. The type of mixing at the research location is perfect because the river water discharge is relatively tiny. With ideal mixing, the organic carbon material carried by the river becomes trapped and accumulates around the estuary, especially during high tide compared to low tide. According to Triatmodjo (2012), at low tide, the material is pushed into the river and spreads into the sea, which can cause a decrease in the load in the river.

Oceanography parameters influences, such as tidal currents, are significant in determining the distribution of organic carbon in mangrove ecosystems. Research by Murdiyarso et al. (2015) showed that organic input from rivers and tidal dynamics greatly influence carbon in mangrove sediments. Thus, variations in TOC between locations and times (low and high tides) can affect the carbon storage capacity of mangrove ecosystems (Yuwono & Qhomariyah, 2016).

Table 2: Total organic Carbon in river

Location	Low tide (mg/L)	High tide (mg/L)
River in Bakau Besar	18.96	66.36
River in Bakau Kecil	20.54	79.00

Relationship between TOC in mangrove sediment with TOC in rivers at high tide and low tide in Figure 6. The results of simple regression analysis showed a negative relationship between TOC in rivers and TOC in mangrove sediments, with a determination coefficient of R^2 = 0.85 in Bakau Besar. Meanwhile, Bakau Kecil also showed negative results, with a determination coefficient of R^2 = 0.5. This indicates that the increase in TOC in rivers is inversely proportional to the TOC content in mangrove sediments, which may be caused by dilution or sedimentation processes. Similar research by Hickmah et al. (2021) found that organic carbon storage in mangrove sediments is influenced by factors such as sediment grain size and proximity to water flow, which affect the distribution and accumulation of organic matter in the ecosystem.

Estimated carbon exports entering the area around mangrove forests come from rivers (Ho et al., 2014). Mangroves near rivers are the most extensive and developed mangroves. The carbon budget in rivers contributes to mangrove forests, one of the most carbon in the world (Adame et al., 2015).

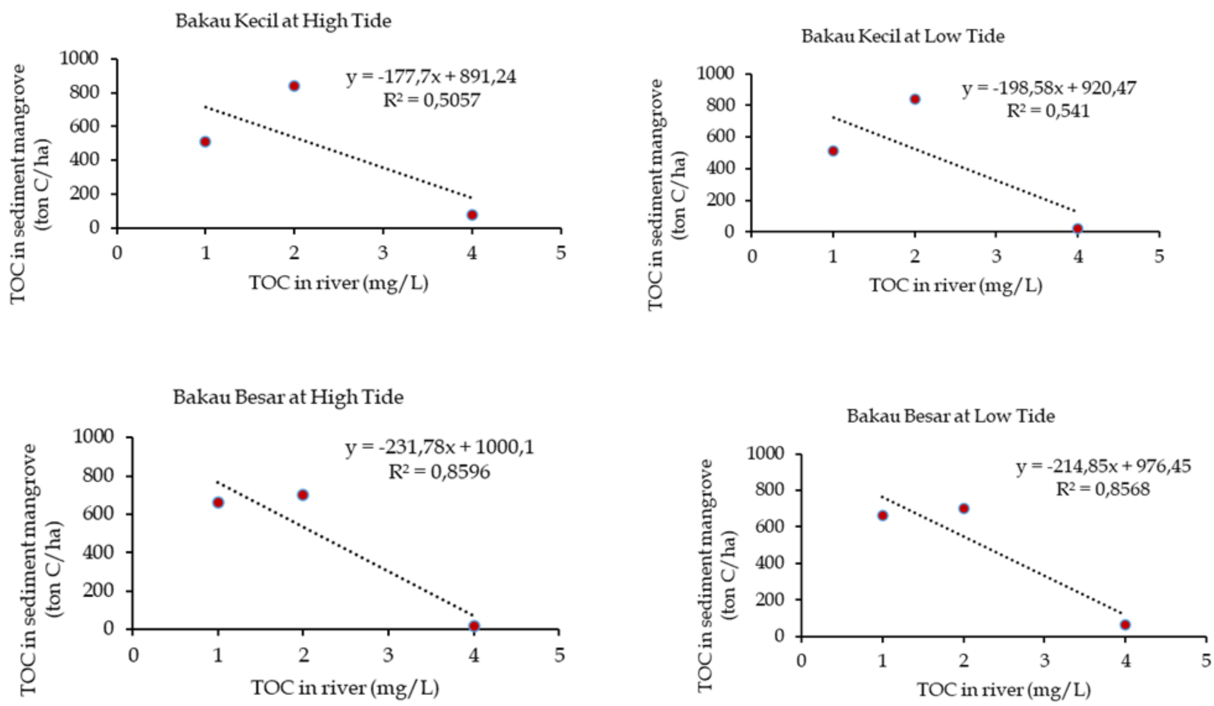

Figure 6. Relationship between TOC in water and TOC in mangrove sediment

Conclusion

The study results showed a negative relationship between total organic carbon (TOC) in the river and TOC in mangrove sediments. This is indicated by the coefficient of determination R^2 = 0.85 in Bakau Besar and R^2 = 0.5 in the Bakau Kecil. Thus, the increase in TOC in the river is inversely proportional to the TOC content in the mangrove sediment. In addition, oceanographic parameters, such as tides, also affect TOC levels in both locations. Tidal conditions play a role in carrying organic material from land to rivers, affecting the distribution of TOC in the mangrove ecosystem.

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Author Contributions

Conceptualization, T. N.; methodology, T. N..; software, T.N.; validation, T. N.; formal analysis, T. N.; investigation, L. P. I. A.; resources, T.N.; data curation, T.N.; writing—original draft preparation, T.N.; writing—review and editing, L. P. I. A.;

visualization, L. P. I. A.; supervision, L. P. I. A.; project administration, L. P. I. A.; funding acquisition, T.N. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The author declares that no conflicts of interest or personal relationships could have influenced the work presented in this article.

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