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The Relationship between Total Oil Content in Sediment and the Abundance of Benthic Diatoms in the Waters of Pangkalan Jambi, Bengkalis, Riau

Hubungan Antara Kandungan Total Minyak di Sedimen dengan Melimpahnya Diatom Benttik di Perairan Pangkalan Jambi, Bengkalis, Riau

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Abstract

The research was conducted in December 2025 in the waters of Pangkalan Jambi. The purpose of this research was to analyze the total oil content in sediments, calculate the abundance of benthic diatoms, and explain the relationship between the total oil content in sediment and the abundance of benthic diatoms. The research uses a survey method; three sampling stations with three replications in each station were surveyed. The results showed that the average oil concentration in sediments exceeded the thresholds set by the Department of Water Resources Quality Assurance/Quality Control Program and the Australian and New Zealand Environment and Conservation Council. The results of the calculation of the abundance of benthic diatoms ranged from 2196.14 ind/cm2 to 3362.84 ind/cm^2. The highest abundance is around small ports, while the lowest abundance is around the river mouth. Based on simple linear regression, the relationship between sediment oil content and benthic diatom abundance was y = 8281.7 – 1.1367x, with a coefficient of determination (R^2)= 0.875 and a correlation coefficient (r) = 0.935. The value of r states a moderate relationship with a constant value b, which is negative, indicating that the higher the oil content, the lower the abundance of benthic diatoms in sediments.

Keywords: Pangkalan Jambi Village, Oil, Sediment, Benthic Diatom

Abstrak

Penelitian dilakukan pada Desember 2025 di perairan Pangkalan Jambi. Tujuan dari penelitian ini adalah untuk menganalisis kandungan minyak total dalam sedimen, menghitung kelimpahan diatom bentik, dan menjelaskan hubungan antara kandungan minyak total dalam sedimen dengan kelimpahan diatom bentik. Penelitian menggunakan metode survei; Tiga stasiun pengambilan sampel dengan tiga replikasi di setiap stasiun disurvei. Hasil penelitian menunjukkan bahwa konsentrasi minyak rata-rata dalam sedimen melebihi ambang batas yang ditetapkan oleh Program Jaminan Mutu / Kontrol Kualitas Departemen Sumber Daya Air dan Dewan Lingkungan dan Konservasi Australia dan Selandia Baru. Hasil perhitungan kelimpahan diatom bentik berkisar antara 2196,14 ind/cm2 hingga 3362,84 ind/cm^2. Kelimpahan tertinggi ada di sekitar pelabuhan kecil, sedangkan kelimpahan terendah berada di sekitar muara sungai. Berdasarkan regresi linier sederhana, hubungan antara kandungan minyak dalam sedimen dengan kelimpahan diatom bentik adalah y = 8281,7 – 1,1367x, dengan koefisien penentuan (R^2) = 0,875 dan nilai koefisien korelasi (r) = 0,935. Nilai r menyatakan

hubungan moderat dengan nilai konstan b, yang negatif, menunjukkan bahwa semakin tinggi kandungan minyak, semakin rendah kelimpahan diatom bentik dalam sedimen.

Kata kunci: Desa Pangkalan Jambi, Minyak, Sedimen, Diatom Bentik

1. Introduction

Marine pollution is a major environmental issue currently faced and is often associated with anthropogenic activities. The rising level of marine pollution may be attributed to a lack of public awareness and stakeholder concern about the importance of preserving marine ecosystems. Oil pollution is one of the most common forms of marine pollution and may occur either intentionally or unintentionally. Oil spills can significantly disrupt aquatic ecosystems and may lead to the mortality of marine organisms. The incidence of oil pollution in Indonesian waters continues to increase annually due to rising oil demand for industrial activities and the rapid expansion of maritime transportation (Supriyo & Rusito, 2022).

One of the phytoplankton groups commonly found in marine waters is diatoms (*Bacillariophyceae*). Diatoms contribute approximately 25% of global photosynthetic activity and account for 40–45% of marine primary productivity, making them more productive than all tropical rainforests worldwide combined. Based on their habitat, diatoms can be classified into planktonic diatoms, which live suspended in the water column, and benthic diatoms, which attach to specific substrates (Nugroho, 2019). Benthic diatoms are diatoms that attach to substrates, including sediments, and can provide information on changes in aquatic environmental conditions because their habitats are relatively sessile and sensitive to both physical and chemical changes. Therefore, benthic diatoms are widely used as bioindicators of aquatic ecosystems. In addition, the relatively short life cycle of benthic diatoms enables them to respond rapidly to marine pollution, which may alter their diversity and abundance (Rahman et al., 2022).

Pangkalan Jambi Village is a coastal area in Bukit Batu District, Bengkalis Regency, directly adjacent to the Bengkalis Strait, leading to intensive anthropogenic activities in the surrounding waters. Shipping activities and residential settlements that generate domestic waste potentially contribute to oil pollution in these waters. Oil continuously entering the aquatic environment may accumulate in sediments, disrupting benthic organisms and thereby affecting aquatic productivity and potentially reducing fishermen's income (Purwanto et al., 2020). Information on pollution in Pangkalan Jambi Village remains limited, particularly regarding oil pollution in sediment influenced by residential and shipping activities. Therefore, this study is important as a reference for monitoring aquatic environmental quality by examining the relationship between total oil content in sediments and the abundance of benthic diatoms in Pangkalan Jambi Village, Bengkalis Regency, Riau Province.

2. Material and Method

2.1. Time and Place

This study was conducted in December 2025 in the waters of Pangkalan Jambi, Bengkalis Regency, Riau Province, Indonesia. The analysis of total oil content in sediments was carried out at the Marine Chemistry Laboratory. In contrast, the analysis of benthic diatom abundance was conducted at the Marine Biology Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Riau, Pekanbaru, Riau Province.

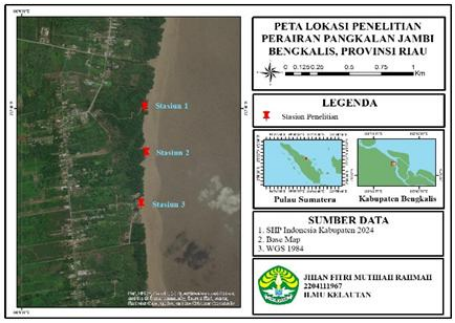

Figure 1. Map of research stations

2.2. Methods

This study employed a survey method to collect primary data through direct field observations. Sampling stations were determined using a purposive sampling method, with sampling locations situated in the waters of Pangkalan Jambi, Bengkalis Regency, Riau Province, Indonesia. Three sampling stations were established, each

consisting of three sampling points. Station 1 was located in the estuarine area, Station 2 in the mangrove area, and Station 3 in the small harbor area.

2.3. Procedures

2.3.1. Oil Sample Analysis

Sediment samples were collected during the lowest tide using a core sampler. Surface sediments were collected, weighed, and placed into labelled plastic bags, with 500 g collected from each sampling point. Subsequently, 100 g of each sediment sample was subsampled for analysis of total oil content. The procedure for analyzing oil content in sediments was performed using the Soxhlet method (AOAC, 2005), with the following calculation formula:

$$\text{Oil Content (mg/kg)} = \frac{(B - A)\ \text{mg}}{\text{Sample Weight (kg)}} \text{ x } 100\%$$

Description: A= Weight of the empty round-bottom flask (mg); B =Weight of the round-bottom flask and extracted oil (mg)

2.3.2. Benthic Diatom Abundance Analysis

Benthic diatom samples were collected from the upper 1 cm layer of sediment using a core sampler with a diameter of 4 inches (10.16 cm) and a length of 10 cm (surface area of 81.03 cm²). The samples were then rinsed with distilled water and filtered through a 25 µm mesh sieve to separate sediment particles from benthic diatoms. The filtered samples were transferred into labelled sample bottles and preserved with 4% Lugol's solution. Subsequently, the sample bottles were stored in an ice box and transported to the laboratory for further analysis. In addition, water quality parameters were measured at the same location, including temperature, pH, salinity, water transparency, current speed, and organic matter content.

Diatom samples were observed using an Olympus CX21 microscope at a magnification of 10 × 10, with identification based on the taxonomic references of Purwanto et al. (2020). The abundance of benthic diatoms was determined using the field-of-view method: the diatom samples collected in the field were first homogenized to ensure diatoms were evenly distributed and had an equal probability of being observed. The abundance of benthic diatoms was calculated using a modified Lackey microtransecting method (APHA, 1995):

$$N = \frac{3Oi}{Op} x \frac{Vr}{3Vo} x \frac{1}{A} x \frac{n}{3p}$$

Descriptions:

N	= Number of diatoms per unit area (Ind/cm²)	Vo	= Volume of 1 drop of sample (0.05 ml)
Oi	= area of the cover glass (484 mm²)	A	= Area of the core sampler (81.03 cm²)
Op	= area of the field of view (1,306 mm²)	n	= Number of diatoms collected
Vr	= Volume of solution in the sample bottle (100 ml)	p	= Number of fields of view (12)

2.4. Data Analysis

Differences in oil content and benthic diatom abundance among stations were analyzed using a *One-Way* ANOVA. Furthermore, the relationship between oil content in sediments and benthic diatom abundance was analyzed using simple linear regression.

3. Result and Discussion

3.1. Water Quality

Pangkalan Jambi Village is located in Bukit Batu District, Bengkalis Regency, Riau Province, Indonesia, directly adjacent to the Bengkalis Strait. The village covers approximately 10 km² and is characterized by relatively flat topography, with elevations ranging from 2 to 6 m above sea level. Geographically, the area is located at 01°17′26.8″ LU and 102°08′42.5″ BT. Dompas border the village to the north, Tanjung Belit Village to the south, Bandar Jaya Village to the west, and the Bengkalis Strait to the east (BPS, 2025). The waters surrounding this village are part of a complex estuarine ecosystem that receives freshwater from major rivers and saline water from the sea, making the environment highly productive and nutrient-rich. In addition, these waters serve as a shipping route and are bordered by densely populated residential areas, where various anthropogenic activities may affect the aquatic environment of Pangkalan Jambi Village (Rianti et al., 2025).

The water quality parameters measured in this study included temperature, pH, salinity, water transparency, current speed, and organic matter content. These measurements were taken at each station. The results of water quality measurements showed temperatures ranging from 25 to 28 °C, pH values between 6.76 and 6.87, salinity between 15 and 16 ppt, water transparency between 30 and 35 cm, current speed between 0.16 and 0.26 m/s, and organic matter content between 5.52 and 9.89%.

Table 1. Results of water quality parameters

Parameter	Unit	Stations		
		1	2	3
Temperature	°C	26	28	25
pH	-	6,87	6,76	6,79
Salinity	‰	16	15	15
Water Transparency	cm	30	30	35
Current Speed	m/det	0,16	0,26	0,19
Organic matter	%	5,52	9,89	8,97

3.2. Oil Content in Sediments

The average oil content in the sediments in these waters ranges from 4304.761 to 5335.516 ppm. For more details, see Table 2.

Table 2. Oil content in sediments (ppm)

Station	Sampling Points	Oil in Sediment	Average ± Std Dev
1	1	5309.116	5335.516 ± 27.40792
	2	5363.832	
	3	5333.600	
2	1	4802.556	4790.993 ± 40.73222
	2	4824.693	
	3	4745.729	
3	1	4366.050	4304.761 ± 60.48254
	2	4245.118	
	3	4303.115	
Average total oil content			**4810.423**

The average oil content in sediments from the waters of Pangkalan Jambi, Bengkalis Regency, Riau Province, exceeded the threshold limits established by the Department of Water Resources Quality Assurance/Quality Control Program (1995) (>2,000 ppm) and the Australian and New Zealand Environment and Conservation Council (ANZECC) (>550 ppm). Therefore, Stations 1, 2, and 3 can be classified as heavily polluted, potentially threatening the survival of benthic organisms inhabiting the sediment. The average oil content in sediments at Station 1 was 5335.516 ppm. This station is located in the estuarine area at the outer boundary of Pangkalan Jambi Village, adjacent to Dompas. The surrounding area is characterized by mangrove forests and is located near residential settlements and the Pertamina RU II Sei Pakning refinery. The presence of oil in this area is suspected to originate from shipping activities, oil waste from the Pertamina RU II Sei Pakning refinery dispersed by water currents, and anthropogenic activities such as direct domestic waste disposal into the sea by local communities.

According to Wulandari et al. (2019), estuarine areas function as accumulation zones for particles and contaminants transported by river flow and land-based anthropogenic activities. Reduced current velocity in estuarine waters facilitates the deposition and accumulation of fine sediment particles carrying petroleum hydrocarbons on bottom sediments, particularly in areas close to land-based waste inputs, industrial activities, and marine transportation routes.

Station 2 had an average oil content of 4790.993 ppm. This station is located within a mangrove area still influenced by estuarine conditions and receives oil contaminants originating from industrial activities and from domestic waste discharged along the river. Mangroves are complex and dynamic ecosystems where hydrophobic and persistent contaminants, such as oil, can persist in sediments for extended periods. Accelerated urbanization and industrialization surrounding mangrove habitats increase the vulnerability of these ecosystems to oil contamination, potentially significantly affecting productive coastal ecosystems (Almeida et al., 2021).

Station 3 was located in a small harbor area and had an average oil content of 4304.761 ppm, making it the station with the lowest average oil content among all stations. The relatively low oil content in this area was presumably associated with lower shipping activity intensity and smaller harbor size, resulting in a lower potential for oil spills or discharges into the waters and a limited contribution to oil accumulation in the sediments. Fishing activities, such as loading and unloading catches and using fuel for small fishing vessels, still contributed to oil in the waters, although in relatively small amounts. Consequently, these activities did not lead to a significant increase in oil concentration in this area. Pulungan & Badrun (2023) reported that oil content in coastal sediments may vary depending on the intensity of shipping activities and the characteristics of the aquatic environment. Areas with lower shipping activity generally exhibit lower oil concentrations than those affected by river runoff or intensive industrial activity.

3.3. Identification and Abundance of Benthic Diatoms

The benthic diatom species found in the waters of Pangkalan Jambi, Bengkalis Regency, Riau Province, varied among stations (Table 3). Based on Table 3, a total of 21 benthic diatom species were identified. The highest number of species was recorded at Station 3 with 18 species, while the lowest number was recorded at Station 1 with 11 species. The abundance of benthic diatoms in the waters of Pangkalan Jambi is presented in Table 4

Table 3. Benthic diatom species identified

No	Spesies	Station		
		1	2	3
1.	*Navicula* sp.	+	+	+
2.	*Nitzchia* sp.	+	+	+
3.	*Pinnularia* sp.	+	+	+
4.	*Amphora* sp.	+	+	+
5.	*Fragilaria* sp.	+	+	-
6.	*Isthmia* sp.	+	+	+
7.	*Gomphonema* sp.	+	-	+
8.	*Gyrosigma* sp.	+	-	+
9.	*Leptocylindrus* sp.	+	+	+
10.	*Rhizosolenia* sp.	+	+	+
11.	*Guinardia* sp.	+	-	+
12.	*Coconeis* sp.	-	+	+
13.	*Synedra* sp.	-	+	+
14.	*Cymbella* sp.	-	-	+
15.	*Ceratium* sp.	-	+	+
16.	*Pleurosigma* sp.	-	+	+
17.	*Surirella* sp.	-	-	+
18.	*Oscillatoria* sp.	-	+	+
19.	*Caloneis* sp.	-	+	-
20.	*Striatella* sp.	-	+	+
21.	*Achnanthe* sp.	-	+	-
Total		11	16	18

Notes : (+) detected, (-) not detected

Table 4. Average abundance of benthic diatoms

Stasiun	Sampling Points	Abundance of Benthic Diatoms	Average ± Std Dev
1	1	2264.77	2196.14 ± 314.5022
	2	2470.66	
	3	1852.99	
2	1	2676.54	2882.43 ± 205.8900
	2	2882.43	
	3	3088.32	
3	1	3294.21	3362.84 ± 118.8706
	2	3500.1	
	3	3294.21	

The abundance of organisms in aquatic environments can be expressed as the number of individuals per unit area. The abundance of benthic diatoms varied among stations, presumably influenced by differences in environmental conditions at each station. More stable aquatic environments generally support higher species diversity (Sitindoan et al., 2020). The highest average abundance of benthic diatoms was recorded at Station 3, located in a small harbor area with a sandy mud substrate, with a value of 3362.84 ind/cm². This condition was presumably associated with environmental characteristics more favourable for diatom growth, including muddy sediments with relatively high organic matter content and nutrient availability, which could support benthic diatom growth. This finding is consistent with the study of Rusmiati et al. (2021), which reported that muddy substrates generally contain higher concentrations of organic matter and tend to accumulate organic materials, making them more suitable as nutrient sources for benthic diatoms. In addition, this station had the lowest oil content among all stations, resulting in lower environmental pressure from oil pollution on benthic diatom abundance.

The lowest abundance of benthic diatoms was recorded at Station 1, located in the estuarine area, with an average value of 2196.14 ind/cm². This condition was presumably related to the dynamic environmental characteristics of estuarine areas, influenced by the mixing of freshwater and seawater and by high inputs of materials from terrestrial sources. These conditions tend to create unstable physicochemical characteristics in the water and sediments, thereby affecting the abundance of benthic diatoms. In addition, the proximity of Station 1 to the Pertamina RU II Sei Pakning oil refinery was also presumed to contribute to the high oil content in the sediments. This condition may reduce the abundance of benthic diatoms by exerting ecological pressure through the toxic effects of oil contamination and disrupting physiological processes and photosynthetic activity. Rahman et al. (2022) reported that various anthropogenic activities along river systems have the potential to generate waste containing pollutants that may alter water quality, thereby affecting the distribution and community structure of diatoms.

3.4. The Relationship between Total Oil Content in Sediment and the Abundance of Benthic Diatoms

Using simple linear regression, the relationship between oil content and benthic diatom abundance is described by the mathematical equation $y = 8281.7 – 1.1367x$. Since the constant b is negative, this indicates a negative correlation between benthic diatom abundance and sediment oil content: as oil content increases, benthic diatom abundance decreases. The correlation coefficient measures the relationship between two quantitative variables. This relationship between the two variables may be due to a cause-and-effect relationship or may be coincidental.

The correlation coefficient between oil content in sediments and benthic diatom abundance was r = 0.935, indicating a very strong relationship. According to Razak (1991), a correlation coefficient of 0.91-0.99 indicates a very strong relationship between variables.

The coefficient of determination (R^2) was 0.875, indicating that 87.5% of the variation in benthic diatom abundance was influenced by oil content, while other environmental factors influenced the remaining 12.5%. According to Manokaran (2022), physical factors (temperature, water transparency, and current speed), chemical factors (pH, salinity, nitrate, and phosphate), and biological factors may influence the abundance of benthic diatoms in sediments. Puspita et al. (2021) reported a negative relationship between oil content and diatom abundance in the coastal waters of Pandaratan Beach, indicating that oil contamination has adverse effects on diatom abundance. According to Tanjung et al. (2020), when oil spills occur in marine environments, oil undergoes various physical and chemical transformations. Some of these processes result in the loss of certain oil fractions from the sea surface, while others allow residual oil materials to remain in the marine environment. Although spilt oil may degrade naturally in marine waters, the rate and duration of degradation depend on the oil's initial physical and chemical characteristics.

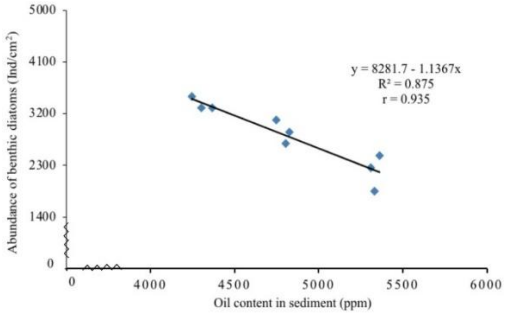

Figure 2. The relationship between oil content in sediments and the abundance of benthic diatoms

4. Conclusions

The average oil content in sediments from the waters of Pangkalan Jambi, Bengkalis Regency, Riau Province, exceeded the threshold values established by the Department of Water Resources Quality Assurance/Quality Control Program and the Australian and New Zealand Environment and Conservation Council (ANZECC). A total of 21 benthic diatom species were identified, with the highest benthic diatom abundance recorded at Station 3 (small harbor area) and the lowest at Station 1 (estuarine area). The results of the simple linear regression analysis showed a strong negative relationship between total oil content in sediments and benthic diatom abundance, with a correlation coefficient (r) of 0.935 and a coefficient of determination (R^2) of 0.875. These results indicate that 87.5% of the variation in benthic diatom abundance was influenced by total oil content in the sediments. In comparison, the remaining 12.5% was influenced by physical, chemical, and biological parameters in the surrounding aquatic environment.

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