BIODIVERSITAS
Volume 25, Number 1, January 2024
Pages: 329-336

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250138

Spatial variability of organic matter in two mangrove ecosystems in Langkawi, Kedah, Malaysia

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Manuscript received: 22 November 2023. Revision accepted: 28 January 2024.

Abstract. *Ramli R, Pardi F, Singh HR, Roslani MA, Aziz KNA, Kamaruddin SA. 2024. Spatial variability of organic matter in two mangrove ecosystems in Langkawi, Kedah, Malaysia. Biodiversitas 25: 329-336.* Organic matter is a crucial factor influencing mangroves' structure and species composition. The present study aimed to assess and compare the organic matter content in the sediment of Pulau Dayang Bunting and Sungai Kilim mangroves ecosystem in Langkawi, Kedah. The spatial variation of the organic matter contents was measured from the sediment at different zones in a line transect at each location. The mean of organic matter content recorded in the Pulau Dayang Bunting mangroves community was recorded from 13.67% to 15.74% and 13.06% to 16.57% in the Sungai Kilim mangrove community which were classified in the medium category. Results of Two-way ANOVA analysis revealed significant differences in the organic matter content between mangroves communities and only organic matter content in Station 2 was significantly different at the lower, middle, and upper zones (ANOVA one way, $P<0.05$). Only salinity has a negative correlation with the organic matter content in the study area (r (34) = [-0.41], p = [0.014]). The upper zones exhibited a greater concentration of organic matter due to enhanced accumulation facilitated by the vertical water mixing. Mangroves age, vegetation density, salinity, and sediment types are also crucial factors in maintaining organic matter content in the mangrove ecosystem.

Keywords: Mangroves ecosystem, organic matter, sediment

INTRODUCTION

Mangroves are a group of trees and shrubs that grow on the soft, anaerobic mud of saline coastal ecosystems and are frequently inundated by tides (Song et al. 2022). Mangroves are well recognized for their role in providing various goods at local and global levels (Machava-António et al. 2022). In addition to their general importance to the economy, mangroves are also responsible for many ecological processes, such as coastal protection, nutrient cycling and sinking, water quality regulation, sediment accretion, and biodiversity conservation (Romañach et al. 2018). These contributions have promoted mangroves as among the most productive ecosystems in the world (Alongi 2020).

Recognizing that mangroves play a crucial role in ecosystem services, it is vital for the community to preserve the mangroves' resilience. According to Poker and MacDicken (2014), one of the most crucial protective functions of forests is related to soil. Soil or sediment is an essential part of the aquatic ecosystem because it gives plants the nutrients they need to grow and provides a habitat for microorganisms and macroorganisms to live (Dewiyanti et al. 2021). Mangrove sediment differs from marine sediments in terms of salinity variation on a daily and seasonal basis and organic matter content (Kida and Fujitake 2020). In the mangrove ecosystem, organic matter is primarily produced from decaying vascular plants and animals that may originate from both autochthonous sources, such as mangrove litter and benthic microalgae, and allochthonous sources, such as phytoplankton and seagrass detritus which might be imported by tides from adjacent ecosystems (Henriques et al. 2021).

Organic matter acts as a major storage and source of soil carbon which is a crucial factor influencing the structure and species composition of mangroves (Hossain and Nuruddin 2016). Organic matter in the sediment positively affects all functions, from fertility to the sediment structure (Lal et al. 2021). Sediment with higher organic matter content has a better structure, which helps absorb water and retain nutrients (Shilla 2021). Furthermore, it promotes the growth of the mangrove trees by supplying energy from carbon compounds, nitrogen for protein production, and other nutrients (Keesstra et al. 2016). A high supply of vital nutrients increases primary production in mangroves which in turn provides shade and shelter to various aquatic and terrestrial biota. However, several factors influence the accumulation of organic matter in mangrove sediment, such as waterlogging (Mohammed et al. 2014), deforestation (Carugati et al. 2018; Arias-Ortiz et al. 2021), sedimentation (Bao et al. 2013; Pérez et al. 2018), sea level rise (Dang et al. 2022), and climate change (Ward et al. 2016). These events could severely impact the community regarding livelihoods, safety, health, environment, and cultural values.

Both Pulau Dayang Bunting and Sungai Kilim are included in Langkawi Geopark, which is comprised of the Dayang Bunting Marble Geoforest Park and the Kilim Karst Geoforest Park, respectively (Mohd Fauzi et al. 2018). The establishment of geoparks exemplifies a sustainable development strategy that is not only balanced in terms of socioeconomic and cultural progress, but also in terms of the preservation of geoheritage (Halim and Ishak 2017). The mangrove forest in Langkawi covers approximately 3,142 ha, serves as a shelter and feeding ground for fish and shellfish, indirectly providing protein source to local communities, and offers significant value in the cultural, recreational, and ecotourism industries (Abdullah Halim et al. 2019). Considering the significance of mangroves to coastal communities, understanding the physical and chemical properties of mangrove sediment that is crucial for mangroves' health is imperative for both scientific research and conservation initiatives.

Studies relating to sediment organic matter content in Malaysia are still scant (Kamaruzzaman et al. 2010). Monitoring organic matter content and its influencing factors helps in developing effective conservation and management strategies to maintain the health and functioning of mangrove ecosystems. Moreover, recent years have seen an increase in risks to mangrove ecosystems, particularly in changing weather associated with climate change. Incorporating mangrove forests into climate change adaptation strategies requires an understanding of the spatial distribution of mangrove soil carbon stocks (Sanderman et al. 2018). Since no baseline data was available for the sediment organic matter content, it was difficult to draw a definitive conclusion in the study area. Thus, this study aims to assess and compare the sediment's organic matter content in the mangrove ecosystems of Pulau Dayang Bunting and Sungai Kilim, along with an investigation into the factors influencing the organic matter content. It was envisaged that the findings of this study would quantify the spatial variability of the organic matter content, hence providing the baseline information that could be used for long-term monitoring programs primarily for conservation purposes.

MATERIALS AND METHODS

Study area

Field sampling was conducted from December 2021 to February 2022. The sampling site was marked by a handheld GPS on the sampling site. The spatial variation of the organic matter contents was measured from the sediment at different mangrove ecosystem, namely Pulau Dayang Bunting and Sungai Kilim (Figure 1). Station 1 (06° 12' 23.59" N, 99° 48' 35.70" E) and Station 2 (06° 13' 14.2" N, 99° 48' 56.1" E) are located in Pulau Dayang Bunting mangroves ecosystem, which primarily consists of *Rhizopora apiculate* Blume, and some species of *Brugeira* sp., and *Xylocarpus granatum* J.Koenig. From our observations, this area appears to be a pristine location with very few fishing activities from the locals who practice artisanal fishing to fulfill their daily economic needs. Meanwhile, Station 3 (06° 24' 25.8" N, 99° 51' 34.8" E) and Station 4 (06° 25' 0.60" N, 99° 52' 36.7" E) are situated in the Sungai Kilim mangroves ecosystem, which is dominated by *Ceriops tagal* (Perr.) C.B.Rob., *R. apiculata* and some species of *Rhizophora mucronata* Lam. and *X. granatum.* The vegetation in these sampling locations exhibits greater density and age than the mangrove trees found in Pulau Dayang Bunting. These areas have been recognized as a main attraction for tourists who want to explore the stunning beauty of the mangroves with limestone substrates via boat cruising along the Sungai Kilim.

Sampling strategies

The spatial variation of the organic matter contents was measured from the sediment of different zones (lower, middle, and upper zone), and the distance between each zone is 20 m accordingly in a line transect, as illustrated in Figure 2. Three replicates of sediment samples (10 cm depth) were collected randomly in a 0.25m^2 quadrat at each zone by using a metal corer (Marchand 2017). Each core sample was placed in a plastic bag, labeled, and returned to the laboratory for further processing. Additional sediment cores were also obtained for particle grain size analysis in each quadrat. Porewater parameters have been measured in situ with a handheld device to measure its salinity (ppt), temperature (°C), and pH. All the sediment samples were collected during low tide for accessible purposes.

Total organic matter analysis

The Loss on Ignition (LOI) method was deployed to analyze organic matter content at a 10 cm depth. The wet soil samples were dried at 60°C in an oven until the weight of the dried soils was constant (Fourqurean et al. 2014). The dried soil samples were then burned in a furnace at 450°C for 4 hours before being weighed. Organic matter content was calculated by using the following equation:

$$\% \text{ Loss of ignition} = \frac{\text{dry mass before combustion (mg)} - \text{dry mass after combustion (mg)}}{\text{Dry mass before combustion (mg)}} \, x \; 100$$

Particle size analysis

The dried sediment samples were sieved at 2 mm mesh size and treated with 15 mL of 30% Hydrogen Peroxide (H_2O_2) to remove the organic matter. The suspension was kept on a heating plate at 50°C for one hour, and the clear supernatant was removed with a pipette. The treatment was repeated two to three times until the samples were completely bleached and all organic matter was removed (Abdulkarim et al. 2021). Five mL of Calgon solution was added before being introduced into the dispersion unit device of the laser particle analyzer (Laser Diffraction Particle Size Analyzer, Mastersizer 2000) for particle size measurement. Statistical analyses were made with the laser particle sizer control program and MS Excel, while sediment grain size was converted to units of phi (ϕ). The type of sediment substrate was determined by using textural triangle according to the percentage of sand, silt, and clay fraction (Polakowski et al. 2021).

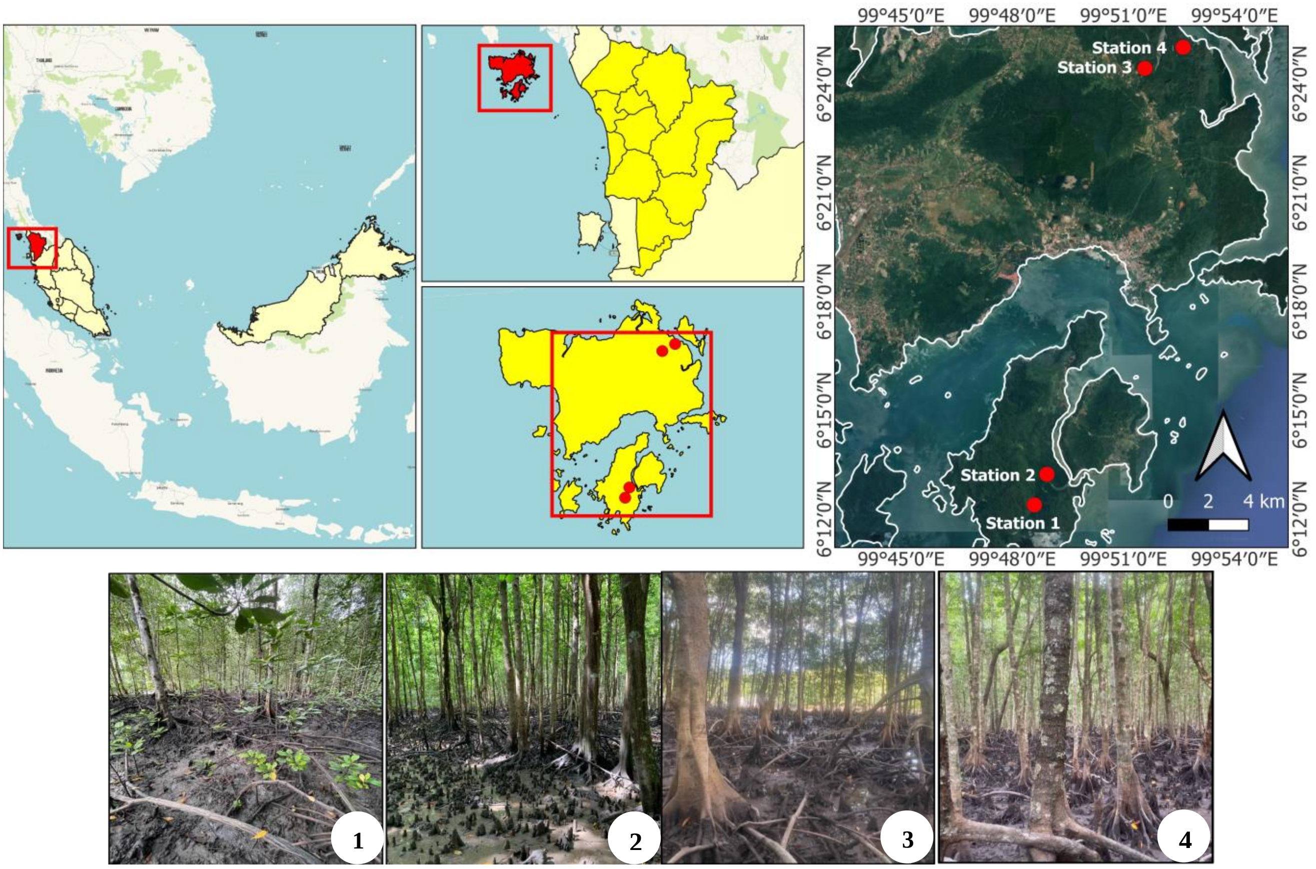

Figure 1. The maps show the location of Station 1 and 2 in the Pulau Dayang Bunting mangrove ecosystem and Station 3 and 4 in the Sungai Kilim mangrove ecosystem. The picture below the map shows the sampling station (Station 1-4)

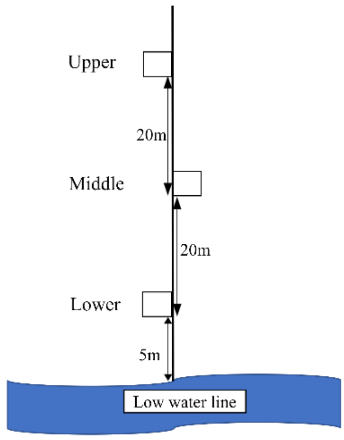

Figure 2. Illustration of the transect line in the study area

Statistical analysis

The data analysis was performed by using Statistical Package for the Social Sciences (SPSS) version 29 package. Several statistical tools were applied to determine the normality and significant differences between the sampling stations from the calculated mean and standard deviation. Data distribution was checked by using Kolmogorov-Smirnov and Shapiro-Wilk Tests. If applicable, means are compared using a parametric test; otherwise, medians are used to compare the groups using nonparametric methods (Mishra et al. 2019). The differences of organic matter and the physicochemical properties between the zones and stations were analyzed by the Analysis of Variance (ANOVA). Pearson correlation was performed to investigate the correlation between the organic matter content with the sedimentary parameters (sediment mean phi, clay, silt, and sand content) and physicochemical parameters (salinity, pH and temperature) of the sediment in both mangrove ecosystems.

RESULTS AND DISCUSSION

The variation of results observed from the spatial investigation of organic matter content in both mangrove ecosystems were discussed**.** The current spatial variation and the possible factors affecting the spatial trends were further justified.

Physico-chemical parameters (pH, salinity, and temperature) of the mangrove sediment

Porewater salinity, pH, and temperature obtained from three zones (lower, middle, upper) of 4 stations were presented in Table 1. The overall mean of porewater salinity was 32.52 ppt with minimum value of 28 ppt and maximum value of 36.20 ppt. There are significant differences of salinity among the stations [F (3,35) = 6.617, p = 0.001] as $p<0.05$), particularly at Station 2, Station 3, and Station 4 (Post Hoc: Tukey test). The mean recorded for temperature was 27.75°C with minimum value of 25.93°C and maximum value of 29.17°C. There are also significant differences in temperature value among the stations [F (3,35) = 50.505, p<0.001] as p<0.05), specifically at Station 1 and Station 2 (Post Hoc: Tukey test). Meanwhile, pH score for 6.11 as the minimum value, and 7.04 as the maximum value with the mean of 6.48. The value of pH is recorded significantly different [F (3,35) =12.864, p<0.001], particularly at Station 3 and Station 4 (Post Hoc: Tukey test).

Sediment texture of the mangrove sediment

The mean grain size for sediment was ranged from 5.61 ϕ to 6.84 ϕ for the stations in mangroves of Pulau Dayang Bunting, and the sediment was dominated by the fine silt category except for the lower zone in Station 1, which composed of medium silt sediment (Table 2). For the stations in the mangroves of Sungai Kilim, the values of mean grain size ranged from 5.04 ϕ to 7.32 ϕ. Station 3 was dominated by the medium silt sediment category; meanwhile, the finer size of sediment was recorded in Station 4. These areas were dominated by the fine silt sediment category except for the lower zone, which recorded higher mean grain size, and the sediment fell into the very fine silt category. The sediment texture, based on the mean particle composition percentages, revealed that the sediment of both mangrove communities was characterized by the silty loam texture except for the middle and upper zones of Station 2, which recorded higher percentage of clay fraction and fell into the silty clay loam category. The result of one-way ANOVA also shows a significant difference in the sediment particle size among the stations [F (3,35) = 11.257, p<00.1].

Sediment fraction of the mangrove sediment

The composition of the various particle sizes varied slightly among the stations (Figure 3). The major variation was observed at Station 3 (all zones) and the lower zone of Station 1, which had a higher mean sand percentage of approximately more than 27% compared to the other stations, which was recorded lower than 17%. The silt content for all study areas ranged between 54% and 71%, with the upper zone at Station 1 having the highest mean silt content (70.53%). Meanwhile, the upper zone at Station 3 had the lowest mean silt content (53.71%). The mean clay content ranged between approximately 8% to 40%, with the upper zone at Station 3 having the lowest clay content and the lower zone at Station 4 having the highest clay content, accounting for 8.29% and 39.56%, respectively. The result of one-way ANOVA also showed that all the sediment fractions are significantly different in all stations [Sand; F (3,35) = 23.39, p<0.00; Clay; F (3,35) = 16.91, p<0.00; and Silt; F (3,35) = 9.91, p<0.00] especially in station 3 (Post Hoc: Tukey test).

Organic matter of the mangrove's sediment

The organic matter content in Stations 1, 2, and 3 showed an increasing pattern from the lower zone towards the upper zone, except for Station 4, which showed a fluctuation pattern. The lower zone in Station 4 recorded the highest organic matter content, followed by the upper and middle zones. The variation of organic matter content according to the zone in all stations (Station 1-Station 4) was depicted in Figure 4. Organic matter content recorded in Pulau Dayang Bunting mangroves community was recorded from 13.67% (lower zone), 14.28% (middle zone), and 14.81% (upper zone) in Station 1. Lower reading was recorded in the lower zone in Station 2 (12.19%), followed by the middle zone (13.99%), and the highest content was scored at the upper zone with 15.74%. In the Sungai Kilim mangrove community, the organic matter content in Station 3 showed a sharp increase from 13.06% in the lower zone to 16.13% in the middle zone, and the reading steadily increased to 16.43% in the upper zone. The organic matter content in Station 4 shows slight changes where the reading fluctuates from 16.57% (lower) to 16.09% (middle) and 16.27% in the upper zone. The means of organic matter content recorded from all zones in both Pulau Dayang Bunting and Sungai Kilim stations were in medium category as the percentage of organic matter content in sediments was classified into 5 (five) groups (Imra et al. 2021), namely very high with a value of >35%, high with a value of 17-35%, medium with a value of 7-17%, low with a value of 3.5-7%, and very low with a value of <3.5%.

Table 1. Physico-chemical properties of sediment in both mangrove stations (mean ±SD)

Station	Zone	Salinity (ppt)	pH	Temperature (°C)
1	Lower	33.0±0	6.55±0.17	26.17±0.1
	Middle	34.0±0	6.93±0.02	26.3±0.4
	Upper	28.0±0	6.36±0.06	25.93±0.1
2	Lower	36.20±0	6.11±0.01	29.13±0.06
	Middle	36.00±0	6.66±0.07	29.17±0.12
	Upper	29.10±0	6.30±0.10	28.03±0.06
3	Lower	34±0	6.20±0.07	28.67±0.49
	Middle	36±0	6.14±0.16	27.60±0.20
	Upper	34±0	6.09±0.01	27.03±0.15
4	Lower	30±0	6.95±0.08	28.03±0.06
	Middle	28±0	7.04±0.17	28.13±0.15
	Upper	32±0	6.45±0.22	28.05±0.35

Table 2. Mean (phi) and sediment texture in both mangrove stations

Station	Zone	Mean particle size, (ϕ)	Grain size class	Sediment type
1	Lower	5.61	Medium silt	Silty loam
	Middle	6.53	Fine silt	Silty loam
	Upper	6.82	Fine silt	Silty loam
2	Lower	6.20	Fine silt	Silty loam
	Middle	6.45	Fine silt	Silty clay loam
	Upper	6.84	Fine silt	Silty clay loam
3	Lower	5.67	Medium silt	Silty loam
	Middle	5.23	Medium silt	Silty loam
	Upper	5.04	Medium silt	Silty loam
4	Lower	7.32	Very fine silt	Silty loam
	Middle	6.26	Fine silt	Silty loam
	Upper	6.27	Fine silt	Silty loam

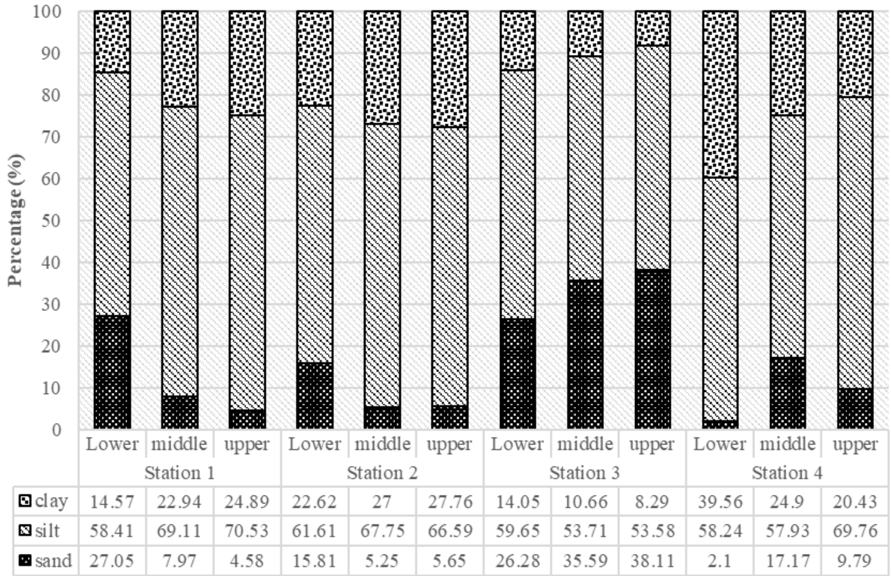

Figure 3. The characteristics of sediment fraction in study areas

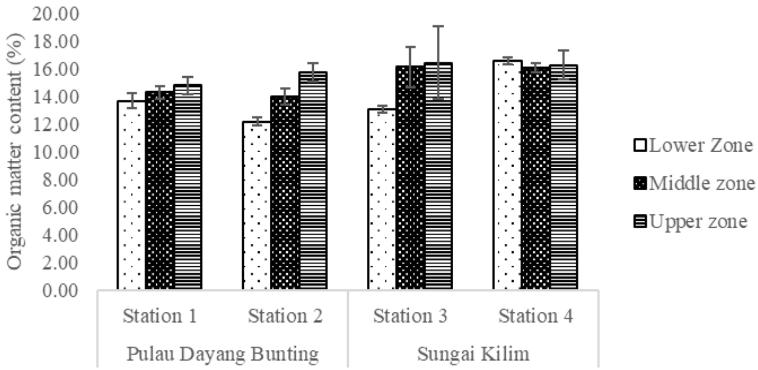

Figure 4. Mean of organic matter content according to the zone in Station 1-4

The assumption of normality has been performed before pursuing variance analysis. A data normality test aims to determine the normality or symmetry of the distribution of gathered research data. The Smirnov and Shapiro-Wilk Kolmogorov tests for data normality demonstrate the goodness of fit test on the observed variables (Zakaria et al. 2019). The results of the normality test showed that the significant values in the Kolmogorov-Smirnov test ($p = 0.200$) and Shapiro-Wilk test ($p = 0.752$) were greater than 0.05, which indicates that the organic matter readings are normally distributed (Table 3). The standard normal distribution is the most important for continuous probability distribution. It has a bell-shaped density curve described by its mean and standard deviation, and extreme values in the data set do not significantly impact the mean value (Mishra et al. 2019). As the continuous data followed the normal distribution, a Two-way Analysis of Variance (ANOVA) was carried out to investigate the variability of the organic matter content among the stations and zones.

The result of the Two-way ANOVA analysis revealed that there was a statistically significant interaction between the station and zones ($F(6,36) = 3.121$, $p = 0.021$) (Table 4). Simple main effects analysis showed that total organic matter content at all stations did have a statistically significant difference on the zones (lower, middle, and upper) ($p<0.01$), and all the zones also did have a statistically significant difference between the stations ($p<.001$).

One-way ANOVA was performed to examine any significant difference in organic matter content among each station's zones (lower, middle, and upper). Table 5 shows that there was a significant difference in organic matter content at Station 2 [$F(2,6) = 30.151$, $p = 0.01$] as $p<0.05$. Post Hoc comparisons using the Tukey test proceeded, and the results indicated that only organic matter content at Station 2 was significantly different at all zones (lower, middle, and upper zone) at $p<0.05$. Meanwhile, there was no significant difference in organic matter content between zones at Station 1,3 and 4, as the p-value is more significant than 0.05.

Table 3. Data normality test results using the Kolmogorov-Smirnov and Shapiro-Wilk test

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
OM content	0.092	36	0.200*	0.980	36	0.752

Note: *This is a lower bound of the true significance, a. Lilliefors Significance Correction

Table 4. Results from Two-way ANOVA for the interaction of all stations and zones on the organic matter content

Source of variation	DF	SS	MS	*F*	*P*
Station	3	30.144	10.048	10.009	<.001
Zone	2	23.238	11.619	11.574	<.001
Station*zone	6	18.801	3.133	3.121	.021
Total	36	8128.318			

Note: DF: Degree of Freedom; SS: Sum of Squares of variance; MS: Mean Squares of variance; F: F ratio; P: Probability

Relationship of organic matter content with sedimentary and physicochemical parameters

A Pearson correlation coefficient was computed to assess the linear relationship between the sedimentary and physicochemical parameters with the organic matter content in the mangrove community in Pulau Dayang Bunting and Sungai Kilim. The result showed that only salinity has a weak negative correlation with the organic matter content, r (34) = [-0.41], p = [0.014] throughout the study areas.

Discussion

Sediments are the most important sites for organic matter decomposition and nutrient regeneration in coastal marine environments. Addise et al. (2022) state that sediment properties vary from place to place in the landscape, even within a short distance. The factors that influence the mangrove carbon stocks are well described in Zaman et al. (2023). As discovered by Kauffman et al. (2020), species composition plays a crucial role in altering the organic matter dynamics by the root production of some species to retain nutrients more effectively than others. As mentioned before, the mangrove trees in the study areas of Pulau Dayang Bunting are less dense and younger compared to the vegetation in Stations 3 and 4 in Sungai Kilim, resulting in lower organic matter content. As reported by Mashoreng et al. (2022), the upper 10 cm of the sediment layer depends on the age of the mangrove vegetation due to the accumulation of mangrove litter fall over time (Chen et al. 2018; Tang et al. 2023).

The present study demonstrates that the organic matter content was higher at the upper zone compared to the lower zone at three stations (Stations 1, 2, and 3). Moreover, the organic matter content was significantly different at each of the zones in Station 2, revealing that there is spatial variation in organic matter accumulation. This result corroborates with findings of Chaikaew and Chavanich (2017), which suggested that areas further from shore or upper zone with a high density of mangroves tend to have a vertical mixing of water due to strong waves and tides and manage to circulate suspended matter which resulted in keeping the organic matter remained in this zone. Furthermore, the interaction between hydroperiod (i.e., frequency, duration, and depth of flooding) and salinity also exerts a substantial influence on root productivity in accumulating organic matter, as shown by the different ecotypes of mangroves (fringe, basin, and inland) in San Andres, Colombia (Medina-Calderón et al. 2021).

The salinity reported in the studied areas is in the polyhaline and euhaline categories (salinity>18 ppt), which is considered high due to the sampling sites' proximity to the river, as soil salinity increases with decreasing distance. According to Ahmed et al. (2022), elevated salinity levels can adversely affect various tree structural variables, including tree height, DBH (Diameter at Breast Height), stand basal area, leaf area, nutrients, and growth. These effects, in turn, have the potential to restrict mangrove productivity. The origins of the organic material may also influence the variation in organic matter concentration between stations. The differences in composition might be attributed to the different sources of organic materials, such as tree litter (i.e., leaves, propagules, twigs, and roots) that originated locally (Friesen et al. 2017) and from the nearshore or near ocean areas (Chaikaew and Chavanich 2017). Furthermore, study locations that are characterized by riverine mangroves are sheltered from strong currents, unlike seaward mangroves, which may flush organic materials into the sea, thus reducing the organic matter content (Pazi et al. 2016).

Table 5. Results from one-way ANOVA for differences of organic matter content between the zones (lower, middle, upper) in each station

		Sum of squares	df	Mean Square	F	Sig.
Station 1	Between Groups	1.941	2	0.971	3.354	0.105
	Within Groups	1.737	6	0.289		
	Total	3.678	8			
Station 2	Between Groups	18.869	2	9.435	30.151	<0.001
	Within Groups	1.877	6	0.313		
	Total	20.747	8			
Station 3	Between Groups	20.890	2	10.445	3.478	0.099
	Within Groups	18.019	6	3.003		
	Total	38.910	8			
Station 4	Between Groups	0.337	2	0.169	0.412	0.680
	Within Groups	2.459	6	0.410		
	Total	2.797	8			

In addition, other factors, such as mean particle size, may be crucial in determining the organic matter content of sediments. As discovered by previous studies, organic matter content tends to increase in finer sediment (Hossain and Nuruddin 2016; Shaari et al. 2020). In the present study, the sediment particle size distribution varied slightly from medium silt to very fine silt category and was characterized as silty loam and silty clay loam type of sediment. Sediments with high silt and clay content retain more water than sandy sediments, making them optimal for the leaching process. This facilitates the release of organic carbon, nutrients, and tannins within the sediment (Friesen et al. 2017). Moreover, these types of sediments can resist erosion during rainy events, hence reserving the organic content in the sediment (Li et al. 2016). It is imperative to acknowledge the limitations of this study by recognizing that certain influential factors, such as rainfall, tidal action, and the feeding activities of macro- and microorganisms, affect the fate of organic matter input in the mangrove sediment and are outside the defined scope of this investigation.

The present study found that the organic matter content in the mangrove community of Pulau Dayang Bunting and Sungai Kilim is in the medium category. There is also spatial variation of organic matter content in all stations. Significant differences in organic matter content from the lower zone to the upper zone can be observed at Station 2. The organic matter content in the mangrove ecosystem is substantially influenced by factors such as mangrove age, vegetation density, salinity, sediment grain size, and sediment fraction. The preliminary organic matter content data could be used to improve understanding of the long-term dynamics of organic matter storage in mangrove sediments and enhance sustainable and adaptive management strategies for coastal ecosystem networks.

ACKNOWLEDGEMENTS

The authors are grateful to the Ministry of higher Education (MOHE) and UiTM Malaysia for providing the scholarship and special gratitude to the Marine Research Station (MARES) team for their cooperation during the field sampling, research process, and writing of this manuscript.

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