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THE EFFECT OF COASTAL AND CHANNEL MANGROVES SEDIMENT ON BIOTURBATION DISTRIBUTION

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Abstract:

Mangroves are a type of tropical tree that thrives and flourishes in harsh conditions where most vegetation struggles. Despite their resilience, mangrove ecosystems face significant threats from deforestation, pollution, and human activities. As an exceptionally efficient habitat for the capture and stabilization of sediment, the mangrove region is also supported by the bioturbation activity where organisms burrow and play an important role in the carbon and nutrient cycle while shaping soil geomorphology within the ecosystem. Many discoveries on the distribution of bioturbation have been carried out in coastal

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areas regarding grain size, soil density, and others. However, the difference in bioturbation activities on different physical attributes such as coastal, channels, and creeks areas has not yet been well addressed especially in Malaysia. Thus, this study proposes to elucidate the difference in bioturbation distribution between coastal and channel regions in the mangrove areas. The aim is to determine bioturbation distribution within coastal and channel regions by investigating the sediment characteristics and bioturbation frequencies along these two regions. The stratified random quadrat sampling method has been used for bioturbation frequencies, inhabitant species, and population richness. The sediment was characterized with a standard soil dry-sieving method and further analysed by laser diffraction method for fine particle distribution. In examining the effect of physical attribute influence on the bioturbation distribution, a two-way ANOVA assessment was carried out. This study has found that coastal and channel had different sediment distribution and the bioturbation frequencies were influenced by different inhabitants in both regions. Thus, the result of this study supports that coastal and channel regions have significant differences in the bioturbation process. The outcome of this study perhaps will increase awareness among the community members and their involvement in the enrichment and nurturing of ground areas, especially mangrove forests (SDG14).

Keywords:

Bioturbation, Coastal Mangrove, Mangrove Channel, Mangrove Sediment

Introduction

Mangroves are one of a group of salt-tolerant plant communities growing in the transition zones of fresh and marine water systems. Mangroves play an important role in coastal areas as sediment traps, carbon sequesters, and many other benefits (Spalding et al., 2019; Sarker et al., 2021; Banerjee et al., 2021). Along the coastal line, within the mangrove forests, there are two types of mangrove areas involved in this study which are coastal and channel regions (Gandaseca et al., 2016; Sippo et al, 2020). Conversely, the threat to this ecosystem is also alarming with deforestation, pollution, and human activities for the past decade. Understanding the dynamics of ecological processes in these areas is essential for conservation efforts and sustainable management of mangrove forests (Hashim et al., 2023).

Over the past few years, many researchers have studied aspects related to the distribution of burrowing animals and the factors that influence them, known as bioturbation (Lanuru, 2020; Wiesebron et al., 2021; Egawa et al., 2021). Bioturbation not only influences local ecology and sediment properties but also has broader implications for biogeochemical cycling towards the oceans (Tarhan, 2018). However, research into the distribution of bioturbation on different geological sites between coastal and channel areas is still not well addressed particularly in Malaysia.

Bridging this gap, the study aims to investigate whether the physical attributes of coastal and channel mangroves exhibit distinct characteristics and influence the distribution of bioturbation in two specific mangrove areas. These physical attributes include factors such as the condition of the earth's surface, sediment types, and feature compositions. Due to that, the study focused on examining both the frequency of bioturbation events and the diversity of organisms involved in these processes within the two types of mangrove environments. The investigation of physical attributes and bioturbation distribution in various mangrove types may shed new light

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on a comprehensive understanding of the intricate interplay between ecological processes and sediment dynamics within these ecosystems in Malaysia. Mangroves of Kilim Geoforest Park (KGP) and Bagan Nakhoda Omar (BNO) coast ought to be studied as their characteristics are well-suited for representing both coastal and channel mangroves, and both are vulnerable to human activities (Figure 1).

Figure 1: The Kilim Geoforest Park (KGP) Mangrove Channel And Bagan Nakhoda Omar (BNO) Coastal Mangrove Are Well-Suited Sites For Representing Coastal And Channel Characteristics, And Both Are Vulnerable To Human Activities.

Literature Review

Mangrove ecosystems are vital components of global biodiversity, providing essential ecological services and supporting numerous species. However, these ecosystems are increasingly threatened by human activities and climate change-induced events (Sarker et al., 2021; Egawa et al., 2021). Understanding the complex interactions within mangrove ecosystems is crucial for effective conservation and management. The study reviewed recent research findings on the ecological dynamics of mangrove ecosystems, focusing on the role of bioturbation and sediment dynamics in shaping these environments, and the implications of mangrove channels and coastal characteristics on bioturbation processes and ecosystem functioning (Hashim et al., 2023; Pan et al., 2023).

Recent studies have highlighted the significant influence of bioturbation on sediment dynamics and ecosystem health in mangrove ecosystems. Organisms such as crabs, shrimp, and worms play crucial roles in nutrient cycling, sediment mixing, and carbon sequestration through their burrowing activities (Fusi et al., 2022). Soft, less compact sediments have been found to facilitate faster burrowing and more vigorous sediment mixing, leading to increased nutrient cycling and carbon storage. Understanding sediment dynamics is essential for predicting ecosystem responses to environmental changes and informing conservation strategies (Egawa et al., 2021, Bittelli et al., 2022).

Climate change also poses significant threats to coastal mangrove ecosystems, with events such as mangrove dieback leading to profound impacts on carbon cycling. Shifts in carbon sources and sinks due to mangrove mortality can result in increased CO_2 emissions and decreased

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carbon storage, exacerbating climate change (Sippo et al, 2020). Rising sea levels and global warming further compound these threats, underscoring the urgent need for conservation efforts to protect mangrove biodiversity and ecosystem health (Hashim et al., 2023). On the other hand, human activities, including deforestation, pollution, and habitat destruction, pose significant threats to mangrove ecosystems worldwide. Industrial pollution, heavy metals, pesticides, and oil spills can contaminate mangrove sediments, jeopardizing the health of these ecosystems and the species that depend on them (Pan et al., 2023). Urgent conservation efforts are needed to mitigate these threats and safeguard mangrove biodiversity.

In discussing the implications of mangrove channels and coastal characteristics on bioturbation processes, it is essential to consider the distinct hydrodynamic and sediment characteristics between coastal and channel mangrove areas. Differences in hydrodynamics and sediment properties can influence the abundance and diversity of benthic organisms and their bioturbation activities, shaping ecosystem functioning (Wiesebron et al., 2021). Additionally, the degree of hydrological connectivity between mangrove channels and coastal areas can influence the spatial heterogeneity of bioturbation processes within mangrove ecosystems (Hashim et al., 2023).

Therefore, mangrove ecosystems are invaluable habitats that provide critical ecological services and support diverse species. However, they are facing increasing pressures from human activities and climate change-induced events. Understanding the ecological dynamics of mangrove ecosystems, including the role of bioturbation and sediment dynamics within channel and coastal regions, is crucial for effective conservation and management. By implementing holistic conservation strategies that address both anthropogenic threats and natural processes, we can protect mangrove ecosystems for future generations.

Methodology

Study Area

Environmental and faunal sampling was carried out in two separate mangrove sites located in the KGP channel and BNO coast. The BNO coast is in Selangor, Malaysia which represents the coastal mangrove region while, the KGP is located in Langkawi Kedah, Malaysia, representing the mangrove channel region. BNO mangrove sites were located on extensive mudflats fringed by dense mangroves facing the Straits of Malacca (Figure 2). The culture beds on the mudflat were located approximately 2 km from the coastline. The two primary industries of BNO are fishing and aquaculture.

Additionally, BNO is often visited by fishing enthusiasts since there is an accessible jetty that provides boat rides to Kelong Paradise, an offshore fishing spot. Meanwhile, KGP is one of the three Geoforest parks associated with the Langkawi Geopark. The two primary industries for KGP are fish farming and operating tourism activities. KGP consists of an ancient geological heritage, and natural wonders, home to a myriad of flora and fauna, and the active local community of Kilim Village is well-known (Salleh & Mahdzar, 2020). Due to these advantages, it is regarded as the most successful ecotourism destination in Langkawi, where economic activities have vastly improved. However, human activities and over-exploitation could lead to a negative impact on the environment, and pollution and disrupt the wildlife's lifestyle (Fauzi et al.,2018).

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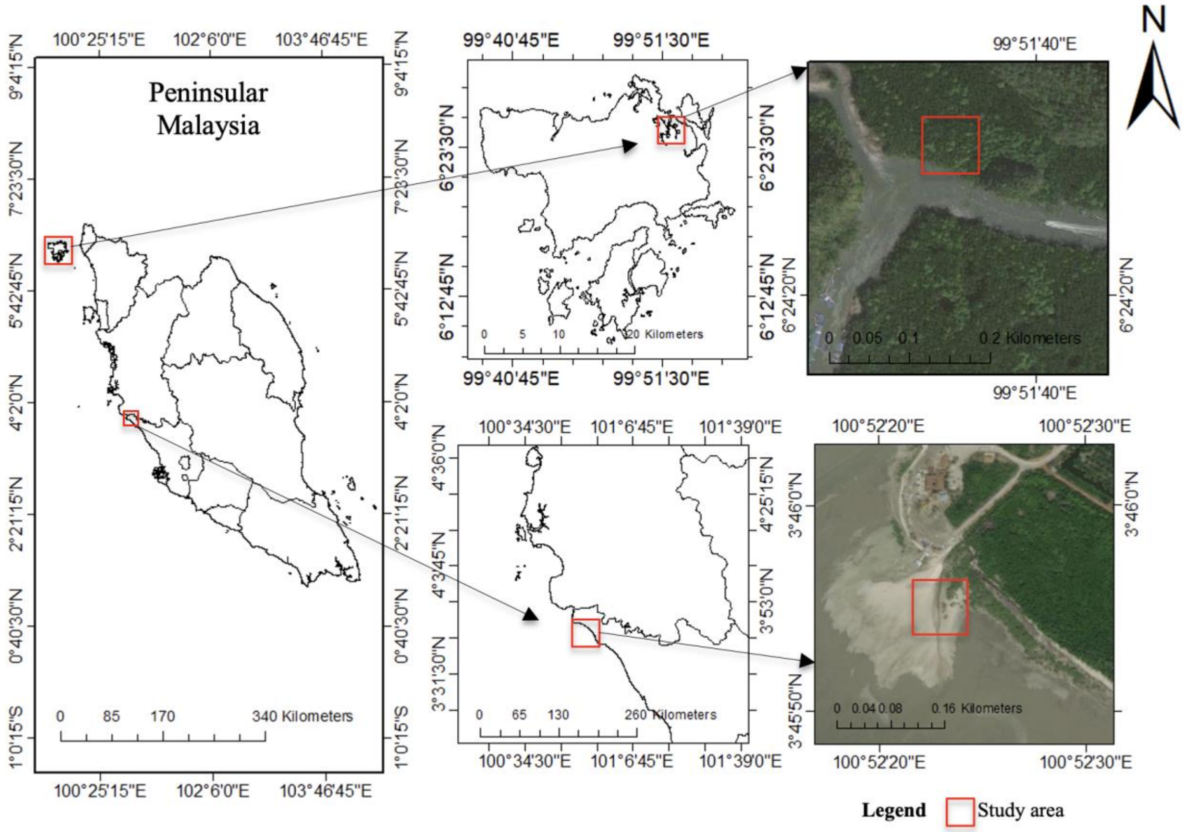

Figure 2: The Two Regions Of Interest (ROI) Of Coastal And Channel Regions Representing Different Physical Attributes In The Mangrove Environment For The Study Area.

Sampling Setup

In December 2022, sampling activities were carried out in the regions of interest (ROI) as primary in-situ data. For this study, the random quadrat sampling method was selected. As tide inundation has a different impact on sediment timely as tide ebbing, each sampling area was divided into three zones to delineate areas that near the coast/river line, middle, and landward (Figure 3). Stratified Random sampling is a method or protocol for directly counting organisms in a certain proportion within a habitat that covers population abundance and bioturbation frequencies in estimating bioturbation distribution within every division/group identified. This method was chosen because it relies on sample randomization to ensure an unbiased estimation (Larson et al., 2019).

Data Collection

In investigating the relationship between the physical attributes of coastal and channel mangroves toward bioturbation distribution the study did observation on burrowed hole frequency, sediment analysis, and inhabitants which include mangrove and faunal within the study area plot.

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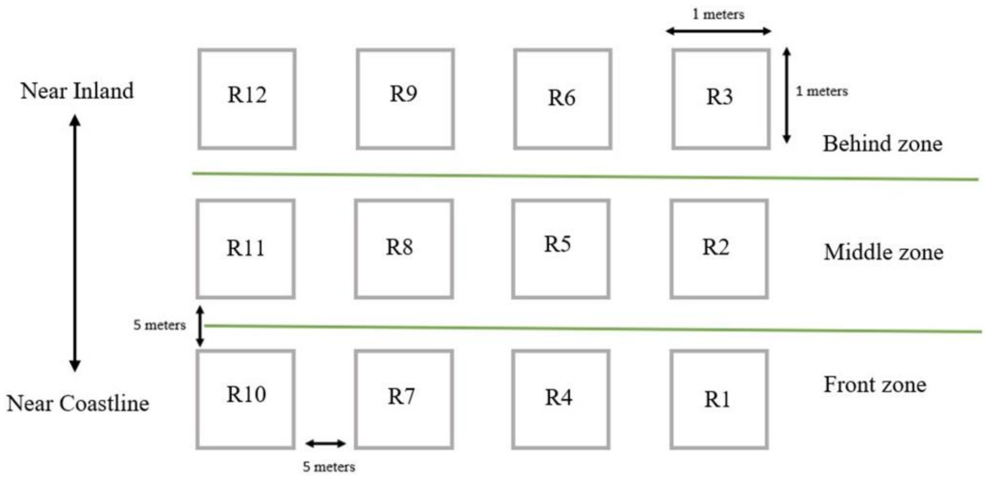

Figure 3: The Illustration Of The Quadrat Sampling Method Utilizing A Stratified Random Sampling Approach And Zone Division Relative To Water To Landward Region For Each Study Site.

The study counted burrowed holes in quadrats however, it didn't delve into the detailed size and shape of the holes. Mangrove species were observed in both study areas to understand their adaptations to different sediment types, their effects on sediment deposition and erosion, and their role in nutrient cycling. Mangroves play a crucial role in sediment trapping, with sediment types directly impacting the distribution of mangrove species. In addition to observing burrowers and faunal organisms, recording mangrove species helps assess their diversity in both areas. Related to sediment, the sediment analysis from each study area was sampled by sediment corer with 7 cm diameter and 10 cm deep and further analysed in the laboratory. The laser diffraction approach was used as it is a non-destructive method that provides accurate and efficient measurement of particle size distribution in sediments (Bittelli et al., 2022). The analysis includes mean, skewness, and kurtosis, which are statistical measures used in sediment analysis to describe the characteristics of particle size distribution. These parameters provide valuable information about the environmental conditions, transport processes, and depositional history associated with the sediments. The overall flow of this study is illustrated in Figure 4.

Analysis

The study utilized sediment analysis, with a focus on parameters such as mean, sorting, skewness, and kurtosis. This approach allows for a robust assessment of sediment properties, supporting the study's objectives of investigating the relationship between sediment characteristics and bioturbation distribution in coastal and channel mangroves. While to identify and analyse the diversity of burrower species, the study used the Simpson index and Shannon-Weiner index, chosen for their provision of robust and interpretable measures of burrower species diversity. This choice supports the study's goal of understanding the ecological dynamics within coastal and channel mangrove environments. Then, to further determine any significant impact over sediment characteristics and zonation divided in the distribution, the study employed two-way Analysis of Variance (ANOVA) from SPSS software, a statistical tool commonly used to assess how different variables or factors affect an outcome, in this case, bioturbation distribution. The tests will also help identify differences in

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responses between different size classes of each species, providing a comprehensive understanding of how various factors influence bioturbation in mangrove ecosystems.

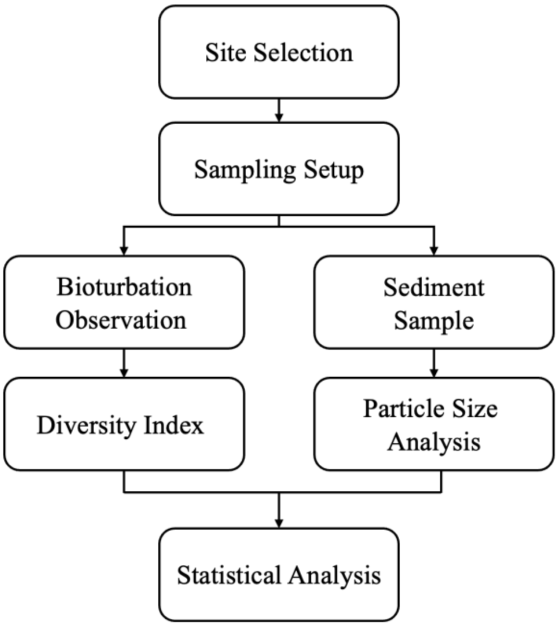

Figure 4: A Flowchart Illustrating The Study Framework.

Results and Discussions

Mangrove Species

Mangrove species are crucial for bioturbation because their burrowing activities enhance nutrient cycling, sediment aeration, sediment structure, biodiversity, and carbon sequestration. These processes are vital for the functionality and sustainability of mangrove ecosystems, supporting the diverse life forms that depend on these unique habitats. Due to that, this study has surveyed both regions to understand the mangrove species distribution within the areas.

The distribution of mangrove species at BNO is quite varied where six genera are randomly present in this coastal mangrove area (Table 1). There were no new species or genera recorded from the present study conducted compared to local communities of Pertubuhan Sahabat Bakau Kampung Dato' Hormat's (PSHBKDH). Meanwhile, there are slightly different distributions of mangrove species on KGP compared to BNO mangroves. KGP mangroves recorded as many as five genera in 2022, consisting of *Ceriops sp*., *Xylocarpus sp*., *Avicennia sp*., *Bruguiera sp*., and *Rhizophora sp*.

In the BNO mangrove forest, there are present of various species including Ceriops sp. and *Xylocarpus sp*., which are known to able to tolerate intermediate salinity. KGP is connected to the sea and has this intermediate salinity level due to their estuarine nature, making them suitable environment for *Ceriops sp*. and *Xylocarpus sp*. Other species like *Acrostichum sp*. are found in BNO mangrove areas, which are farther from the coastline and less frequently inundated by seawater. Additionally, species like *Excoecaria sp*. and *Sonnertia sp*. adapted well to muddy and sandy habitats, which are physical characteristics of the BNO mangrove area.

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Table 1: Mangrove Species Found At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected.

	Species	BNO	KGP
1	*Acrostichum sp.*	X	
2	*Avicennia sp.*	X	X
3	*Bruguira sp.*	X	X
4	*Ceriops sp.*		X
5	*Excoecaria sp.*	X	
6	*Rhizophora sp.*	X	X
7	*Sonneratia sp*	X	
8	*Xylocarpus sp.*		X

Particle Size Analysis (PSA)

The study used the dried sieve method to compare coastal (BNO) and channel (KGP) mangrove area sediment. Figure 5 shows that BNO mangroves had the lowest mean particle size (1.905), indicating a sandstone type classified as medium sand. In contrast, KGP mangroves had a mean of 5.836, indicating a siltstone type classified as medium silt. This difference shows that BNO mangroves have a coarse or fine grain size (sandstone) compared to the finer grain size (siltstone) of KGP mangroves.

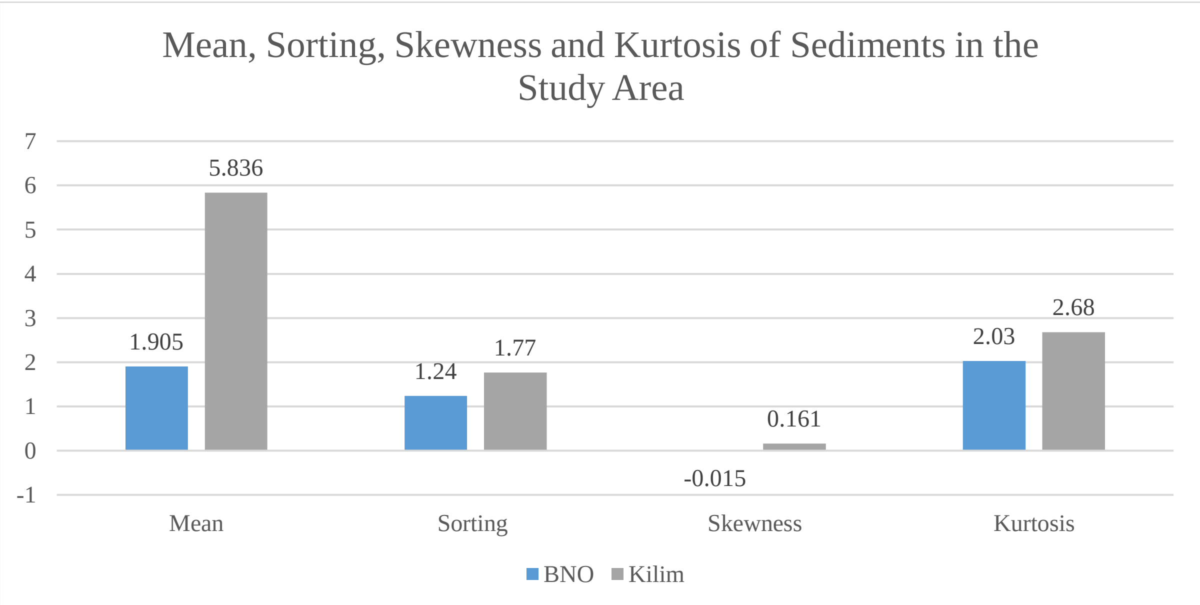

Figure 5: The Graph Of Sediment Analysis At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected.

Additionally, the study examined sorting, skewness, and kurtosis where it was found that KGP sediment had a sorting value of 1.77 and BNO had a value of 1.24. This indicates a relatively poor sorting at KGP and BNO sorting was better than KGP. Skewness reading was highest in KGP (0.161), with BNO having the lowest (-0.015). This result indicates that KGP has a slight bias toward larger particle sizes, while the BNO skewness reading indicates a slight bias

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towards smaller particle sizes. For the kurtosis result, it was highest in KGP (2.68) indicating a distribution with a relatively sharp peak and BNO had a value of 2.03 indicating a distribution with a slightly less pronounced peak compared to KGP.

Overall, these findings suggest that the sediment characteristics differ between the KGP and BNO sampling areas. KGP sediment appears to be more poorly sorted, slightly skewed towards larger particle sizes and has a distribution with a sharper peak compared to BNO sediment. Conversely, BNO sediment is better sorted, slightly skewed toward smaller particle sizes, and has a distribution with a less pronounced peak compared to KGP. However, these characteristics could suggest that the KGP channel area is experiencing ongoing sedimentation, while the BNO area is experiencing less active sedimentation, possibly due to lower energy levels or reduced sediment input compared to KGP. These differences could be attributed to various factors such as sediment sources, transport processes, and depositional environments specific to each sampling area.

The sediment was further analysed using laser diffraction, providing additional composition insights into particle size distribution in coastal and channel areas (Figure 6). KGP channel had the highest percentage of silt and clay at 77.30%, followed by BNO with 76.5%. In terms of silt percentage, KGP had the highest at 62.37 and BNO had the lowest at 49.56%. The sand percentage was highest in BNO at 23.49%, and KGP at 22.69%. The difference in composition percentage in the two areas proves further details of distinct sediment composition between coastal mangrove and channel mangrove, which are of significance in understanding the difference of geographic setting in the area.

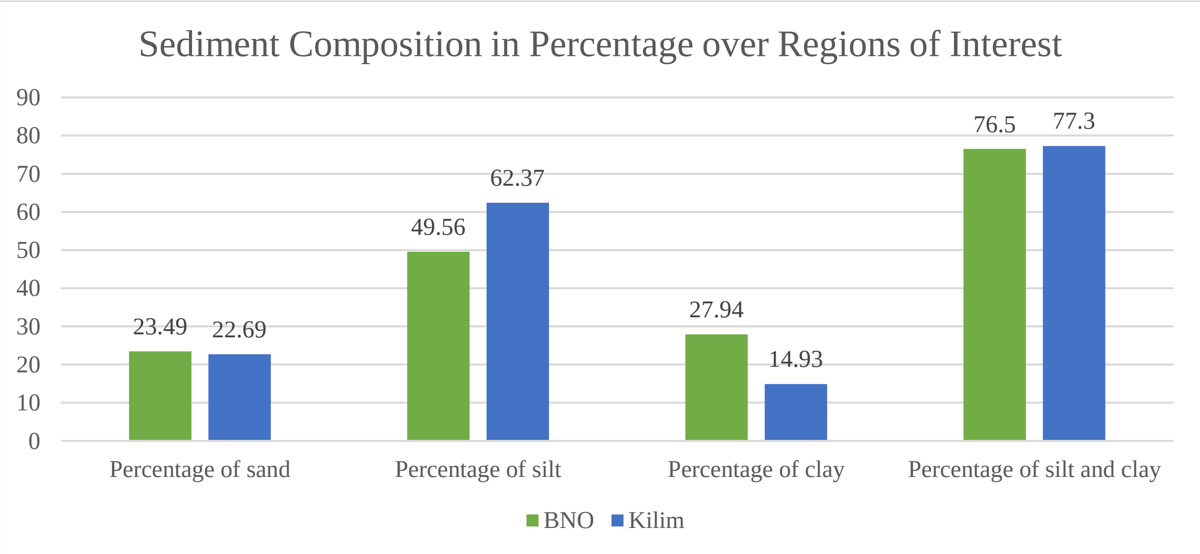

Figure 6: The Graph Of Sediment Compositions At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected.

Bioturbation Frequency

In this study, burrowers are the animal species that play a role in the bioturbation process by creating holes in mangrove sediment. The study has identified twelve genera of burrowers during the sampling activities, including species like *Alitta succinea*, *Menippe mercenaria*, *Scylla serrata*, *Ocypodidae sp.*, *Plebidonax deltoides*, *Cerithidea obtusa*, *Boleophthalmus pectinirostris*, *Paguroidea sp.*, *Hediste diversicolor*, *Donax vittatus, and Donax gouldii.* The

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highest individual number recorded among the two sampling areas totals 133 individuals and the most populous species in the BNO mangrove area was *Menippe mercenaria*, with a recorded count of 34 individuals. Meanwhile, there are 15 individuals of *Scylla serrata* the highest population in KGP. These genera were observed to be distributed in specific zones within the mangrove habitat that suited their living conditions, showing the burrowers have preferences for zones. There is a positive trend in bioturbation frequency regarding the zonation as seen in both BNO and KGP (Figure 7). Where this shows as the zonation changes, the bioturbation frequency also changes. This is due to the inundation period and desiccations effect where burrowers prefer landward areas with nutrient and food availability, which can be a challenge for burrowers to find food and shelter from the scorching sun in the front area, especially during the low tide events (Fusi et al., 2022).

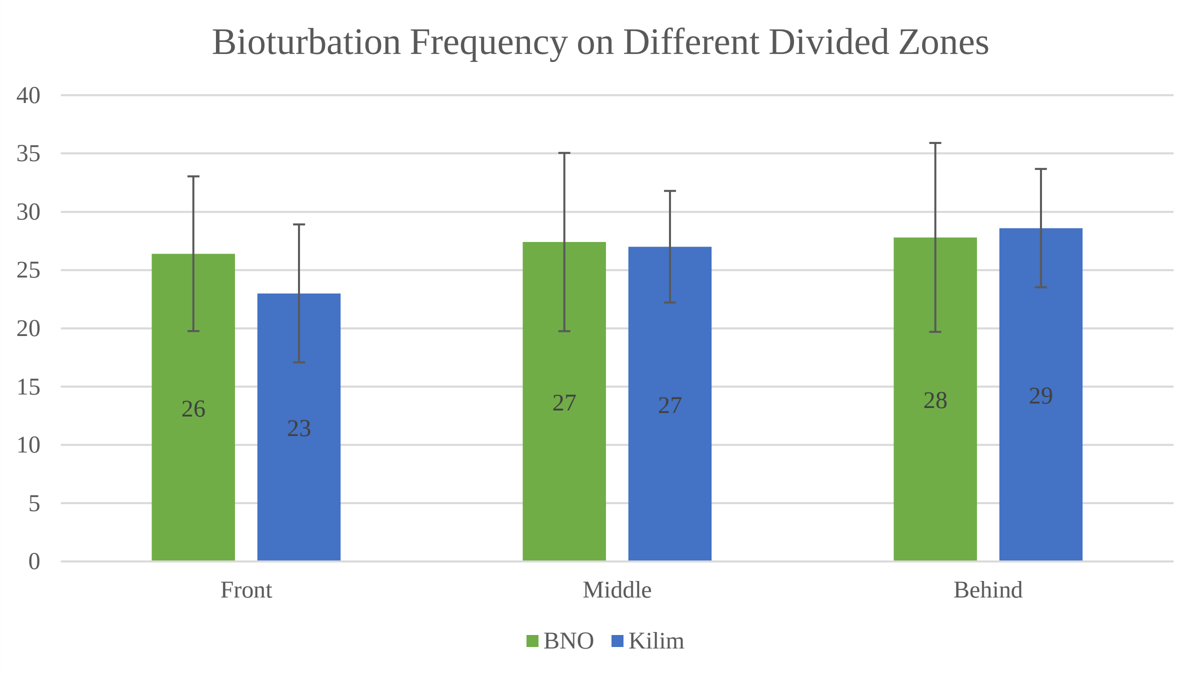

Figure 7: The Graph Of Comparisons Of Bioturbation Diversity Index At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected According To Their Zone Divided From Water Bodies To Landward.

In purpose to identify and analyse the diversity of burrower species, the study employed the Simpson index and Shannon-Weiner index (Egawa et al., 2021). The Simpson index focuses on counting more common or dominant species, meaning that a few rare species do not significantly affect diversity. On the other hand, the Shannon-Weiner index is strongly influenced by both species' richness and the presence of rare species, providing a comprehensive assessment of biodiversity in the studied area. The study finds the highest bioturbation diversity is in the BNO mangrove area, with a reading of 1.67 and KGP had a reading of 0.65 (Figure 8). These data show that the BNO mangrove area has a higher bioturbation species richness and the presence of particularly rare species. Areas closer to the coastline exhibited higher species richness, particularly in the front and middle zones, as compared to the zone behind, as supported by mathematical analysis. Additionally, the Simpson diversity index, which also assesses the bioturbation species diversity, was highest in the BNO mangrove area with a value of 0.79 and KGP had the lowest index at 0.29. These findings further confirm that the BNO coastal mangrove area exhibits the highest bioturbation

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diversity and variety of species when compared to the other mangrove areas in different geographic settings, based on the calculated diversity indices.

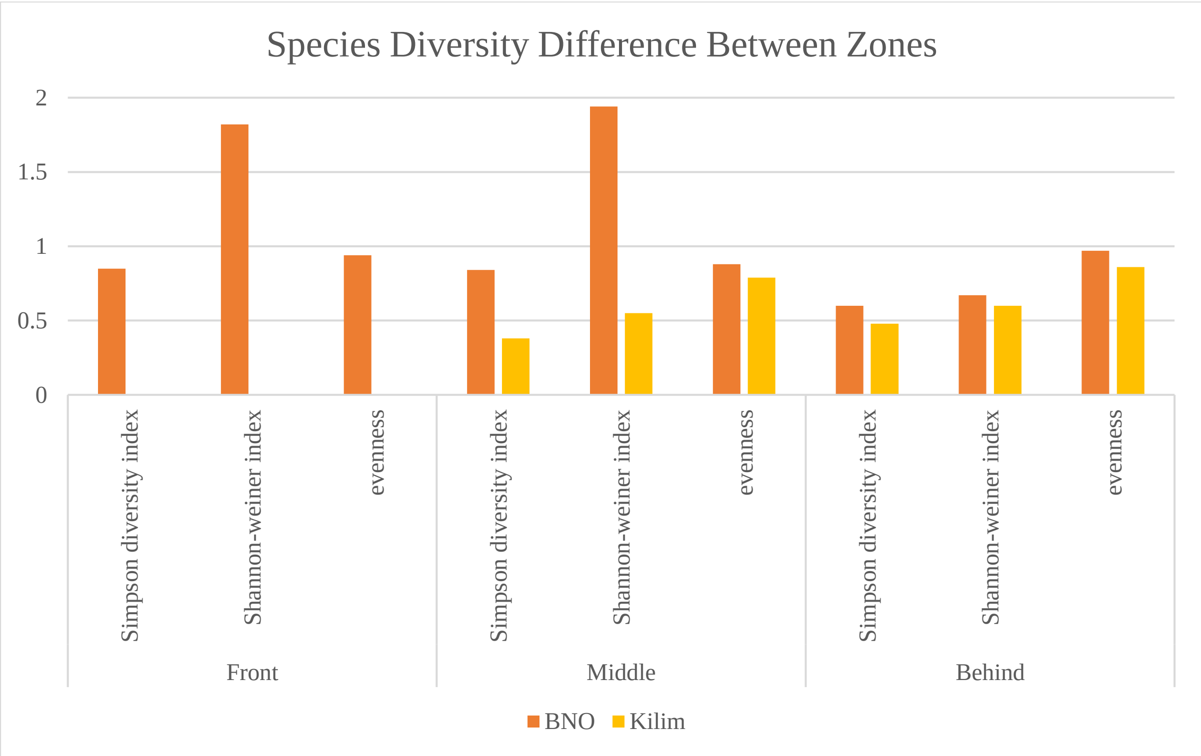

Figure 8: The Graph Of Multiple Bioturbation Diversity At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected According To Their Zone Divided From Water Bodies To Landward.

Relationships of Different Physical Attributes on Bioturbation Frequencies

Utilizing two-way ANOVA, this study found that the BNO mangrove area had the higher mean bioturbation frequency values for each zone, with the middle zone recording an average frequency of 38.75, which is significantly different from the front and behind zones with frequencies of 20.25, and 12.25 relatively (Table 2). In comparison, the KGP mangrove area had a lower mean bioturbation frequency of 14.00 which is similar to BNO where the middle is significantly different from the front and behind zones.

Table 2: The Two-Way Analysis Of Variance (ANOVA) Between Sites, Zones, And Bioturbation Frequency At Channel (KGP) And Coastal (BNO) Mangroves Within The Study Area Selected.

	BNO	KGP
BEHIND	12.250 ± 3.862 ^{A,b}	6.250 ± 1.893 ^{B,b}
MIDDLE	38.7500 ± 9.743 ^{A,a}	14.000 ± 1.826 ^{B,a}
FRONT	20.2500 ± 10.210 ^{A,b}	7.7500 ± 1.500 ^{B,b}

*Note: Capital letters (A, B) represent significant differences on study sites (BNO, KGP), and small letters (a,b) represent significant differences for the zonation from water bodies landward (front, middle, behind).

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The results highlight a notable influence of the mangrove area on bioturbation frequency, with the BNO mangrove area consistently showing higher mean values than the KGP mangrove area. There is also observed mean bioturbation frequencies vary distinctly across different zones of front, middle, and behind. Specifically, the middle zone consistently records the highest values for both BNO and KGP mangrove areas, providing insights into how bioturbation is distributed within these zones. The observed variations in bioturbation may have cascading effects on nutrient cycling, sediment dynamics, and overall ecosystem health (Pan et al., 2023). This suggests that the type or characteristics of mangrove areas play a significant role in shaping the bioturbation patterns.

Both regions show different physical attributes in particle size analysis (PSA), where the channel mangrove has the highest percentage of silt and clay compared to the coastal mangrove, showing the sediment at the channel's mangrove is finer compared to the coastal mangrove. The fine sediment will allow the burrowers to make the bioturbation process easier. However, the result of this study shows a different perspective due to the presence of high human activity around channel mangroves causing the resuspension and disturbance of sediments (Ismail et al., 2018; Goedefroo et al., 2023).

In the assumption that the highest mean value for species richness and population occurs linearly to the highest distribution of bioturbation. The result of this statistical analysis proves that the coastal mangrove area of BNO has the highest mean values for species richness, population, and bioturbation distribution compared to the channel mangrove area (KGP). Given the differences in bioturbation frequency between BNO and KGP mangrove areas, the study underscores the importance of considering mangrove characteristics when developing management and conservation strategies. Tailoring approaches based on the unique ecological dynamics of each mangrove area could enhance the effectiveness of conservation efforts and ecosystem management.

Conclusion

In a nutshell, bioturbation is a key ecological process influencing sediment structure, nutrient cycling, and microbial activity and this study has identified parameters and locations for the distribution of bioturbation, focusing on mangrove species, sediment characteristics towards species richness for burrowers, and frequency of species. The findings of the study suggested that the physical attributes of KGP and BNO do possess distinct characteristics that influence the difference in bioturbation frequency and organism biodiversity between coastal and channel mangrove areas, thus reaching the study objectives outlined. Realizing the difference between the two types of mangroves from the point of view of bioturbation allows for better planning to ensure that human activities do not affect the natural biodiversity in the area. Using diversity indices like Shannon-Weiner's and Simpson's, the study found that the BNO coastal mangrove area exhibited the highest species richness and frequency of burrowers than the KGP mangrove in the selected study area. The results indicated a rich and varied bioturbation process in that mangrove area. Studying in mangrove areas is challenging in terms of accessibility, and this limitation is also an advantage to the mangrove forest itself in preventing the invasion of predators and protecting small burrowers from carrying out their functions within the area. Looking ahead, the study suggests future research should consider the monsoon cycle's influence on habitat environments and animal populations, future studies should conduct sampling in the same month across all areas to account for these seasonal variations.

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