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Spatial and temporal distribution of macrobenthic polychaetes (Animalia: Annelida) comparing mangrove forest and aquaculture zone at Karimunjawa Island, Jepara District, Indonesia

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Abstract. *Putro SP, Sihab A, Titisari RS, Anarizta LA, Hodaifa G. 2024. Spatial and temporal distribution of macrobenthic polychaetes (Animalia: Annelida) comparing mangrove forest and aquaculture zone at Karimunjawa Island, Jepara District, Indonesia. Biodiversitas 25: 178-189.* Polychaetes are bioindicator of pollution in a water area due to their high abundance and sensitivity to different organic matter content in sediment. This study aimed to determine the type and structure of the community and the correlation of polychaeta community structure with environmental characteristics in the waters of the mangrove area and the aquaculture zone of BTN Karimunjawa, Central Java. Sampling was done using the Random Sampling method at three stations each in KJABB IMTA, monoculture and mangrove. Data processing using Two-way ANOVA test, k-dominance curve, Multidimensional Scaling (MDS), Principal Component Analysis (PCA), and BIO-ENV. In this study, 9 families and 16 genera of polychaeta were obtained and Spionidae family group ranked first in the abundance of organisms. The calculation of the index shows that the level of diversity and uniformity is low-medium, with no dominance in general. Based on the results of the Two-way ANOVA test showed no significant differences in the composition of polychaeta variability, spatially and temporally. The MDS ordination plot shows the grouping of organism variability between stations based on their biological composition. Further analysis using k-dominance curves showed that station 2 monoculture had the highest level of diversity and the lowest level of dominance. BIO-ENV analysis proves that environmental parameters with a strong influence on polychaeta abundance include C-organic, pH and coarse sand fraction (r: 0.418). PCA analysis showed clustering based on sediment substrate size composition (silt, coarse sand, gravel). This study indicates that polychaeta community structure between stations and periods showed no significant differences, and the relationship between biotic and abiotic parameters showed that C-organic, pH and coarse sand fraction are some of the abiotic parameters that most affect the abundance of polychaeta.

Keywords: Aquaculture, coastal region, macrobenthic polychaetes, mangrove, Spionidae

INTRODUCTION

Coastal regions are endowed with diverse natural resources, supporting various economic activities such as aquaculture, conservation, and marine tourism (Calleja et al. 2022). However, in Indonesia, these areas are increasingly impacted by unsustainable human activities, causing habitat loss, species displacement, erosion, and sedimentation, especially in estuaries (Rizal et al. 2020; Adyasari et al. 2021). In the Karimunjawa Islands, the local community engages in various natural resource utilization activities within their diverse coastal and coral reef ecosystems, with fishing zones serving as major tourist attractions (Lukman et al. 2022; Setiyanto et al. 2023). The intensification and diversification of anthropogenic activities in the coastal zones of the Karimunjawa Islands pose significant threats to environmental equilibrium, impacting local biodiversity (Putra et al. 2024). This degradation is especially concerning in shallow water and mangrove ecosystems, where increasing pollution and habitat disruption have led to a loss of native species and a risk of invasion by non-native species (Wijaya et al. 2021; Fajrin et al. 2024). Environmental quality disruptions can undermine ecosystem stability and favor the dominance of invasive species.

Macrobenthic organisms, which play a vital role in food chains and ecosystem functioning, are among those most affected by environmental changes (Souza et al. 2021). Anthropogenic impacts generally extend to these benthic organisms, whose responses can significantly influence overall ecological processes within ecosystems (Farantika et al. 2020; Putro et al. 2022). Given ongoing pollution, it is crucial to continuously monitor environmental parameters, including physical, chemical, and biological factors. Biomonitoring, which uses living organisms to assess pollution levels, is a valuable method for tracking environmental changes (Pastorino et al. 2020). Macrobenthic organisms are commonly used as bioindicators due to their important ecological roles and sensitivity to environmental conditions (Nkwoji 2023). Macrobenthos organisms are invaluable to coastal and marine ecosystems, performing essential ecological functions such as serving as food web components, improving sediment structure, aiding in nutrient cycling, moving materials, and contributing to decomposition processes. They are frequently used for routine biomonitoring assessment and environmental studies to assess environmental disturbance. Typically, macrobenthic animals remain in the same location throughout their lives, especially sedentaria group, enabling them to be suitable for site-specific impact assessment. Other characteristics that made macrobenthos a suitable bioindicator agent are easily identified (taxonomically), slow-moving, easily found, and having high correlation to certain habitats, species, and other taxa groups that able to determine water quality (Hutton et al. 2015; Sahidin et al. 2021; Chowdhury et al. 2022; Putro et al. 2023). Around 80% of benthic organisms are epifauna, organisms that adapted to living within solid substrate. The rest of it is endofauna, which inhabit soft sediments. Macrobenthic organisms adapted to specific ecological niche, which can be seen through their behavioral patterns and morphological properties (Hemery et al. 2015; Putro 2024).

Polychaetes, a class of annelid worms, are particularly important in assessing the health of aquatic ecosystems. Polychaetes serve as excellent bioindicators for detecting pollution due to their abundance and sensitivity to varying organic matter content in sediments (Wafula et al. 2020). Their abundance, slow movement, and broad distribution make them effective bioindicators for identifying pollution and assessing habitat quality. Additionally, polychaetes' sensitivity to different organic matter content in sediments allows them to provide indirect estimates of ecosystem health (Priyandayani et al. 2018). Besides their role in organic matter decomposition within mangrove ecosystems, polychaetes also contribute to seabed sediment stabilization through activities, such as dredging, borring, bioturbation, thus highlighting their importance in these environments. Their population structure, including species composition, abundance, and biomass, offers indirect insights into ecosystem health, particularly in disturbed areas (Putro et al. 2022; Maximov and Berezina 2023). Moreover, the effectiveness of polychaetes as bioindicators stems from several factors, such as their wide distribution, slow movement, ease of collection, and year-round availability (Mdaini et al. 2021).

The Karimunjawa Islands, with their unique combination of mangrove areas and aquaculture zones, provide a diverse habitat that is ideal for studying macrobenthic polychaetes. These ecosystems present distinct environments where polychaetes flourish, making them excellent subjects for investigating the impacts of human activities. Despite their ecological importance, research on polychaetes in the waters surrounding Menjangan Besar Island in Karimunjawa is still limited. Therefore, continuous and systematic studies are needed to monitor environmental conditions, focusing on the spatial and temporal distribution of macrobenthic polychaetes and the implications of organic enrichment on community disturbance levels in these habitats.

MATERIALS AND METHODS

Study area

Research was carried out using the Purposive Random Sampling Method in July and September 2021, at Karimunjawa Island, Jepara District, Indonesia. Sampling locations consist of 3 stations, i.e. IMTA cage site (5°52'56.5"S, 110°25'41.2"E), monoculture site (5°52'57.5"S, 110°25'43.5"E) and mangrove areas (5°49'22.5"S, 110°27'54.4"E), with 3 replicates for each station (Figure 1). Polychaeta identification, observation and sorting were carried out at the Integrated Laboratory, Universitas Diponegoro. Substrate texture and organic material analysis will be carried out at the Soil Mechanics Laboratory and Environmental Engineering, Universitas Diponegoro.

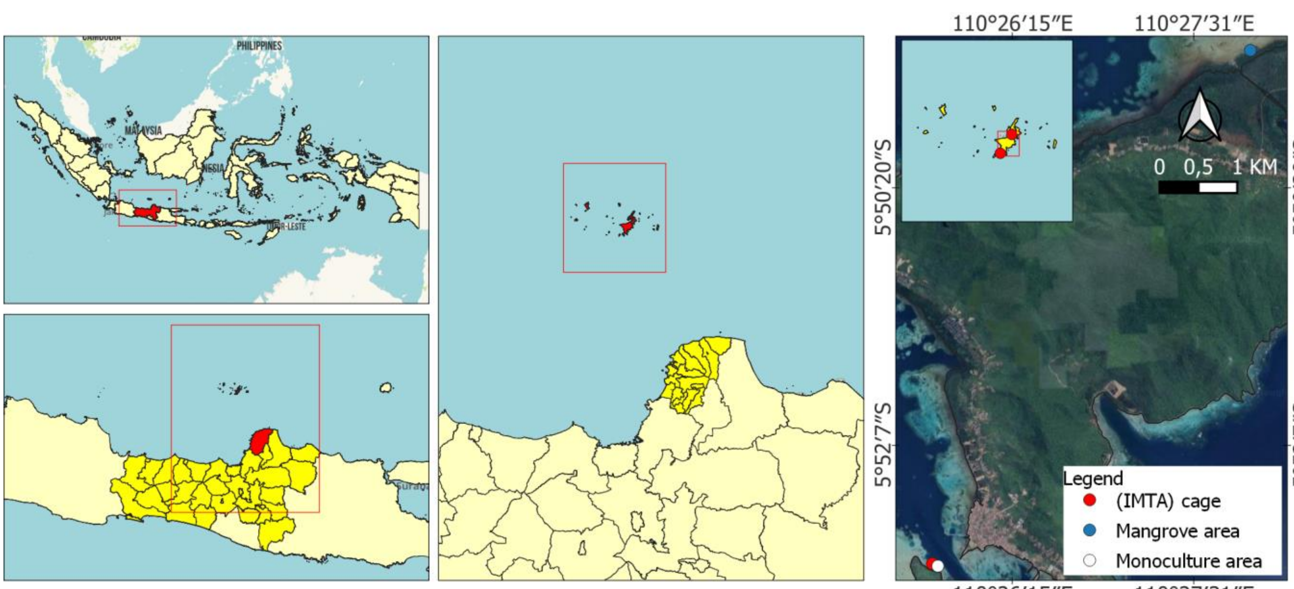

Figure 1. Map of sampling stations, representing mangrove area, monoculture area, and IMTA cage sites at Karimunjawa Islands, Jepara, Central Java, Indonesia

Table 1. Description of each sampling location

Station	Coordinate	Sampling location	Description
1	5°52'56.5"S, 110°25'41.2"E	Integrated Multi-Trophic Aquaculture (IMTA) cage	Active aquaculture site with IMTA method
2	5°52'57.5"S, 110°25'43.5"E	Monoculture area	Active aquaculture site with conventional monoculture method
3	5°49'22.5"S, 110°27'54.4"E	Mangrove area	Estuarine mangrove area with minimum anthropogenic activities

Sampling methods

Physical parameter measurements were conducted concurrently with the collection of water and sediment samples. At each designated station, sediment was collected using an Ekman Grab (152×152×152 mm) and transferred to labeled plastic jars. To preserve sample integrity, 10 drops of 10% formalin were added immediately after collection. Following preservation, the samples were rinsed and filtered to remove extraneous materials, and polychaete specimens were isolated from sediment particles through sieving. Using a Nikon SMZ25 high-resolution stereomicroscope, the specimens were sorted, placed in micro vials containing 70% ethanol, and systematically cataloged by collection station. Species identification was performed using a taxonomic guide, and the macrobenthic polychaete species were recorded along with relevant indices. These processes took place at the Center of Marine Ecology and Biomonitoring for Sustainable Aquaculture (Ce-MEBSA), Universitas Diponegoro, with sample collection and identification repeated at one-month intervals at the same stations and replicate sites. The identification of polychaetes species, we used several identification books such as "*Polychaetes*" by Rouse (2001), "*The Polychaete Worms: Definitions and Keys to the Orders, Families and Genera*" by Fauchald and Pleijel (1977), and "*Polychaetes and Allies: The Southern Synthesis*" by Pamela et al. (2000).

Sediment samples underwent thorough analysis for grain size composition using stacked sieves on a mechanical shaker to differentiate between coarse and fine sand fractions. A hydrometer analysis quantified finer sediment fractions silt (particles <62 microns) and clay (particles <4 microns) following Folk's (1974) methodology. Additionally, total nitrogen (N total) and total organic carbon (C organic) content were measured to evaluate organic matter levels. The measurement of N total used wet destruction + indophenol method, while C organic used Walkley & Black method (Jha et al. 2014; Sumartono et al. 2023). Water quality assessments utilized the U50-Horiba Water Quality Checker (WQC) to measure temperature, pH, salinity, and dissolved oxygen (DO) at a depth of 50 cm below the water surface, ensuring alignment of sediment and water sampling stations for consistency.

Data analysis

The identified macrobenthos organisms were analyzed using Shannon-Wiener diversity index (H'), to determine the level of diversity in each location. The formula of H' is as following (Lu et al. 2011):

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

Where,
H' : Shannon-Wiener diversity index
pi : The proportion of individual of species i
ln : Natural log

Data analysis employed both parametric and non-parametric methods. Parametric analyses were performed using IBM SPSS Statistics 25. Two-way ANOVA was used when the source of diversity that occurs is not only due to one factor (treatment). Other factors that may be the source of response diversity must also be considered. These other factors can be other treatments or factors that are already conditioned. Consideration of including a second factor as a source of diversity is necessary if the factors are grouped (blocks), so that the diversity between groups is very large, but small in the group itself. If the results show a significant difference, it will be tested further using Tukey's post hoc HSD (Honestly Significant difference) for several comparisons ($p \leq 0.05$).

Non-parametric analyses were conducted with PRIMER v6.1.5 software to investigate the relationships between environmental factors and the structure of the polychaeta community through visual two-dimensional diagrams (Legendre 2012). The data processing methods for non-parametric analysis included Multi-dimensional Scaling (MDS), Principal Component Analysis (PCA), BIO-ENV, and *k*-dominance curves. The non-parametric analysis incorporated data on the polychaeta community, sediment substrate composition, sediment chemical properties, and water parameters.

MDS analysis was conducted to determine the grouping of polychaeta variability based on abundance and number of species, while BIO-ENV evaluated the correlations between environmental quality and polychaeta abundance using the Pearson correlation coefficient between distances in the response matrix and the environmental distance matrix. Sediment and water data underwent square root transformation and were normalized using Euclidean Distance Similarity. The schematic diagram of the BIO-ENV procedure is presented in Figure 2, illustrating the steps taken to analyze the relationship between sediment and water quality parameters and polychaeta abundance.

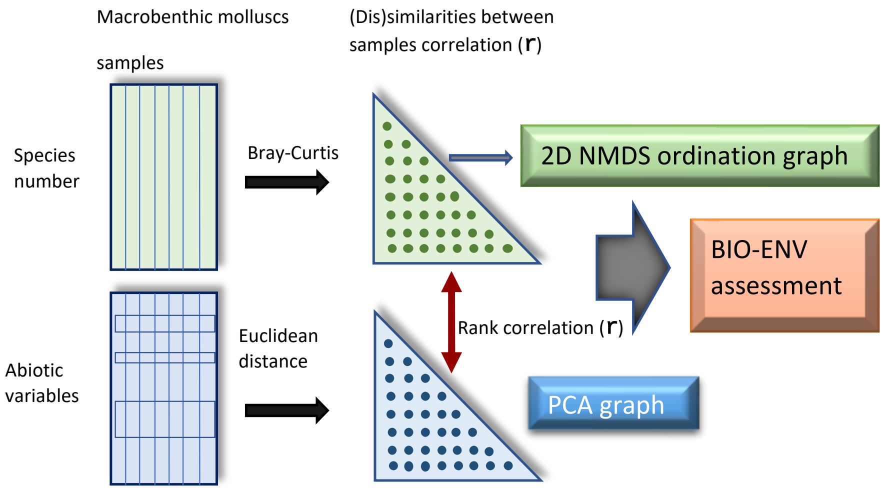

Figure 2. Schematic diagram of the MDS, PCA and BIO-ENV procedure: selection of the abiotic variable subset maximising rank correlation (p) between biotic and abiotic (dis)similarity matrices (modified from Clarke and Warwick 2001; Putro et al. 2023)

RESULTS AND DISCUSSION

Polychaeta is a group of macrobenthos animals that have community structure dynamics that are influenced by variability in the quality of the aquatic environment and sediments. Some species are sensitive to environmental changes, especially the organic content of the substrate, while others are able to survive in unfavorable (extreme) environmental conditions. Based on the results of sampling, polychaeta found in the stations of the aquaculture zone (KJABB IMTA, monoculture area) and mangrove areas Kemujan Island, Karimunjawa sampling at all stations and time obtained 9 families and 16 genera. Families found include Capitellidae, Maldanidae, Nephtyidae, Nereididae, Oweniidae, Paralacydoniidae, Paraonidae, Spionidae, Trichobranchidae. Similar polychaeta families are found in the West African continental margin (Sobczyk et al. 2021).

High abundance of families and genera registered make remember what was recorded on the Ghanaian coast (253 polychaete species). Direct total species richness comparison with other regions of the world is not reasonable and difficult, because sample collection is varied from one study to other, specially, the depth range, type of gear used, etc. As an example of another study, Boyé et al. (2019) recorded 234 polychaete species in shallow water habitats along the coast of Brittany (e.g., subtidal seagrass beds).

In this study, observations of the polychaeta class at all stations and times obtained 16 genera namely *Capitella* sp., *Clymenella* sp., *Maldane* sp., *Praxillella* sp., *Nephtys* sp., *Namalycastis* sp., *Owenia* sp., *Myriochele* sp., *Galathowenia* sp., *Paralacydonia* sp., *Aricidea* sp., *Spiophanes* sp., *Spio* sp., *Scolelepis* sp., *Prionospio* sp., and *Terebellides* sp.. The obtained image of several polychaetes, based on the results of the Two-way ANOVA test showed no significant differences in the composition of polychaeta variability, spatially and temporally. This indicates that the sampling stations are more likely to have a similar macrobenthic polychaetes structure. The images of obtained polychaetes in this research can be seen in Figure 3, while the proportion of polychaetes abundance can be seen in Figure 4. The polychaete family Spionidaea (27-38%) and Oweniidea (26-33%) are the most abundant in the samples collected.

At the IMTA area, the community was dominated by Spionidae (37%) and Paralacydoniidae (30%), suggesting that a few families dominate, likely influenced by specific environmental conditions such as water quality and organic matter, which create favorable conditions for opportunistic species like Spionidae (Putro et al. 2020). Similarly, the monoculture area was also dominated by Spionidae (38%), but the presence of other families such as Maldanidae (26%) and Oweniidae (15%) indicates a slightly more diverse composition compared to the IMTA area. The dominance of Spionidae highlights its opportunistic nature in organic matter-rich environments. Spionidae is usually one of the most found polychaeta families in deep-sea soft sediments (Quintanar-Retama et al. 2022). Spionids are frequently categorized as interface feeders, meaning the animals can switch from surface deposit feeding to suspension feeding as water current speeds and the flux of suspended food increase (Taghon et al. 1980).

The presence of taxa like Maldanidae and Oweniidae suggests greater compositional diversity in the monoculture area. These results are likely influenced by more controlled farming practices, though the area still exhibits some species dominance by opportunistic or tolerant taxa (Putro et al. 2020). Oweniidae has been extensively reported from around the world, in water temperatures from 1 to 30ºC and from the intertidal to depths exceeding 2 km (Dauvin and Thie-baut 1994). Koh and Bhaud (2001) tested populations of Owenia from the Mediterranean and southern Korea. Furthermore, Giangrande et al. (2021) emphasized the ecological importance of polychaetes, which are widespread across marine ecosystems and play a significant role in the functioning of benthic communities. They establish high densities in some seabed habitats and act as ecosystem engineers by providing new substrates for other benthic species.

Table 2. Polychaeta abundance data

Family, genus	Average abundance of polychaeta (ind.m^{-2})		
	IMTA	Monoculture	Mangrove
Capitellidae			
Capitella sp.	0	40	100
Maldanidae			
Clymenella sp.	0	80	0
Maldane sp.	0	20	80
Praxillella sp.	20	100	0
Nephtyidae			
Nephtys sp.	0	120	0
Nereididae			
Namalycastis sp.	80	0	0
Oweniidae			
Owenia sp.	20	0	80
Myriochele sp.	60	0	0
Galathowenia sp.	80	20	20
Paralacydoniidae			
Paralacydonia sp.	60	80	0
Paraonidae			
Aricidea sp.	0	20	0
Spionidae			
Spiophanes sp.	80	0	20
Spio sp.	100	120	0
Scolelepis sp.	20	120	0
Prionospio sp.	0	60	0
Trichobranchidae			
Terebellides sp.	20	0	0
Total abundance	540	780	300
Total species	10	11	5

In the Mangrove area, there was a more even distribution among families, with Capitellidae, Maldanidae, and Spionidae each contributing 27-33%. This result suggests a balanced and diverse community structure, typical of a natural, less disturbed environment where species co-exist more equitably. The mangrove area had positive effects on macrobenthos abundance and diversity, enhancing sediment stability, habitat complexity, and protection from predators (Miri et al. 2023).

The Shannon-Wiener diversity index (H') of polychaetes in this research ranged between 0.828-1.550. The H' index in IMTA and monoculture station were higher than in mangrove station. Supported by Parakkasi et al. (2019), higher diversity in aquaculture zones can be caused by organic enrichment and aquaculture management, leading to increasing abundance and diversity of macrobenthic organisms. The graph of Shannon-wiener diversity index (H') of this research can be seen in Figure 5.

Multi-Dimensional Scaling (MDS) analysis with abundance and number of polychaeta species

Multi-Dimensional Scaling (MDS) analysis was conducted using polychaeta abundance and genus count data transformed with Log(x+1). The reason for utilizing abundance data in MDS analysis is that this type of raw data is complex, containing many variables. MDS facilitates the transformation of this data into visually representative and informative formats. Clarke (1993) noted that MDS allows for the visualization of abundance data in a lower-dimensional space, which aids in understanding and interpreting data structures visually. Abundance data is often high-dimensional, representing the presence or abundance of multiple species; thus, MDS helps reduce this dimensionality, resulting in more concise yet informative data. Furthermore, the Bray-Curtis matrix was employed to determine the similarity of the data. The ordination plot of the MDS analysis results can be seen in Figure 6. This non-metric multidimensional scaling method was used to provide a visual interpretation of the polychaeta community data for each station.

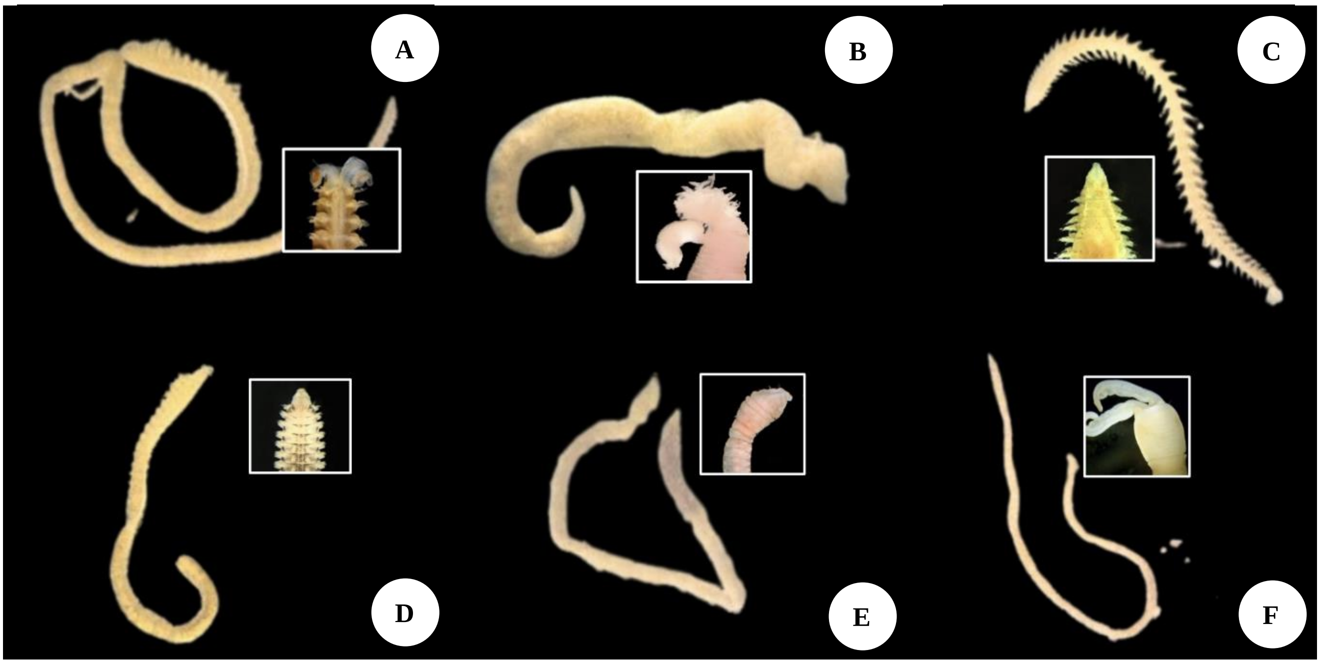

Figure 3. Documentation of obtained polychaeta in this research: A. *Spiophanes* sp.; B. *Terebellides* sp.; C. *Paralacydonia* sp.; D. *Spio* sp.; E. *Capitella* sp.; F. *Galathowenia* sp. INSET: morphology of prostomium for each species

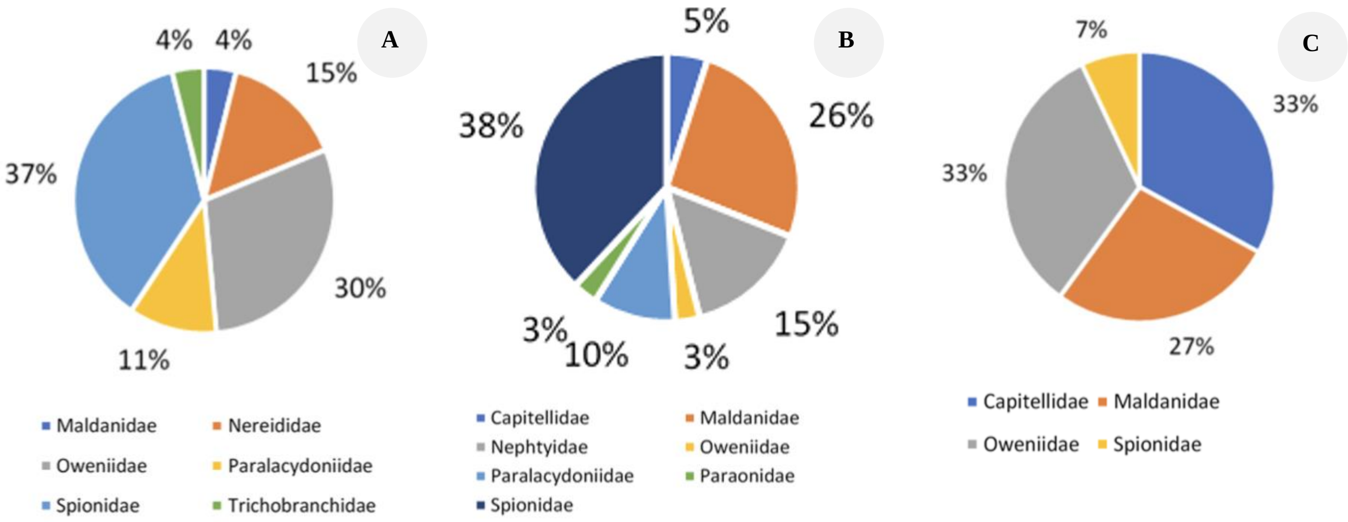

Figure 4. Diagram of polychaeta family average abundance proportion in each sampling station. A. Polychaeta family average abundance proportion in IMTA site; B. Polychaeta family average abundance proportion in monoculture site; C. Polychaeta family average abundance proportion in mangrove site

The MDS based on polychaete abundance highlighted several distinct major and minor clusters of individuals from the analyzed areas. Variability among organisms across sampling periods resulted in groupings between stations, leading to the formation of three groups of polychaeta based on their biological composition. This indicates that the biota composition of each group differed. Overall, the spatial and temporal dissimilarity among the three areas was confirmed by the MDS results (Figure 6). Based on MDS analysis, IMTA stations (L1T1, L1T2, L1T3) show consistency in polychaeta species compositions over time (July and September) and often cluster with some monoculture stations (L2T1, L2T2, L2T3), suggesting similar environmental conditions across both IMTA and monoculture areas. These results are further supported by the similarity in polychaeta families, with both IMTA and monoculture areas being dominated by Spionidae and Maldanidae families. According to Díaz-Castañeda and Harris (2004), the ability of Spionidae to thrive in nutrient-rich environments is a key physiological adaptation that explains their dominance in these areas. Spionidae, which are deposit feeders, allow them to thrive in environments rich in organic matter, typically associated with aquaculture practices (Chor et al. 2022). The residual organic material in these sediments, likely from feed residues in monoculture area, enables Spionidae and other opportunistic taxa to rapidly exploit these conditions.

However, there are slight differences in the proportions of less dominant families, such as the higher presence of Paranoidae and Owenidae in monoculture area, which might account for some variation, but it does not lead to significant separation in MDS result. The temporal consistency observed in both areas, indicated by the close clustering of stations from July and September, supports the result that these environments provide stable conditions for polychaeta families, with minimal seasonal fluctuation in family composition. According to Sahidin and Wadianto (2016), differences in the variability of polychaeta structure are caused by differences in sediment substrate type and organic matter content. The highest abundance is in the station of monoculture, which is presumably related to abiotic factors such as organic matter and coarse sand substrate type. Additionally, Díaz-Castañeda and Harris (2004) stated that the Spionidae and Capitellidae families are deposit feeders that consume organic matter that remains in the sediment. Both families are included in opportunistic taxa that can quickly exploit organic-rich sediments. The residual organic matter is thought to be the feed residue from aquaculture practices at monoculture area. According to Díaz-Castañeda and Harris (2004), an increase in the organic matter content of the sediment can result in an increase in deposit-feeding species. Martinez et al. (2013) noted that the Maldanidae family includes species sensitive to various contaminants, while the Nephtyidae family is considered a bioindicator.

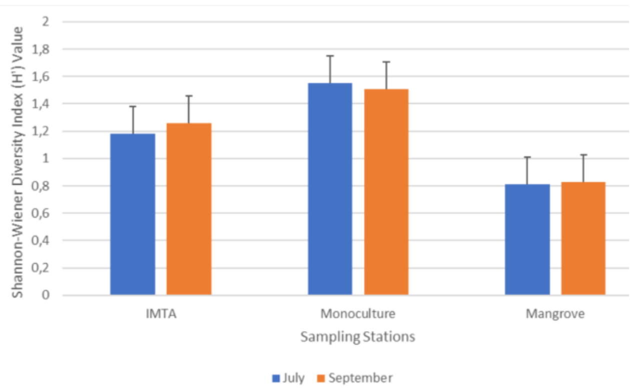

Figure 5. Histogram of average Shannon-Wiener diversity index (H') value

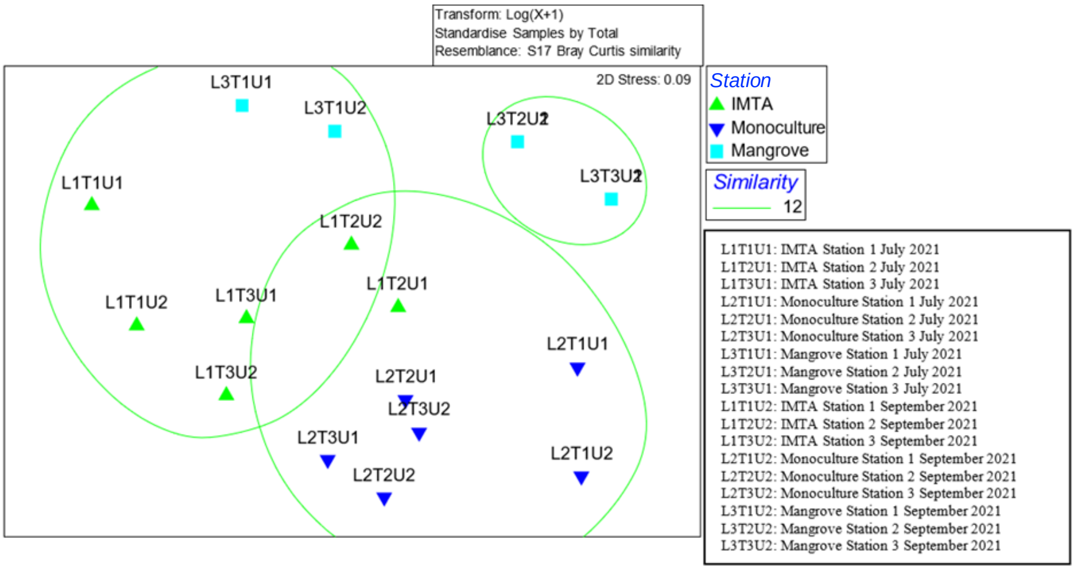

Figure 6. Results of MDS analysis with abundance and number of polychaeta species

In contrast to the IMTA and monoculture areas, the mangrove area (L3T2, L3T3) exhibits a distinct polychaete family structure. This result is likely due to the strong presence of Oweniidae and Capitellidae (Figure 4), which suggests physiological adaptations to the unique environmental conditions in mangrove ecosystems, resulting in clear differentiation from the IMTA and monoculture areas in the MDS results. This suggests that the environmental conditions in the mangrove area are significantly different from those in the aquaculture conditions, leading to the abundance of specific polychaeta families. The distinct clustering of the mangrove stations in the MDS results indicates that this site, in particular, may have environmental conditions that set it apart even from other mangrove stations (L3T1). Furthermore, the stability of this station's community over time (July and September) suggests that these conditions are consistent, providing a stable habitat for the polychaeta families adapted to mangrove environments.

The differences in polychaeta family composition across IMTA, monoculture, and mangrove areas can largely be attributed to the environmental conditions and habitat characteristics of these ecosystems. The emergence of opportunistic taxa such as the Spionidae family correlates with the presence of excessive organic enrichment in the sediment, especially in monoculture sites. The presence of opportunistic taxa is thought to represent the monoculture aquaculture system, which has the potential to cause disturbances to the environment compared to the IMTA aquaculture system. According to Putro (2014), species that are included in opportunistic taxa are individuals that can take advantage of unfavorable conditions (disturbances) from their environment by increasing their reproductive power. The utilization of opportunistic taxa can help the community, especially Pokdakan (fish farmer groups), monitor environmental disturbances in the aquaculture area.

K-Dominance curve analysis using polychaeta community abundance

Further analysis using the k-dominance curve (PRIMER v6.1.5) shows a curve based on the abundance of the polychaeta community at Stations at each station and period. The results of the k-dominance curve analysis can be seen in Figure 7.

It is known that the curve of monoculture-station 2 for the July 2021 period (L2T2U1) shows below the other curves, implying that it has the highest level of diversity and the lowest dominance. The lowest diversity is found at IMTA-station 2 in September 2021 (L1T2U2), mangrove-station 3 in July 2021 (L3T3U1), and mangrove-station 1 (L3T1U2), mangrove-station 3 (L3T3U2) in September 2021. The sediment structure in the monoculture station tends to have adequate availability of organic elements for polychaeta organisms. According to the opinion of Warwick et al. (1991) the lowest curve shows the composition of the dominant fauna or the highest at its stations, while the curve that is in a position above the other curve indicates the lowest faunal composition or low diversity. In addition, organic matter had an adverse effect on the evaluation of polychaete assemblages, particularly in relation to diversity and trophic group composition. It indicates that the impact of organic matter may be more profound on entire communities than on individual species (Fernández-Rodríguez et al. 2019). Furthermore, the quantity and quality of food, as well as shifts in consumer access to it, could potentially modify the structure of benthic fauna communities and their food sources (Chen et al. 2021).

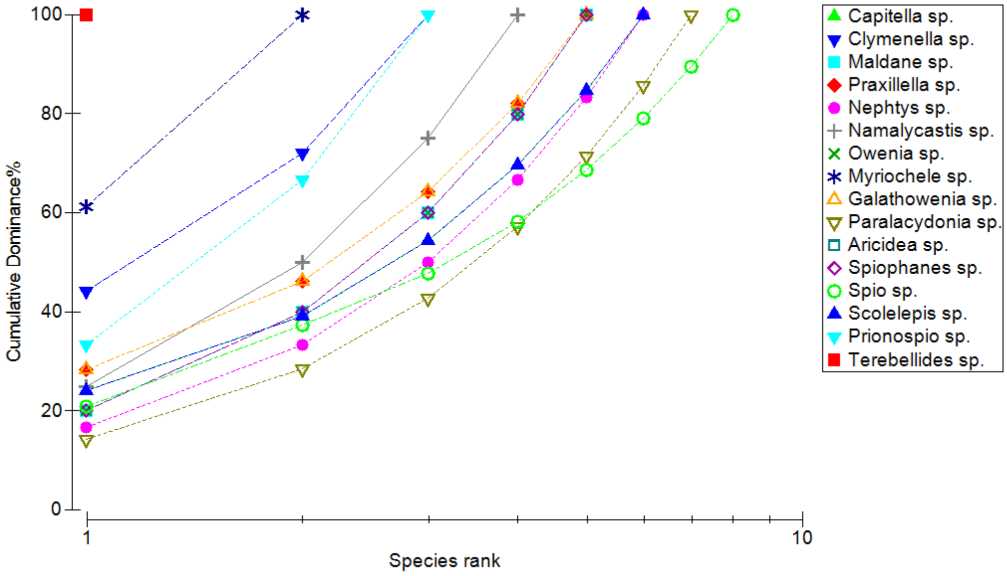

Figure 7. Results of K-Dominance curve analysis using abundance of polychaetes

Correlation between abiotic-biotic parameters using BIO-ENV analysis

The abiotic factors, comprising water and sediment physico-chemical parameters, are important in supporting the survivability of polychaetes. Obtained data of abiotic parameters in three sampling stations can be seen in Table 2 and Table 3. Further analysis was done to determine influential abiotic factors using BIO-ENV analysis.

The results of the analysis of the relationship between biotic and abiotic parameters can be seen in Table 4 shows that C-organic, pH and coarse sand fraction are some of the abiotic parameters that most affect the abundance of polychaeta (r: 0.418). It can be interpreted that C-organic, pH and coarse sand fraction are the strongest factors in the distribution of polychaeta. According to Samidurai et al. (2012), the high concentration of C-organic in the sediment will have an impact on the high diversity of polychaeta. According to Priyandayani et al. (2018), the concentration of C-organic and other organic matter in the sediment can make a food source or nutrients for polychaeta organisms that affect the abundance.

Based on BIO-ENV analysis, pH is one of the abiotic parameters that most affect the structure of the polychaeta community. The pH ranged between pH 7 to pH 9 with an average pH in both periods is 8, this value can be categorized as neutral. This range is still within the tolerance limits of polychaeta, proven in BIO-ENV nonparametric analysis, which shows that pH is one of the strong factors in the distribution of polychaeta. In accordance with the statement of Lucey et al. (2018), the abundance of polychaetes declines significantly at extremely low pH levels (as low as 6.99), creating unfavorable conditions for these organisms. pH values that fall outside the normal range, especially those below approximately 7, adversely affect the growth and recruitment of these species. This is supported by the statement from Priyandayani et al. (2018) that the pH range of the substrate that can support the survival of polychaeta is between 7.0-7.5.

The sediment in aquaculture areas has a significant impact on nutrient concentrations in the water, including oxygen and nitrogen, with sandy substrates exhibiting higher levels than muddy substrate types (Hu et al. 2022). The type of coarse sand substrate is a crucial physical factor affecting the structure of the polychaeta community. Although sandy sediments have larger particle sizes and lower viscosity, which are not conducive to phosphorus adsorption, finer particles are more prevalent in the distribution and transport of biological phosphorus and possess a greater adsorption capacity (Wang et al. 2020). Furthermore, sandy substrates generally maintain higher oxygen levels compared to mud or finer substrate types, thereby affecting nutrient availability and community dynamics. As a result, sandy sediments demonstrate weak adsorption and strong desorption capabilities, influencing nutrient provision within the ecosystem (Hu et al. 2022). Therefore, currently plays an important role in substrate type and primary products, so hydrodynamics of the current will affect sediment composition and graint size.

Analysis results using sediment and water physical-chemical parameters Principal Component Analysis (PCA)

Environmental parameters were analyzed by Principal Component Analysis (PCA), providing valuable insights into the spatial variation of sediment and water physical-chemical parameters across different aquaculture systems and natural ecosystems, including IMTA, monoculture, and mangrove areas. The results of PCA analysis at each station and period can be seen in Figure 8.

Table 3. Water parameter result

Station	Sampling period	Water parameter			
		Temperature (°C)	pH	DO (mg/L)	Salinity (ppt)
IMTA	I	24.68	7.49	9.52	37.56
Monoculture	I	24.27	9.12	9.74	40.07
Mangrove	I	21.00	8.06	10.02	39.19
Average		23.32	8.22	9.76	38.94
IMTA	II	25.11	8.64	6.24	43.95
Monoculture	II	25.17	8.39	9.60	15.29
Mangrove	II	24.43	6.99	8.93	47.49
Average		24.90	8.01	8.26	35.58

Table 4. Physico-chemical sedimentation parameter result

Station	Sampling period	Sedimentation parameter					
		Grain size composition (%)				Organic compound (%)	
		Gravel	Coarse sand	Soft sand	Silt	C-organic	N-total
IMTA	I	1.42	26.09	67.11	5.23	0.44	0.05
Monoculture	I	5.55	32.08	57.25	5.12	0.28	0.08
Mangrove	I	1.11	11.35	72.13	15.46	0.41	0.04
Average		2.69	23.17	65.50	8.60	0.38	0.06
IMTA	II	2.34	23.91	69.86	3.74	0.29	0.05
Monoculture	II	1.08	30.42	64.10	4.42	0.26	0.11
Mangrove	II	5.26	15.35	66.86	12.43	0.28	0.04
Average		2.89	23.23	66.94	6.86	0.28	0.07

Table 5. Result analysis for BIOENV to determine correlation between biotic and abiotic factors

Correlation value	Selected variables	Variable amount
0.418	1, 4, 8	3
0.416	1, 2, 4, 8	4
0.415	4, 8	2
0.414	2, 4, 8	3
0.413	8	1
0.412	2, 8	2
0.411	1, 2, 4, 5, 10	5
0.410	1, 2, 4, 5, 8	5
0.410	1, 4, 5, 8	4
0.409	2, 4, 5, 8	4

Notes: 1: C-Organic; 2: N-total; 3: Temperature; 4: pH; 5: DO; 6: Salinity; 7: Gravel; 8: Coarse Sand; 9: Soft Sand; 10: Silt

The mangrove sites show a strong association with silt, soft sand, and C-organic content, as seen from their position on the PCA result (Figure 8). These sites are characterized by muddy or sandy soils that are submerged during high tide and exposed during low tide. Mangroves, with their robust root systems, are well adapted to waterlogged conditions, filtering water and protecting coastlines from erosion. They also support a rich biodiversity, including birds, fish, and macrobenthos. This result is consistent with the known characteristics of mangrove ecosystems, which typically facilitate organic matter accumulation through their root systems, which enhance sediment stability and promote finer sediments, leading to higher sediment organic carbon content compared to other environments (Yan et al. 2024). Furthermore, numerous studies have indicated that mangroves play a significant role in facilitating sedimentation processes in coastal areas, largely due to their vegetation structures. In particular, the aerial roots of mangroves contribute to enhanced sediment trapping and accretion (Hongwiset et al. 2022). However, Herbeck et al. (2020) emphasized that excessive organic enrichment may account for the loss of up to 76% of mangrove forests, particularly due to the biogeochemical effects in estuarine areas and sediments, which are enriched with organic carbon and nitrogen compared to other coastal ecosystems. These findings highlight the role of mangroves in coastal protection and sediment deposition. The high organic content in mangrove areas provides a conducive environment for various macrobenthic organisms, including polychaeta, which rely on such conditions for habitat and nutrition, as reflected in the MDS results (Figure 5).

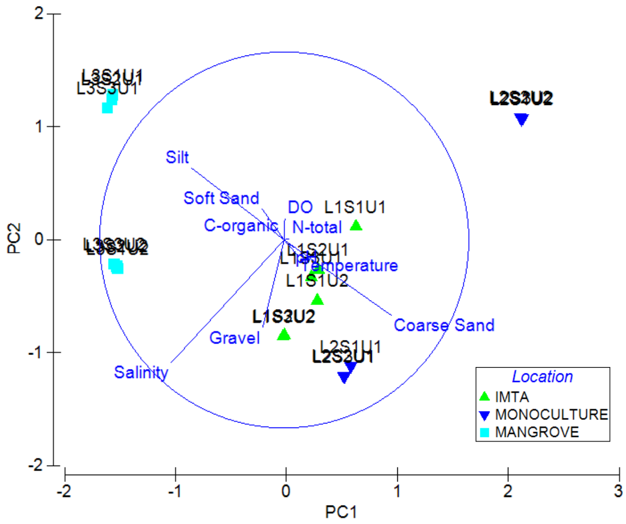

Figure 8. PCA analysis results using sediment and water physical-chemical parameters

In contrast, the monoculture sites are more closely related to coarse sand and gravel substrates. These coarser sediments are typical of intertidal zones, where tidal fluctuations influence sediment characteristics, including total organic carbon (TOC) content, nitrogen levels, and carbon/nitrogen ratios. The accumulation of organic carbon in these areas varies based on their distance from vegetated regions, leading to increased sediment movement and reduced organic matter accumulation. As a result, these coarse substrates generally have lower nutrient retention due to their limited capacity to hold nutrients over extended periods (Mao et al. 2021). Monoculture sites are typically dominated by a single type of organism, exhibiting reduced macrobenthos diversity and a higher prevalence of specific species, indicating reduced nutrient retention and primary productivity, leading to a more homogenous benthic community (Prahmawaty 2018). The particle size and type of substrate are some of the ecological factors affecting organic matter and the spread of macrobenthos. Substrates that have finer grains are more able to accumulate organic matter. A study by Putro et al. (2024) emphasized the characteristics of sediments influenced by aquaculture activities for both freshwater (Rawapening Lake) and marine water (Karimunjawa) ecosystems, in particular silk and clay composition. The spatial distribution of polychaeta communities in these systems, as shown in the MDS results (Figure 6), reflects the influence of these physical conditions, with reduced biodiversity due to limited habitat complexity compared to mangrove systems.

The IMTA area appears to be more influenced by water quality parameters, such as dissolved oxygen (DO), total nitrogen (N-total), and temperature. PCA analysis showed trends in abiotic factors of gravel substrate type that correlated with IMTA sites. This suggests that IMTA area, rather than being driven by sediment characteristics, is shaped by the quality of the water column, which is critical for the health and productivity of the multiple species cultivated simultaneously. Shinde et al. (2024) highlight that IMTA area rely on the integration of species at different trophic levels, where waste from one species is utilized as nutrients for others, leading to a more balanced and sustainable aquaculture environment. The correlation between IMTA sites and water quality parameters in the PCA supports this notion, indicating that such systems require careful management of water quality to maintain their ecological and economic benefits.

Interestingly, the PCA analysis did not show a clear temporal distinction between the July and September sampling periods. This suggests that the environmental parameters influencing these ecosystems remained relatively stable over the two-month period, with spatial variation being the primary driver of differences among the sites. This stability could be attributed to the resilience of the ecosystems to short-term environmental fluctuations or the consistent management practices in the aquaculture systems. However, longer-term studies would be needed to assess seasonal or annual variability, which could have more significant impacts on sediment composition, water quality, and biological communities.

In conclusion, polychaeta found in the station of aquaculture zone (KJABB IMTA, monoculture site) and mangrove areas Kemujan Island, Karimunjawa sampling obtained 9 families, namely Capitellidae, Maldanidae, Nephtyidae, Nereididae, Oweniidae, Paralacydoniidae, Paraonidae, Spionidae, Trichobranchidae, with 16 genera namely *Capitella* sp., *Clymenella* sp., *Maldane* sp., *Praxillella* sp., *Nephtys* sp., *Namalycastis* sp., *Owenia* sp., *Myriochele* sp., *Galathowenia* sp., *Paralacydonia* sp., *Aricidea* sp., *Spiophanes* sp., *Spio* sp., *Scolelepis* sp., *Prionospio* sp., and *Terebellides* sp. The results of the parametric statistical analysis did not reveal any significant differences in the polychaete community structure among the three sampling stations. However, subsequent multivariate analyses, including non-metric multidimensional scaling (nMDS), k-dominance curves, and principal component analysis (PCA), were able to identify distinctions in polychaete structure across the three sampling stations. The results of BIO-ENV analysis show the correlation value of abiotic factors that C-organic, pH and coarse sand fraction are some of the abiotic parameters that most affect the abundance of polychaeta (r: 0.418). The results of PCA analysis showed that each station in both periods was influenced by different environmental parameters. However, we believe that future research needs to be conducted. We recommend routine biomonitoring especially in aquaculture zones in Karimunjawa Island for maintaining the sustainability of marine ecosystem.

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