Pakistan J. Zool., pp 1-10, 2024. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20240629073450

Biodiversity of Marine Benthic Invertebrates in Port Qasim: Impacts of External Disturbances and Mangroves

Shahid Amjad[1], Jamshaid Iqbal[1]* and Muhammad Omar Arif Syed[2]

[1]*Environment and Energy Management Institute of Business Management (IoBM), Karachi, Sindh, Pakistan*
[2]*Environmental Management Consultant (Pvt) Limited, Karachi, Sindh, Pakistan*

Article Information
Received 29 June 2024
Revised 25 July 2024
Accepted 04 September 2024
Available online 4 December 2024 (early access)

Authors' Contribution
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by, SA, MO, AS and JI. The first draft of the manuscript was written by SA and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Key words
Marine benthic invertebrates, Port Qasim, Benthic ecosystem, Biodiversity, Pakistan, Karachi

ABSTRACT

From 2018 to 2022, a study was conducted in the navigational channel of Port Qasim to explore different taxonomic groups of marine benthic invertebrates (MBIs) across three different locations. The study focused on examining the distribution of nine common invertebrates. The highest average number of benthic organisms (7.8 per 10cm^3) was observed at location 3, including 9 groups. Location 2 demonstrated 5 benthic invertebrates per 10cm^3, represented by 9 groups, whereas location 1 exhibited 3 individuals per 10cm^3, comprising 7 groups. To evaluate observed differences analysis of variance (ANOVA) was applied, showing a significant difference ($p < 0.05$) among marine benthic invertebrate groups at various sampling locations. Additionally, the study investigated the correlation between Diversity (H') and Evenness (J) through linear regression analysis, revealing a weak correlation ($r^2 = 0.2598$). The variation in MBIs abundance and biodiversity across the selected locations is attributed to seasonal changes, external disturbances from port activities, and the presence of mangrove forests. Such disturbances cause alterations in duration of pollutant levels, and the flushing rates of seawater in the shipping channel, resulting in a disrupted benthic ecosystem. The long-term survival and health of marine benthic invertebrates require minimizing the impacts of external disturbances through combination of strategies such as integrated coastal zone management, reducing pollution and continuous monitoring and research.

INTRODUCTION

The marine benthic zone is generally characterized by sediment surface and sub-surface layers of the ocean. The benthic zone can be classified based on depth into; (i) littoral zone, the shallowest part of the benthic zone, (ii) sublittoral zone, extending to the continental slope from the edge of littoral zone, (iii) abyssal zone, deep-sea floor and (iv) hadal zone, the deepest part of the ocean (Torn *et al*., 2017). The marine benthic zones, with dynamic environments are considered one of the immense ecological zones in the oceans hosting a wide variety of organisms (Greene *et al*., 2008). Microorganisms like bacteria and archaea, protozoa, echinoderms, sponges, fish and invertebrates are some commonly found organisms in marine benthic zones (Choi, 2016). Typical invertebrates in marine benthic zones include, worms, mollusks (clams and mussels etc.), gastropods (snails) and crustaceans such as crabs and lobsters (Loskutova, 2020).

Marine benthic invertebrates (MBIs) mainly consist of macrofauna (between 1.0 mm and 5 mm in size) and, meiofauna (from 64 µm to 1.0 mm in size) inhibiting the interstitial spaces in between sand grains. The MBIs exhibit diverse anatomy and physiology comprising spherical, elongated and shelled body plans and from very soft to hard outer skeletons. Most of MBIs possesses asymmetrical bodies while very few have either bilateral or radial symmetries as well (Saulsbury, 2020). Marine benthic invertebrates usually live-in situations with less oxygen levels. Most have established specialized respiratory edifices such as gills and have modified their body surface to ensure maximize intake of oxygen and osmoregulation (Calado and Leal, 2015).

The vertical distribution of benthic fauna is usually restricted to the Redox Potential Depth (RPD) layer that ranges in mud flats from 10-20 cm depth in compact sediment types. Below the RPD layer is the anoxic region where anaerobic bacteria produce hydrogen sulphide

* Corresponding author: jamshaid.iqbal@iobm.edu.pk
0030-9923/2024/0001-0001 $ 9.00/0

(H_2S) by decomposing the organic matter in sediments (Nascimento and Amaral, 2023).

Marine benthic invertebrates are a vital component of marine food webs, serving as the prey for larger marine organisms. The distribution and abundance of MBIs help maintain ecological balance through influencing the dynamics of prey-predator relationships in benthic ecosystems (Yamanaka *et al*., 2012). The MBIs also contribute to nutrient cycling in benthic zones, thus, releasing essential nutrients back into the water (Mermillod-Blondin *et al*., 2005). Some benthic invertebrates, such as sponges and corals contribute to the physical structure of benthic habitats by providing breeding grounds and shelter for marine organisms (Henseler *et al*., 2019).

Corals and mollusks also contribute to carbon sequestration in marine ecosystems besides their contribution in global seafoods (Rossi and Rizzo, 2020). Currently the research is also underway to explore the medical and pharmaceutical uses of MBIs such as their potential for treating cancers and their antiviral properties. In the mangrove ecosystems, marine benthic invertebrates play crucial roles in overall well-being and functioning of these coastal ecosystems. Benthic zone in a mangrove system mainly includes the mud, sediments and the roots of mangrove trees (Cannicci *et al*., 2008). In a mangrove benthic system, the microbes decompose plant litter into organic detritus - a fundamental commodity for the transfer of energy from lower to higher trophic level (Palit *et al*., 2022). The marine invertebrates in these systems, play an important role in mixing the organically enriched bottom sediments and act as the key linkages in energy transfer in benthic food chains (Snedaker, 1984). The extensive mangrove forests along the Indus delta coastline provide crucial habitat and breeding grounds for many marine species (Ahmed *et al*., 2021).

Indus delta mangroves also serve as a crucial ecological buffer, protecting the coast from storm surges and erosion. The most common species of mangrove in the delta is the Avicennia marina which is adapted to some of the most extreme temperatures and salinity conditions in the Indo-Pacific region (Snedaker, 1984). Marine benthic invertebrates can be exposed to various external disturbances from anthropogenic (e.g., pollution, fishing and coastal development etc.) and natural (such as, storms, turbulences and wave actions) sources. These disturbances can have significant negative effects on the behavior, physiology and the overall ecological roles of MBIs (Cimon and Cusson, 2018). The coastal development activities can affect the health of benthic ecosystems by inducing the altered sedimentation patterns, habitat destruction, and increased nutrient runoff (Nepote *et al*., 2017).

Research reports that the MBIs are good indictors of physical disturbance to bottom sediments and pollution related studies (Gray, 1997; McCann, 2000). In a disturbed ecosystem, some of the populations of benthic invertebrates may be able to adapt in disturbed ecological condition and multiply, with one opportunist specie such as, the Nematode/Polycheate worms having a higher number of individuals and biomass (Gravina *et al*., 2020). However, some invertebrates are unable to withstand the external disturbances and they either migrate or sometimes perish impacting the overall biological diversity of benthic invertebrates in the area (Carrier-Belleau *et al*., 2021).

Benthic ecosystems along Port Qasim, Karachi can be the best example of disturbed ecosystems. Shipping operations, industrial activities and vehicular movements are a constant source of disturbance for these benthic ecosystems. Populations of benthic invertebrates present in surface sediments are distributed in shallow water creeks by the bow waves, created by passing vessels in the creek ecosystems. Mangroves play a crucial role in maintaining the Port Qasim benthic ecosystems by providing habitats for various invertebrate species, protecting coastlines from erosion, and serving as nurseries for many invertebrate organisms (Alamgir *et al*., 2024).

Understanding the effects of external disturbances on benthic invertebrates is the key for effective management and conservation of these ecosystems. The biological communities may vary in number of species they contain which is important in understanding the structure of the community and the overall health of the coastal ecosystems. Therefore, the present study has been designed to evaluate the MBIs biodiversity at selected locations in the study area and, to evaluate how the external disturbances at Port Qasim such as, shipping operations have affected the ecological relationships and overall biodiversity of benthic invertebrates in this ecosystem. Literature reveals very rare such studies conducted at sea ports in Pakistan therefore, the present study is expected to be a significant contribution and input particularly for the relevant policy makers in Pakistan.

MATERIALS AND METHODS

Study area

Three sampling sites were selected along the port Qasim and monitored regularly for benthic organisms from 2018 to 2022. These sampling sites are situated near an energy terminal frequently utilized by fuel transport vehicles. The Port Qasim was developed in 1978 to cope up the increasing trade in Pakistan. Port Qasim is an important economic hub of Pakistan, managing a significant portion of the maritime trade of Pakistan. It has many terminals for bulk cargo, containers and energy products. Table I presents essential characteristics of the chosen sites, while their specific locations are illustrated in Figure 1.

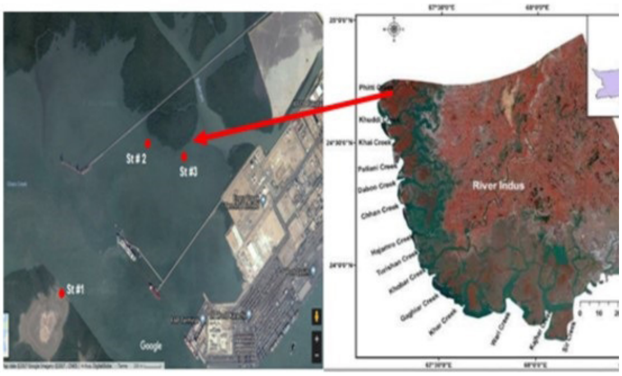

Fig. 1. Sampling locations for marine benthic invertebrates (MBIs) in the coastal creek of Port Qasim Authority (PQA).

Sampling procedures

A shallow draft boat was used to access the sampling locations. A hand-held grab sampler was deployed for the collection of bottom sediments. Submerged benthic samples were collected from depths of 2-3 meters. Sampling coordinates were recorded using a handheld GPS, aiding in revisiting the sampling locations. Through this study the sampling was undertaken during daylight hours at ebb tide.

The collected sediment samples were stored in wide-mouth plastic containers and preserved in the field using 5% formalin. The benthic sediment samples were drawn into perplex glass trays of about 20 cm length, 13.5 cm width and 4 cm height. From each sediment sample, a 10 cm^3 volume was used to evaluate the presence of benthic invertebrate organisms. All subsampling was performed in triplicate.

Two sieves of mesh sizes 1.0 mm and 5 mm were used to segregate the Macrofauna from sampling sediments whereas, for the separation of Meiofauna sieves of mesh size 64 µm to 1.0 mm were used. Rose Bengal solution with 5% strength was used for staining and identification of the organisms. The MBIs were observed under the stereo microscope photographed and, identified using standard identification sheets. Nine common taxonomic groups were considered for comparison; Foraminifera, Gastropod shells, Oligochaetes, Polycheates, Bivalve shells, Nematode, Gammarus Isopod, Insects, and Crustacean larvae.

Biodiversity Index and species evenness was employed. Communities with a large number of species that are evenly distributed are more diverse compared to the communities with few species that are dominated by a single species.

The following Shannon-Wiener diversity index was used for calculating invertebrate's biodiversity and Pielou's Species Richness/Evenness (Shannon and Weaver, 1997; Pielou, 1966).

$$\text{Shannon's Biodiversity Index (H)} = \Sigma \text{ pi} \times \ln \text{pi}$$

and $\text{Pi} = S \div N$

Where; S is the number of individuals of one species, N is the total number of all individuals in a sample and ln is the natural logarithms.

$$\text{Pielou's Evenness Index (E)} = H \div lnS$$

Where; H= Shannon's-Wiener Diversity Index and S= Total number of species in the sample

Analysis of Variance (ANOVA) was performed to evaluate the variations in abundance of the MBIs at 0.05 confidence level. Tukeys Ad Hoc test was undertaken to evaluate/compare the difference of MBIs between the locations. A simple linear regression was performed between MBIs diversity values (H') and evenness (J). All statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) and Microsoft Excel software.

Table I. Key features of sampling location for marine benthic invertebrates (MBIs).

Site No	Sampling coordinates	Key features of Sampling Site	Habitat
1	24^0 46' 06.9" 67^0 18' 15.7"	This specific sampling site encompasses the immediate effects of tanker and ship movement within the port, as well as the construction and operation of berths. Across the channel lies a vessel berthing facility where mangrove saplings have been planted.	Muddy/silt substrate
2	24^0 46' 41.7" 67^0 19' 05.5"	This site is located in close proximity to the natural mangrove population.	Muddy/silt substrate
3	24^0 46' 49.6" 67^0 19' 14.0"	This sampling location represents the protected area with natural mangrove population.	Muddy/silt substrate

RESULTS AND DISCUSSION

Over the five-year period from 2018 to 2022, nine distinct taxonomic groups were observed at the selected locations including; Foraminifera, Gastropod shells, Oligochaetes, Polycheates, Bivalve shells, Nematode, Gammarus Isopod, Insects, and Crustacean larvae. The overall order of abundance of benthic invertebrates (MBIs/10cm^3) at all selected locations was Gastropod shells >Nematodes > Oligochaetes > Polycheates > Bivalve shells > Foraminifera >Gammarus Isopod >Crustacean larvae > insects (Fig. 2).

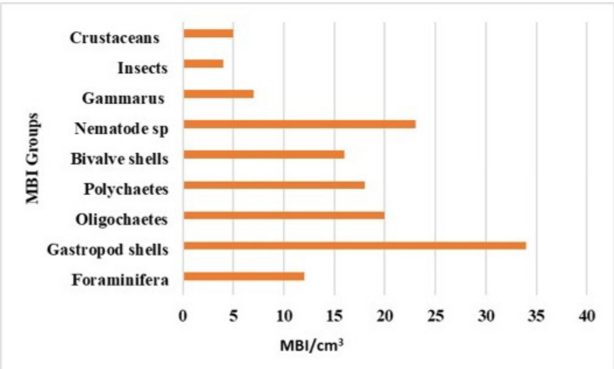

Fig. 2. Marine benthic invertebrates taxonomic groups and abundance observed from 2018-2022 at three sampling locations.

Research shows that the gastropods have improved ability to adapt in diverse substrate types and ecological niches (Leung *et al.*, 2020). This may because the gastropods exhibit multiple feeding strategies, including carnivory, herbivory and scavenging which allows them to exploit several food resources available in the benthic environments. Moreover, the reproductive strategies in gastropods are more efficient with many species producing huge number of eggs leading to high population densities (Leung *et al.*, 2020). The external disturbances at Port Qasim seem to have less influence on the diversity of gastropods because the gastropods exhibit better tolerance and resilience to environmental fluctuations such as water quantity and quality, temperature and salinity, allowing them to persist in variety of marine benthic habitats. The protective mechanisms in some gastropods such as, warning coloration and protective shells increase their chances of survival in benthic ecosystems (Diederich *et al.*, 2015). The abundance of gastropods is very important for the stability of benthic ecosystems because they play crucial roles in marine food chains and food webs serving as both predator and prey (Lajtner *et al.*, 2022).

The abundance of nematodes may be linked to the supply of detritus from mangrove roots because most of the nematodes are decomposers feeding upon dead organic materials from plants and animals (Moens *et al.*, 2013). Some nematodes can also consume other organic materials, including algae, bacteria, fungi, and other small organisms which may be abundantly present at selected locations mainly because of the mangrove trees. Like gastropods, the nematodes can also adapt diverse microhabitats within the benthic sediments, allowing them to exploit different ecological niches (Ptatscheck and Traunspurger, 2020).

The lower number of crustaceans and insects may be due to several factors. Most of the crustaceans (except crabs and lobsters) and insects are primarily adapted to the terrestrial and fresh water habitats. Therefore, the physiological adaptations in these invertebrates may not be or less compatible for the challenges offered by the benthic ecosystems such as the limited supply of oxygen. At marine benthic environments the crustaceans and insects may face osmoregulation difficulties due to the presence of high concentrations of salts at these habitats. Being better adapted for freshwater and terrestrial environment, most of crustaceans and insects may also face the predation pressure by other organisms at benthic zones.

The descriptive statistics in Table II indicates that location 3 exhibited the highest mean number of benthic invertebrates (7.8/10 cm^3) represented by the nine groups as well as the highest variance, and the widest confidence interval, indicating greater variability in the benthic invertebrates compared to the other locations. As mentioned in Table I, location 3 is dominated is usually

Table II. Descriptive statistics of cumulative marine benthic invertebrates (MBIs) observed at the 3 sampled locations.

Sampling locations	Mean individuals	Variance	Standard deviation	Standard error	Total individuals	Total species	Mini-mum	Maxi-mum	Mean confidence interval
1	3.71	9.61	3.1	1.033	26	7	0	9	6.279
2	4.78	11.69	3.42	1.14	43	9	2	12	7.64
3	7.78	32.44	5.696	1.899	70	9	2	18	21.197

less affected by the shipping operations and other activities at Port Qasim perhaps leading to higher number of benthic invertebrates there. Furthermore, the complicated root systems of protected mangrove trees at site may create a complex and sheltered habitat and provide the hiding places and safe shelter for benthic invertebrates, offering protection from predators and water currents. Mangroves trees also serve as nursery grounds for marine faunae, including many benthic invertebrates (Ellison, 2008).

Location 2 was observed to contain approximately 5/10 cm^3 organisms represented by 9 groups and location 1 exhibited the lowest (≈ 4/10 cm^3) mean number of individuals represented by 7 groups. Location 1 being situated close to the Port Qasim terminal, is experiencing continuous disturbances by the routine activities at port. Various activities at sea ports can substantially impact the biodiversity of marine benthic invertebrates, mainly through pollution, habitat alteration and introduction of invasive species. For example, the dredging activities to uphold the shipping channels can disrupt benthic habitats by taking away the sediment and changing the physical structure of the seabed. The removal of dredge spoil can restrict benthic organisms, disturb their habitats, and can cause sedimentation, effecting the reproduction ability of the organisms. Movements of ships often discharge ballast water, introducing non-native species into new environments that can outcompete the native species of benthic invertebrates (Gabel *et al*., 2011).

Oil spills and sewage discharge at sea ports can pollute the water and sediments in benthic zones resulting to poisoning the benthic organisms. Accumulation of toxic substances in benthic sediments can affect the overall health and reproductive success the organisms. Furthermore, the noise and vibrations at ports can potentially disturb the reproduction, feeding and communication among benthic invertebrates (Bejarano and Michel, 2016). Port authorities and other stakeholders should implement measures such as pollution prevention, habitat restoration, ballast water management strategies, and monitoring programs to evaluate the health of benthic invertebrates and control conservation efforts.

Comparatively higher number of benthic individuals at site 2 is probably because of the newly planted mangrove trees at this site. In the young mangroves sapling area usually, there are the high rate and frequency of soil chemical reactions such as ion exchange, redox reactions and nutrient cycling resulting in high concentration of available nutrients and food for the benthic organisms (Kon *et al*., 2010). Moreover, site 2 is located away from the shoreline in relatively deep waters experiencing relatively less disturbances from port activities resulting in healthier biodiversity of benthic invertebrates there.

Table III shows the cumulative distribution behavior of benthic organisms at all selected locations. Most of the MBIs groups exhibited a random pattern of distribution while a few species were distributed in aggregate patterns. The distribution of invertebrates is mainly dependent on the surface currents that redistribute the planktonic larvae in benthic zones. A random distribution pattern usually indicates that the invertebrate larva has been pushed away from the locations where they have spawned. In addition to surface currents, an aggregation pattern is also the function of reproduction, where the benthic organisms tend to colonies together (Awad *et al*., 2002).

Table III. Cumulative distribution pattern of marine benthic invertebrates (MBIs) observed in the study area.

Species	Variance	Mean	d.f.	Aggregation
Foraminifera	13.00	4.00	2	Random
Gastropod shells	49.33	11.33	2	Aggregated
Oligochaetes	16.33	6.67	2	Random
Polycheates	49.00	6.00	2	Aggregated
Bivalve shells	2.33	5.33	2	Random
Nematode	8.33	7.67	2	Random
Gammarus sp.	4.33	2.33	2	Random
Insects	1.33	1.33	2	Random
Crustacean larvae	0.33	1.67	2	Random

Where, d.f. is degree of freedom.

Statistically, the relations between variance and the arithmetic mean determines the dispersion of a population. If the variance is greater than the mean, the population is said to be randomly distributed while a smaller variance indicates a regular or aggregated pattern of distribution. The aggregated populations of invertebrates are usually found in clumps in marine benthic zones. The variation in distribution pattern of MBIs at selected site over a time period is probably a suitable measure to assess how the abundance, distribution pattern and biodiversity of MBIs can vary because of ecological disturbance in the water column due to the shipping operations and other activities at Port Qasim.

Table IV indicates the values of Shannon Weiner biodiversity index and evenness of MBIs at different locations. Evenness (J’) measures how evenly individuals are distributed among different species. A value of 1 indicates perfect evenness, while lower values suggest uneven distribution. Location 1 has the highest evenness, indicating a relatively even distribution of species. Location 2 has the lowest evenness, suggesting a more uneven distribution of species. A higher Shannon Index value suggests greater biodiversity within a community. This occurs when there are more species, and the individuals are more evenly distributed. Conversely, a lower Shannon Index indicates lower diversity, which may result from the dominance of a few species or an uneven distribution of individuals. This interpretation aligns with the findings of Jost (2007). The biodiversity index finds applications environmental management. It allows scientists and policymakers to assess the impact of human activities on biodiversity and monitor changes over time (Magurran, 2004). Studies such as habitat restoration, monitoring shifts in Shannon Index values can provide valuable information on the success of restoration efforts. Hence, regular continuation of long-term monitoring of benthic ecosystem is recommended.

Table IV. The values of Shannon Weiner biodiversity index and evenness of marine benthic invertebrates (MBIs) at different location.

Index	Location 1	Location 2	Location 3
Shannon H' log base$_{10}$	1.657	1.958	1.994
Shannon Hmax log base$_{10}$	1.946	2.197	2.197
Evenness J'	0.852	0.891	0.907

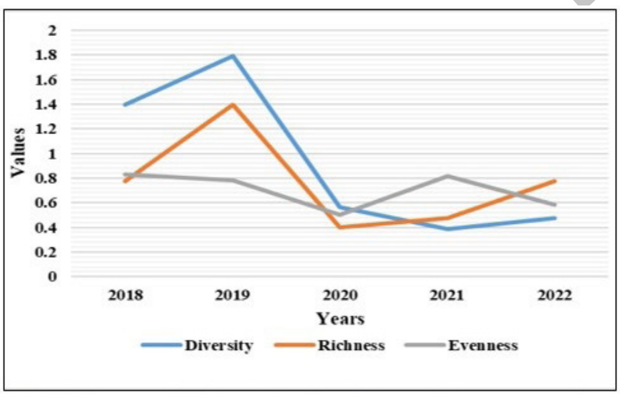

Fig. 3. Shannon-Weiner Biodiversity and Evenness values between 2018-2022.

Figure 3 shows the Shannon–Weiner biodiversity index, species richness (the number of different species) and evenness (distribution of individuals among species) over the five years period from 2018-2022. The Shannon –Weiner biodiversity values closer to 3.0 are considered to have a higher and more stable biodiverse community. The diversity index appears to have fluctuated over the 5-year period, with notable decreases in 2020 and 2021, followed by a modest increase in 2022. Species richness also showed fluctuations, with the highest value observed in 2019 and 2022. Species evenness also showed varied some fluctuations over the five years period, but it generally remained within a relatively narrow range.

Overall, a mix of natural environmental changes and human activities can contribute to the drop in biodiversity of marine benthic invertebrates over the time. The period from 2019 to 2021 was mainly dominated by COVID 19 when shipping activities were significantly reduced at Port Qasim. However, during this period, extensive repair and maintenance activities had been carried at Port Qasim, disturbing the habitat of benthic organisms and resulting to decrease in overall biodiversity and species richness and evenness from 2019 to 2021. It also seems that ocean acidification was also higher during this period which can affect the ability of benthic invertebrates to build and maintain their skeleton and shells, particularly for species such as mollusks.

Biodiversity is a powerful tool for quantifying the health of the ecosystem. The Shannon Index because it considers not only the number of species present but also how evenly individuals are distributed among those species. This makes it a more robust measure than simply counting species. As explained by Pielou (1966) in her classic work on ecological diversity, the Shannon Index provides a balanced assessment of both diversity and dominance. The variation in the distribution pattern of MBIs over a time period is probably is sustainable measure as to how abundance, distribution pattern and biodiversity can vary because of ecological disturbance in the water column due to shipping activity. The distribution of invertebrates is dependent on the surface current that redistributes the planktonic larval form to locations away from where they were spawned they are hence random in their population densities. Aggregation is also a function of reproduction, where the benthic organisms tend to colonies together. The interstitial MBIs are good organisms to measure due to their limited mobility in the disturbed environment, they either have to adapt to the changing environment to become opportunistic organisms or perish. Evenness is a critical component of the Shannon Index. It reflects the equitability of species abundance. In cases where multiple species are present, the Shannon Index increases when species are evenly distributed and decreases when some species dominate the community. Thus, evenness influences the overall diversity values, as highlighted by McGill *et al*. (2007).

Linear regression between Evenness (J) and Diversity (H') shows a weak correlation r^2 =0.2598 (Fig. 4). In a healthy ecosystem the correlation between Evenness and diversity is stronger.

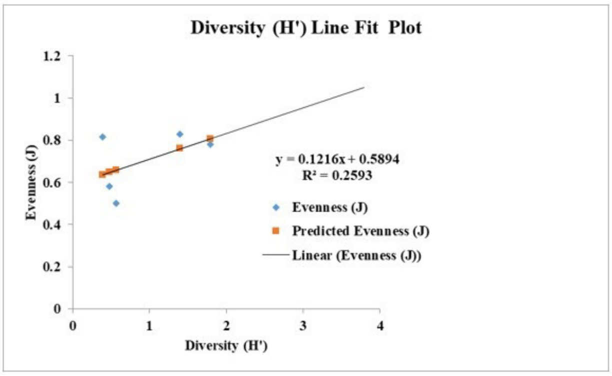

Fig. 4. Relationship between marine benthic invertebrates (MBIs) Diversity (H') and Evenness (J).

The small p-value of 0.003 suggests that there is evidence to reject the null hypothesis, which means that the variances of the groups are not equal. In other words, the groups being compared have significantly different variances (Table V).

Table V. Levene test for marine benthic invertebrates (MBIs) homogeneity of variance.

Levene statistic	df1	df2	Significance
9.735	2	12	0.003

Where, df is degree of freedom. *p* value < 0.05 shows significance.

Table VI. Results of ANOVA for the benthic organisms under study at p<0.05.

Source	Sum of squares	df	Mean square	F value	p vlaue
Between groups	2.287	2	1.143	6.505	0.012
Within groups	2.109	12	0.176		
Total	4.396	14			

Where, df is degree of freedom. *p*<0.05 shows significance of data.

The ANOVA shows the differences in means between groups and within groups for the variable Benthic Invertebrates. The F-statistics tests whether the means between groups are significantly different at 0.05 level (Table VI).

The ANOVA indicates that there are statistically significant differences in the variable "Benthic Organism" between the groups being compared. The significance level of 0.012 suggests that there is a significant difference. Tukey' Ad Hoc Multiple comparison test was performed to evaluate which group differed significantly at 0.05 (Table VII).

CONCLUSION

The marine benthic zones create vital ecological niches supporting diverse organisms vital for the functioning and stability of the ecosystems. The benthic invertebrates such as, crustaceans and gastropods, play crucial roles in habitat structuring, nutrient cycling and energy transfer within marine ecosystems. While their importance, the benthic organisms face threats from various natural and anthropogenic disturbances, such as habitat alteration, pollution and climate change, which can significantly impact their diversity, abundance and distribution.

Research conducted at Port Qasim discovered distinct variations in the distribution and abundance of marine benthic invertebrates across three sampling locations. Sites nearer to the shipping activities demonstrated a lower biodiversity mainly due to the disturbances caused by port operations. On the other hand, areas with natural mangrove trees exhibited a higher biodiversity, highlighting the protective role of mangroves in supporting the benthic ecosystems. Analysis of biodiversity indices highlighted fluctuations over the study period, influenced by both natural environmental changes and human activities. The COVID-19 pandemic, resulting in reduced shipping activities, impacted the biodiversity of benthic invertebrates, indicating the sensitivity of these organisms to

Table VII. Multiple comparisons between marine benthic invertebrates (MBIs) at monitored locations.

Locations comparison		Mean difference (I-J)	Standard error	p value	95% confidence interval	
					Lower bound	Upper bound
MBI location 1	MBI location 2	0.19940	0.26517	0.738	-0.5080	0.9068
	MBI location 3	-0.71040*	0.26517	0.049	-1.4178	-0.0030
MBI location 2	MBI location 1	-0.19940	0.26517	0.738	-0.9068	0.5080
	MBI location 3	-0.90980*	0.26517	0.013	-1.6172	-0.2024
MBI Location 3	MBI location 1	0.71040*	0.26517	0.049	0.0030	1.4178
	MBI location 2	0.90980*	0.26517	0.013	0.2024	1.6172

*The mean difference is significant at the p<0.05.

disturbances. Furthermore, ocean acidification and habitat alterations contributed to fluctuations in species richness and evenness. Understanding the responses of marine benthic invertebrates to disturbances is crucial for effective management and conservation of coastal ecosystems. Measures such as pollution prevention, habitat restoration, and monitoring programs are essential for maintaining the health and resilience of benthic ecosystems. Additionally, long-term monitoring of biodiversity indices can provide valuable insights into ecosystem dynamics and the success of conservation efforts.

Further research into the ecological roles of benthic invertebrates and their responses to environmental changes is necessary for developing targeted conservation strategies. Collaborative efforts involving scientists, policymakers, and local communities are vital for safeguarding the biodiversity and ecological integrity of marine benthic ecosystems in the face of increasing anthropogenic pressures.

DECLARATIONS

Acknowledgement

We are thankful to EMC private limited for their technical support to collect the samples and we are also grateful to Port Qasim Authority for their administrative support to conduct this study.

Funding

No funds, grants, or other support was received and the authors have no relevant financial or non-financial interests to disclose.

Ethical statement

The study have been conducted in accordance with the ethical standards and protocols related to site visits and data collection.

Statement conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Ahmed, W., Wu, Y., Kidwai, S., Li, X., Mahmood, T. and Zhang, J., 2021. Do Indus Delta mangroves and Indus River contribute to organic carbon in deltaic creeks and coastal waters (Northwest Indian Ocean, Pakistan). *Cont. Shelf. Res.,* **231:** 104601. https://doi.org/10.1016/j.csr.2021.104601

Alamgir, A., Khan, M.A., Shaukat, S.S. and Kazmi, J.H., 2024. Monitoring of anthropogenic impact on the Port Qasim coastal area, Karachi, Pakistan. *Appl. Water Sci.,* **14:** 1-11. https://doi.org/10.1007/s13201-023-02055-5

Awad, A.A., Griffiths, C.L. and Turpie, J.K., 2002. Distribution of South African marine benthic invertebrates applied to the selection of priority conservation areas. *Divers Distrib.,* **8:** 129-145. https://doi.org/10.1046/j.1472-4642.2002.00132.x

Bejarano, A.C. and Michel, J., 2016. Oil spills and their impacts on sand beach invertebrate communities: A literature review. *Environ. Pollut.,* **218:** 709-722. https://doi.org/10.1016/j.envpol.2016.07.065

Calado, R. and Leal, M.C., 2015. Trophic ecology of benthic marine invertebrates with bi-phasic life cycles: What are we still missing? *Adv. Mar. Biol.,* **71**: 1-70. https://doi.org/10.1016/bs.amb.2015.07.001

Cannicci, S., Burrows, D., Fratini, S., Smith, III T.J., Offenberg, J. and Dahdouh-Guebas, F., 2008. Faunal impact on vegetation structure and ecosystem function in mangrove forests: A review. *Aquat. Bot.,* **89:** 186-200. https://doi.org/10.1016/j.aquabot.2008.01.009

Carrier-Belleau, C., Drolet, D., McKindsey, C.W. and Archambault, P., 2021. Environmental stressors, complex interactions and marine benthic communities' responses. *Sci. Rep.,* **11:** 4194. https://doi.org/10.1038/s41598-021-83533-1

Choi, J.W., 2016. Benthic animals. In: *Oceanography of the East Sea (Japan Sea)* (eds. K.I. Chang, C. Park, D.-J. Kang, S.-J. Ju, S.-H. Lee, M. Wimbush). Springer, Cham. https://doi.org/10.1007/978-3-319-22720-7_14

Cimon, S. and Cusson, M., 2018. Impact of multiple disturbances and stress on the temporal trajectories and resilience of benthic intertidal communities. *Ecosphere,* **9:** e02467. https://doi.org/10.1002/ecs2.2467

Diederich, C.M., Chaparro, O.R., Mardones-Toledo, D.A., Garrido, G.P., Montory, J.A. and Pechenik, J.A., 2015. Differences in feeding adaptations in intertidal and subtidal suspension-feeding gastropods: Studies on *Crepidula fornicata* and *Crepipatella peruviana*. *Mar. Biol.,* **162:** 1047-1059. https://doi.org/10.1007/s00227-015-2648-2

Ellison, A.M., 2008. Managing mangroves with benthic biodiversity in mind: Moving beyond roving banditry. *J. Sea Res.,* **59:** 2-15. https://doi.org/10.1016/j.seares.2007.05.003

Gabel, F., Stoll. S., Fischer, P., Pusch, M.T. and Garcia, X.F., 2011. Waves affect predator–prey interactions between fish and benthic invertebrates. *Oecologia,* **165:** 101-109. https://doi.org/10.1007/s00442-010-

1841-8

Gravina, M.F., Bonifazi, A., Del Pasqua, M., Giampaoletti, J., Lezzi, M., Ventura, D. and Giangrande, A., 2020. Perception of changes in marine benthic habitats: The relevance of taxonomic and ecological memory. *Diversity,* **12:** 480. https://doi.org/10.3390/d12120480

Gray, J.S., 1997. Marine biodiversity: Patterns, threats and conservation needs. *Biodiv. Conserv.,* **6:** 153–175. https://doi.org/10.1023/A:1018335901847

Greene, H.G., Oconnell, V., Brylinsky, C.K. and Reynolds, J.R., 2008. Marine benthic habitat classification: what's best for Alaska. In: *Marine habitat mapping technology for Alaska*. pp. 169-184. https://doi.org/10.4027/mhmta.2008.12

Henseler, C., Nordström, M.C., Törnroos, A., Snickars, M., Pecuchet, L., Lindegren, M. and Bonsdorff, E., 2019. Coastal habitats and their importance for the diversity of benthic communities: A species-and trait-based approach. *Estuar. Coast Shelf. Sci.,* **226:** 106272. https://doi.org/10.1016/j.ecss.2019.106272

Jost, L., 2007. Entropy and diversity. *Oikos,* **116:** 811-826.

Kon, K., Kurokura, H. and Tongnunui, P., 2010. Effects of the physical structure of mangrove vegetation on a benthic faunal community. *J. exp. Mar. Biol. Ecol.,* **383:** 171-180. https://doi.org/10.1016/j.jembe.2009.11.015

Lajtner, J., Kozak, A., Špoljar, M., Kuczyńska-Kippen, N., Dražina, T., Sertić Perić, M. and Zrinščak, I., 2022. Gastropod assemblages associated with habitat heterogeneity and hydrological shifts in two shallow waterbodies. *Water,* **14:** 2290. https://doi.org/10.3390/w14152290

Leung, J.Y., Russell, B.D. and Connell, S.D., 2020. Linking energy budget to physiological adaptation: How a calcifying gastropod adjusts or succumbs to ocean acidification and warming. *Sci. Total Environ.,* **715:** 136939. https://doi.org/10.1016/j.scitotenv.2020.136939

Loskutova, O.A., 2020. Benthic invertebrate communities of lakes in the Polar Ural mountains (Russia). *Polar Biol.,* **43:** 755-766. https://doi.org/10.1007/s00300-020-02677-4

Magurran, A.E., 2021. Measuring biological diversity. *Curr. Biol.,* **31:** 1174-1177. https://doi.org/10.1016/j.cub.2021.07.049

McCann, K.S., 2000. The diversity-stability debate. *Nature,* **405:** 228–233. https://doi.org/10.1038/35012234

McGill, B.J., Etienne, R.S., Gray, J.S., Alonso, D., Anderson, M.J., Benecha, H.K., White, E.P., 2007. Species abundance distributions: Moving beyond single prediction theories to integration within an ecological framework. *Ecol. Lett.,* **10:** 995-1015. https://doi.org/10.1111/j.1461-0248.2007.01094.x

Mermillod-Blondin, F., François-Carcaillet, F. and Rosenberg, R., 2005. Biodiversity of benthic invertebrates and organic matter processing in shallow marine sediments: An experimental study. *J. exp. Mar. Biol. Ecol.,* **315:** 187-209. https://doi.org/10.1016/j.jembe.2004.09.013

Moens, T., Braeckman, U., Derycke, S., Fonseca, G., Gallucci, F., Gingold, R. and Vincx, M., 2013. Ecology of free-living marine nematodes. In: *Handbook of zoology* (ed. A.S. Rhaesa). pp. 109-152. https://doi.org/10.1515/9783110274257.109

Nascimento, C.G. and Amaral, A.C.Z., 2023. Benthic invertebrate macrofauna. In: *Brazilian sandy beaches*. Cham, Springer International Publishing. pp. 91-126. https://doi.org/10.1007/978-3-031-30746-1_4

Nepote, E., Bianchi, C.N., Morri, C., Ferrari, M. and Montefalcone, M., 2017. Impact of a harbour construction on the benthic community of two shallow marine caves. *Mar. Pollut. Bull.,* **114:** 35-45. https://doi.org/10.1016/j.marpolbul.2016.08.006

Palit, K., Rath, S., Chatterjee, S. and Das, S., 2022. Microbial diversity and ecological interactions of microorganisms in the mangrove ecosystem: Threats, vulnerability, and adaptations. *Environ. Sci. Pollut. Res.,* **29:** 32467-32512. https://doi.org/10.1007/s11356-022-19048-7

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol.,* **13**: 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Ptatscheck, C. and Traunspurger, W., 2020. The ability to get everywhere: Dispersal modes of free-living, aquatic nematodes. *Hydrobiologia,* **847:** 3519-3547. https://doi.org/10.1007/s10750-020-04373-0

Rossi, S. and Rizzo, L., 2020. Marine animal forests as carbon immobilizers or why we should preserve these three-dimensional alive structures. In: *Perspectives on the marine animal forests of the world* (eds. S. Rossi and L. Bramanti). pp. 333-400. https://doi.org/10.1007/978-3-030-57054-5_11

Saulsbury, J., 2020. Crinoid respiration and the distribution of energetic strategies among marine invertebrates. *Biol. J. Linn. Soc.*, **129:** 244-258. https://doi.org/10.1093/biolinnean/blz167

Shannon, C.E. and Weaver, W., 1997. The mathematical theory of communication. *MD Comput.,* **14:** 306-

317.

Snedaker, S.C., 1984. Mangrove: A summary of knowledge with emphasis on Pakistan. In: *Marine geology and oceanography of Arabian sea and coastal Pakistan* (eds. B.U. Haq, and J.D. Milliman). Van Nostrand Reinhold Company Inc, NY. pp. 255-262.

Torn, K., Herkül, K., Martin, G. and Oganjan, K., 2017. Assessment of quality of three marine benthic habitat types in northern Baltic Sea. *Ecol. Indic.,* **73:** 772-783. https://doi.org/10.1016/j.ecolind.2016.10.037

Yamanaka, T., White, P.C., Spencer, M. and Raffaelli, D., 2012. Patterns and processes in abundance–body size relationships for marine benthic invertebrates. *J. Anim. Ecol.,* **81:** 463-471. https://doi.org/10.1111/j.1365-2656.2011.01921.x