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A Comparative Study of Intertidal Macrofaunal Diversity on Two Distinct Shorelines, Gulf of Khambhat, Gujarat, India

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ABSTRACT

The western coast of India features a variety of coastal habitats, including the Gulf of Kutch and the Gulf of Khambhat, both located in Gujarat. Despite being in the same region, the two gulfs differ in tidal range, sediment load, and ecological characteristics. The aim of this comparative study is to analyze the intertidal macrofaunal diversity and associated physico-chemical characteristics of two distinct shorelines in the Gulf of Khambhat: Koliyak (muddy coast) and Gopnath (rocky coast). The intertidal zone of Koliyak is characterized by a muddy substrate interspersed with small rocky areas, whereas Gopnath's intertidal zone consists of a rocky substrate with numerous small to large, shallow tide pools. The macrofaunal diversity at both study sites along the Gulf of Khambhat: Koliyak (muddy shore) and Gopnath (rocky shore) was assessed using univariate diversity indices, including Shannon-Wiener diversity, Simpson's dominance, Margalef's species richness, and Pielou's evenness. The rocky intertidal zone at Gopnath supports a higher diversity of molluscs and macroalgae (seaweeds) compared to the muddy shore at Koliyak, likely due to the presence of extensive seaweed-covered substrates that provide both food and structural habitat for diverse macrofaunal assemblages. Temperature, salinity, pH, and total dissolved solids (TDS) were within normal ranges at both locations, though turbidity levels varied. The findings of this study provide site-specific insights into how intertidal macrofaunal communities respond to environmental variability and substrate type in the Gulf of Khambhat. While the scope is geographically limited, the results contribute baseline ecological information that can support future comparative studies in similar tropical intertidal systems.

Keywords Comparative study, Macrofaunal diversity, Muddy coast, Rocky coast, Gastropods.

INTRODUCTION

Marine ecosystem particularly the intertidal zone is one of the most dynamic zones that is the interface between sea and terrestrial environment. The Indian

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Ocean extends over 30% of the global ocean area and is rimmed by 36 littoral and 11 surrounding nations sustaining about 30% of the world's population India is bestowed with three gulfs viz. Gulf of Kachchh, Gulf of Khambhat and Gulf of Mannar. Gujarat, located on the Western coast of India, encompasses two ecologically significant gulfs—the Gulf of Kachchh and the Gulf of Khambhat. The Gulf of Khambhat is characterized by high tidal amplitude, dynamic hydrodynamics, and substantial sediment influx, making it a unique system for studying intertidal biodiversity (Mitra *et al.* 2020). While its tidal and geomorphological dynamics have been well documented, comparatively fewer studies have focused on the ecological characteristics and macrofaunal assemblages of its intertidal zones (Bhadja *et al*. 2014). Rocky beaches are demonstrably extensive features that provide a stable substrate for a diversified biota consisting of marine invertebrates and marine algae that use a range of capabilities for attachment and subsequent growth in a rough-water situation. Rocky shores are the most extensive littoral habitats exposed to eroding waves and thus, are ecologically very important and characterized by a diverse array of macrofaunal species adapted to the fluctuating conditions of tidal exposure. Habitat complexity in rocky intertidal zones leads to higher species diversity and more specialized ecological niches (Underwood & Chapman 1998, Bauer *et al.* 2024, Dodiya & Poriya 2024).

Muddy intertidal zones are dynamic ecosystems characterized by fine sediments and fluctuating environmental conditions, supporting a diverse array of macrofaunal communities. The composition and diversity of these communities are influenced by factors such as sediment characteristics, tidal exposure, and anthropogenic impacts (Sukumaran 2021, Douglas *et al.* 2024, Zhang *et al.* 2023, Mancuso *et al.* 2023). Explores how muddy shores and estuaries have relatively low species diversity compared to rocky intertidal zones due to environmental stability and sediment characteristics. Understanding the diversity and distribution of macrofaunal communities in muddy intertidal zones is essential for assessing the health and functioning of these ecosystems. Such knowledge aids in the development of effective conservation and management practices to protect these vital coastal habitats.

In marine sediments, macrofaunal communities play a pivotal role in ecosystem functioning. They contribute substantially to benthic biomass and drive key ecological processes such as bioturbation the reworking of sediments by burrowing and feeding activities which enhances organic matter decomposition and facilitates nutrient cycling (Booth *et al.* 2023, Ciraolo *et al*. 2025, Kauppi *et al*. 2023, Bernardino *et al.* 2020). These activities alter sediment structure and chemistry, influencing oxygen penetration, redox conditions, and habitat suitability for microbial and meiofaunal communities (Vadher *et al*. 2020).

MATERIALS AND METHODS

Study area: Gujarat, one of India's longest maritime states, encompasses two major gulfs the Gulf of Kachchh and the Gulf of Khambhat. The Gulf of Khambhat, covering approximately 3,210 km^2, lies between 21°00' N–22°18' N and 72°15' E–72°45' E. The gulf's funnel-shaped structure, with a wide mouth (~200 km) tapering to a narrow head (~6 km), contributes to its exceptionally high tidal amplitude, second only globally. The Gulf of Khambhat, also known as the Gulf of Cambay, is a funnel-shaped inlet of the Arabian Sea located along the western coast of India in Gujarat. This morphology, combined with strong hydrodynamics and heavy sediment load, creates highly dynamic intertidal environments that influence habitat complexity and species distribution. While tidal circulation and sediment transport in the gulf have been well studied, ecological investigations, particularly of intertidal macrofaunal communities, remain limited. The present investigation carried out at two different sites, Koliyak (a muddy coast) and Gopnath (a rocky coast), from Gulf of Khambhat. The intertidal area of Koliyak (N 21˚ 35' 51.226'') E 72˚ 17' 33.259'') is highly muddy with small patches of rocks (Fig. 1). During low tides, it exposed near about 600 to 900 meter. Gopnath coast (N 21˚ 21' 10.56, E 72˚ 10' 62.53") is major rocky habitat having scanty mud patches on rocks (Fig. 1). Tide pools and puddles are distributed in scattered manner of various size and shape with own characteristics in rocky habitat. During each field visit, approximately 350 to 450 meters of the intertidal zone was exposed during low tide, allowing for effective sampling across the shore profile.

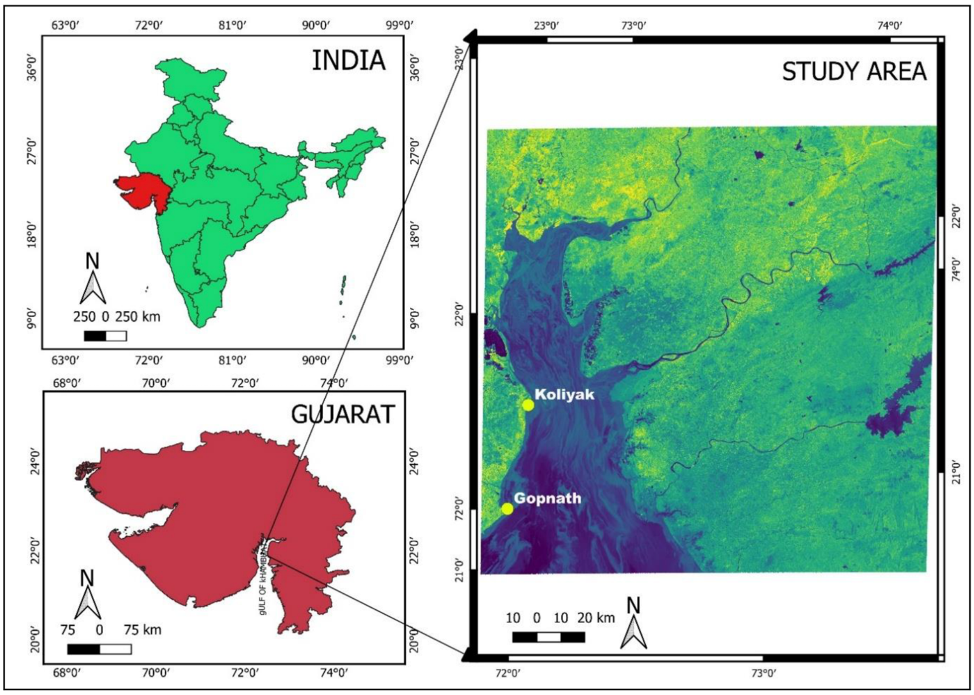

Fig. 1. Location of study sites (Map generated using QGIS 3.34 with spatial data obtained from DIVA-GIS (https://www.diva-gis.org/)).

Sampling methods: Sampling occurred monthly during the lowest tide, over 12 consecutive months to capture seasonal variation. Quadrats were used for systematic sampling. At each site 1 m² quadrats were randomly placed within stratified intertidal zones. Each quadrat configuration was sampled independently each visit. All macrofaunal organisms were photographed and identified to the lowest taxonomic level using WoRMS. Samples were brought to the laboratory, stored in cleaned, air dried plastic bottles for further water analysis. Out of 52 samples collected, few of them shown in Plate 1. The air and water temperature were measured on site using a standard mercury centigrade thermometer. The water pH was measured by Multi-Parameter (PCSTestr-35). The water salinity was measured by using hand refractometer. The turbidity was measured by Nephelometer (CL 52D).

Data analysis: Shannon-Wiener and Simpson's diversity index, Pielou's evenness index, and Margalef's richness index were calculated using different sophisticated statistical tools software (ex: Past 4.03).

RESULTS

Water quality parameters: Both sites exhibit typical seasonal fluctuations, with peak temperatures in summer and lower values in winter (Table 1). The difference between Koliyak and Gopnath in temperature patterns is marginal, indicating that substrate type has limited direct influence on temperature. However, temperature indirectly affects other parameters such as pH, TDS, and biological activity, thereby influencing the overall water chemistry. The intertidal waters at both locations are slightly alkaline throughout the year. Koliyak shows more fluctuation in pH, particularly dropping during the summer and monsoon seasons. This variability is likely associated with increased microbial decomposition and nutrient runoff in the muddy substrate, which may contribute to acidifying conditions. Gopnath, with its stable rocky substrate, maintains a more consistent pH profile, likely due to reduced organic decomposition and sediment trapping. Salinity trends are similar at both sites, decreasing notably during the monsoon due to freshwater influx.

Plate 1. Macrofaunal diversity at both sites (A. *Nereis* sp., B. *Emplectonema* sp., C. *Turricula nelliae*, D. *Astralium semicostatum*, E. *Nassarius stolatus*, F. *Matuta victor*, G. *Gyrineum natator*, H. *Onchidium* sp., I. *Metopograpsus thukuhar*, J. *Pirenella cingulata*, K. *Assiminea brevicula*, L. *Trocus radiatus*, M. *Boleophthalmus dussumieri*, N. *Diopatra cuprea*, O. *Chiton peregrines*).

Table 1. Macrofaunal diversity at studied sites.

Sl. No.	Phylum	Family	Genus/Species	Koliyak	Gopnath
1	Cnidaria	Actiniidae	*Anthopleura thallia* (Gosse 1854)	–	+
2	Nemertea	Emplectonematidae	*Emplectonema* sp.	+	+
3	Annelida	Onuphidae	*Diopatra cuprea* (Bosc 1802)	+	+
4		Nereididae	*Nereis* sp. 1	+	+
5			*Nereis* sp. 2	+	–
6		Unidentified	*Unidentified*	–	+
7	Molluscs	Trochidae	*Trochus radiates* (Gmelin 1791)	+	+
8			*Umbonium vestiarium* (Linnaeus 1758)	+	+
9		Tegulidae	*Tectus tentorium* (Gmelin 1791)	–	+
10		Neocyclotidae	*Amphicyclotulus dominicensis* (Bartsch 1942)	–	+
11		Turbinidae	*Astralium semicostatum* (Kiener 1850)	+	+
12			*Astralium stellare* (Gmelin 1795)	–	+
13			*Turbo bruneus* (Röding 1798)	+	+
14		Cerithiidae	*Clypeomorus bifasciata* (GB Sowerby II 1855)	+	+
15			*Clypeomorus batillariaeformis* (Habe & Kosuge 1966)	+	+
16		Muricidae	*Lataxiena bombayana* (Melvill 1893)	–	+
17			*Semiricinula tissoti* (Petit de la Saussye 1852)	+	+
18		Littorinidae	*Echinolittorina malaccana* (Philippi 1847)	+	+
19			*Littoraria intermedia* (Philippi 1846)	–	+
20			*Littoraria scabra* (Linnaeus 1758)	+	+

Table 1. Continued.

Sl. No.	Phylum	Family	Genus/Species	Koliyak	Gopnath
21		Nassariidae	*Nassarius stolatus* (Gmelin 1791)	+	+
22			*Nassarius dorsatus* (Röding 1798)	+	+
23			*Nassarius reeveanus* (Dunker 1847)	+	+
24		Olividae	*Agaronia gibbosa* (Born 1778)	+	+
25			*Agaronia nebulosa* (Born 1778)	+	+
26		Potamididae	*Pirenella cingulata* (Gmelin 1791)	–	+
27		Assimineidae	*Assiminea brevicula* (Pfeiffer 1855)	+	+
28		Planaxidae	*Planaxis sulcatus* (Born 1778)	–	+
29		Cymatiidae	*Gyrineum natator* (Roding 1798)	+	+
30		Epitoniidae	*Amaea minor* (Sowerby II 1873)	+	–
31		Ostreidae	*Saccostrea cucullata* (Born 1778)	–	+
32		Nacellidae	*Cellana karachiensis* (Winckworth 1930)	–	+
33		Buccinidae	*Cantharus spiralis* (Gray 1839)	+	+
34		Clavatulidae	*Turricula nelliae spuria* (Hedley 1922)	+	+
35		Turridae	*Turris clausifossata* (Kilburn, Fedosov & Olivera 2012)	–	+
36		Neritidae	*Nerita oryzarum* (Recluz 1841)	–	+
37			*Nerita undata* (Linnaeus 1758)	–	+
38		Calliostomatidae	*Calliostoma tranquebaricum* (Roding 1798)	+	+
39		Onchidiidae	*Peronia verruculata* (Cuvier 1830)	+	+
40		Hamineidae	*Aliculastrum cylindricum* (Helbling 1779)	–	+
41		Laternulidae	*Laternula anatine* (Linnaeus 1758)	+	+
42		Tellinidae	*Serratina capsoides* (Lamarck 1818)	+	+
43		Octopodidae	*Octopus vulgaris* (Cuvier 1797)	–	+
44		Chitonidae	*Chiton peregrinus* (Thiele 1909)	–	+
45	Arthropoda	Balanidae	*Amphibalanus amphitrite* (Darwin 1854)	–	+
46		Chthamalidae	*Euraphia withersi* (Pilsbry 1916)	–	+
47		Dotillidae	*Scopimera globosa* (De haan 1835)	+	+
48		Diogenidae	*Clibanarius infraspinatus* (Hilgendorf 1869)	+	+
49			*Diogenes avarus* (Heller 1865)	+	+
50		Portunidae	*Scylla serrata* (Forsskal 1775)	+	+
51		Macrophthalmidae	*Macrophthalmus laevis A* (Milne-Edwards 1867)	+	+
52		Grapsidae	*Metopograpsus thukuhar* (Owen 1839)	–	+
53		Eriphiidae	*Eriphia smithii* (Macleay 1838)	–	+
54		Matutidae	*Matuta victor* (Fabricius 1781)	–	+
55	Chordate	Gobiidae	*Boleophthalmus dussumieri* (Valenciennes 1837)	+	+

However, Gopnath retains relatively higher salinity levels, especially in winter, which may be attributed to less freshwater retention and faster drainage over rocky surfaces. Conductivity follows

Table 2. Comparative analysis of water quality parameters at both study sites.

	Koliyak			Gopnath		
Water parameters	Winter	Summer	Monsoon	Winter	Summer	Monsoon
Air temperature (°C)	28.3±4.1	32.2±4.3	31.5±1.8	27.2±3	32.7±4.8	30.9±2.9
Water temperature (°C)	26.2±1.2	29.7±2.1	30.4±0.9	25.3±2	31.9±0.8	30.3±0.7
pH	8.4±0.1	7.9±0.4	7.9±0.4	8.2±0.1	8±0.2	8.1±0.1
Salinity (‰)	35±0.6	34.6±0.7	33.5±0.6	35.4±0.2	34.0 ±0.6	32±1
TDS (ppt)	10.56±0.9	16.98±1.2	11.99±1.6	8.29±0.6	13.3±0.4	11.81±0.3
TSS (g /lit)	2.86±0.4	4.62±0.5	4.72±0.4	2.17±0.3	3.6±0.3	4.57±0.5
Conductivity (mS)	12.92±0.7	8.50±0.6	12.73±0.3	11.06±0.3	7.31±0.6	19.91±0.5
Turbidity (NTU)	566±34	572±29	400±50	371±12	539±09	497±17

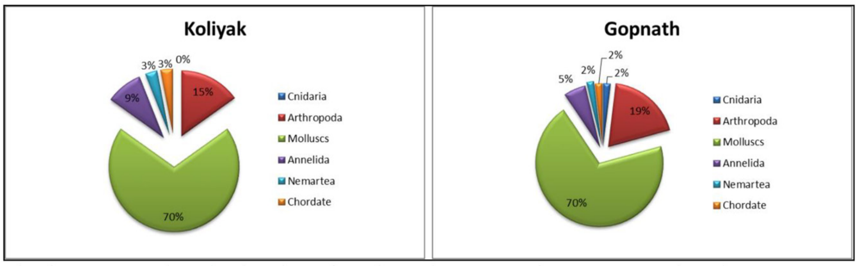

Fig. 2. Phylum wise distribution of the intertidal macrofauna at sampling site.

a similar seasonal pattern, with values influenced by dissolved ion concentration. Koliyak shows higher conductivity during winter and monsoon, possibly due to the release of ions from organic-rich muddy sediments, whereas Gopnath shows higher conductivity in summer, perhaps linked to evaporation and concentration effects.

Koliyak consistently records higher Total Dissolved Solids (TDS), especially during summer (Table 2). The fine-grained muddy substrate retains organic matter and enhances microbial activity, both of which contribute to increased dissolved materials. Similarly, Total Suspended Solids (TSS) are markedly higher at Koliyak across all seasons. This is due to the nature of the substrate—muddy shores are more prone to resuspension and sediment mobilization due to wave action, leading to turbid and sediment-laden waters. Conversely, Gopnath's rocky substrate is more stable and compact, resulting in lower suspended solids and clearer water. Consistent with TSS, turbidity is significantly higher at Koliyak. The fine particles of muddy substrates remain suspended for longer durations, especially during turbulent conditions. Turbidity levels correlate with higher TSS and indirectly with biological productivity, as increased turbidity can reduce light penetration and affect primary production. Gopnath, having clearer water, benefits from greater light availability and potentially different algal or faunal communities.

Overall, these findings indicate that while both sites experience similar seasonal trends, the muddy substrate at Koliyak amplifies variability in water quality parameters, particularly in terms of suspended solids, pH and conductivity, whereas the rocky substrate at Gopnath promotes greater environmental stability.

Species composition

A total of 55 macrofaunal species belonging to 40 families were recorded from the intertidal zones of Koliyak and Gopnath. Among these, the phylum Mollusca was the most dominant group, represented by 38 species, followed by Arthropoda with 10 species, Annelida with 4 species, and one species each from Nemertea, Cnidaria and Chordata (Table 1).

Species composition within two distinct coastal habitats revealing a pattern of dominance. The community composition was notably dominated by Mollusca, which accounted for 70% of the total species richness. This dominance reflects the typical ecological character of intertidal zones, where mollusca including gastropods and bivalves. Arthropods represent the second-largest group though their proportion varies slightly between the 15% and 18%, comprising primarily small crustaceans. The remaining species, comprising smaller percentages (9%, 5%, and minor proportions), occupy specialized ecological niches (Fig. 2).

The intertidal communities at Gopnath (rocky shore) and Koliyak (muddy shore) exhibit marked differences in diversity and community composition, as reflected by standard ecological indices.

Simpson's dominance index (D) revealed higher dominance at Gopnath (D = 0.949) relative to Koliyak (D = 0.9165), indicating a stronger influence of a few numerically dominant species, particularly in the structurally complex rocky habitat (Fig. 3).

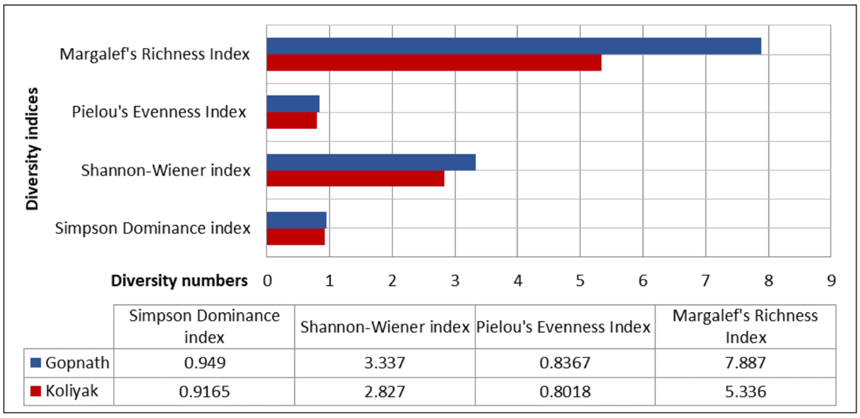

Fig. 3. Diversity indices of both the studied site.

Shannon-Wiener diversity (H') was considerably higher at Gopnath (H' = 3.337) compared to Koliyak (H' = 2.827), suggesting that the species assemblage at the rocky coast is not only richer but also more equitably distributed, contributing to a more resilient ecological network (Fig. 3).

Margalef's richness index (d) further underscored the taxonomic richness of Gopnath (d = 7.887), likely attributable to greater habitat heterogeneity and niche diversity inherent to rocky substrates. In contrast, the muddy habitat at Koliyak supported a comparatively less diverse assemblage (d = 5.336) (Fig. 3).

Pielou's evenness index (J') while high at both sites, was greater at Gopnath (J' = 0.8367) than Koliyak (J' = 0.8018), reflecting a more balanced distribution of individuals among species in the rocky shore community (Fig. 3).

The biodiversity indices collectively suggest that Gopnath supports more diverse and ecologically a balanced community than Koliyak, as reflected in higher values for the Shannon-Weiner index, Margalef's richness index and Pielou's evenness index. The dominance index, however, indicates that both sites have some degree of species dominance, albeit slightly higher in Gopnath. These variations can be attributed to differences in habitat structure, hydrodynamic conditions, substrate types, and ecological interactions, which influence species distribution and abundance in intertidal environments. This suggests that the rocky habitat supports a more diverse and balanced ecological community due to its structural complexity and resource availability.

DISCUSSION

The rocky shores provide various microhabitats such as tide pools, crevices, and overhangs, allowing for a greater variety of species to coexist Gopnath, a rocky coast, tend to have more diverse habitats and support a wide range of species. This microhabitats provide niche for different organisms leading to higher species diversity. In contrast, muddy shores have a more homogeneous and less structured habitat, leading to lower species diversity (Sukumaran 2021). Koliyak, a muddy coast have fewer distinct habitats and more homogeneous in terms of substrate and environmental condition. This can be result in lower species diversity. Rocky shores often experience upwelling that provides nutrients to sustain rich intertidal communities including algae and filter. Muddy shores are typically nutrient-rich due to organic sediment accumulation but may suffer from low oxygen levels limiting species diversity. Similar patterns are observed in studies of Indian coastal ecosystems. For example, research on the Western coast of India shows that rocky intertidal zones have diverse marine life, including barnacles, mussels and gastropods, whereas muddy coasts are dominated by deposit feeders like crabs and worms (Ingole *et al.* 2002). Here, both habitats share a dominant mollusc presence, the variation in the less prevalent species underscores the impact of habitat complexity on biodiversity. This aligns with ecological theories stating that habitat heterogeneity promotes species richness, as seen in rocky shores compared to more uniform muddy coasts.

The comparative analysis of biodiversity indices between the rocky intertidal habitat of Gopnath and the muddy intertidal habitat of Koliyak reveals significant differences in community structure and ecological balance. Consistently higher values for the Shannon-Wiener diversity index (H'), Margalef's richness index (d), and Pielou's evenness index (J') at Gopnath unequivocally demonstrate that this rocky habitat supports a more diverse and ecologically balanced community than the muddy Koliyak habitat. The Shannon-Wiener index reflects both species richness and evenness, indicates a greater complexity and stability in the Gopnath community. This increased diversity likely enhances ecosystem resilience to environmental fluctuations (Tilman 1996, 1997). The higher Margalef's richness index at Gopnath suggests a greater number of distinct species driven by the structural complexity of the rocky substrate.

Rocky intertidal zones with their heterogeneous topography creates a mosaic of microhabitats (Bauer *et al.* 2024) which offering a wider range of niches than the relatively uniform muddy substrate of Koliyak. This heterogeneity fosters a greater diversity of species as observed in our findings. Furthermore, the higher Pielou's evenness index at Gopnath implies a more equitable distribution of species abundance. This balanced community structure is crucial for maintaining ecological stability, as it reduces the potential for dominance by a few species and promotes resource partitioning (Weitzman *et al.* 2021).

Despite the overall higher diversity at Gopnath, the Simpson's dominance index (D) indicates that both sites exhibit a degree of species dominance with a slightly higher dominance at Gopnath. This suggests that while Gopnath is more diverse a few species still exert a strong influence on the community structure. This could be attributed to the specific ecological adaptations of dominant species to the prevailing environmental conditions at both locations.

The observed variations in biodiversity indices between Gopnath and Koliyak can be attributed to several key factors. Habitat structure plays a crucial role where the rocky intertidal zone of Gopnath offering a complex three-dimensional structure that supports a greater variety of species compared to the relatively flat and homogeneous muddy intertidal zone of Koliyak. Hydrodynamic conditions, substrate types, and ecological interactions also contribute to these differences (Begon *et al.* 2006). For instance, the rocky habitat may provide more stable attachment sites for sessile organisms and greater refuge from predation, whereas the muddy habitat may be subject to higher levels of sediment disturbance and lower oxygen availability (Bambhaniya & Raval 2023, Sukumaran 2021).

Our findings align with numerous studies highlighting the importance of habitat complexity in driving intertidal biodiversity. For example, studies on rocky shore communities have consistently shown that increased structural complexity leads to higher species richness and diversity (Dos Santos 2014). Similarly, research on muddy intertidal habitats has emphasized the influence of sediment characteristics and hydrodynamic conditions on community structure (Ward *et al.* 2022).

A comparative analysis of water parameters between Koliyak (muddy shore) and Gopnath (rocky shore) reveals several factors influencing intertidal macrofaunal distribution. Koliyak exhibits higher turbidity (400-572 NTU) and TSS (2.86–4.72 g/liter) compared to Gopnath (turbidity: 371–539 NTU, TSS: 2.17–4.57 g/liter), which is characteristic of muddy environments with finer sediments that limit light penetration and affect feeding strategies of macrofauna (Tuttle-Raycraft and Ackerman 2019). These conditions in Koliyak favor deposit feeders and burrowing organisms, while the clearer waters and stable substrate of Gopnath support visually oriented predators and sessile filter feeders. Both sites experience seasonal salinity fluctuations decreasing during the monsoon from 35‰ (Koliyak, winter) to 33.5‰ (Koliyak, monsoon) and from 35.4‰ (Gopnath, winter) to 32‰ (Gopnath, monsoon), which can influence the distribution of macrofauna with varying osmoregulatory capabilities (Javanshir 2013). Both sites are alkaline, Koliyak's greater pH variation (7.9–8.4) compared to Gopnath (8.0–8.25) may have differential effects on macrofaunal physiological processes.

CONCLUSION

In conclusion, the biodiversity indices clearly indicate that the rocky intertidal habitat of Gopnath supports a more diverse and ecologically balanced macrofaunal community than the muddy habitat of Koliyak. This distinction can be attributed primarily to the greater habitat complexity offered by the rocky substrate, which provides numerous microhabitats and refuges. Additionally, other environmental variables such as substrate stability, wave exposure, salinity fluctuations, and possibly lower anthropogenic disturbance may also influence the structure and diversity of the benthic and epifaunal communities observed at the two sites. These variations with seasonal fluctuations creates a distinct environmental conditions that are critical in determining the distribution and adaptation of intertidal macrofauna. Further research is needed to investigate the specific ecological interactions and environmental factors that contribute to these observed differences. These results emphasize the critical role of habitat structure in shaping intertidal communities. While this study establishes the difference in biodiversity between these two intertidal habitats, further research is needed to elucidate the specific ecological interactions and environmental variables driving these patterns. Detailed investigations into the functional roles of key species and the impacts of anthropogenic pressures in both rocky and muddy intertidal ecosystems will provide a more comprehensive understanding of their ecological dynamics.

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