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Assessment of the relationship between environmental variables and benthic fauna along Padubidri region, Karnataka

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Abstract
Monthly assessment of benthic fauna in response to environmental variables investigated along Padubidri, Karnataka, from January 2023 to December 2024. Stratified random sampling method was applied for sampling. A total of 25 benthic species were identified and grouped under four different classes: bivalve (10), gastropod (11), scaphopod (1), and echinoderm (3). The environmental variables such as air temperature (28.36 to 31.21 °C), water temperature (29.79 to 33.24 ºC), transparency (1.65 to 5.30 m), pH (7.39 to 8.04), dissolved oxygen (4.43 to 6.71 mg/l), salinity (28.97 to 38 psu), TDS (31874.29 to 60525.71 mg/l), TSS (131.14 to 577.14 mg/l), biologic oxygen demand (1.37 to 2.78 mg/l) were recorded in optimum level. Variations in nutrient concentration such as NH_3-N (1.84 to 13.73 µg-at.NH_3-N/l), NO_2-N (0.57 to 2.72 µg-at.NO_2-N/l), NO_3-N (0.73 to 3.81 µg-at.NO_3-N/l), PO_4-P (0.87 to 2.57 µg-at.PO_4-P/l) and SiO_2-S (36.74 to 59.32 µg-at.SiO_2-S/l) were noted. The scaphopod, *Dentalium* sp., and polychaete showed dominance throughout the study period. The diversity indices express that the benthic diversity was moderate along the coast. The variation in an abundance of benthic fauna could be attributed to changes in environmental variables.

Keywords: Benthic fauna, environmental variables, water quality, organic carbon, correlation

Introduction
In coastal marine ecosystems, the benthic zone is essential for maintaining energy flow, nutrient recycling, and productivity (McLusky and Elliott, 2004) [31]. Ecosystem activities depend on "benthos," which are organisms that live in the benthic zones (Coull, 1977; Jayachandran *et al.*, 2019c; Lalli and Parsons, 1997) [7, 22, 26]. They may support pelagic and offshore populations by transferring energy to higher trophic levels and taking part in the breakdown of particulate organic materials (Lee, 1997; Schrijvers *et al.*, 1996) [27, 47]. According to size, benthos can be divided into four groups: mega benthos (more than 10.0 mm), macrofauna (greater than 1.0 mm), meiofauna (0.063 to 1.0 mm), and microfauna (less than 0.063 mm) (Mare, 1942) [30]. They can be characterized as sessile or sedentary organisms, have a long lifespan, and are susceptible to sediment and water mass changes. The physicochemical environment significantly impacts the distribution and composition of benthic fauna at many different scales (Hall *et al.*, 1994) [17]. The benthic assemblage of species differs along geographic gradients longitudinally (Heip *et al.*, 1992) [18] and latitudinally (Gray, 2002; Hillebrand, 2004) [15, 19]. According to Kunitzer *et al.* (1992) [25], Rees *et al.* (1999) [40], and Sanvicente-Anorve *et al.* (2002) [43], depth, temperature, water circulation patterns, and sediment type are the main factors influencing species composition in the northeastern Atlantic, particularly in the Channel and the North and Irish Sea regions. Additionally, organic carbon content and sediment transport have been recognized as essential factors at the regional level (Basford *et al.*, 1989; Eleftheriou and Basford, 1989; Heip *et al.*, 1992; Sanvicente-Anorve *et al.*, 1996) [5, 11, 18, 42].
Numerous studies have also shown their significance in energy transmission in the aquatic food chain and their relatively rapid response to natural and man-made disturbances (Jayachandran *et al.*, 2019b; Perus *et al.*, 2007; Simboura and Zenetos, 2002) [21, 38, 51]. This study aims to determine the relationship between patterns in the occurrence of benthic fauna

as demonstrated by benthic invertebrate assemblages and changes in environmental conditions along the Padubidri areas. We examine differences in environmental variables and biological features over the regions, then investigate relationships and determine traits and environmental factors that best represent the interactions.

Materials and Methods

The sampling location (Latitude 1307'21.01" N and Longitude 74043'10.20" E) is in the southern area of Karnataka. Stratified random sample approach was used to conduct monthly in-situ sampling from January 2023 to December 2023, except for the monsoon season (June to September 2023). The collected benthic specimens were used for additional identification after being preserved in a 5% formaldehyde solution.

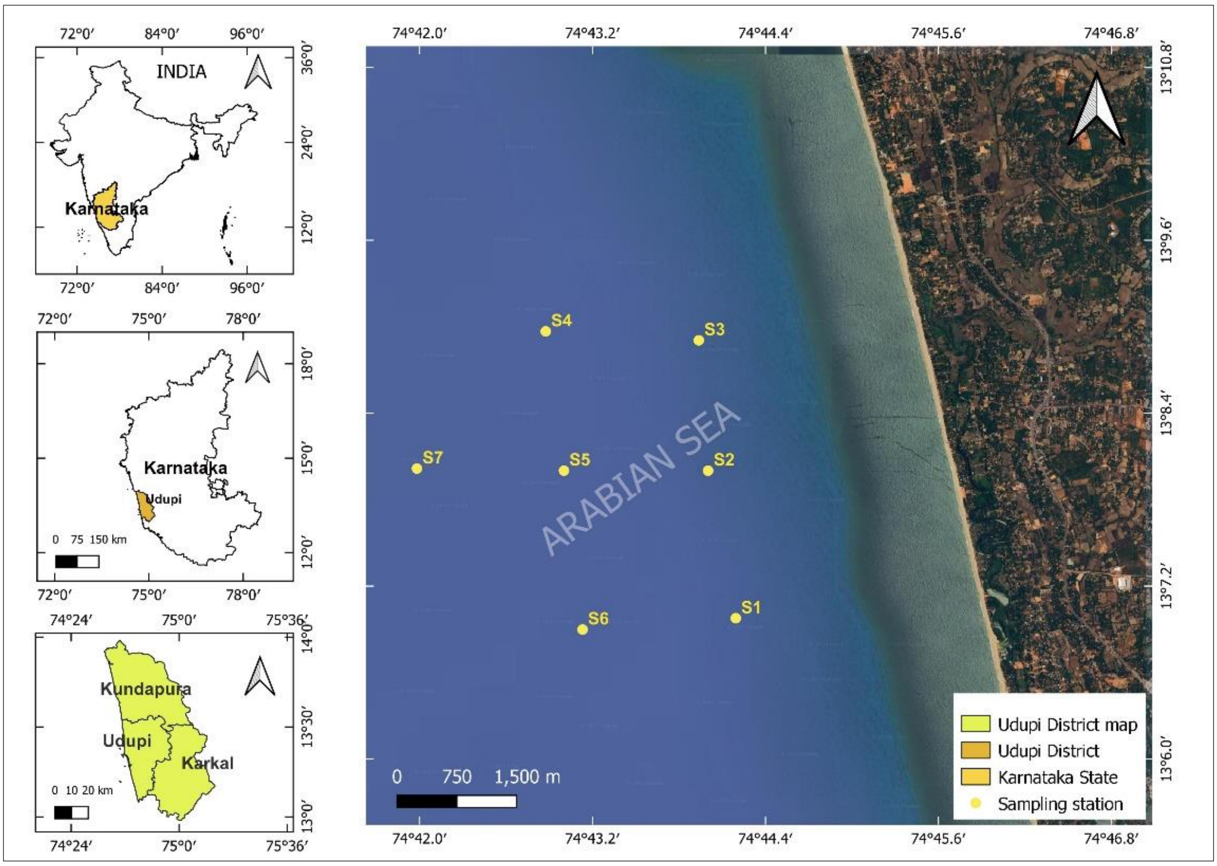

Plate 1: Map showing sampling stations

The species diversity metrics, including the Simpson index (Simpson, 1949) [52], the Shannon-wiener diversity index (Shannon and Weaver, 1949) [49], evenness, and dominance, were computed using PAST4.07 software to determine the benthic fauna distribution pattern. The correlation between environmental variables and benthic fauna was investigated using SAS programming.

Results and Discussion

I. Environmental variables

Environmental variables are regarded as one of the most essential features capable of altering the marine environment, and there have been significant temporal and regional variances. Environmental factors, including air temperature, water temperature, transparency, pH, dissolved oxygen, salinity, total dissolved solids (TDS), total suspended solids (TSS), ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus, silicate-silicon, organic carbon, and biological oxygen demand (BOD) influence the diversity and distribution of benthos. The above environmental characteristics were measured to assess their effect on benthos distribution in the research area.

The air and water temperatures (Figures 1A and 1B) ranged from 28.36 to 31.26 ^{o}C and 29.79 to 33.24 ^{o}C, respectively. The air temperature was the lowest in May (28.36 ^{o}C) and the highest in November (31.26 ^{o}C). The highest water temperature was recorded in November (33.24 ^{o}C), with the lowest in January (29.79 ^{o}C). Numerous researchers have documented the variation in air temperature around the Indian coast. According to Jasmine *et al.* (2015) [20], the air temperature ranges from 27.0 to 33.5 °C. Seasonal air temperatures for the pre-monsoon (32.1 °C) and monsoon (26.2 ^{o}C) seasons off the Tamil Nadu were noted by Sekar *et al.* (2012) [48]. Likewise, Gopalakrishnan (1970) [13], Philip (1970) [39], and Ajin *et al.* (2014) [2] reported variations in air temperature throughout the West Coast, ranging from 19.9 to 30.4 ^{o}C, 32.8 ^{o}C, and 28 to 33 ^{o}C, respectively. The water temperature is precisely proportional to the air temperature. The change in water temperature could be attributed to the change in air temperature. The water transparency ranges between 1.65 and 5.30 m (Figure 1C). The maximum transparency value was reported in April (5.30 m), while the minimum was in January (1.65 m). Water transparency is directly related to total suspended solids. The increased concentration of suspended particles in the water during January could have decreased transparency.

The month-wise water pH ranged between 7.39 and 8.04 (Figure 1D). The highest pH was observed in March (8.04), while the minimum was in May (7.39). A low pH level in coastal waters in May is most likely related to ocean acidification, which occurs when the ocean absorbs increasing amounts of carbon dioxide from the atmosphere, lowering the pH and making the water more acidic.

The monthly dissolved oxygen ranged between 4.43 and 6.71 mg/l (Figure 1E). The maximum dissolved oxygen was reported in May (6.71 mg/l), while the smallest in February (4.43 mg/l). Seasonal variations in the dissolved oxygen level of Karnataka's nearshore waters were observed by Lingadhal *et al.* (2023) [28]. According to Balakrishnan *et al.* (2017), the dissolved oxygen content of Tamil Nadu's coastal waters varied from 4.125 to 4.963 mgl^{-1}. According to Gopalakrishnan (1970) [13], the dissolved oxygen value along the Okha coast ranged from 5.3 to 6.7 mgl^{-1} along the west coast.

The monthly mean salinity fluctuated between 28.97 and 38.00 psu (Figure 1F). The maximum salinity was measured in December (38.00 psu), while the smallest salinity was in May (28.97 psu). A study conducted in nine coastal lakes near the southern Baltic Sea found that species diversity decreased with increasing salinity. However, specific diversity metrics indicated minor positive trends that lacked statistical significance (Mrozińska *et al.*, 2021) [33]. According to Balakrishnan *et al.* (2017) [3], the salinity in Tamil Nadu's coastal waters varied from 26.1 to 36.2 psu. Jasmine *et al.* (2015) [20] reported water salinity varying between 34 and 34.8 psu from Gopalpur to Machilipatanam seashore along the east coast. According to Sekar *et al.* (2012) [48], the water salinity along Tamil Nadu's coast varied from 33 to 34.3 psu.

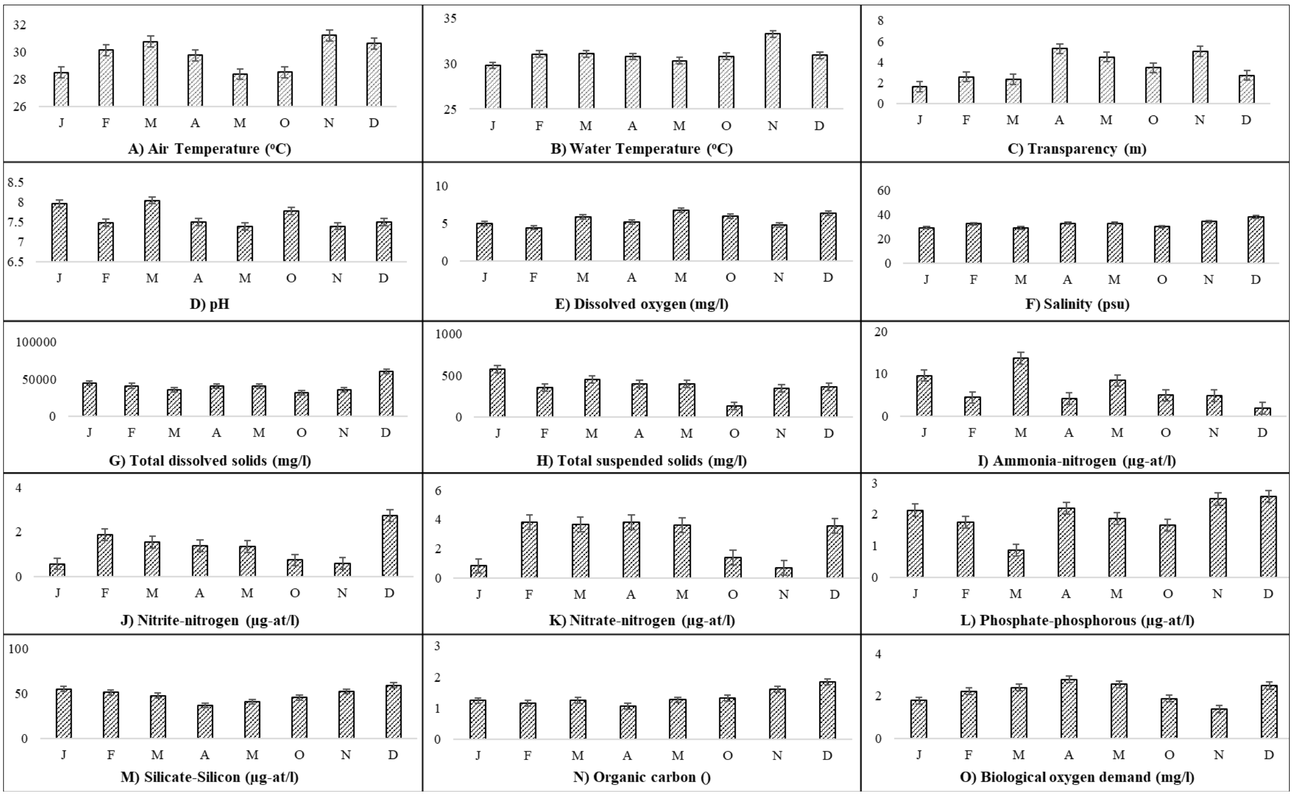

Fig 1: Graphical presentation of environmental variables recorded during the investigation

The total amount of dissolved substances, including salts, minerals, and organic matter, in water is referred to as "total dissolved solids" (TDS). Several studies indicate that TDS levels can considerably alter the richness of benthic communities. The monthly dissolved solids varied between 31874.29 and 60525.71 mg/l (Figure 1G). The highest total dissolved solids were reported in December (60525.71 mg/l), whereas the lowest were in October (31874.29 mg/l). The effects of TDS on benthic species could change regionally based on local environmental characteristics such as temperature, salinity, and depth.

The total suspended solids (TSS) varied between 131.14 and 577.14 mg/l (Figure 1H). Maximum total suspended solids were reported in January (577.14 mg/l), while the minimum total suspended solids in October (131.14 mg/l). The relationship between TSS and benthic invertebrates is complicated. Diverse species have different tolerances for turbidity and sedimentation. Deposit feeders might flourish when sedimentation is high and organic matter accumulates, while suspension feeders might be more common where sedimentation is low and water clarity is high (Wijsman *et al.*, 1999; Reiss *et al.*, 2015) [58, 41]. It is possible that the low rainfall and river runoff in October contributed to the low TSS levels.

The ammonia-nitrogen content ranged between 1.84 and 13.73 µg-at.NH_3-N/l (Figure 1I). The high ammonia-nitrogen concentration was observed in March (13.73 µg-at.NH_3-N/l), whereas the lower concentration was recorded in December (1.84 µg-at.NH_3-N/l). According to Gopinath *et al.* (2013) [14], the coastal waters of Puducherry and Nagapattinam have ammonia concentrations ranging from 0.02 to 1.32 µg-at.NH_3-N/l. In coastal waters near Mangaluru, Nayak (2015) [35] observed ammonia-nitrogen levels ranging from 0.36 to 12.65 µg-at. NH_3-N/l.

The nitrite-nitrogen is one of the intermediary forms of nitrogenous nutrients. The nitrite-nitrogen content varied from 0.57 to 2.72 µg-at.NO_2-N/l (Figure 1J). The higher nitrite-nitrogen content was recorded in December (2.72 µg-at.NO_2-N/l), whereas the lower in January (0.57 µg-at.NO_2-N/l). The current study's values are slightly lower than those from earlier research in the same area. Chethan (2012) [6] and Shruthi (2016) [60] found that the Mangaluru coastal waters have an annual range of 0.042 to 5.58 µg-at.NO_2-N/l. The nitrate-nitrogen concentration ranged between 0.73 and 3.81 µg-at.NO_3-N/l (Figure 1K). The maximum nitrate-nitrogen content was observed in February (3.81 µg-at.NO_3-N/l), while the minimum was in November (0.73 µg-at.NO_3-N/l). In coastal waters, Satpathy *et al.* (2010) [46] observed that the nitrate-nitrogen level varied from below detectable lavel to 69.18 µmol l^{-1} for surface water and 0.03 to 69.91 µmol l^{-1} for sub-surface water samples. Similarly, Kumar *et al.* (2018) [24] recorded a shift in concentration from 0.39 to 7.43 µmol l^{-1} and 0.77 to 6.95 µmol l^{-1} for surface and sub-surface waters from Pattinapakkam coastal waters. Physiological activities mainly cause fluctuations in nitrate levels and inorganic compounds.

The phosphate-phosphorus concentration varied from 0.87 to 2.57 µg-at.PO_4-P/l (Figure 1L). The high phosphate-phosphorus concentration was recorded in December (2.57 µg-at.PO_4-P/l), while the low phosphate-phosphorus concentration in March (0.87 µg-at.PO_4-P/l). The suspended particles may absorb phosphorus and deposit it in the sediment. According to Bandyopadhyay and Biswas (2021) [4], the coastal water in the southwest Bay of Bengal has a phosphorus-phosphate level of 1.03 µg-at.PO_4-P /l. Along the Mangaluru coastline, Katti *et al.* (2003) [23] found phosphate concentrations ranging from 0.05 to 3.00 µg-at. PO_4-P/l.

The silicate-silicon content varied from 36.74 to 59.32 µg-at.SiO_2-S/l (Figure 1M). The highest silicate-silicon concentration was detected in December (59.32 µg-at.SiO_2-S/l), while the minimum was in April (36.74 µg-at.SiO_2-S/l). Muruganantham *et al.* (2012) [34] observed a silicate range from 3.2 to 54.92 µg-at.SiO_2-S/l on the Southeast coast of India. According to Sushanth and Rajashekhar (2012) [54], the coastal waters of the Uttara Kannada district have silicate concentrations ranging from 0.10 to 161.0 mg/l.

The monthly organic carbon fluctuated between 1.07 and 1.85% (Figure 1N). The maximum organic carbon was recorded in December (1.85%), while the lowest organic carbon was observed in April (1.07%). The organic carbon values along the west coast at Malvan, Terekhol, Aguada, Velsao, and Karwar varied from 1.00 to 2.65%, according to Vizakat *et al.* (1991) [57]. Dwivedi *et al.* (1973) [10] found organic carbon concentrations ranging from 0.00038 to 0.0732% in coastal waters of Goa.

The biological oxygen demand (BOD) ranged between 1.37 and 2.78 mg/l (Figure 1O). The highest biological oxygen demand was found in April (2.78 mg/l), while the minimum was in November (1.37 mg/l). High BOD conditions frequently lead to enhanced nutrient release from sediments, particularly ammonium and phosphate, into the overlying water column. This nutrient enrichment can further intensify eutrophication, leading to additional organic matter accumulation and further increases in BOD, generating a feedback loop that affects benthic ecosystems (Hale *et al.*, 2016) [16].

Benthic composition and abundance

Benthos are organisms inhabiting the seafloor and playing a vital role in marine ecosystems. They contribute to the maritime ecosystem by acting as a food supply, bioindicators, and essential components of carbon cycling. Benthos can indicate water pollutants' presence, concentration, and influence in aquatic habitats since they are susceptible to contamination. The amount and diversity of macro-invertebrates in a waterbody can represent the pollution level.

Table 1: Monthly variation in benthic fauna recorded during the current investigation

Species	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Bivalves								
Arca sp.	82	122	145	157	119	153	152	69
Anadara granosa	0	65	48	43	69	26	120	139
Bivalve Spats	508	151	90	105	143	101	116	133
Cardium sp.	0	59	46	32	40	58	141	80
Donax cuneatus	0	66	62	80	120	103	71	101
Katelysia opima	0	22	59	54	71	50	57	120
Meretrix meretrix	253	145	77	79	116	78	97	150
Perna viridis	129	39	32	76	27	38	67	80
Modiolus sp.	0	12	14	58	18	0	0	38
Pecten sp.	0	23	0	0	48	10	47	144
Gastropods								
Babylonia spirata	145	25	12	76	37	45	72	69
Cavolinia sp.	143	99	112	119	86	71	76	73
Cerithedia sp.	170	151	89	134	122	59	105	21
Conus sp.	0	6	8	14	9	11	23	0
Oliva sp.	0	0	0	7	1	8	0	0
Patella vulgata	190	44	18	40	34	85	81	25
Turricula nelliae	107	130	134	142	112	25	0	0
Telescopium telescopium	129	32	12	23	107	54	37	67
Trochus radiatus	12	7	0	11	19	67	54	31
Turitella sp.	38	41	16	27	57	54	36	67
Umbonium vestiarium	0	13	0	0	0	103	55	70
Scaphopods								
Dentalium sp.	168	293	387	286	475	367	417	516
Echinodermata								
Astropecten indicus	0	6	5	3	3	9	8	15
Ophiocoma sp.	61	26	9	8	125	44	37	22
Polychaetes	169	101	200	176	257	104	180	231

In the current study, a total of 25 benthic species (Table 1) were recorded, identified, and classified under four different groups such as bivalve (10), gastropod (11), scaphopod (1), and echinoderm (3). The scaphopod, *Dentalium* sp., exhibits maximal abundance, followed by Polychaetes, Bivalve spat, and *Arca* sp.. Group-wise, bivalves revealed the highest dominance and occurrence across the study period. It includes a total of 10 benthic species, such as *Arca* sp., *Anadara granosa*, Bivalve Spats, *Cardium* sp., *Donax cuneatus*, *Katelysia opima*, *Meretrix meretrix*, *Perna viridis*, *Modiolus* sp. and *Pecten* sp. Numerous researchers have studied the distributions of Donacidae bivalve around the Indian coast. Along the east coast, two species of bivalves, *Donax incarnatus* and *D. scortum*, were recorded (Paul *et al.*, 2014; Mitra and Misra, 2006) [37, 32]. Bivalve species, including *D. incarnatus*, *D. speculum*, *D. scortum*, and *D. cunaetus*, have been abundant along India's west coast in recent years (Thippeswamy and Joseph 1988; Achuthankutty 1978; Sivadas *et al.*, 2012; Pai and Kanekar 2016) [1, 36, 53, 55].

During the investigation, *Babylonia spirata*, *Cavolinia* sp., *Cerithedia* sp., *Conus* sp., *Oliva* sp., *Patella vulgata*, *Turricula nelliae*, *Telescopium telescopium*, *Trochus radiatus*, *Turitella* sp., and *Umbonium vestiarium* were all observed in the order of gastropods. The gastropods *Babylonia spirata*, *Olivancillaria gibbosa*, and *Oliva vidua* were reported by Venkatraman and Venkataraman (2012) [56] from Kasimedu, Marina, Beasant Nagar, and Thiruvanmiyur along the east coast. D'Souza and Shenoy (2020) [8] reported the presence of *O. oliva* along the Karnataka coast throughout the pre-and post-monsoon seasons. According to Paul *et al.* (2014) [37], *Turitella attenuate* is abundant along the northeast coast of India. Venkatraman and Venkataraman (2012) [56] reported the gastropod *Tibia delicatuala*, and *T. attenuate* from the Chennai coast.

In scaphopod, a single species of *Dentalium* was recorded with the highest abundance and distribution throughout the study. The highest abundance was found in December (516 nos/m^2), while the lowest was found in January (168 nos/m^2). Along the southwest and southeast coast, the occurrence of *Dentalium* sp. was recorded by Devi *et al.* (1999) [9] and Gopalakrishnan and Nair (1998) [12].

The order Echinodermata encompasses *Astropecten indicus*, *Ophiocoma* sp. and Polychaetes. The polychaete was the second-highest dominating species recorded throughout the research period. Among Echinodermata, *A. indicus* showed relatively low distribution and abundance (3 to 15 nos/m^2). Along the east coast, the occurrence of echinoderm, *Astropecten indicus*, *Ophionereis dubia*, *Glycera alba*, and *G. convoluta* was documented (Mitra and Misra, 2006; Sastry *et al.*, 2012) [32, 45]. Along the west coast, Sastry *et al.* (2019) [44] recorded a single species of brittle star, *O. porrecta*, from Lakshadweep Island. Similarly, Lokhade (2012) [29] recorded the abundance of *A. indicus* only during the post-monsoon season (0.5714 no m^{-2}) along the coast of Maharashtra.

Correlation coefficient between environmental variable and benthic faunal groups

The tabulated matrix (Table 2) indicated that water temperature has a significant correlation with air temperature (r=0.753, $p<0.05$). At the same time, pH showed a negative association with salinity (r= -0.767, $p<0.05$) and ammonia-nitrogen (r= -0.709, $p<0.05$). The value of salinity adversely correlates with ammonia-nitrogen (r= -0.753, $p<0.05$) while positively correlated with phosphate-phosphorus (r=0.740, $p<0.05$) and organic carbon (r = 0.708, $p<0.05$). The amount of total dissolved solids displayed a positive association with the amount of nitrite-nitrogen (r= 0.719, $p<0.05$) and bivalve (r = 0.826, $p<0.05$). The concentration of nitrite-nitrogen is positively related to the concentration of nitrate-nitrogen (r = 0.788, $p<0.05$). In contrast, nitrate-nitrogen concentration positively correlates with the value of biological oxygen demand (r = 0.913, $p<0.05$). Silicate-silicon concentration is positively linked with abundance of bivalve (r = 0.708, $p<0.05$). A negative correlation (r= -0.767, $p<0.05$) was found between the amount of organic carbon and gastropods, whereas a strongly negative correlation (r= -0.873, $p<0.01$) was found between gastropods and scaphopods.

Table 2: Correlation co-efficient among environmental variables and benthos collected from the study area

	A	D	F	G	J	K	M	N	Q
A	1								
B	0.753*								
C	0.101								
D	-0.181	1							
E	-0.296	-0.002							
F	0.444	-0.767*	1						
G	0.168	-0.224	0.703	1					
H	0.019	0.289	-0.153	0.335					
I	-0.157	0.709*	-0.753*	-0.406					
J	0.384	-0.265	0.626	0.719*	1				
K	0.175	-0.230	0.259	0.289	0.788*	1			
L	0.102	-0.629	0.740*	0.560	0.065	-0.294			
M	0.360	0.155	0.311	0.566	0.245	-0.335	1		
N	0.456	-0.255	0.708*	0.568	0.356	-0.215	0.701	1	
O	-0.079	-0.138	0.198	0.339	0.673	0.913**	-0.468	-0.278	
P	0.548	-0.285	0.679	0.826*	0.586	0.156	0.708*	0.540	
Q	-0.546	0.334	-0.650	-0.335	-0.568	-0.285	-0.241	-0.767*	1
R	0.482	-0.236	0.350	-0.004	0.528	0.520	-0.095	0.378	-0.873**
S	-0.058	-0.138	0.091	0.053	0.194	0.423	-0.320	0.036	-0.427
**. Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05 level.									

Note: A- Air temperature, B-Water temperature, C-Transparency, D-pH, E-Dissolved oxygen, F-Salinity, G-Total dissolved solid, H- Total suspended solid, I-Ammonia-nitrogen, J-Nitrite-nitrogen, K-Nitrate-nitrogen, L-Phosphate-phosphorus, M-Silicate-silicon, N-Organic carbon, O-Biologic oxygen demand, P-Bivalves, Q-Gastropod, R-Scaphopod and S-Echinoderm

Diversity indices

Throughout the study, monthly assessments of benthic diversity were calculated along the Padubidri region. In October, the Shannon Wiener diversity index peaked at 2.732, but it fell to 2.376 in March. Similarly, the highest and lowest values of the Simpson index were recorded in March (0.867) and April (0.912). The Evenness value was at its lowest (0.566) in March and highest (0.795) in January. In March, the Dominance index peaked at 0.132; in April, it fell to 0.087 (Figure 2).

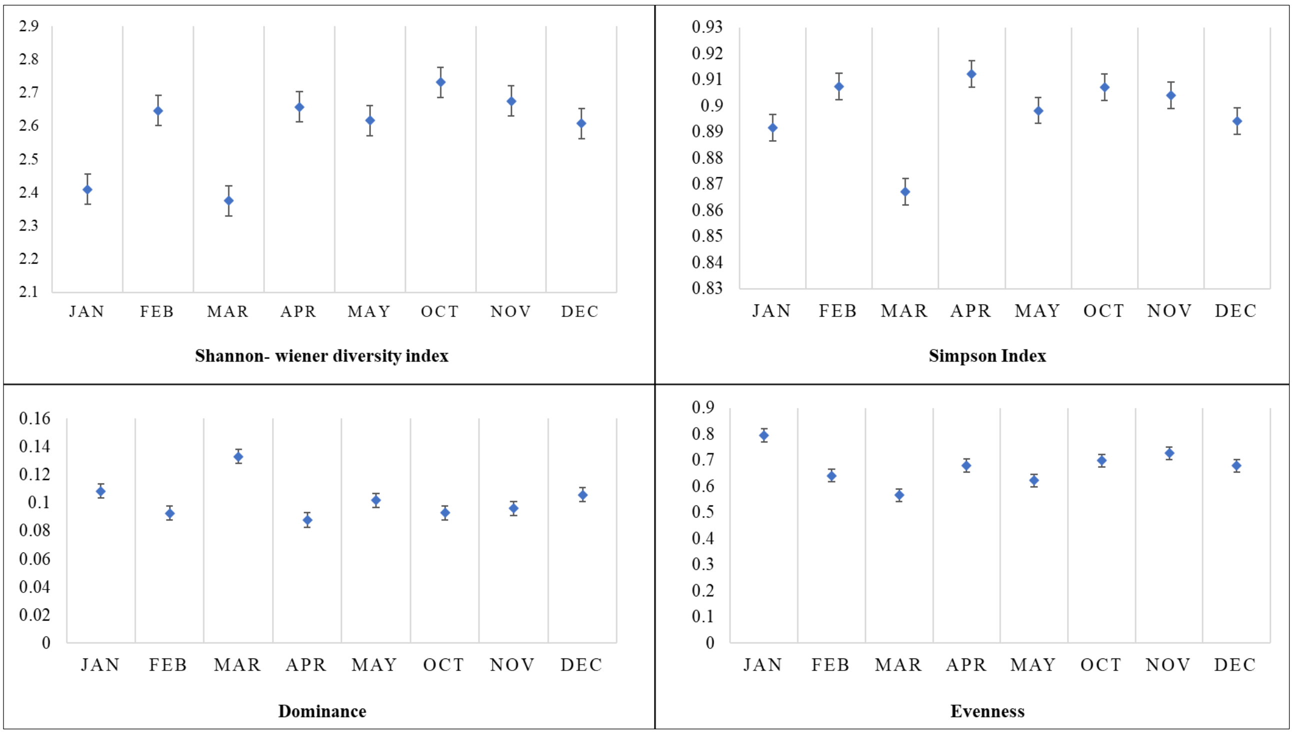

Fig 2: Graphical presentation of diversity indices of benthos in the Padubidri region

Conclusion

The coastal waters of the Padubidri region provide a novel habitat for benthic species. The overall observation of the annual changes in an abundance of benthic fauna reveals that harsh environmental conditions along the Padubidri region influence their diversity.

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