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Spatio-temporal comparison of intertidal macrofaunal communities along anthropogenically influenced Mandvi coast, Gulf of Kachchh, India

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Abstract

Natural and human disturbances can affect population and community assemblages in complex ways. The present study was carried out from June 2019 to January 2020, along the Northern Gulf of Kachchh (can also be spelled as Kutch), western India wherein an effort was made to investigate the intertidal assemblage at three distinct but spatially closely located stations (Kathda, Mandvi, and Modhva). The efforts were also made to correlate anthropogenic effects with intertidal assemblage. The Mandvi station served as an anthropogenically active area whereas the other two remained as control stations with minimal disturbance. Replicate quadrat samples on fixed transect lines and wet biomass analyses were carried out for three seasons. In total, 43 species, viz. Mollusca (21), Crustacea (12), Polychaeta (7), Nemertea (1), and fishes (2) were recorded. Cumulatively, during pre-monsoon, post-monsoon and winter, overall population densities ranged from 0 to 999 individuals/m^2; biomass from 0 to 899 g/m^2, and the Simpson evenness index score remained between 0.15 to 0.89. Overall, high density and diversity were observed during winter (December 2019 and January 2020) with the maximum number of two Mollusc species *Umbonium vestiarium* and *Cerethidia cingulata*. High densities were observed at the Modhva station followed by Kathda and Mandvi stations. Relatively lower intertidal macrofaunal diversity and density were clearly observed at Mandvi station which is a famous tourist destination. Comparative data recorded in the present study can serve as a vital baseline and can be a part of future monitoring processes, especially at anthropogenically influenced stations.

Key words: Abundance, anthropogenic influence, intertidal community, Gulf of Kachchh (Kutch)

Introduction

Estuarine and marine organisms visible to the naked eye (>0.5 mm) commonly inhabit benthic habitats, where they can be found buried in sediment or attached to a fixed substrate like rocks, reefs, or mangrove root complexes (Zavala and Dávila, 2016). Their diversity and varied populations along the intertidal areas form complex community structures. Macrofaunal communities dominating these intertidal areas are a major component of intertidal ecosystem functioning (Virnstein, 1987; Sheridan, 1992). The distribution patterns of soft bottom, benthic macrofauna are driven by a complex interplay of biological and abiotic phenomena (Gray and Elliott, 2009). On the other hand, rapid industrial and population growth along the coastal stretches has placed disproportionate stress on coastal and marine ecosystems (Barragán and de Andrés, 2015; Karbassi et al., 2017). Sale et al. (2014) state that approximately 37% of people live within this 100 km stretch of the coast. This large human population and their activities have directly and indirectly affected the biodiversity of coastal ecosystems worldwide, thereby creating anthropogenic stress on the biota (Murphy and Romanuk, 2014; McCauley et al., 2015).

Such stress at one level of organization may also have an impact on another level (Halpern et al., 2008; Gunderson et al., 2016; Liess et al., 2016). Since it is difficult to detect the effects of anthropogenic stress at the individual organismic level, they are more often investigated at a population or community level (Crowe et al., 2000). Intertidal beaches are more often exposed to human activities like recreation and tourism, which may directly affect benthic fauna therein (Machado et al., 2017). The effects of human trampling on intertidal fauna have been intensively studied, (Povey and Keough, 1991; Fletcher and Frid, 1996; Keough and Quinn, 1998; Schiel and Taylor, 1999; Mariana and Sergio, 2009; Bessa et al, 2017). Also, studies have reported the impact of various factors on the spatio-temporal distribution of macrobenthos (Cai et al., 2003; 2013; Machado et al., 2017).

The Gulf of Kachchh (GoK, also spelled as Kutch) is located in western India and is one of three Gulfs found in India. It is known for its rich biodiversity values, supported by varied habitats including coral reefs, mangroves, creeks, mudflats, islands, rocky shores, and sandy shores, which sustain a wide range of flora and fauna including Mangroves – 10 species, Algae – 174 species, Ascidians – 1 species, Fishes – 365 species, Poriferans – 69 species, Cnidarians – 102 species, Molluscs – 357 species, Crustaceans – 115 species, Annelids – 4 species, and Echinoderms – 35 species (Singh et al, 2004; Dixit et al., 2010). The southern border of the GoK has an important coastal stretch declared as a Marine National Park, rich in coral ecosystems which are highly valued ecologically and economically (Dixit et al., 2010), while the northern border of the GoK is formed by a single district, i.e. Kachchh with a coastal length of ~406 km. This northern stretch also supports diverse intertidal habitats from sandy and muddy beaches to mangroves in rich complex creek systems (Thivakaran and Sawale, 2016). On the other hand, this northern stretch also has numerous coastal developments, tourism activities, and industrial settlements owing to its geographical location. Most of the studies to date along the Kachchh coast are confined to mangrove macrofauna and gastropod assemblages (GUIDE, 2005; Saravanakumar et al., 2007; Kardani et al., 2014; Thivakaran and Sawale, 2016).

Considering that intertidal communities can be affected by the degree of anthropogenic activities, the present study tried to understand intertidal community structure and biomass at three stations along the Kachchh coast (hereafter written as the northern Gulf of Kachchh) - Kathda, Modhva, and Mandvi - which are spatially close (within a 14 km range), but present different degrees of anthropogenic exposure. An attempt was made to answer the following two questions - i) how does the intertidal community structure and biomass change temporally across habitat variation? and ii) do anthropogenically affected stations differ from the rest in terms of intertidal community patterns and biomass?

Material and Methods

The present study was conducted along three sampling stations, namely, Kathda (22°50'3.22" N, 69°18'.50" E), Mandvi Beach (22°49'25.10" N, 69°20'29.06" E), and Modhva (22°47'4.37" N, 69°26'3.91" E) which are spatially close and very similar in habitat (Figs. 1 and 2; Table 1). The study was conducted from June 2019 to January 2020 with monthly data collection. As Kachchh district does not show significant month-to-month climatic differences, except in winter, and as the stations experience a coastal climate, monthly data was categorized into pre-monsoon, post-monsoon and winter. The average temperature variabilities recorded at the three stations were - Pre-monsoon: 27.3–33.3 °C, Mean 29.6 °C; Post-monsoon: 21.7–32.3 °C, Mean 27 °C and Winter: 13.5–27 °C, Mean 20.3 °C (Source: https://en.climate-data.org/asia/india/gujarat/mandvi).

Mandvi is a known tourist destination because of its vast sandy beach which remained the focal point to test the high anthropogenic influence. The other two stations, Kathda and Modhva, are close to Mandvi. Kathda represents a small creek with mixed kind habitats formed by a silty clay zone, some sandy patches, and a small mangrove patch with minimal human influence. The third station, Modhva is characterized by a flat sandy beach with a small, seasonal fishing hamlet (Fig. 2).

Collection from the three stations was carried out during low tides. Ten quadrats of 30 X 30 cm^2 were placed on predefined transect lines (at each station) and the macrofauna in each quadrat were counted and recorded. Organisms that could not be identified in the field were sampled and preserved in 5% formaldehyde and brought to the departmental laboratory and identified using standard literature (Chhapgar, 1957; Day, 1967; Ng et al., 2008, Apte, 2015). During the study, only live specimens in the quadrats were considered (especially for molluscs). Dead shells found in and around the transect were not considered, avoiding the error of counting carried or washed up shells from nearby shores. For macrofaunal biomass, the collected surface samples, in addition to macrofauna up to 15 cm depth were collected and wet-sieved using a standard 0.5 mm test sieve (35 ASTM - American Society for Testing and Materials). Total biomass was weighed in the field using a portable balance (KERRO) to the nearest 0.1 g. The quadrat data was taken in two replicates and pooled to a standard unit (density and biomass per square meter). Although an attempt was made to identify the individuals to species/genus level, some groups like polychaetes were identified to their respective families only (Day, 1967) to avoid misleading identification.

The data collected was categorized by season as pre-monsoon (June-July), post-monsoon (September, October and November) and winter (December-January).

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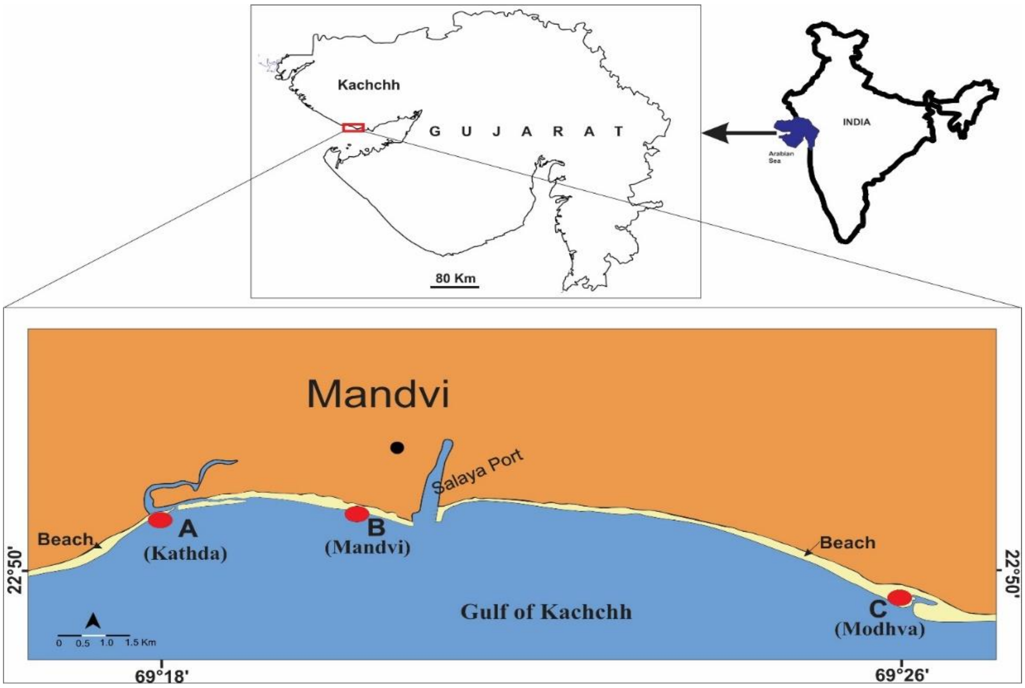

Figure 1: Showing the study area and the three selected stations (A, B and C) along the northern coastline of Gulf of Kachchh, western India. (A- Kathda, B- Mandvi and C- Modhva), (Source: Map modified from Google earth).

The total diversity of the stations, richness, density, biomass and diversity indices were calculated using the PAST-4 statistical software. Any additional diversity indices were cross-verified and calculated using an online diversity calculator (http://www.alyoung.com/labs/biodiversity_calculator.html).These different diversity indices used in the present study were:

Simpson's diversity index (D) used here as a mathematical measure that characterizes species diversity in a community (Simpson, 1949). Wherein 0 indicates infinite diversity while 1 indicates no diversity

$$Simpson\ Index\ D = \frac{\sum ini(ni\text{-}1)}{N(N\text{-}1)}$$

n = the total number of individuals of a species, N = the total number of individuals of all the species.

Alternatively, the inverse of the Simpson diversity index was also used as a diversity indicator or dominance indicator, wherein values closer to 1 indicate higher diversity.

$$Simpson\ Dominance\ Index\ D = 1 - \frac{\sum_i n_i(n_i\text{-}1)}{N(N\text{-}1)}$$

The Shannon-Weiner index (Barnes et al. 1998) predicts the uncertainty in the given community which may also refer to species diversity.

$$Shannon\text{-}Weiner\ Index\ H' = \frac{N \ln N - \Sigma_i n_i(n_i\text{-}1)}{N(N\text{-}1)}$$

Berger – Parker Dominance Index indicates the dominance of any particular species.

$$Berger\text{-}Parker\ Index = \frac{n_{max}}{N}$$

Menhinick's index was also used in the present study.

$$Menhinick's\ index = \frac{S}{\sqrt{N}}$$

Where S = the number of species recorded and N = the total number of individuals

$$Margalef\ Diversity\ Index = \frac{S\text{-}1}{\ln N}$$

$$Equitability\ index = -\frac{\Sigma_i \left(\frac{n_i}{N} \cdot \ln \left(\frac{n_i}{N}\right)\right)}{\ln N}$$

The seasonal difference and its significance comparison were made using a one way ANOVA, column statistics and Skewness, which were studied using the statistical software GraphPad Prism 5.

Results

Intertidal areas at the three stations were studied to test how the macrofaunal community structure and biomass vary across the stations and seasons. The accumulated macrofauna at the three stations are represented by a total of 43 species (Kathda – 17 species, Mandvi – 10 and Modhva – 26 species) during the study period. The overall composition of macrofauna was divisible into five Phyla, namely Arthropoda (mainly crustaceans), Mollusca (Gastropoda and Bivalvia), Polychaeta, Nemertea and 'Chordata', which included mudskipper fish species.

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Figure 2: Images showing the habitat at the three stations a). Kathda – A small creek system with mixed habitat conditions b). Mandvi – A famous tourist destination with sandy beach and high tourist activity and c). Modhva – Sandy beach with minimum human activity.

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Table 1: Basic column statistics for abundance of intertidal assemblages and One Way ANOVA for three stations, Kathda, Mandvi and Modhva, along the northern Gulf of Kachchh.

Density analysis									
Station	Kathda			Mandvi			Modhva		
	Pre-monsoon	Post-monsoon	Winter	Pre-monsoon	Post-monsoon	Winter	Pre-monsoon	Post-monsoon	Winter
Minimum	21	12	27	0	0	0	24	3	63
Maximum	126	216	882	15	15	18	180	417	999
Mean	60.17	66.26	269.3	5.333	4.889	9.5	87.67	59.26	503.7
SD	25.4	47.97	274.3	4.187	2.9	4.854	45.93	81.71	336.9
SE	5.988	9.232	64.66	0.9868	0.5581	1.144	10.83	15.72	79.41
One-way Analysis of Variance									
p Value		<0.0001***			0.0006***			<0.0001***	
F value		12.07			8.335			33.94	
R-Square		0.28			0.217			0.5308	
Skewness	0.6404	1.536	1.082	1.029	1.672	-0.02083	0.6642	3.682	0.1217
S.O.V.	**SS**	**df**	**MS**	**SS**	**df**	**MS**	**SS**	**df**	**MS**
Treatment (between columns)	543420	2	271710	254.8	2	127.4	2420000	2	1210000
Residual (within columns)	1350000	60	22505	917.2	60	15.29	2139000	60	35654
Total	1894000	62		1172	62		4560000	62	

Legends used in tables: SD – Standard Deviation, SE – Standard Error, SS – Sum of squares, df – Degrees of freedom, MS – Mean square, S.O.V. – Sources of variation.

The total macrofaunal assemblage at all three stations was dominated by Molluscs (21 species, 49% of the total composition) and crustacean arthropods (12 species, 28% of the total composition), and then followed by seven species of polychaetes (16% of the total composition). The chordate fish (Mudskippers) and nemertean worms remained miscellaneous groups forming only 5% (2 species) and 2% (1 species), respectively (Fig. 3). The maximum intertidal diversity was recorded from the Modhva station with 18 species of molluscs (69%), 6 species of crustaceans (23%) and 2 species of polychaetes (8%). The 17 species recorded from Kathda, were dominated by 6 species of crustaceans (35%) and 5 species of molluscs (29%), but there were also three species of polychaetes (18%), 2 species of mudskippers (12%) and 1 species of nemertine worm (6%). The third station Mandvi was represented by only three groups, with an equal number of molluscs and polychaetes, four species (40%), and two species of crustaceans (20%) (Fig. 3).

Results show that a high density of macrofauna, mainly molluscs, dominated in the winter months. The maximum density was seen at Modhva, with an average of 194.3 ± 34.16 individuals/m^2 (Maximum 999 individuals/m^2 and minimum 3 individuals/m^2) followed by Kathda with 122.53 ± 22.01 individuals/m^2 (maximum 882 individuals/m^2 and minimum 12 individuals/m^2) and Mandvi with 6.33 ± 0.54 individuals/m^2 (maximum 18 individuals/m^2 and minimum of zero individuals in a few quadrats). Within these intertidal communities, the gastropod species, *Cerethidia singulata* Gmelin, 1791 and *Umbonium vestiarium* Linnaeus, 1758 contributed richly with a maximum density of *C. singulata* with 867 individuals/m^2 (average 87 ± 14.7 individuals/m^2) and *U. vestiarium* 456 individuals/m^2 (average 97.9 ± 16.4 individuals/m^2). The Soldier crab (*Dotilla* sp.) and the Fiddler crab (*Astruca lacteal* De Haan, 1835) were found to be the major contributors to overall abundance among the crustaceans. Moreover, the crustacean (especially crabs) and mollusc populations showed an antagonistic relationship where the pre-monsoon was dominated by the crustaceans and the winter season was dominated by molluscs. This occurred at two stations, Kathda and Modhva. A higher density of molluscs was maintained at all the stations during the winter season (Figs. 4 and 5). Mandvi showed distinct low density and diversity among the selected stations (Fig. 5).

Biomass at the three locations ranged from a minimum of zero to a maximum of 899 g/m^2. The highest biomass was recorded at Kathda (average 136 ± 23.04 g/m^2, maximum 899 and minimum of 3.2 g/m^2) followed by Modhva (average 133.3 ± 26.12 g/m^2, maximum 771.6 and minimum of 1.5 g/m^2) and Mandvi (average 1.75 ± 0.24 g/m^2, maximum 10.20 and minimum 0 g/m^2). Although Mandvi station showed predominantly lower biomass, it showed high polychaete biomass during the winter whereas other stations had high biomass of molluscs during the same season (Fig. 6). Polychaetes at Mandvi were dominated by species in the following genera *Nereis*, *Eunice* and *Sabella*. It was observed that the overall intertidal species density was closely related to respective biomass (Fig. 7) except in the case of *Boleophthalmus* sp. (mudskippers).

An analysis of variance (ANOVA) revealed that the abundance between intertidal communities varied across the seasons and stations. The ANOVA results supported the non-uniform abundance and dispersal of intertidal macrofaunal communities at Kathda ($p< 0.0001$, $F= 12.07$), Mandvi ($p= 0.0006$, $F= 8.337$) and Modhva ($p< 0.0001$, $F= 33.94$). The Skewness analysis at all three stations revealed asymmetry in distribution across seasons and stations. The details of column statistics and ANOVA are presented in Table 1. A similar pattern was also observed in the case of intertidal biomass which showed high variations (with significant *p* values) in alignment with the abundance at all locations (Table 2).

Table 2: Basic column statistics for wet biomass values of intertidal assemblages and One Way ANOVA for three stations, Kathda, Mandvi and Modhva, along the northern Gulf of Kachchh.

Biomass analysis									
Station	Kathda			Mandvi			Modhva		
	Pre-monsoon	Post-monsoon	Winter	Pre-monsoon	Post-monsoon	Winter	Pre-monsoon	Post-monsoon	Winter
Minimum	25.8	3.2	33.33	0	0	0	15.3	1.5	33.3
Maximum	98.05	191.1	899.6	3.24	6	10.2	128.1	247.5	771.6
Mean	69.28	72.94	297.2	0.985	1.364	3.116	51.13	34.98	362.9
SD	19.67	52.02	281	0.9966	1.27	2.683	34.18	49.72	271.2
SE	4.637	10.01	66.23	0.2349	0.2443	0.6324	8.057	9.569	63.92
One-way Analysis of Variance									
p Value		<0.0001***			0.0009***			<0.0001***	
F value		13.86			7.96			29.93	
R-Square		0.31			0.209			0.499	
Skewness	-0.4596	0.7028	0.9974	0.833	2.108	1.012	1.212	3.379	0.2297
S.O.V	**SS**	**df**	**MS**	**SS**	**df**	**MS**	**SS**	**df**	**MS**
Treatment (Between columns)	655482	2	327741	48.11	2	24.05	1331000	2	665654
Residual (within columns)	1419000	60	23653	181.2	60	3.019	1335000	60	22242
Total	2075000	62		229.3	62		2666000	62	

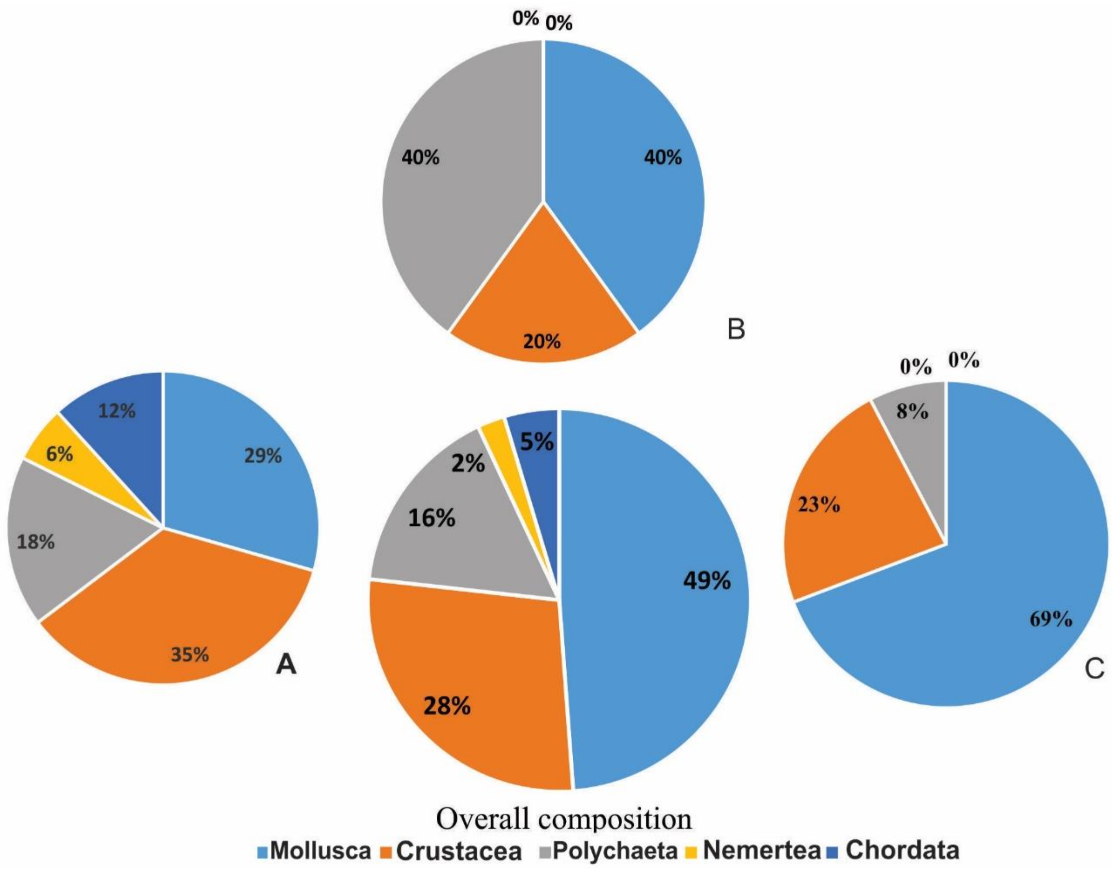

Figure 3: Percentage composition of macrofaunal assemblage, overall and between the three stations along the northern coastline of Gulf of Kachchh, western India (A- Kathda, B- Mandvi and C- Modhva).

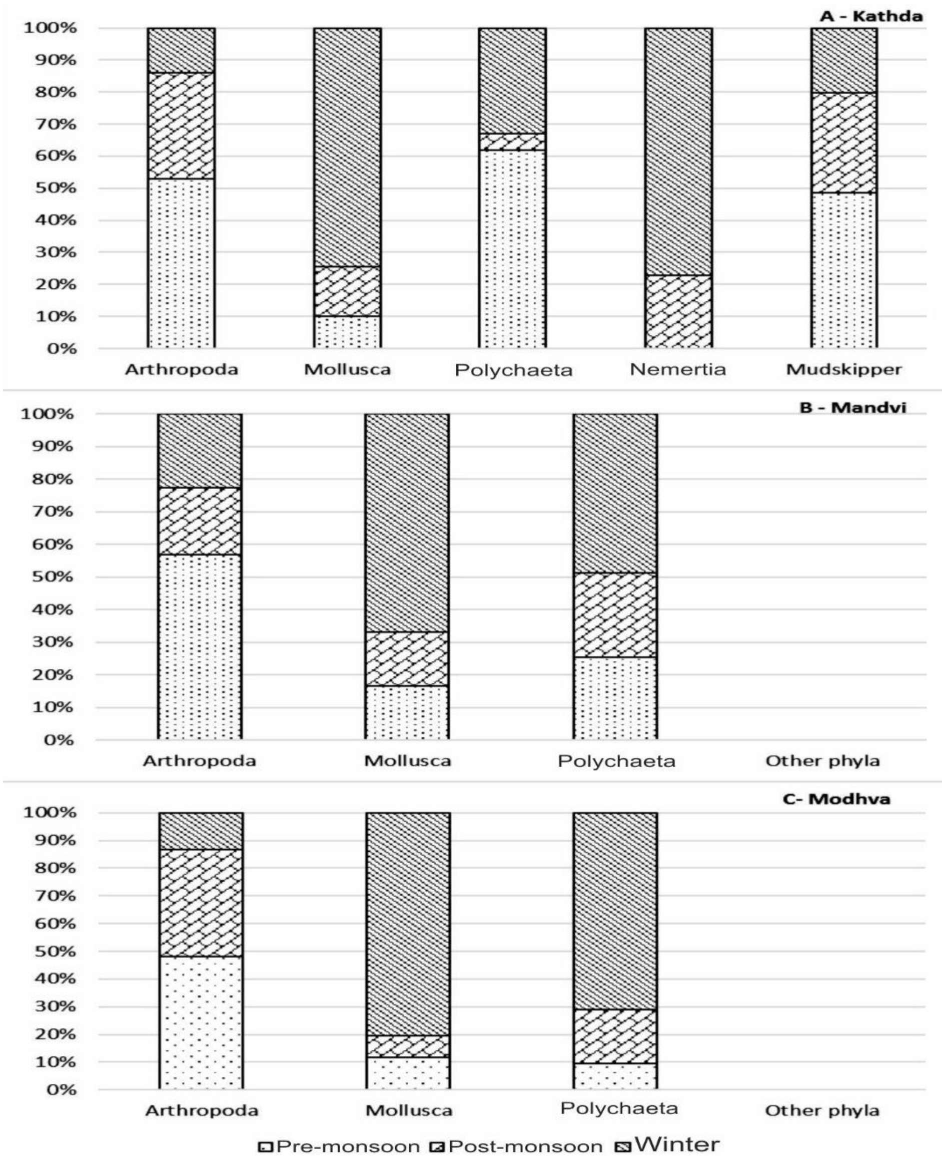

Figure 4: Seasonal flux in community composition, A) Kathda B) Mandvi and C) Modhva.

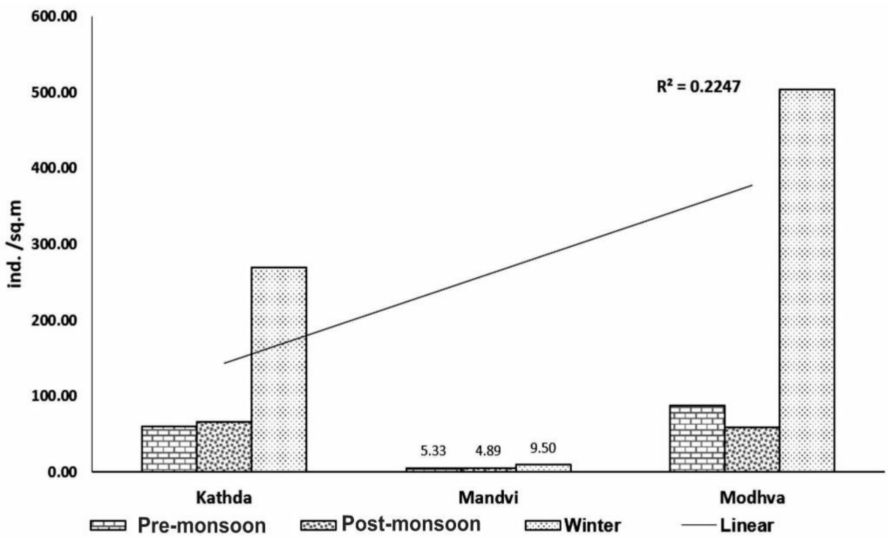

Figure 5: Seasonal macrofaunal densities across three stations, Kathda, Mandvi and Modhva with linear regression and correlation coefficient calculated (R-value). The low densities at Mandvi are presented by data labels for clarity.

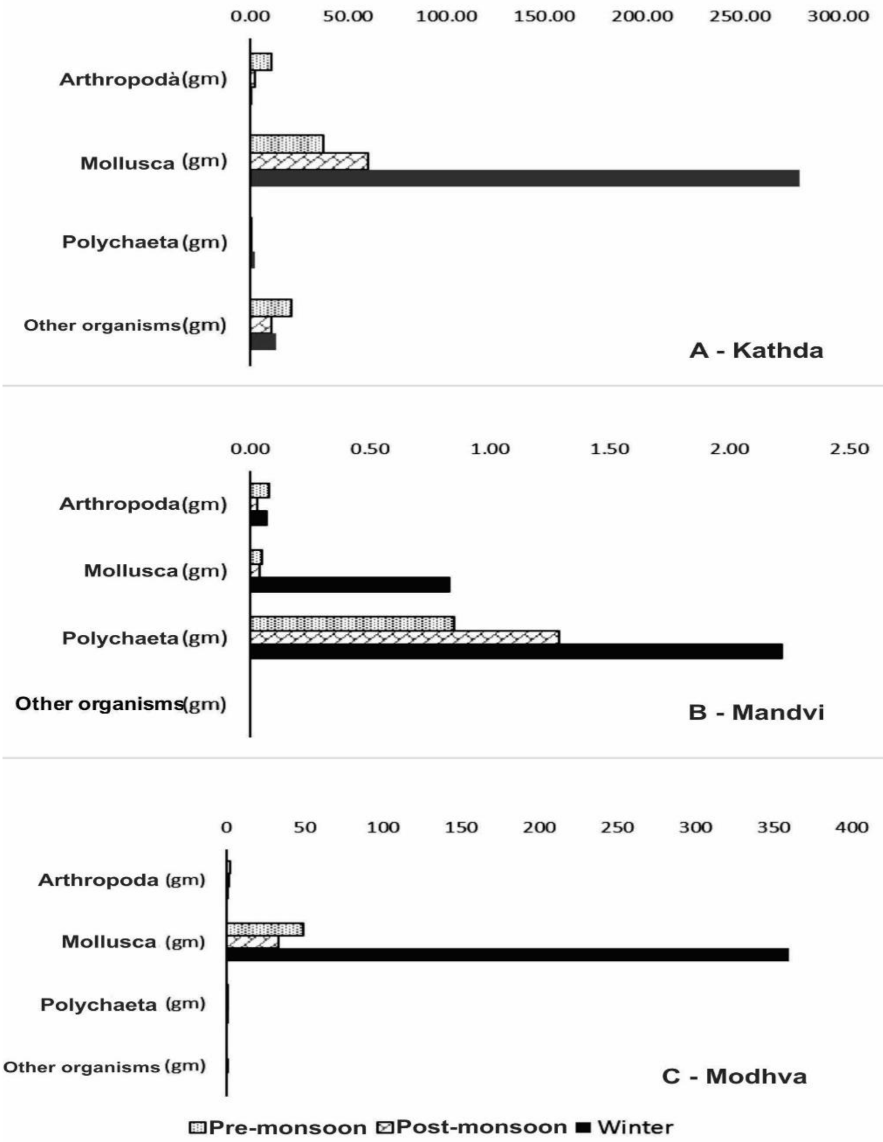

Figure 6: Taxonomic seasonal biomass of intertidal macrofaunal assemblage at Kathda, Mandvi and Modhva along the northern Gulf of Kachchh, western India.

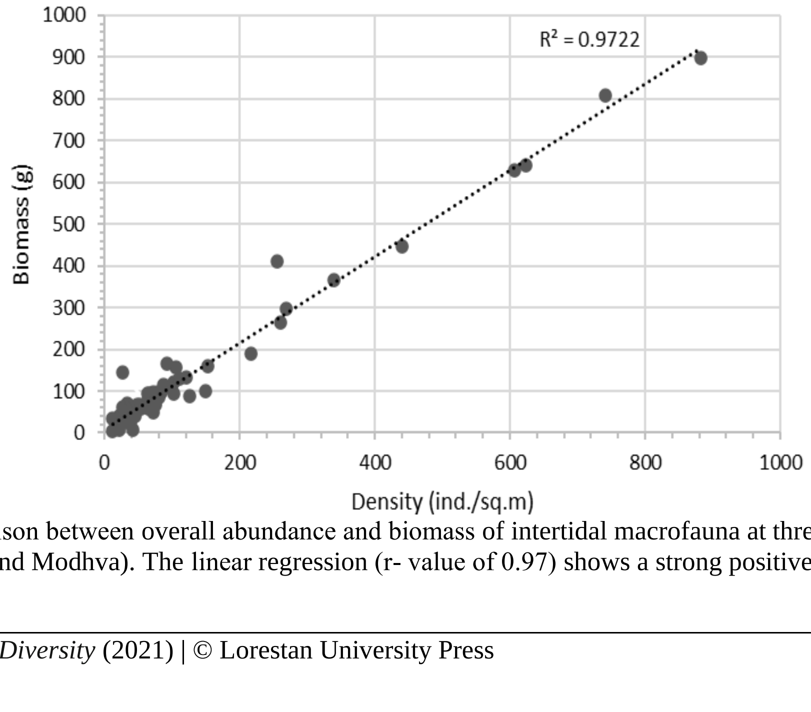

Figure 7: Comparison between overall abundance and biomass of intertidal macrofauna at three selected stations (Kathda, Mandvi and Modhva). The linear regression (r- value of 0.97) shows a strong positive relationship.

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Diversity indices and values help to better understand the community patterns and spatial variation (Mouchet et al., 2010). The different diversity and dominance indices used are presented in Table 3. The Simpson evenness index ranged from 0.15 to the highest at 0.84 wherein Kathda showed the highest value during the post-monsoon season while the overall lowest was recorded from Mandvi. The Shannon diversity index ranged from 0.4 to 2 with the highest values from Mandvi showing more or less even abundance. The maximum evenness was observed at Mandvi, while seasonally it was the post-monsoon and winter with higher values (Table 3).

The Berger-Parker dominance index, expressing the dominance and distribution pattern, ranged from 0.2 to 0.92 with the highest at Kathda (0.92) followed by Modhva (0.48) and finally Mandvi (0.25). The most diversity was recorded during post-monsoon and winter (as per Table 3). The richness of the intertidal macrofaunal communities, as projected through the Margalef Richness index, presented overall highest richness at Modhva (2.43) followed by Kathda (1.58) and again, finally Mandvi (1.54). Seasonally, winter showed the maximum diversity at all the study locations. These high richness values in winter can be attributed to increased molluscan diversity during winter with a record of 20 gastropod species at Modhva. Mandvi and Modhva showed prominent habitat similarity by having sandy intertidal areas and five common species, while Kathda differed by having a mixed type of intertidal area (Fig. 2). Classical clustering was used to understand the distribution pattern of the species across the stations (Fig. 8).

Whereas, to represent the sequential resemblance or variations in the habitat, abundance and diversity among the stations, a scatter plot of multivariate analysis was used between richness, abundance and the stations (Fig. 9). This scatter plot also indicated the higher degree of deflection in terms of the abundance of the dominant species *Umbonium vestiarium* and *Cerethidia cingulata*, as presented in Figure 9.

Discussion

Intertidal macrofaunal assemblages can form an important component to understanding an ecosystem's health and stress, based on any changes (Machado et al., 2017). These macrofaunal communities are highly dependent on various environmental factors such as seasonality, local topography, and habitat factors, as well as anthropogenic factors (Bloch and Klingbeil, 2015). Similar studies on macrofaunal communities along the Indian coastline have been carried out by several researchers, but they normally targeted offshore waters (Ingole et al., 2010; Raja, et al., 2014; Ingole et al., 2016). The coastal stretches of the Gulf of Kachchh are characterized by varied habitats (sandy, muddy, creeks and mangroves) and challenging climatic factors like aridity and scanty rainfall (Sarvanakumar et al., 2007). Such habitat complexities tend to serve as important factors controlling benthic assemblages (Pandya and Vachhrajani, 2010).

The present study tried to understand the community attributes, like abundance and biomass, across stations that were spatially very close but had distinct habitat and human influences. The stations Mandvi and Modhva, located at a spatial distance of fewer than 5 km, presented similar habitat with a sandy intertidal beach and similar environmental conditions. Yet, a remarkable difference was observed between Mandvi (10 species and maximum density of 9.5 individuals/ m^2) and Modhva (26 species and maximum density of 503 individuals/m^2). Out of the 43 total species observed, 20 species were found only at Modhva, which is most likely the result of the vast intertidal span and minimum human disturbance. Molluscs, such as *Umbonium vestiarium* and *Cerithedia cingulata*, inhabited the mid-tidal zone at Modhva and Kathda. These two species primarily contributed to the high abundance and biomass at these stations, especially during the winter. The predominant abundance and biomass of *Umbonium* sp., among other macrofauna, has previously been reported by Zhang et al. (2016) in intertidal zones of the Shuangtaizi estuary, China. In the present study, the differences in species diversity between characteristically similar stations can be the result of the magnitude of anthropogenic activity, as well as the vast intertidal span at Modhva.

Table 3: Biodiversity indices for the intertidal macrofaunal communities for three stations, Kathda, Mandvi and Modhva, along the northern Gulf of Kachchh.

Station	Season	Simpson Index (D)	Dominance Index	Shannon Index (H')	Menhinick Index	Equitability Index	Berger-Parker Dominance Index (D)	Margalef Richness Index
Kathda	Pre-monsoon	0.25	0.75	1.4	0.12	0.81	0.32	0.64
	Post-monsoon	0.84	0.16	0.44	0.14	0.18	0.92	1.2
	Winter	0.19	0.81	1.8	0.29	0.79	0.26	1.3
	Overall	0.7	0.29	0.79	0.14	0.28	0.83	1.58
Mandvi	Pre-monsoon	0.33	0.67	1.3	0.29	0.73	0.5	0.82
	Post-monsoon	0.34	0.66	1.4	0.32	0.73	0.55	0.97
	Winter	0.41	0.59	1.3	0.3	0.57	0.61	1.2
	Overall	0.15	0.84	2	0.53	0.87	0.25	1.54
Modhva	Pre-monsoon	0.35	0.65	1.3	0.09	0.61	0.52	0.78
	Post-monsoon	0.36	0.64	1.5	0.18	0.55	0.57	1.5
	Winter	0.45	0.55	0.96	0.08	0.33	0.5	1.6
	Overall	0.34	0.65	1.41	0.17	0.43	0.48	2.42

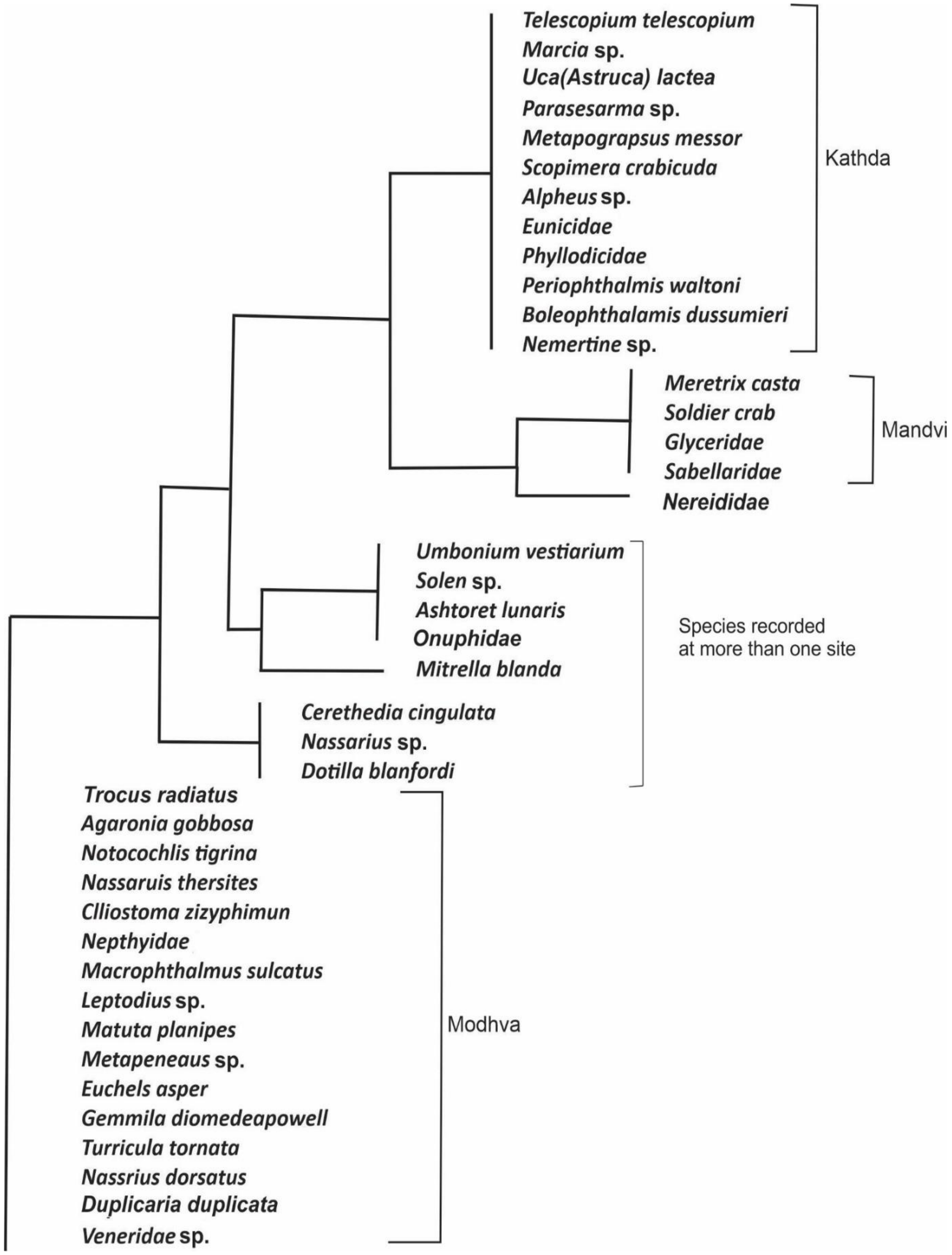

Figure 8: Cluster analysis of intertidal macrofaunal communities for three stations, Kathda, Mandvi and Modhva (Northern Gulf of Kachchh). Clusters marked with site names show the species/families only present at those stations during the present study.

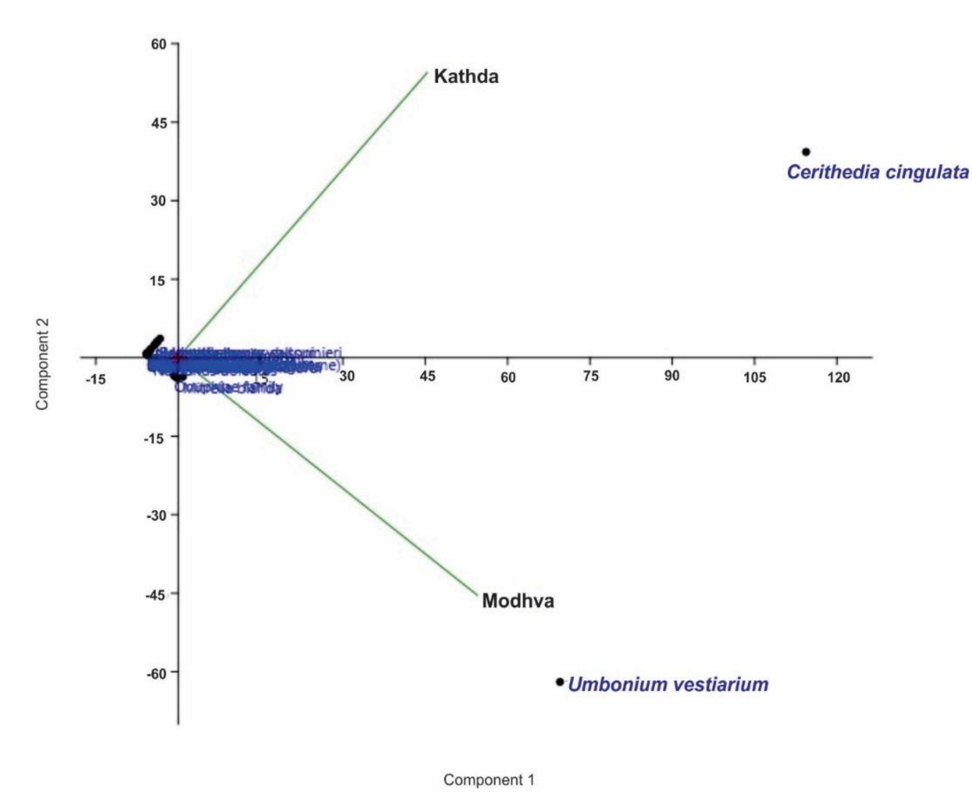

Figure 9: Scatter plot showing distribution and relative abundance of species across the three stations, Kathda, Mandvi and Modhva, along the northern Gulf of Kachchh. Note the deflected population density of the two molluscs *Cerithedia cingulata* and *Umbonium vestiarium*.

On the contrary, Kathda recorded high indices values, especially in terms of abundance and dominance and species richness. These higher abundance values at Kathda could be because of habitat heterogeneity formed by mangrove patches, muddy zones and mixed sandy patches, which can directly influence the abundance and distribution of macrofaunal assemblages. Similar observations showing the influence of microhabitat on intertidal community structure are also earlier reported by several researchers (Levin and Talley, 2002; Pandya and Vachhrajani, 2010; Kon et al., 2011; Pandya, 2011; Leung and Tam, 2013; Leung, 2015).

Our results indicate that the overall abundance of macrobenthos was higher in winter, followed by the post-monsoon and then pre-monsoon periods. Such high mollusc abundance in winter was also recorded in the mangroves of Kachchh by Thivakaran and Sawale (2016) and more broadly in tropical intertidal areas by Salem et al. (2014). Moreover, other studies have reported high densities of intertidal assemblages during November to February (post-monsoon and winter) along the west coast of India (Ansari et al., 1986; Bhadja et al., 2014). Earlier studies along other coastal stretches of Kachchh had reported higher abundance and diversity figures with 51 species of macrofauna in the mangroves of Kharo creek (Thivakaran and Sawale, 2016) and abundances ranging from 4 individuals/m^2 to 2444 individuals/m^2. A similar study from the mangroves of the same region recorded densities with a mean 400 to 2400 individuals/m^2 (Saravanakumar et al., 2007). Seasonal observations by Saravanakumar et al. (2007) were found to be in line with the present study resulting in high diversity during winter. Yet, compared to the aforementioned studies (Saravanakumar et al., 2007; Thivakaran and Sawale, 2016) the present study reported overall low density ranging from 0 to 999 individuals/m^2. The low densities reported in the present study can be attributed to the sandy habitat at all three stations, while the earlier studies in Kachchh area by Saravanakumar et al. (2007) and Kardani et al. (2014) represent mangrove forests.

However, the study on gastropod dynamics at Mandvi by Kardani et al. (2014) reported average values from 346 to 1003 individuals/m^2 with the highest densities in the monsoon. These values of Kardani et al. (2014) were closer to the densities reported in the present study (0 to 999 individuals/m^2).

Biomass

Although a positive relationship was observed between abundance and biomass, it can largely depend on the size of an individual. The occupancy of older and larger individuals may have lower abundance but increase biomass (Bijleveld et al., 2018). In the present study, it was observed that abundance and biomass mostly followed a similar trend (Fig. 6). Gastropods were found to be the most dominant group contributing to biomass at

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two stations Kathda and Modhva, while Mandvi was dominated by polychaetes (Fig. 6). The literature shows that intertidal areas along Gujarat state having mangrove and sandy habitats are normally dominated by either crustacean or molluscan assemblages as reported previously (Saravanakumar et al., 2007, Pandya, 2011; Thivakaran and Sawale, 2016). Unusually, the intertidal assemblage at Mandvi was dominated by polychaetes in both abundance and biomass, which may be a due to a high organic matter load at Mandvi, caused by tourism activities. This high tourist pressure includes factors such as, food stalls, recreational horse and camel rides on the beach adding animal feces, and degradable food waste dumping onto intertidal sediments. Tsutsumi (1990), in his study, correlated high polychaete abundance and biomass to high total organic matter in the area. Furthermore, polychaetes are more infaunal and are less disturbed by trampling, compared to crustaceans and mollusca, which are often seen on the beach surface.

Anthropogenic influences

The selected three stations were within a 14 km stretch of beach and are assumed to have very similar abiotic conditions. One of the hypotheses of the present study was to test the assumption that the degree of anthropogenic pressure influences macrofaunal abundance, diversity and biomass? Mandvi is a popular tourist destination, as well as a leisure beach for the local public. Based on the number of tourists visiting Mandvi beach from the year 2003 to 2013, an average of nearly 0.15 million tourists visits this beach every year (Department of Tourism, 2010; Shukla, 2014). Apart from this, the site also experiences local and unrecorded visitors. Such high human activity can be one of the reasons for low diversity and abundance at Mandvi due to the effect of trampling. Several researchers have previously reported trampling and other anthropogenic activities negatively influencing local intertidal macrofaunal communities (Van De Werfhorst and Pearse, 2007; Portugal et al., 2016, Mendez et al, 2017; Cimon and Cusson, 2018).

A study by Quadros et al. (2009) reported the effect of anthropogenic stress on a polychaete assemblage at Thane creek along the west coast of India. Such anthropogenic pressure can eliminate the vulnerable species from the impacted area, thus causing a decline in species richness, which can in turn act as an indicator of such human-induced influences (Portugal et al., 2016). This could be the reason for the absence of some common species, like *Cerithedia cingulata* and *Dotilla* sp., on the Mandvi coast while the same were present at nearby sandy stations. The trampling impact by humans and their recreational activities on these beach stations can easily influence these intertidal forms and can be better understood by a dedicated study with experimental setups to establish the impact at the species and habitat levels.

An attempt was made to address two questions raised during the inception of the study. i). Does the intertidal community structure and biomass change temporally across habitat variation? Though spatially close, the stations showed prominent differences in richness and abundance, both spatially and temporally. ii). Do anthropogenically affected stations differ from the rest in terms of intertidal community patterns and biomass? The most anthropogenically active site, Mandvi, showed significantly lower diversity and density compared to nearby stations, which had a similar habitat type. It can be concluded that intertidal community dynamics are sensitive and vary significantly. Adding to this, anthropogenic pressure can potentially alter these natural dynamics.

Based on the present study it is suggested that continuous monitoring programs and long-term studies are required to keep track of intertidal community changes, especially for the coastal areas with significant anthropogenic pressure.

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Conflict of interest

The authors declare that there are no conflicting issues related to this research article.

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