CIBTech Journal of Zoology ISSN: 2319–3883
Online, International Journal, Available at http://www.cibtech.org/cjz.htm
2022 Vol.11, pp.154-165/Soniya et al.
***Research Article** (Open Access)*

COMPARATIVE ACCOUNT OF MOLLUSCS FROM A ROCKY COASTLINE OF GUJARAT, INDIA: DOES SPATIO-TEMPORAL CHANGES AFFECTS THE POPULATION?

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ABSTRACT
This study reports on patterns of distribution and diversity of intertidal gastropods and total molluscs from a rocky intertidal shore at Veraval of the south Saurashtra coastline in NW India. The coastline of this region is known to have high ecological importance, but few studies have quantitatively analyzed spatiotemporal distributions of coastal biota. Gastropods are especially prevalent on this shore and were the focus of this study, in order to better understand how they are distributed, the potential reasons for those distributions, and how their distributions may affect functioning in these coastal communities. A total of 43 species of gastropods and 11 species of other molluscs were identified using random quadrat sampling during nine field surveys done over seven months. The results showed that, in terms of vertical distribution, the populations of all analyzed gastropods occurred most abundantly in the upper littoral zone compared to the middle and lower littoral zones. Menhinick's diversity index showed species richness was highest in the middle littoral zone (4.15) at site-1 and in the lower littoral zone (3.92) at site-2. In general, it was observed that gastropods were the dominant molluscan type in most of the coastal areas. Neither species diversity, gastropod abundance, or abundance of other molluscs showed significant temporal variability. We discuss how high gastropod abundances were associated with different intertidal levels, where they are likely finding optimum living conditions concerning features including vertical rock surfaces, pools, boulders and in association with other components of the biotic community. Present study provides new information about the structure of gastropods molluscan community in the area and the way the community patterns, and thus also likely the functioning, is changing over time.

***Keywords**: Gastropoda, Mollusca, Diversity, Spatio-Temporal Distribution, Intertidal Zone, South Saurashtra Coast*

INTRODUCTION

Marine gastropods are abundant intermediate predators and very important members of coastal communities. They are having a wide range of feeding habitat. For an instance, oysters are carnivorous whereas most of the limpets play an important role as herbivorous gastropods within their environment (Coleman *et al.*, 2006). Many gastropods are dependent on small mussels and barnacles (Clothers 1985). Cerithiiform gastropods are mostly detritus feeders (Houbrick 1992). As a prey, this group is an essential part of the diet of many molluscivorous intertidal animal (Burkepile,2007). One of the challenging aspects in recent times is marine pollution. Marine environment s in most countries is by now polluted, which may directly affect marine fauna. Many more activities such as over harvesting of gastropods, dumping of waste, land reclamation, dredging are the major threats to the gastropods as well as co-existing marine fauna (Beatley 1991; Suratissa & Rathnayake 2016). In order to understand how the coast will be affected by the community functions, and whether threats can be expected to impact those functions, it needs to be first understood that how the gastropods are distributed on the coast and how those distributions change over time.

A number of studies have focused on molluscan diversity along the Indian coastline (Rao and Rao 1993; Kulkarni and Jaiswar 2000; Rao and Dey 2000; Ramasamy and Murugan 2002; Khalua *et al.*, 2003;

Venkatraman 2005; Ingole *et al.,* 2009; Kurhe *et al.,* 2009; Satheeshkumar and Khan 2010; Shankar *et al.*, 2011; Anandraj *et al.*, 2012; David 2013; Pawar and Al-Tawaha 2017; Yadav *et al.*, 2019). Diversity and ecology of molluscs along the Saurashtra coastline was extensively studied during the last few decades, and these studies examined various distributional patterns of molluscs including *Cerrithium caeruleum* and *Clypeomorus monoliferus* (Patel *et al.*, 1985), *Turbo coronatus* and *Turbo intercostalis* (Malli 1993), and *Cellana karachiensis* (Faladu *et al.*, 2014). Some studies such as Joshi (2010); Vaghela *et al.,* (2010); Gohil and Kundu (2011; 2013a); Vakani *et al.,* (2017) focused on ecology and distribution of key intertidal molluscs in the context of environmental factors. Viswanathan (2017) provided an annotated list of all gastropods known to occur on the Gujarat coast, which included 395 species belonging to 87 families and 199 genera. Various studies on the seasonal changes in distribution, density, diversity and population structure of individual species of gastropods from different rocky shores have been done (Creese and Underwood 1976; Misra and Kundu 2005). Another important aspect is that the molluscan community structure is long since regarded as an effective indicator of overall ecosystem health and species diversity, thus, making them an ideal organism for conservation and biodiversity studies (Rittschof and McClellan-Green 2005). Similarly, some studies reported about the spatial variation in distribution of organisms, which can be helpful to understand the organism-organism and organism-habitat relationships (Findlay 1981; Underwood and Chapman 1996). Present study is appending the existing knowledge by reporting the diversity of gastropod and also non-gastropod molluscs, including assessment of spatio-temporal variations in their distribution pattern from a rocky intertidal shore at Veraval of the south Saurashtra coastline. It is important to understand the marine ecology of the Veraval region because it is a main region for commercial fishing (Ghosh *et al.*, 2010).

MATERIALS AND METHODS

Study area and sampling sites

In the present investigations, Veraval (20º 54' N, 70º 21' E) at the south Saurashtra coast of Gujarat in India was selected (Fig. 1). Veraval was surveyed extensively from August 2016 to February 2017 to monitor the characteristics of the molluscan fauna present there. The rocky-sandy coastline of Veraval is about 3 km long. The entire intertidal zone of the selected coastline was divided into two separate sampling sites.

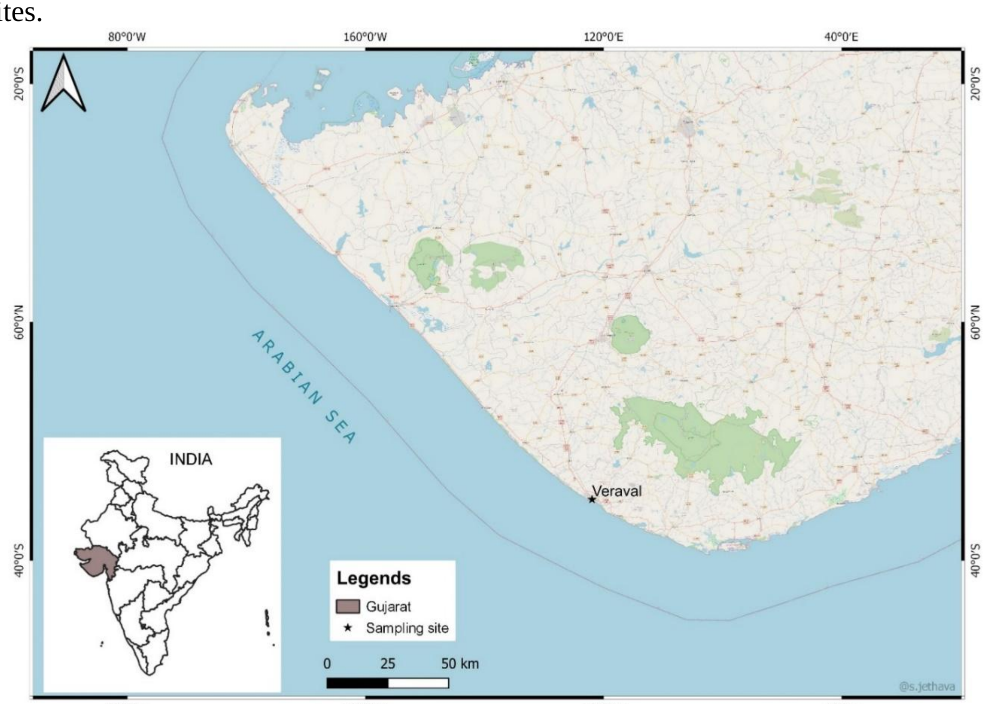


Figure1: Map of the sampling site of the Veraval coastline, Gujarat, India

Sampling site 1 (20º 55' 01.15'' N, 70º 20' 35.29'' E): In this sampling site, more coral pools are present compared to other fauna so that site classified as coral assemblage. This is mainly rocky with a few sandy patches interspersed with many tide pools and puddles. The substratum of the coastline is uneven and after about 100 m to 120 m distance, the end of intertidal zone is reached where a direct steep slope enters into the sub tidal zone. The spray zone is mostly rocky with rounded rocks and small tidepools.

Sampling site 2 (20º 55' 29.36'' N, 70º 19' 46.28'' E): The substratum is flat with narrow crevices over the site floor. The area of this microsite has a network of crevices. Colonies of sessile *Zoanthus* cnidarians colonies were found commonly covering the rock surfaces throughout the site hence it classified as *Zoanthus* assemblage. Location mapping was done by QGIS 3.10.5.

Field sampling, processing and identification of specimens

The surveys were undertaken during the low tides that ranged from 0.01 m to 0.6 m and when there were relatively calm sea conditions. Surveys were conducted following the methods of Benkendorff and Davis (2002). Quadrat methods were used to measure densities of intertidal fauna (Misra 1968). The quadrat size used was 50 x 50 cm. Surveys were done on a monthly basis, with a minimum of 20 randomly placed quadrats being sampled within each site at each month. Identification was mainly done based on keys proposed by Rao (2003), Apte (2014) and Dance (2002). In addition to these, different identification manuals, journals and review reports were also used for identification but the nomenclature was used on the basis of the latest updates of World Register of Marine Species (WoRMS).

Data Analysis

Data for the total number of gastropods, and total number of non-gastropods, were collected for the purpose of spatio-temporal abundance variation and for species richness of gastropods and total molluscs. The Menhinick's Diversity Index was calculated using the equation $D_{Mn}=S/\sqrt{N}$ to estimate species diversity along the different littoral zones, where S stands for total number of species and N stands for total number of individuals (Clarke and Warwick, 1994). The obtained data were subjected to a statistical analysis by Analysis of Variance (ANOVA) to study spatio-temporal variation in the total number of individuals (N) of gastropod and non-gastropods between littoral zones. Statistical analyses were done as per Sokal and Rohlf (1987).

RESULTS AND DISCUSSION

Species diversity

During this study, species in the phylum mollusca were found to be more dominating than other macrofaunal groups at both the sampling sites. A total of 43 (Table 1) species representing 21 different families were noted of gastropod and 11 species representing 7 families were observed of non-gastropod. Among these species only two (*Phidiana militaris* and *Bornella Stellifer*) were not observed from site-2. *Echinolittorina Pascua,* and *Littoraria undulata* were mostly observed from the supralittoral zone which increasing abundance of the number of gastropods in this assemblage. Among 43 gastropods species, five different species in the family Certhiidae (*Cerithium cearulium, Cerithium scabridum, Cerithium zonatum, Clypeomorus bifasciata,* and *Rhinoclavis sinensis*) were comprising most of the population, at 31.43% and 43.60% of the total population at site-1 and site-2 respectively.

Distribution of gastropod and total mollusc

Fig. 2a shows a comparison in the distribution of total molluscs and gastropod molluscs at both the sampling sites during the months of August 2016 to February 2017. The diversity and population sizes of gastropod molluscs were observed to be very high compared to any other class of the phylum mollusca. Mostly, gastropods were the only types of molluscs at the sampling sites (Fig. 2a**).** The Middle littoral zone exhibited higher species diversity as well as individual species populations at site-2 during the month of August and in site-1 during the month of November. In the month of September, the species diversity and species population of gastropods and non-gastropod molluscs remained almost similar in site-1 and site-2. Similar results were observed in the month of December but during January and February the trend showed a different scenario with low population of gastropods and non-gastropods in

Table 1: Taxonomic list of gastropod and non-gastropod species sampled from the inter-tidal zone. '+' and '-' denote presence or absence of the species respectively (+++ highly abundant, ++ abundant, + rare)

Check list of gastropod and non-gastropod molluscs from Veraval, Gujarat, India.

Gastropods

No.	**Family**		**Species**	**Site 1**	**Site 2**
1	Onchidiidae	1	*Peronia verruculata* Cuvier, 1830	++	++
2	Siphonariidae	2	*Siphonaria* sp. G. B. Sowerby I, 1823	+++	+++
3	Cerithiidae	3	*Clypeomorus bifasciata* G. B. Sowerby II, 1855	+++	+++
		4	*Cerithium caeruleum* G. B. Sowerby II, 1855	+++	+++
		5	*Cerithium scabridum* Philippi, 1848	+	++
		6	*Cerithium zonatum* W. Wood, 1828	+	++
		7	*Rhinoclavis sinensis* Gmelin, 1791	+++	++
4	Turbinidae	8	*Lunella coronate* Gmelin, 1791	+++	+++
		9	*Astralium semicostatum* Kiener, 1850	++	++
		10	*Turbo bruneus* Röding, 1798	++	+
		11	*Turbo intercostalis* Menke, 1846	+++	++
5	Bursidae	12	*Bursa granularis* Röding, 1798	+	+
		13	*Talparia talpa* Linnaeus, 1758	+	-
6	Cypraeidae	14	*Mauritia maculifera* Schilder, 1932	+	+
		15	*Mauritia grayana* Schilder, 1930	+	+
		16	*Naria turdus* Lamarck, 1810	+	+
7	Rostellariidae	17	*Naria ocellata* Linnaeus, 1758	+	+
		18	*Tibia insulaechorab* Röding, 1798	+	+
8	Conidae	19	*Conus cumingii* Reeve, 1848	+	+
		20	*Conus figulinus* Linnaeus, 1758	+	+
		21	*Conus achatinus* Gmelin, 1791	+	+
9	Columbellidae	22	*Anachis terpsichore* G. B. Sowerby II, 1822	+++	+++
10	Muricidae	23	*Chicoreus brunneus* Link, 1807	+	+
		24	*Purpura panama* Röding, 1798	+	+
		25	*Tylothais savignyi* Deshayes, 1844	++	+++
		26	*Hypselodoris infucata* Rüppell & Leuckart, 1830	+	+
11	Pisaniidae	27	*Pollia undosa* Linnaeus, 1758	+	+
		28	*Engina zea* Melvill, 1893	++	++
12	Mitridae	29	*Strigatella scutulata* Gmelin, 1791	+	+
		30	*Scabricola guttata* Swainson, 1824	+	++
13	Neritidae	31	*Nerita albicilla* Linnaeus, 1758	++	+
		32	*Nerita undata* Linnaeus, 1758	+++	+
		33	*Nerita costata* Gmelin, 1791	+++	+

14	Trochidae	34	*Monodonta australis* Lamarck, 1822	+++	++
		35	*Trochus radiatus* Gmelin, 1791	++	++
15	Nacellidae	36	*Cellana karachiensis* Winckworth, 1930	+++	++
16	Aplysiidae	37	*Aplysia oculifera* A. Adams & Reeve, 1850	++	+
17	Samlidae	38	*Samla bicolor* Kelaart, 1858	+	+
18	Facelinidae	39	*Phidiana militaris* Alder & Hancock, 1864	+	-
19	Aeolidiidae	40	*Baeolidia palythoae* Gosliner, 1985	++	+
20	Bornellidae	41	*Bornella stellifer* A. Adams & Reeve, 1848	+	-
21	Littorinidae	42	*Echinolittorina pascua* Rosewater, 1970	+++	++
		43	*Littoraria undulate* Gray, 1839	+++	++
Non-gastropods					
22	Chitonidae	44	*Rhyssoplax peregrina* Thiele, 1909	++	+++
		45	*Ischnochiton* Gray, 1847	-	+
23	Veneridae	46	*Sunetta scripta* Linnaeus, 1758	+	+
		47	*Gafrarium divaricatum* Gmelin, 1791	+	+
		48	*Callista erycina* Linnaeus, 1758	-	+
24	Carditidae	49	*Cardita variegata* Bruguière, 1792	+	+
25	Lucinidae	50	*Ctena* Mörch, 1861	+	+
26	Arcidae	51	*Barbatia decussata* G. B. Sowerby I, 1833	-	+
27	Ostreidae	52	*Crassostrea virginica* Gmelin, 1791	+	++
		53	*Saccostrea cucullata* Born, 1778	+	+
28	Octopodidae	54	*Octopus vulgaris* Cuvier, 1797	+	+

site-1 and high in site-2 (Fig. 2b**)**. The species diversity and abundance of all molluscan forms were low in the lower littoral zone. In this zone, during the month of September, many fewer gastropod or non-gastropod molluscs were recorded possibly because of less exposure of water emersion. This is indeed a very irregular and astonishing event most probably due to the strong high tidal activity. The difference in abundance of total molluscs and gastropod molluscs were clearly observed at site-2 during the month of October and in site-2 during November. During August and October, site-1 was observed with the same population size of gastropod and non-gastropods. Site-2 during the months of December and February also showed the same results. (Fig. 2c). Fig. 2 a, b, and c shows comparisons of gastropods and total molluscs along the vertical zone at both the sampling sites.

Species richness in littoral zones

Data on the measures of Menhinick's Diversity Index (Fig. 3a, b) revealed that the value for the upper littoral zone ranged from 0.62 to 1.97 during August and November respectively in site-1 and it ranged from 0.74 to 2.43 during August and October in site-2. Values of the middle littoral zone of site-1 ranged from 2.04 to 4.15 during September and February respectively whereas, in site-2 it ranged from 2.11 to 3.88 during the month of August and October respectively. During monsoon, the lower littoral zone was not exposed so much that the range of diversity was counted less as compared to other zones. Index values for site-1 ranged from 1.15 to 3.4 during September and January respectively and for site-2 it ranged from 1.341 to 3.927 during September and February respectively. Species richness was observed to be highest in middle littoral zone at site-1 and in lower littoral zone at site-2. It was lowest in the upper littoral zone in both the sampling sites. Within the samples, 79% of individuals were gastropods whereas, non-gastropod classes were comprising 21%, including Bivalvia (15%) followed by Polyplacophora (4%) and Cephalopoda (2%) (Fig. 4). A total of 43 species belonging to 21 families and 11 species of non-gastropods representing 7 families were observed and identified during this study period which is illustrated in Fig. 5.

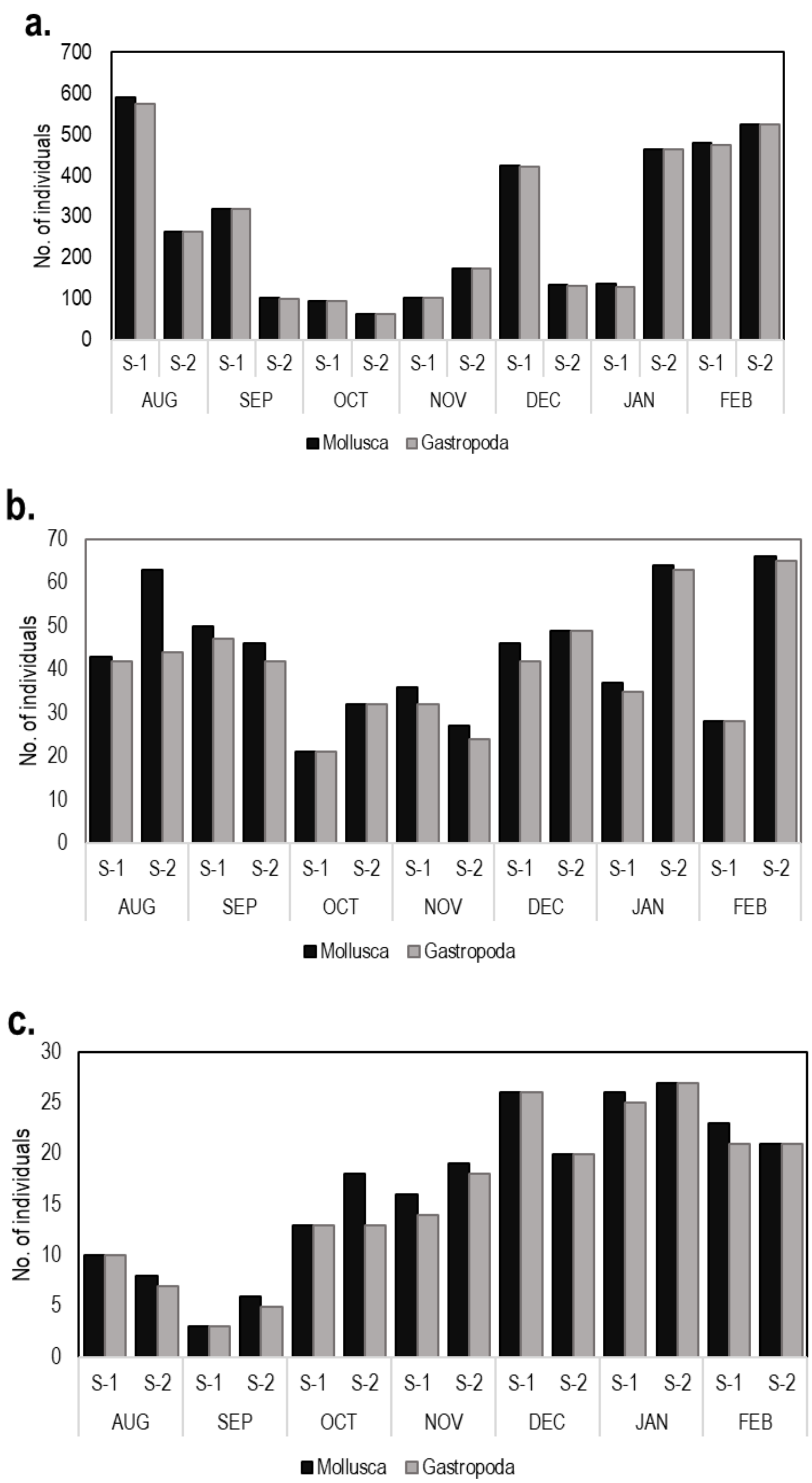
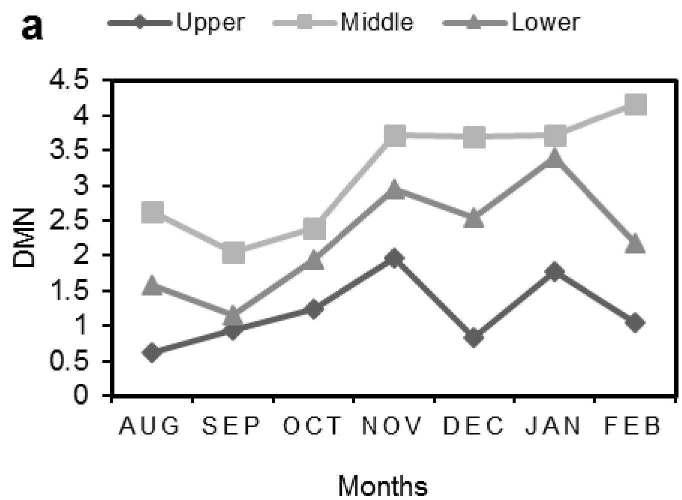


Figure 2: Monthly variations in the number of individuals of total molluscan and gastropod molluscan species in upper (a), middle (b) and lower (c) littoral zones



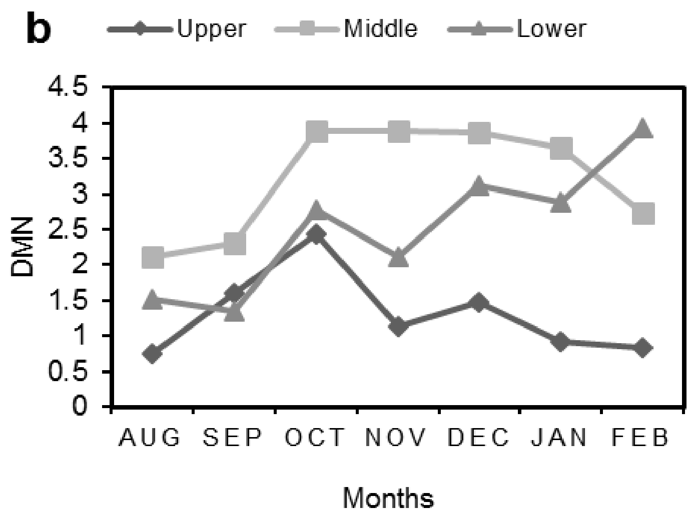


Figure 3: Menhinick's Diversity Index of the major phylum at the upper, middle and lower littoral zone of micro sampling site -1 (a) and micro sampling site -2 (b)

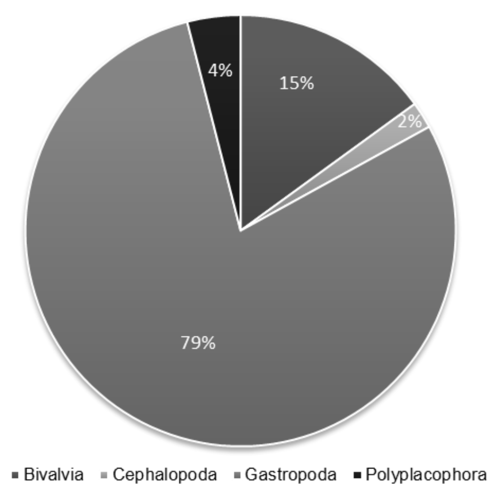


Figure 4: Illustration of class wise population of observed molluscs

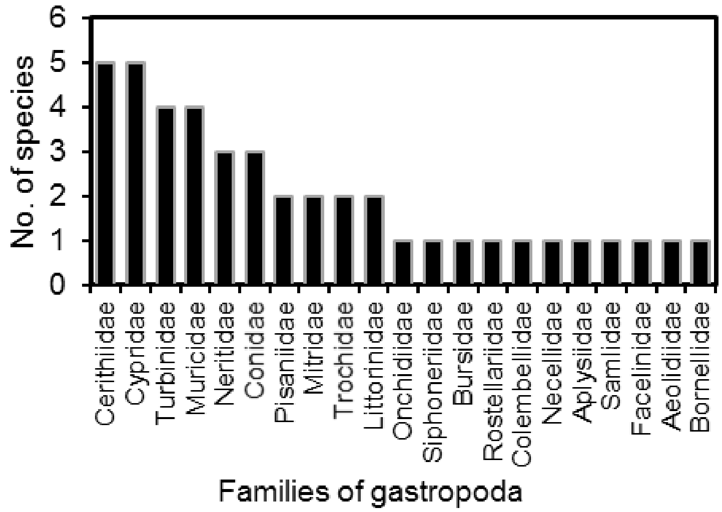


Figure 5: Family wise occurrence of different species along Veraval coastal area

Spatio-temporal distribution

In the present study, the results of ANOVA between different littoral zones showed significant variations as some of the gastropods were found in considerable abundances only in certain zones**.** The results of ANOVA revealed that the diversity index of gastropods had significant spatial variation whereas, temporal variation was not observed. The total population of gastropods and non-gastropods also had significant spatial variation but temporal variation was not observed in both the sampling sites (Table 2).

Table 2: Results showing the F-values (*denotes significance at $P<0.05$) from one-way ANOVA analysing the diversity index, number of gastropods and number of total molluscs present in two sampling sites. Spatial variation (f-critical: 3.55 at df- 2) denotes comparisons of upper, middle and lower littoral zones and Temporal variation (f-critical: 2.84 at df- 6) denotes comparisons between months

	D_{Mn}		**Gastropoda**		**Total mollusca**			
	site 1	site 2	Site 1	Site 2	site 1	site 2	Fcrit	Df
Spatial variation	13.66*	10.59*	13.79*	9.74*	13.62*	9.65*	3.55	2
Temporal variation	0.97	0.72	0.37	0.88	0.37	0.54	2.84	6

It was observed that the gastropods had greater abundances during the winter season in the upper littoral zone. Our study indicated a slight increase in the total number of individuals from monsoon to winter in the middle littoral zone (Fig. 2). The cause for this variation might be related to other environmental factors as temporal variation was not observed. Both the sampling sites were somewhat similar but site-1 provided more microhabitats for gastropods and possibly that is why the diversity and abundance were found to be high in site-1. It is possible that *Lunella coronatus, Echinolittorina pascua*, and *Littoraria undulate* might have played an important role to increase the number of gastropods in site-1 whereas, *Cerithium caeruleum* and *Clypeomorus bifaciata.* were the most dominant species at site-2. The reason for the enhanced species diversity as well as species richness at Site-1 was possibly due to the presence of shelters such as tide pools, puddles and crevices (Hornell 1909; Faladu *et al.*, 2014). Site-2 is dominated by a somewhat flat substratum with occasional shallow tide pools and creeks. The increased diversity of gastropod molluscs was associated with the abundant growth of algae at both the sites, which may help them to acquire shelter as well as food (Hornell 1949). Patches of *Zoanthus* were more in site-2 while coral pools were more in site-1. These pools exhibited larger gastropod populations which produced different assemblages throughout the sampling site.

It has also been observed that the gastropod species were distributed non-randomly in the different littoral zones. Species of *Cellena* and *Siphonaria* were found in the spray and upper littoral zones. The middle zone was mostly dominated by *Peronia veruculata.* As shown in the diversity index, the greatest species diversity was in the middle littoral zone though the numbers of species were less as compared to upper zone. Overall, gastropod molluscs were the dominant group observed in this study and therefore, the phylum mollusca is likely to play an important role (prey as well as predator or grazer) in all assemblages on the littoral area of this coastline. Temporal variation was not observed in both the micro sampling sites probably because of most gastropods being able to withstand high temperature, desiccation and some of the seasonal changes, thus, the populations may not be significantly. Interactions between biotic and abiotic factors are responsible for the temporal and spatial variability in the species abundance in biological communities (Danielson 1991; Misra and Kundu 2005; Ríos-Jara *et al.,* 2009). Though there were no significant temporal variations, significant spatial variations were observed in the populations of mollusca between the vertical zones possibly due to differential recruitment, migration or mortality in response to differing salinity, temperature and levels of desiccation associated with different zones (Hornell 1951). The two sampling sites were adjacent to each other and part of the same coastline. Possibly due to this fact, the diversity of gastropod mollusca did not show significant differences during the study period. However, long-term studies may yield different results as this coastline is susceptible to moderate to high anthropogenic influences.

In the present study, rich species diversity and large abundances of gastropod molluscs were observed along with the other non-gastropods. Populations of gastropods were much higher compared to the non-gastropod individuals (Fig. 4). All the littoral zones of this shore were utilised by gastropods that were present throughout the study period, which shows that these organisms can withstand highly variable environmental conditions. Intertidal zones are known to provide a wide variety of fauna which needs to be protected and preserved for conservation and for fisheries purposes (Benkendorff and Davis 2002). This study has provided information on diversity and distribution pattern of gastropod molluscs which provides scope for application in conservation, ecosystem management and aquaculture.

ACKNOWLEDGEMENTS

Authors are thankful to the UGC-CAS Programme sanctioned to the Department of Biosciences for providing necessary facilities to work. The senior author (SJ) is gratefully acknowledging the UGC for providing National Fellowship for OBC. Gratitude is extended to the visiting scientist Dr. Kiran Liversage, Research Scientist, University of Tartu, Estonian Marine Institute, Estonia, for giving valuable suggestions on and off field. All coast related agencies are thankfully acknowledged for their active support during field work.

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