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Species diversity and distribution of Ostracoda from the surface sediments off Vetharanyam, Tamil Nadu, southeast coast of India

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A study on ostracod diversity, distribution, and their relation with the environment was taken up from the sediment samples of the shelf area off Vetharanyam, Nagapattinam district, Tamil Nadu. Twenty-eight surface sediment samples along 4 transects within a water depth ranging from 4 m to 14.8 m were retrieved. The work was carried out to infer the ostracod species diversity and distribution implying the depositional environment. The sediment characteristics such as calcium carbonate, organic matter, and sand-silt-clay ratio have been determined and correlated for the observed Ostracoda population. The predominant and widely spread sediment types in the area are sandy silt and silty sand. Micropaleontological studies were carried out using standard techniques and thirty Ostracoda taxa were separated. About 5955 Ostracod specimens were recovered with 6 abundant species (*Xestolebris variegata*, *Paijenborchella keij, Loxoconcha gruendeli, Keijella reticulata, Keijella karwarensis)*. The ostracod assemblage recorded herein is indicative of a tropical, shallow, and inner shelf environment.

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INTRODUCTION

Ostracods, having a fossil record ranging from Ordovician to Recent are an abundant and diversified group of unicellular, calcified crustaceans known to inhabit varieties of aquatic environments. The distribution of the Ostracoda and the composition of the assemblage is governed by the ambient conditions such as temperature, salinity, pH, alkalinity, depth, bottom topography, dissolved oxygen, food supply, sediment organic matter, and substrate (Yassini and Jones, 1995; Smith, 1993; Holmes *et al*., 2010; Mesquita *et al*., 2012; Sridhar *et al*., 2018) and are used to reconstruct the past geography, climate, salinity, and ecology (Corbari *et al*., 2005; Smith and Palmer, 2012; Ruiz *et al*., 2013; Elewa, 2018). These forms are mostly benthic and display varied distribution patterns broadly regulated by the sediment texture, depth, and other physicochemical characteristics of the environment in which they thrive.

When compared to the boundless information available for the brackish water ostracods of the Indian subcontinent, not much work has been taken up in the marine regions of the subcontinent except a few (Mohan *et al.*, 2002; Hussain *et al*., 2004, 2007; Baskar *et al.*, 2015: Nishath *et al*., 2015, 2017; Sridhar *et al*, 2002, 2015, 2018; Mohammed Noohu *et al*., 2018; Rajkumar *et al*., 2020). Hence, this study has been taken up for the first time along the Vetharanyam offshore region to establish a relationship between the distribution pattern, diversity, and structural ornamentation of ostracods and the changes in environmental conditions.

STUDY AREA

Investigation for the study of Ostracoda diversity was taken up in the shelf area off Vetharanyam, Nagapattinam district, Tamil Nadu covering an area of about 150 sq. km bounded by the coordinates (a) 10º28'15.62"N: 79°54'25.88"E, (b) 10°28'17.30"N: 80°1'6.68"E, (c) 10°21'47.59"N: 79°55'30.61"E, (d) 10°21'51.52"N: 80°1'16.21"E which forms four transects east off Vetharanyam located in the Bay of Bengal parallel to the Palk strait. Twenty-eight surface samples were collected on a 2 x 4 km grid pattern between the water depth of 4m and 15m (Fig. 1). The region lies in the tropical, shallow shelf region having a gentle slope towards the sea. Earlier studies indicate the dynamicity of the coast and the long history of coastal evolution. (Mohan *et al*., 2000; Baba and Nayak, 2002; Alappat *et al*., 2011; Natesan *et al*., 2013, 2015). The presence of Vetharanyam nose (N) and Sri Lanka (S) causes shore currents to weaken and thus the shoreline shows lesser marine activity. The southbound long-shore current caused the straightening of the Nagapattinam coast from the Kollidam river mouth to the Point Calimere. This region forms a part of the Cauvery delta, an important deltaic region of Southern India, and hence serves as a site of ecological richness with a vast range of geomorphological features such as sub aerial delta, crevasses, cuspate bars and pits, channels, strand plains, estuaries and swamps and serves as an ideal site for the geochemical sink (Martin and Windom, 1991; Montoya *et al*., 1996).

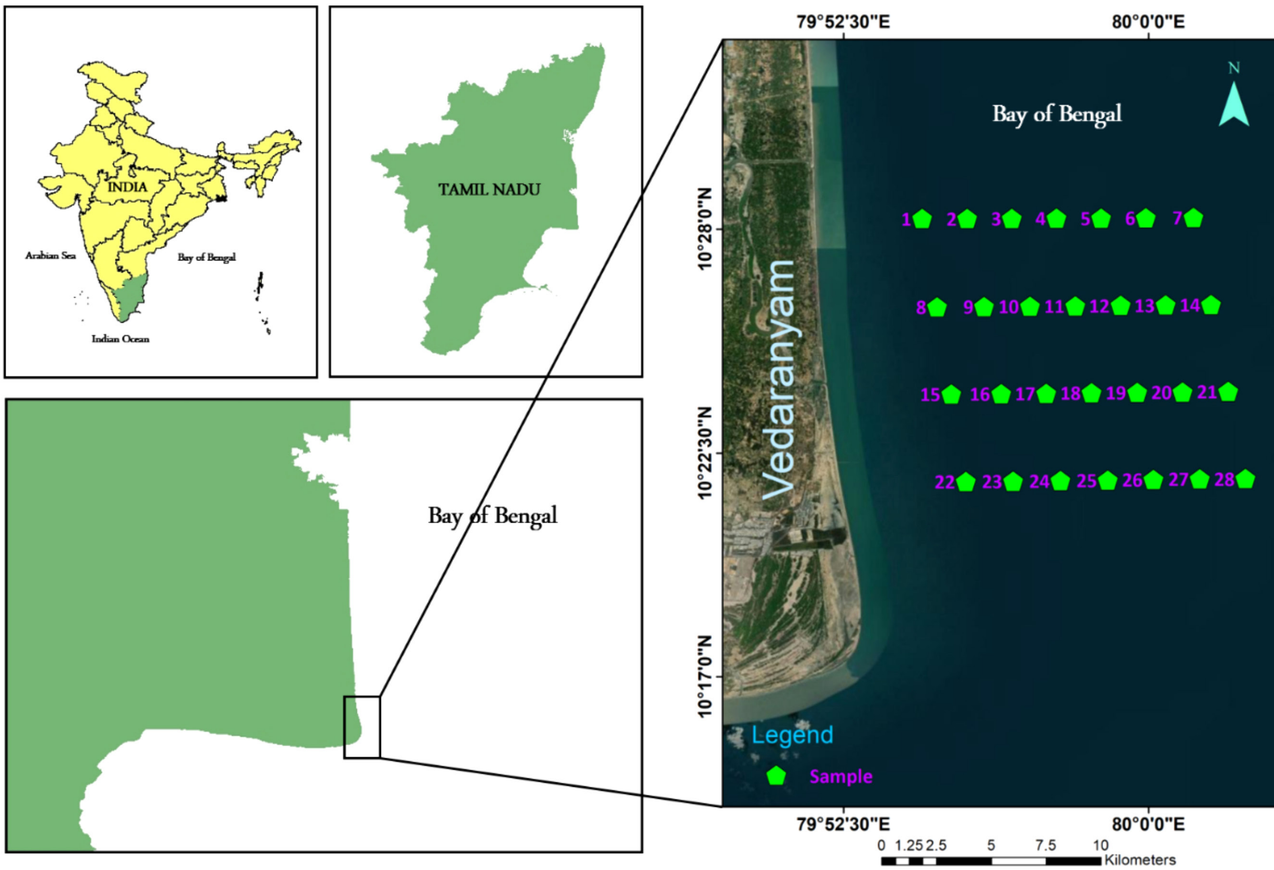

Fig. 1. Study area map with the sampling stations

MATERIALS AND METHODS

Systematic fieldwork was carried out in the Bay of Bengal region by the Geological Survey of India during March 2018. Twenty-eight short cores were retrieved using the Vibro corer through Samudra Kaustubh Cruise from the coastal region along the southern part of the Bay of Bengal. The field-level data were recorded onboard and the cores were sub-sampled and a portion of the top 20 cm sediments are considered as surface samples for the present study. Samples were carefully labeled, sealed into containers with utmost care to avoid any further contamination, and dried in a hot oven under 40°C and subjugated to textural analysis following the standard methods of Krumbein and Pettijohn (1938). The textural nomenclature for the sediment classification was adopted from Folk and Ward (1957). The organic matter content of the sediments was determined by the Walkey Black method, as outlined by Jackson (1958). The readily oxidizable organic carbon contents were determined using the standard method of Gaudette *et al*., (1974). Five grams of sediments were worked upon for microfaunal studies using wet sieving and picking of ostracods. Ostracods species were identified following the classification proposed by Hartmann and Puri (1974).

RESULTS AND DISCUSSIONS

Sediment analysis

Grain size analysis aids in analyzing different processes influencing erosion and deposition by rendering insight into the energy flux, nature of the multifarious transporting agents, and their preview of the depositional environment (Sundararajan and Natesan, 2010). The relative abundance of sand, silt, and clay in the sediments indicate that the region of study is a sand dominant area (with a range of 5 to 94%) followed by silt (with a range of 2 to 92%) (Table-1). Most of the samples are silty sand in nature, followed by silty clayey sand and sandy silt (Figs. 2a – 2c, Table-1). Among these sediment types, silty sand is the most accommodative substrate for the ostracod species in the present region of study. The surficial distribution of the sand, silt, and clay in the region under study as illustrated (Figs. 2a – 2c) indicates a gradual increase in the sand percentage with increasing depth and vice versa with the silt, which explains the accretional nature of the coastal area under study (Natesan *et al*., 2013, 2015). The region in general, grades from sandy silt to silty sand through a thin intermediate region of clayey silty sand.

Table 1. Sedimentological parameters and the total ostracod population of the surface sediments

S.no	Sample No.	Sediment type	%					Total no of ostracod
			Sand	Clay	Silt	OM*	TOC*	
1	1	SANDY SILT	34.03	9.59	56.38	0.29	0.17	69
2	2	SANDY CLAYEY SILT	27.82	31.79	40.39	1.67	0.96	37
3	3	SILTY CLAYEY SAND	43.96	23.48	32.56	1.96	1.13	378
4	4	SILTY CLAYEY SAND	45.94	27.53	26.53	1.57	0.90	249
5	5	SILTY CLAYEY SAND	46.84	31.04	22.12	2.26	1.30	166
6	6	SILTY SAND	60.36	13.7	25.94	2.04	1.17	184
7	7	SILTY CLAYEY SAND	53.99	23.08	22.93	0.59	0.34	203
8	8	SANDY SILT	32.31	6.86	60.83	0.59	0.34	262
9	9	SANDY CLAYEY SILT	31.52	28.87	39.61	2.45	1.41	296
10	10	SANDY SILT	33.58	17.38	49.04	0.49	0.28	217
11	11	SILTY SAND	57.79	13.64	28.57	0.98	0.56	169
12	12	SILTY CLAYEY SAND	41.51	27.84	30.65	1.77	1.01	7
13	13	SILTY CLAYEY SAND	57.46	21.82	20.72	1.38	0.79	442
14	14	SAND	94.66	3.8	1.54	1.28	0.73	96
15	15	SILT	5.09	2.83	92.08	0.82	0.47	414
16	16	SANDY SILT	29.75	14.86	55.39	0.00	0.00	426
17	17	SANDY SILT	34.61	11.06	54.33	0.51	0.29	471
18	18	SANDY SILT	23.25	7.92	68.83	1.12	0.64	306
19	19	SILTY SAND	56.92	11.86	31.22	0.92	0.53	28
20	20	SILTY CLAYEY SAND	52.31	22.91	24.78	1.73	1.00	41
21	21	SAND	90.07	6.18	3.75	1.12	0.64	36
22	22	SANDY SILT	18.55	13.82	67.63	1.63	0.94	213
23	23	SANDY SILT	26.74	9.94	63.32	0.92	0.53	249
24	24	SANDY SILT	33.03	4.99	61.98	1.53	0.88	281
25	25	SILTY CLAYEY SAND	55.91	23.83	20.26	1.73	1.00	62
26	26	SILTY SAND	51.73	12.58	35.69	1.02	0.59	302
27	27	SILTY SAND	47.92	17.69	34.39	1.12	0.64	294
28	28	SAND	82.1	2.83	15.07	0.41	0.23	57
		Total						**5955**
		Average	**45.35**	**15.85**	**38.80**	**1.21**	**0.70**	
		Maximum	**94.66**	**31.79**	**92.08**	**2.45**	**1.41**	
		Minimum	**5.09**	**2.83**	**1.54**	**0.00**	**0.00**	

*(**OM** – Organic Matter **TOC** – Total Organic Carbon)

Organic matter and Total organic carbon

The organic matter content in the study area varies from 0 to 2.45% with an average of 1.21% (Table-1). The spatial distribution of the organic matter shows an appreciable variation and is greater along the northern region wherein there is a copious fluvial input from the Vetharanyam channel. The total organic carbon content of the region ranges from 0 to 1.41% with an average of 0.7% (Table1). The surficial distribution of organic matter and total organic carbon shows a positive correlation with the clay content of the sediment (Figs. 2d and 2e). The terrigenous nature of organic matter accounts for the strong correlation with clayey sediments. The distribution of the total organic carbon supports the findings of Sundararajan and Natesan (2010) who reported that the higher organic carbon content in the sediments of the riverine part is due to the fine nature of the sediments and the comparatively higher rate of sedimentation. Mohan *et al*., (2000) also reported the fluvial affinity of offshore sediments which indicates the sediments from fluvial sources reworked and deposited in the offshore environment, hence explaining the substrate nature of the region.

Distribution and diversity of Ostracoda

In the present study, the widely accepted classification of Ostracoda proposed by Hartman and Puri (1974) has been followed. A total of 30 ostracod species belonging to 22 genera, 13 families, 5 superfamilies, 4 suborders, 2 orders, and 2 subclasses of class OSTRACODA have been identified. Among the 30 species, 1 species belong to the suborder PLATYCOPA while the rest of the species belongs to the suborder PODOCOPA. The taxonomic chart of the Ostracoda, recorded from the study area is documented in Table-2. As many as 5955 ostracod specimens were recovered and the ACR (Abundant – Common – Rare) chart of the specimens was tabulated (Table-3). The relative abundance of the species is represented in the form of a pie chart (Fig. 3) and species accounting for more than 5% of the total population is considered as abundant species in the current study. The major abundant species are *Xestolebris variegata, Paijenborchella keij, Loxoconcha gruendeli, Keijella reticulata, Keijella karwarensis, Keijella whatleyi, Loxoconcha megapora,* and *Loxocorniculum lilljeborgi.*

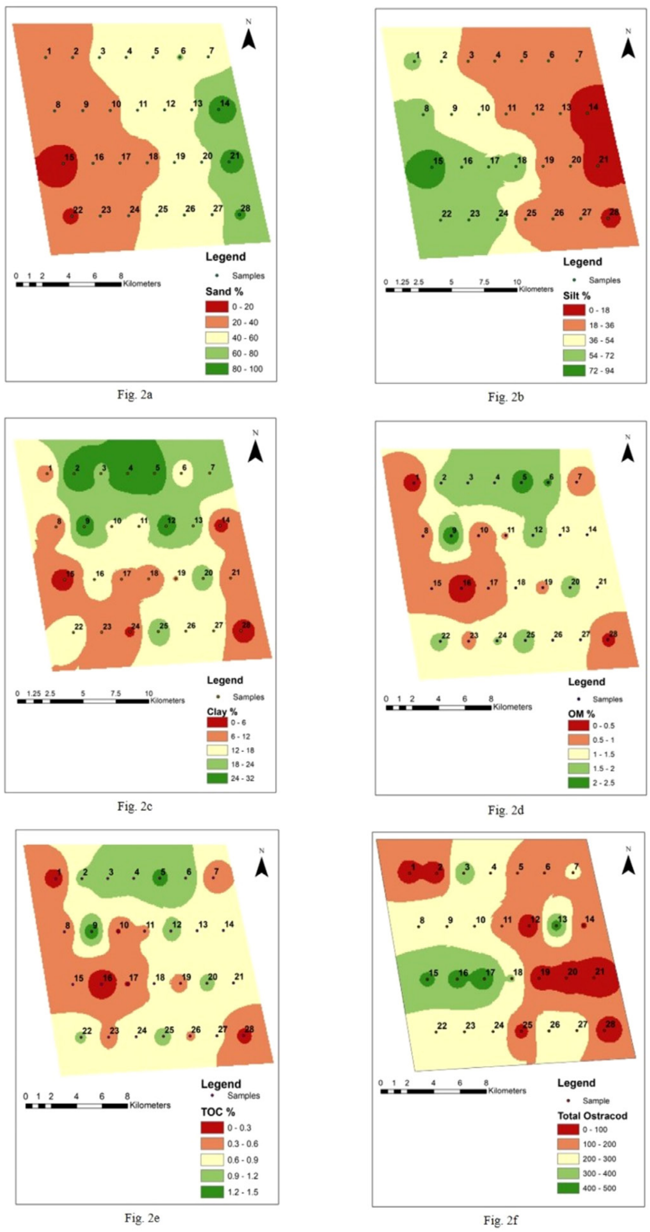

Fig.2a-f. Surficial distribution of Sand, Silt, Clay, Organic Matter, Total Organic Carbon and the spatial assemblage of Ostracoda in Off Vetharanyam region, Bay of Bengal

Surficial distribution maps of the abundant species are also illustrated (Figs. 4a – 4h). The shells are all milky white to light yellow indicating the normal oxygenated environment of deposition. Very few predated forms are found while pyritized forms are completely absent.

The ostracod assemblage obtained attributes to the tropical, shallow marine environmental conditions. The Juvenile forms outnumbered the adult forms in the surface sediments off Vetharanyam. The ratio between the carapaces and open valves was studied to infer the nature and energy of the environment. Out of the 5955 ostracod specimens recovered, 5393 were open valves while the remaining 562 were carapaces. Based on the C/V ratio, it is inferred that the depositional environment is high energy – turbid environment (Mohan *et al.*, 2000; Baba and Nayak, 2002; Sundararajan and Natesan, 2010; Alappat *et al.*, 2011; Natesan *et al.*, 2013, 2015) as open valve outnumbered the carapace (about 91% of the specimen recovered were open valve). Along with Ostracoda, microfossils such as foraminifera and micro-mollusks were also observed from the samples.

Depositional environment and surface ornamentation of ostracods

The ostracod shells exhibit heterogeneity in the surface ornamentation patterns; few species are smooth and devoid of any sculptures while the others are complexly ornamented. The heterogeneity on the shell renders an insight into the environmental interpretation as they are closely associated with the textural characteristics of the substrate. The pioneer studies about the surface ornamentation of the ostracods include (Jones, 1956; Benson, 1961; Hulings and Puri, 1965; Puri, 1966; Krutak, 1972; Brasier, 1980; Annapurna and Rama Sarma, 1982; Vaidya *et al.*, 1995; Sridhar *et al.*, 1998; Hussain *et al.,* 2002, 2004, 2007; Ganesan and Hussain, 2010). When compared to the mammoth of information available regarding the taxonomy, systematics, and internal

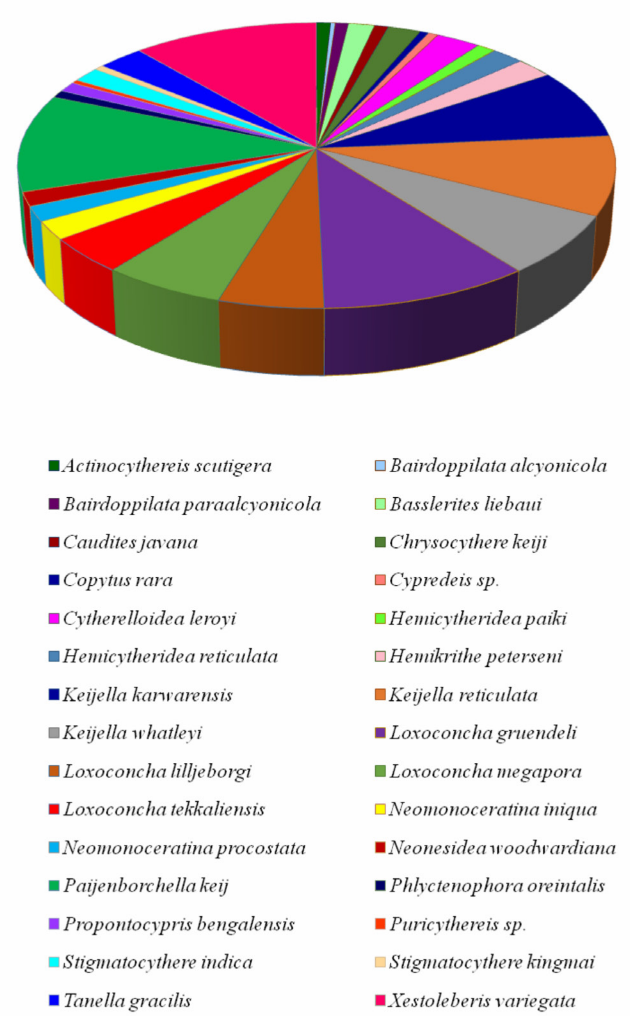

Fig. 3. Pie-chart of relative abundance of species with eight abundant species accounting for 67% of the total population from the surface sediments

Table 2. Taxonomic chart of Ostracoda recorded from the Off Vetharanyam region, Bay of Bengal

Class	Subclass	Order	Suborder	Superfamily	Family	Genus	Species
	PLATYCOPA		Platycopina	Cytherelloidea	Cytherellidae	*Cytherelloidea*	*Cytherelloidea leroyi*
			Bairdiocopina	Bairdiodea	Bairdiidae	*Bairdoppilata*	*Bairdoppilata alcyonicola*
							Bairdoppilata paraalcyonicola
						Neonesidea	*Neonesidea woodwardiana*
			Cypridocopina	Cypridoidea	Candonidae	*Phlyctenophora*	*Phlyctenophora oreintalis*
			Cypridocopina	Pontocypridoidea	Pontocypri-didae	*Propontocypris*	*Propontocypris bengalensis*
			Cytherocopina	Cytheroidea	Cytheridae	*Paijenborchella*	*Paijenborchella keij*
					Cytherideidae	*Cyprideis*	*Cypredeis* sp.
					Hemicytheri-dae	*Caudites*	*Caudites javana*
						Hemicytheridea	*Hemicytheridea paiki*
							Hemicytheridea reticulata
					Leptocytheri-dae	*Tanella*	*Tanella gracilis*
					Loxoconchidae	*Loxoconcha*	*Loxoconcha gruendeli*
OSTRACODA	PODOCOPA	PODOCOP-IDA					*Loxoconcha megapora*
							Loxoconcha tekkaliensis
						Loxocorniculum	*Loxocorniculum lilljeborgii*
					Neocytheridei-didea	*Copytus*	*Copytus rara*
					Schizocytheri-dae	*Neomonoceratina*	*Neomonoceratina iniqua*
							Neomonoceratina procostata
					Trachyleberi-didae	*Actinocythereis*	*Actinocythereis scutigera*
						Basslerites	*Basslerites liebaui*
						Chrysocythere	*Chrysocythere keiji*
						Hemikrithe	*Hemikrithe peterseni*
						Keijella	*Keijella karwarensis*
							Keijella reticulata,
							Keijella whatleyi
						Puricythereis	*Puricythereis* sp.
						Stigmatocythere	*Stigmatocythere indica*
							Stigmatocythere kingmai
					Xestoleberi-didae	*Xestoleberis*	*Xestoleberis variegata*

characters such as muscle scar pattern and pore system of these microcrustaceans, studies regarding the surface ornamentation are sparse. Hence, a venture has been pursued to briefly discuss the consociation of sculptures in ostracod and the textural attributes of the sediments.

A direct relationship between the size and surface ornamentation of the ostracod carapace with the substrate can be ascertained. The substrate texture has control over the type of ostracod fauna that colonize a particular sediment type (Brasier, 1980). The textural stability of substrate sediment exerts a strong influence on marine Ostracoda. Smooth forms are predominant in fine-grained muds, whereas more ornamented forms are being found in coarser or more calcareous sediment (Benson, 1961; Brasier, 1980).

Four ornate forms of ostracods (Smooth and fragile, moderately calcified and pitted, fine to moderately reticulate and ridged and conspicuously ornate) have been depicted and are categorized in the present study.

Highly ornated and heavily calcified forms are commonly present in high-energy environments i.e. shallow water environments inhabiting sandy substrates (Elofson, 1941; Puri, 1966; Malz and Lord, 1976). Van Morkhoven (1962) and Reyment (1971) observed that shells with heavy ornamentation, amphidont hinge, well-developed eyespots, sieve-type normal pores, surficial spines, or ribs and subcentral nodes are characteristic of ultra saline to euhaline condition.

Of the 30 species encountered in the area under study, only 7 are smooth forms, 9 are conspicuously ornate forms,

Table 3. Species diversity of the Ostracoda from the study area

S. No.	Name	Station Number																											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	*Actinocytherei scutigera*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
2	*Bairdoppilata alcyonicola*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
3	*Bairdoppilata paraalcyonicola*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
4	*Basslerite sliebaui*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R
5	*Caudites javana*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
6	*Chrysocythere keiji*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R
7	*Copytus rara*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
8	*Cypredeis* sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
9	*Cytherelloidea leroyi*	R	R	C	R	R	R	R	R	C	R	R	R	R	R	R	R	C	R	R	R	R	R	R	C	R	R	R	R
10	*Hemicytheridea paiki*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
11	*Hemicytheridea reticulata*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R
12	*Hemikrithe peterseni*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	C	R	R	R	R
13	*Keijella karwarensis*	R	R	A	C	C	C	C	R	A	R	C	C	C	C	A	A	A	C	R	R	R	R	C	C	R	C	C	C
14	*Keijella reticulata*	R	R	A	C	C	C	C	R	A	R	C	C	C	C	A	A	A	A	R	R	R	R	A	C	R	C	C	C
15	*Keijella whatleyi*	R	R	C	C	R	C	C	R	A	R	C	C	C	C	A	A	A	C	R	R	R	R	C	C	R	C	C	C
16	*Loxoconcha gruendeli*	R	R	A	A	C	C	C	C	A	R	C	C	C	A	A	A	A	A	R	R	R	R	A	A	R	C	A	A
17	*Loxocorniculum lilljeborgi*	R	R	C	C	R	R	R	R	C	R	R	R	C	C	C	C	A	C	R	R	R	R	C	C	R	C	C	R
18	*Loxoconcha megapora*	R	R	C	C	R	C	C	R	A	R	C	C	C	C	C	A	A	C	R	R	R	R	C	C	R	C	C	C
19	*Loxoconcha tekkaliensis*	R	R	C	R	R	R	C	R	C	R	C	C	C	R	A	C	C	R	R	R	R	R	R	C	R	R	C	C
20	*Neomonoceratina iniqua*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	C	R	R	R	R	R	R	R	R	R	R	R
21	*Neomonoceratina procostata*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R
22	*Neonesidea woodwardiana*	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	C	R	R	R	R	R	R	R	R	R	R	R
23	*Paijenborchella keij*	R	R	A	A	A	A	C	C	A	R	C	C	C	C	A	A	A	A	R	R	R	R	A	A	R	A	A	A
24	*Phlyctenophora oreintalis*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
25	*Propontocypris bengalensis*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
26	*Puricythereis* sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
27	*Stigmatocythere indica*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	A	R	R	R	R	R	R	R	R	R	R
28	*Stigmatocythere kingmai*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
29	*Tanella gracilis*	R	R	C	R	R	R	R	R	C	R	R	R	C	R	R	C	C	R	R	R	R	R	R	R	R	R	R	R
30	*Xestoleberis variegata*	R	R	A	A	A	A	C	C	A	R	C	A	A	C	A	A	A	A	R	R	R	R	A	A	R	A	A	A

(**A** – Abundant = > 25 specimens; **C** – Common = 10 to 25 specimens; **R** – Rare = < 10 specimens)

while the remaining are moderately calcified, pitted, or reticulate ridged forms. The abundance of ostracod with strong ornamentation (more than 75%) infers that the faunal assemblage seems to be deposited under tropical shallow marine and high-energy environments.

CONCLUSION

Thirty ostracod species belonging to twenty-two genera have been identified from twenty-eight surface samples collected from the shelf region of the Vetharanyam offshore, Bay of Bengal. Of these, 8 species are abundant (*Xestolebris variegata, Paijenborchella keij, Loxoconcha gruendeli, Keijella reticulata, Keijella karwarensis, Keijella whatleyi, Loxoconcha megapora,* and *Loxocorniculum lilljeborgi),* 4 species are common while the remaining 18 species are rare. As much as 5955 ostracod shells were recovered and assemblage obtained is the characteristic forms of tropical, shallow, inner shelf environment. The abundance of highly ornamented species and the outnumbered open valves infers the turbid, agitated, moderate to high energy conditions of the region with a relatively slow rate of sedimentation. The ostracod shells are milky white to light yellow in color

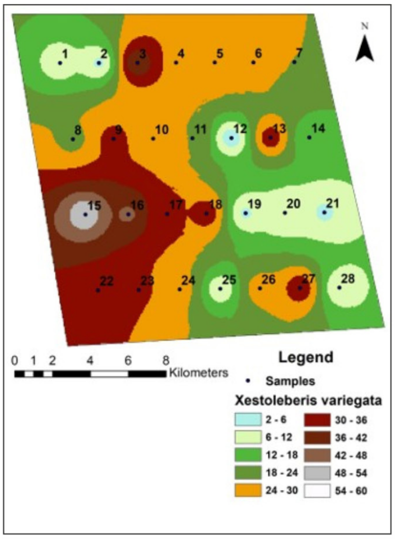

Fig. 4a

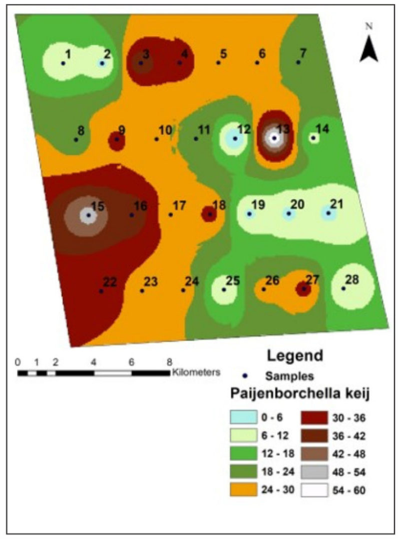

Fig. 4b

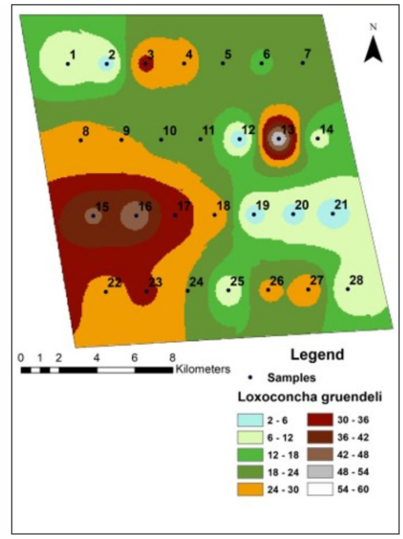

Fig. 4c

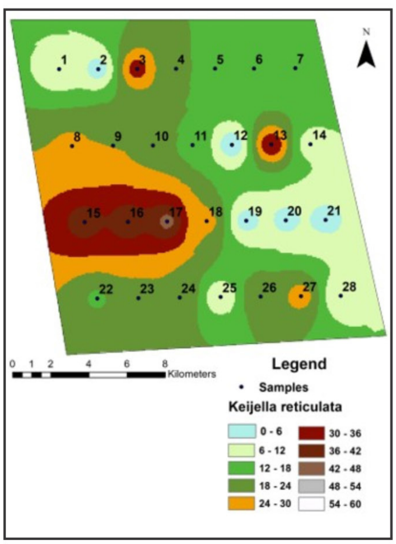

Fig. 4d

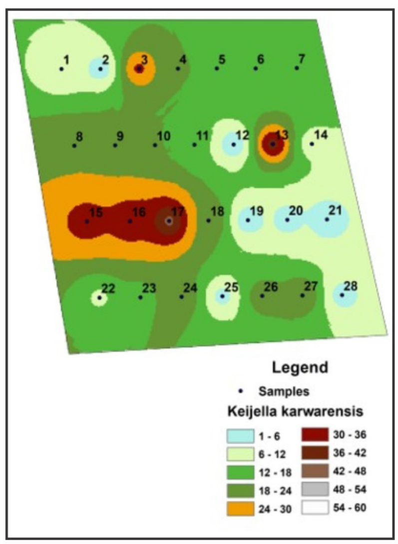

Fig. 4e

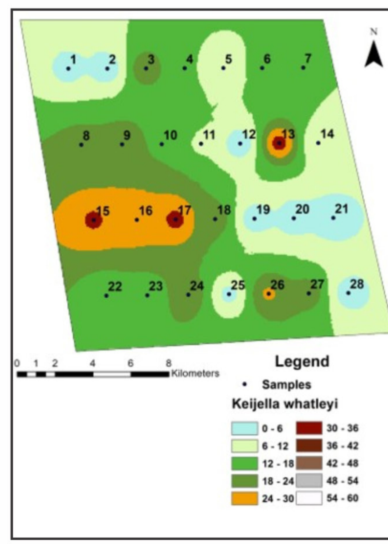

Fig. 4f

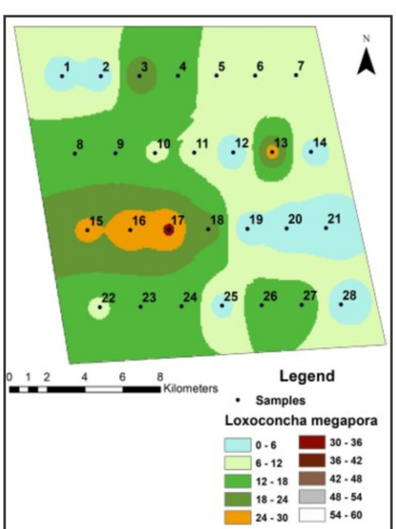

Fig. 4g

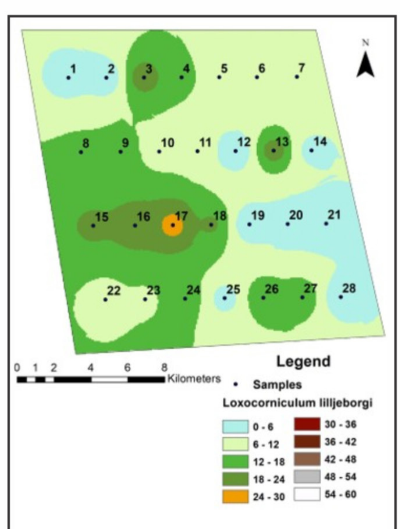

Fig. 4h

Fig. 4a-h. Surficial distribution of abundant ostracod species recorded from Off Vetharanyam region, Bay of Bengal.

with no evidence of pyritization indicate that the sediments are deposited under normal oxygenated environmental conditions. Predated holes are not found on ostracod carapaces. The sediments of the region are mostly sandy silt. Organic matter is less in content with a range of 0 to 2.45% and shows no correlation with the ostracod population. From the occurrence and distribution of the ostracod species, it is conferred that in the present area under investigation, silty sand is a congenial substrate for the growth of the ostracod population. The decrease in sand content with increase depth confers the accretional nature of the Vetharanyam delta. The distribution of clay content along the northern region and its positive correlation with the organic matter infers the fluvial affinity of the sediments from the Vetharanyam canal.

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