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Distribution of recent Ostracoda from the sediments of Gulf of Mannar, Tamil Nadu, southeast coast of India

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Emphasizing the distribution of Ostracoda in the shallow marine environment, fifteen surface sediment samples were retrieved along 5 vertical transects from the Gulf of Mannar, southeast coast of India. Forty-one ostracod species belonging to thirty-seven genera have been identified, out of these *Xestoleberis variegata*, *Tanella gracilis* and *Semicytherura contraria* were the dominant species present in the study area. Sand and silty-sand are the congenial sediment substrate for the ostracod's growth. Calcium carbonate has a sheer control over the ostracod population. Ostracod population decreases as the depth increases in the present study. The inferences made on the external morphology of carapaces indicate that they lie in a moderately agitated and turbulent environment. Ostracod assemblages obtained indicate that the deposition of sediments is under normal oxygenated, tropical, shallow marine, and inner shelf environment. The ratio between the carapaces and open valves of ostracoda is studied to understand the relative rate of sedimentation; the result indicates a relatively faster rate of sedimentation prevails in the study area.

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INTRODUCTION

Tiny bivalved crustaceans, ostracods possess the ability to survive in all aquatic environments (Park and Douglas Ricketts, 2003). The existence of the ostracods in an environment is controlled by physicochemical parameters of the water column, sediment type, and nutrient content (Yassini and Jones, 1995; Nishath *et al.,* 2015; Sridhar *et al.,* 2019). Ostracods are one of the significant microfossil groups used as a tool to infer the palaeo and present ecology, climate, and environment (De Deckker *et al.,* 1988; Barbieri and Vaiani, 2018; Hong *et al.,* 2019; Rajkumar *et al.,* 2020). The distribution and diversity of ostracod species were controlled by several sedimentological and environmental conditions (Puri 1966; Hussain *et al.,* 2016; Nazeer *et al.,* 2018). The current study is a check to decipher the relationship between substrate and ostracod distribution in the Gulf of Mannar.

GULF OF MANNAR

The area under investigation-Gulf of Mannar-lies between the southeast coast of India and the western coast of Sri Lanka and extends over 10500 km^2. Rich in coral, dugongs and seaweeds, Gulf of Mannar, a Biosphere reserve serves as the home for a wide range of organisms nurturing over 3600 species. Gulf of Mannar has 21 uninhabited islands between Tuticorin and Rameshwaram of Tamil Nadu with shallow coral reefs in between them (Thanikachalam, and Ramachandran, 2003; Rao *et al.,* 2008).

FIELDWORK AND SAMPLE COLLECTION

Sediment samples were collected with the help of Van-Veen Graber from shelf to slope (depth ranging from 17.5m to 285m) to study the surficial ostracod distribution. Sample collection was aided by ORV Sagar Manjusha, collaborating with the National Institute of Ocean Technology (NIOT), Chennai during April 2019. Fifteen surface sediment samples were collected adopting 5 transects, with each transect having three varying depth ranges and the depth ranges were measured onboard itself (Figs. 1 and 2). Sediment samples collected were properly sealed in polyethylene zip lock covers, preserved in a deep freezer within the ORV, and transported to the laboratory for further study.

METHODOLOGY

Standard micropaleontological techniques were adopted to separate the ostracods from the sediment matrix. 50 ml of wet sediment sample was subjected to clear washing through 63-micron mesh and air-dried at hot air oven at 40°C. Five grams of air-dried sediment sample subjected to the ostracods studies and the specimens were handpicked under the Stereo-zoom binocular microscope. To understand the environment of deposition, sand silt clay ratio, organic matter, and calcium carbonate percentage were analyzed adapting the methodologies proposed by Krumbein and Pettijohn (1938), Gaudette *et al.* (1974), and Piper (1947) respectively. The textural nomenclature for the sediment analysis was adopted after Folks and Ward (1957). The identification of ostracod species was followed after Hartmann and Puri (1974) classification.

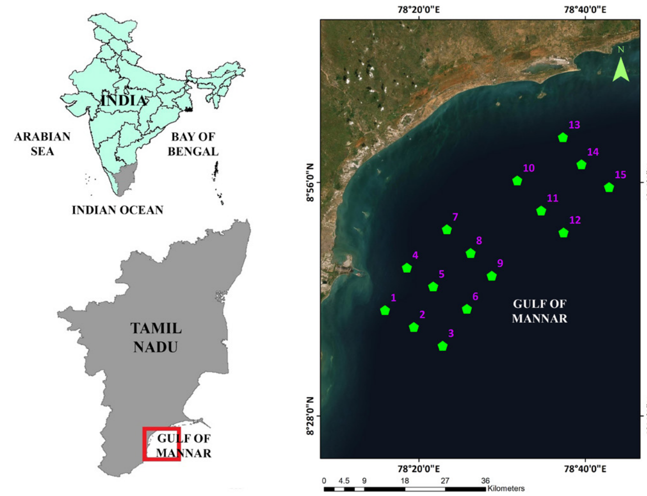


Fig. 1 Sample location and study area map, Gulf of Mannar, India

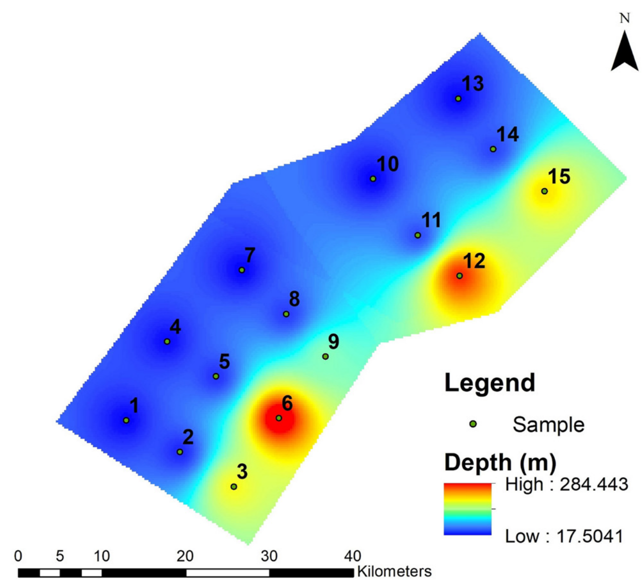


Fig. 2 Spatial distribution map for the depth ranges of surface sediments in the present study

RESULTS AND DISCUSSION

Sediment and ecological parameters

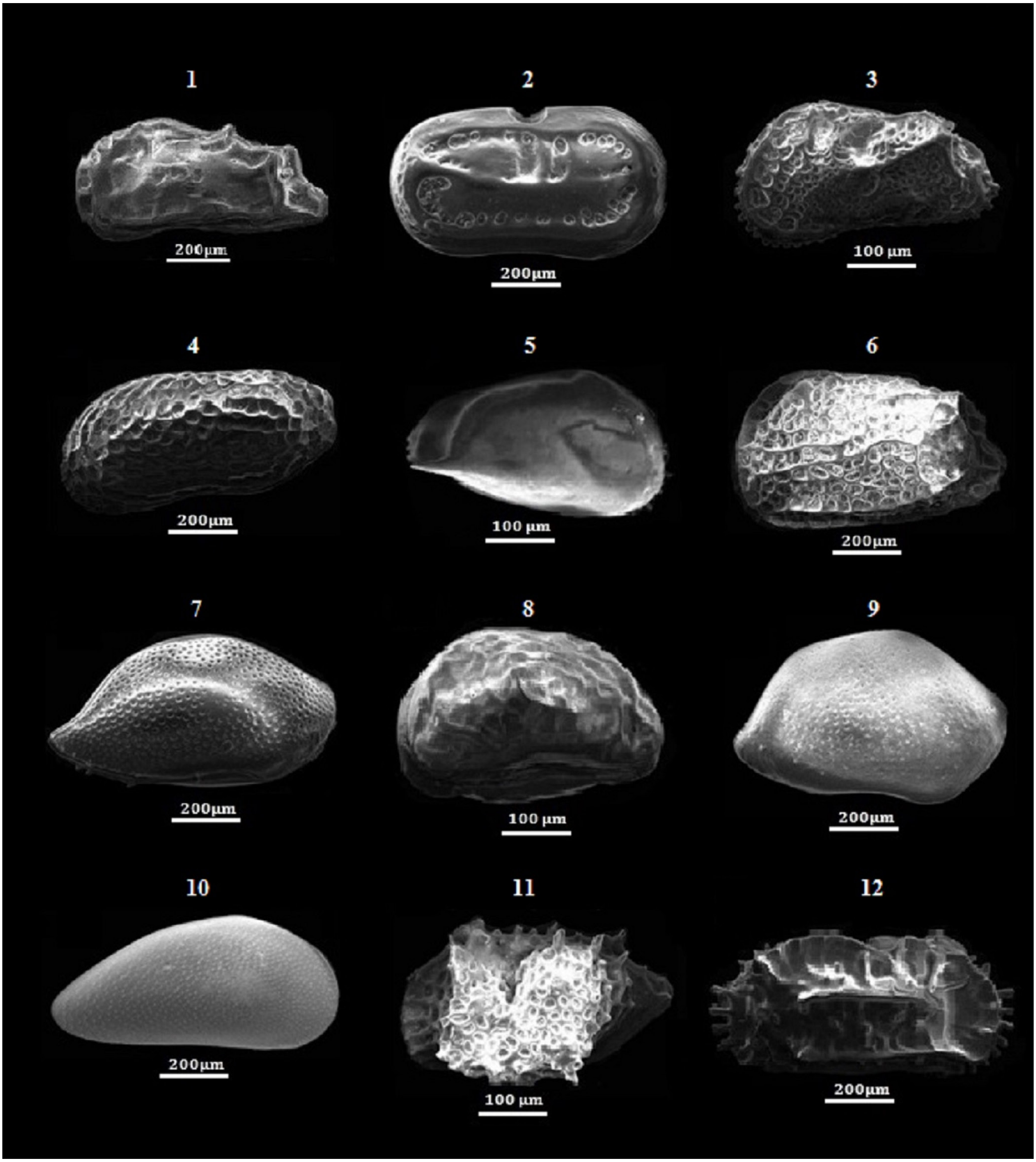
From the sediment samples, the type of substrate, calcium carbonate ($CaCO_3$), organic matter (OM) was analyzed and correlated with the total population of the ostracods. The substrate texture has a sheer control over the kind of Ostracoda colonizing the particular sediment type, smooth shelled forms found in fine mud to highly ornated forms predominant in coarser sediment (Brasier, 1980). Sandy and clayey substrates are congenial environments for ostracods to inhabit (Annapurna and Rama Sarma, 1982; Hussain *et al.,* 2003). The ambient substrate for ostracod growth in the Gulf of Mannar area is found to be sand and silty sand. The substrate types were dependent on the energy condition as well as the coral and seagrass colonies in the Gulf. Sand is attributed to the nearshore region and coral colonies (stations 1-5, 7, 8, 10, and 13) whereas silty-sand (stations 6, 11, 12, 14, and 15) is attributed to the seagrass prone zones and moderately lower energy environment (Fig. 3).

According to Hussain and Rajeswara Rao (1996), the higher percentage of $CaCO_3$ in the Gulf of Mannar is due to the dissolution of pearl and chalk beds in the sediments. Obtained values of $CaCO_3$% range from 40-94.49% (Fig. 4) which is directly related to the substrate type and coral rubbles. Higher $CaCO_3$% in the sandy substrate in the depth range lesser than 50m facilitated by coral reefs and lower values in silty-sand and silt were found in the depth range 50-285 m (Fig. 2). Lower the organic matter higher the population of the Ostracods was reported in the Gulf of Mannar (Hussain and Rajeswara Rao (1996); Baskar et al., 2013). In the present study, OM varies from 0.56-4.11% (Fig. 4). The OM values are lower near a chain of Island groups in the Gulf and it is increasing with depth and silty substrate.OM has an inverse proportion with the total population of Ostracoda.

Total population of Ostracoda

Forty-one species of ostracods belonging to thirty-seven genera were identified in the present study. A total of 2248 specimens of individual ostracods were identified and preserved. Silty sand and sand were the congenial substrate for the ostracod colonizing. The population of Ostracoda was higher towards the shore of island groups and has a decreasing trend with increasing depth (Fig. 5). A higher population in-depth range lesser than 50 m is due to the availability of the nutrients from coral reefs and shallow marine environments. Decreasing population with depth is a result of a highly

Plate I



EXPLANATION OF PLATE I

SEM Images 1, ***Caudites javana,*** LV external view, Image 2 ***Cytherelloidea leroyi,*** RV external view, Image 3 ***Falsocythere maccagnoi,*** LV external view, Image 4 ***Hemicytheridea reticulata,*** LV external view, Image 5 ***Keijella karwarensis,*** RV external view, Image 6 ***Mutilus pentoekensis,*** LV external view, Image 7 ***Neonesidea cracenticlavula,***RV external view, Image 8 ***Ornatoleberis morkhoveni,*** LV external view, Image 9 ***Paranesidea fracticorallicola,*** RV external view, Image 10 ***Propontocypris bengalensis*** RV external view, Image 11 ***Spinoceratina spinosa,*** LV external view, Image 12 ***Stigmatocythere kingmai,*** RV external view.

Table 1 Check-list of Ostracod species and their distribution in the present study

S.no	Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Actinocytheres scutigera* Brady, 1868	0	1	0	2	0	1	3	2	0	2	2	0	1	1	0
2	*Bairdoppilata alcyonicola* Maddocks, 1969	0	6	5	0	4	3	0	7	4	1	5	5	0	4	6
3	*Bythoceratina mandviensis* Jain, 1978	1	1	3	0	2	7	0	0	5	1	1	6	0	0	3
4	*Carinocythereis hamata* Mueller, 1894	5	2	0	9	6	1	6	4	0	9	3	2	6	4	1
5	*Caudites javana* Kingma, 1948	1	4	6	2	7	7	1	8	3	3	6	4	4	9	7
6	*Chrysocythere keiji* Ruggieri, 1961	1	2	0	2	1	0	1	3	0	3	1	0	1	4	0
7	*Cytherella diction* Malz and Jellinek, 1989	0	5	0	1	4	1	2	8	0	3	6	1	1	5	1
8	*Cytherelloidea leroyi* Keij, 1964	13	3	1	9	5	0	11	3	1	7	4	0	9	3	0
9	*Falsocythere maccagnoi* Ciampo, 1971	3	4	0	5	3	1	3	4	0	7	6	0	5	5	0
10	*Hemicytheridea reticulata* Kingma, 1948	1	12	5	0	9	4	2	9	9	1	10	4	3	11	7
11	*Hemicytheridea subulata* Ahmad, Neale and Siddiqui, 1991	5	5	0	4	4	1	6	7	2	5	3	1	7	6	1
12	*Hemikrithe peterseni* Jain, 1978	6	1	1	3	2	0	9	0	1	7	1	1	5	1	1
13	*Kangarina abyssicola* Mueller, 1894	4	2	0	9	4	1	11	3	1	9	3	1	4	2	0
14	*Keijella recticulata* Whatley and Zhao, 1988	3	8	0	2	7	1	5	5	0	1	6	0	3	9	1
15	*Keijella karwarensis* Bhatia and Kumar, 1979	2	3	0	3	1	0	3	8	0	4	5	0	0	4	0
16	*Keijia demissa* Brady, 1868	3	10	1	1	8	0	3	7	0	2	11	0	1	7	1
17	*Lankacythere coralloides* Brady, 1886	4	9	0	5	12	0	3	10	0	4	9	0	5	5	0
18	*Loxoconcha grundeli* Jain, 1978	5	5	0	9	7	1	7	4	0	5	6	1	8	2	0
19	*Loxocorniculum lilljeborgii* Brady, 1868	9	7	1	10	5	0	16	3	0	8	9	1	9	7	0
20	*Macrocyprina decora* Brady, 1866	0	5	0	1	4	2	2	6	0	0	7	0	2	5	1
21	*Mutilus pentoekensis* Kingma, 1948	2	9	1	0	13	0	3	11	0	2	8	1	1	10	2
22	*Neocytheretta murilineata Zhao and* Whatley, 1989	6	3	1	8	5	2	9	4	0	10	2	2	7	0	0
23	*Neomonoceratina iniqua* Brady, 1868	7	2	0	5	3	1	6	3	2	9	5	0	5	1	1
24	*Neomonoceratina porocostata* Howe and Mckenzie, 1989	5	3	1	3	4	2	4	2	1	3	3	1	2	2	0
25	*Neonesidea cracenticlavula* Maddocks, 1969	3	11	3	1	8	4	0	9	3	2	12	4	1	8	2
26	*Ornatoleberis morkhoveni* Keij, 1975	11	5	2	13	4	1	8	5	3	9	3	2	12	4	1
27	*Paijenborchellina indoarabica* Jain, 1978	7	2	0	5	1	0	6	3	0	3	2	0	4	3	0
28	*Paracytheridea* sp.	4	2	0	3	1	0	4	4	1	2	3	0	3	2	0
29	*Paracytheroma ventrosinuosa* Zhao and Whatley, 1989	3	3	1	4	4	0	5	5	0	6	3	1	4	2	0
30	*Paradoxostoma bhatiai* Shyam Sundar *et al.,* 1995	3	5	0	5	6	0	3	7	2	4	3	1	5	2	1
31	*Paranesidea fracticorallicola* Maddocks, 1969	1	7	1	2	6	0	0	5	0	1	4	0	0	6	2
32	*Phlyctenophora orientalis* Brady, 1868	8	6	1	10	5	2	12	4	1	9	7	2	13	3	1
33	*Propontocypris bengalensis* Maddocks, 1969	2	8	2	3	6	1	1	9	0	4	5	2	3	7	0
34	*Quasibradleya plicocarinata* Benson, 1972	7	4	0	5	6	0	9	3	0	6	5	0	8	6	0
35	*Semicytherura contraria* Zhao and Whatley, 1989	5	10	8	3	9	9	2	7	7	4	11	11	3	8	9
36	*Spinoceratina spinosa* Annapurna and Rama Sarma, 1987	1	5	7	0	8	6	0	9	8	1	11	4	0	8	6
37	*Stigmatocythere indica* Whatley and Zhao, 1988	5	4	0	3	5	1	2	3	0	0	6	0	3	2	1
38	*Stigmatocythere kingmai* Whatley and Zhao, 1988	2	4	0	1	6	0	1	3	1	0	5	0	0	2	1
39	*Tanella gracilis* Kingma, 1948	11	8	4	9	5	3	13	4	2	15	7	6	13	3	5
40	*Triebelina tuticorensis* Hussain *et al*., 1998	2	1	0	1	3	0	3	1	0	0	0	0	1	0	0
41	*Xestoleberis variegata* Brady, 1880	8	6	6	10	8	8	15	5	5	12	9	9	7	7	7
	Total	169	203	61	171	211	71	200	207	62	184	218	73	169	180	69

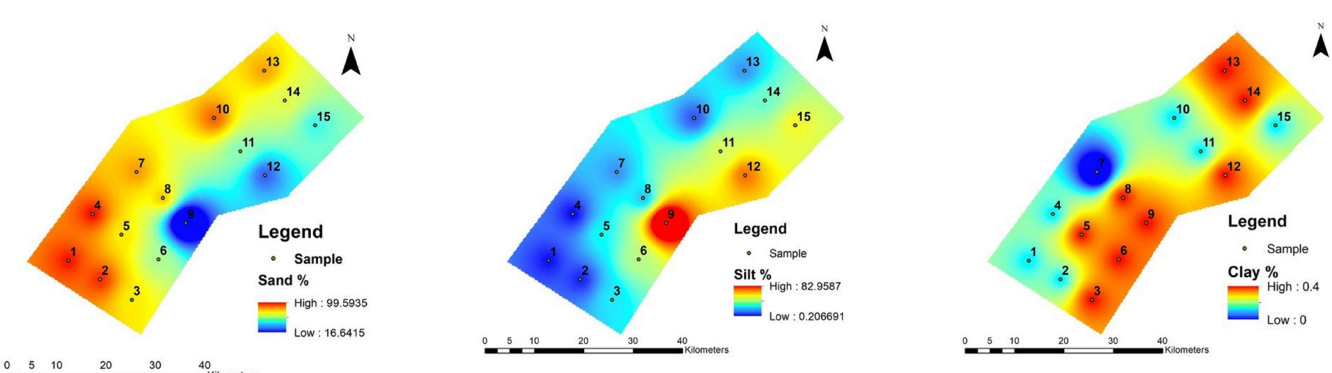


Fig. 3 Spatial distribution map of the Sand, Silt and Clay percentages

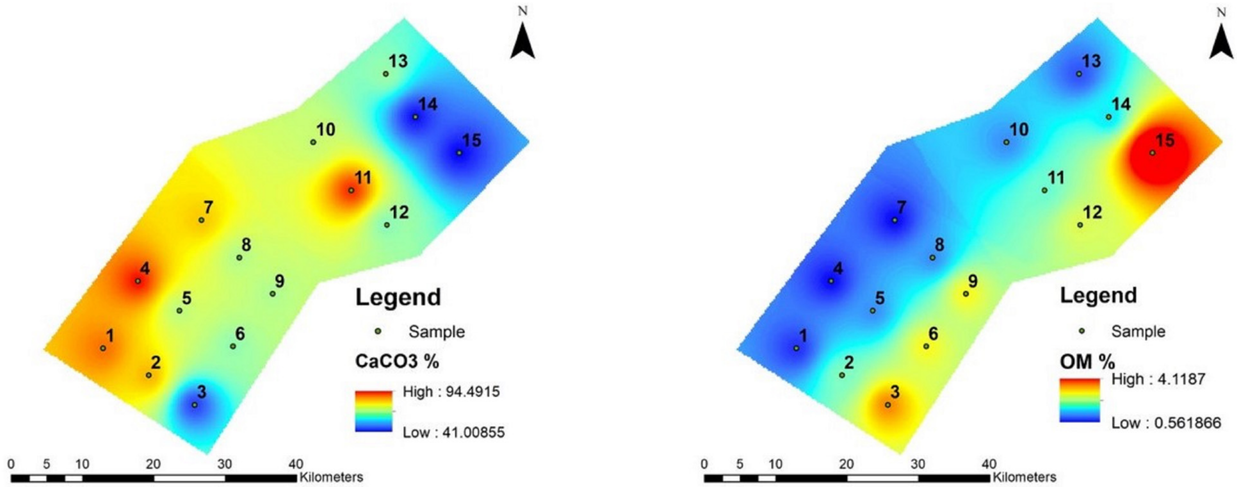


Fig. 4 Spatial distribution map of the $CaCO_3$% and OM%

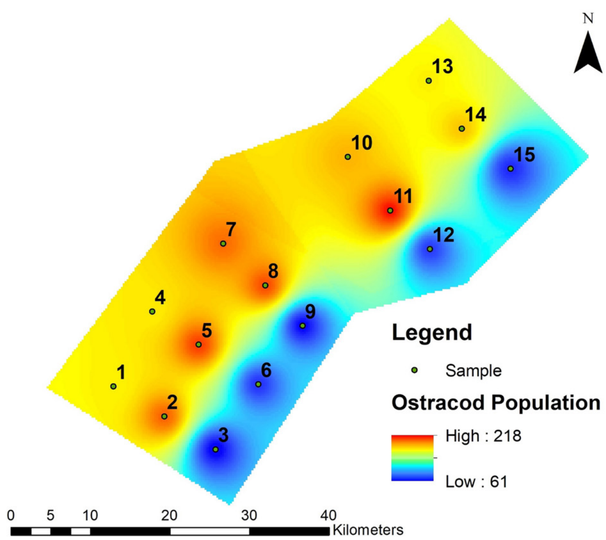


Fig. 5 Spatial distribution map of total ostracod population

turbulent environment influenced by longshore drift current. The distribution of ostracod species in each sampling station is given in Table 1 and the SEM images for the selective species are provided in Plate-I.

Dominant species

Species such as, *Xestoleberis variegata, Tanella gracilis* and *Semicytherura contraria* were dominant in the present study. *X. variegata* and *T. gracilis* are highly recorded in the water depth less than 50 m whereas the abundance of *S. contraria* is increasing towards the deeper water level (50-285m) (Fig. 6). *T. gracilis* is widely distributed in the Indo-Pacific and Atlantic including the Caribbean. The wide geographic distribution of this cosmopolitan species is primary through passive dispersal by ships (Witte, 1993). *X. variegata* has been reported from various Indo-Pacific localities including the Gulf of Mannar, Srilanka (Scott, 1905); the Andaman Islands (Guha, 1968), and the East China Sea (Wang and Zhao, 1985). Zhao *et al.,* 1985 while discussing the distribution of ostracods from the South China Sea stated that *X. variegata* can be referred to as an indicator of warm water conditions. An abundance of *X. variegata* was also reported in Off Tuticorin (Hussain, 1998). *S. contraria* was first reported from the recent sediments of the Malay Peninsula by Zhao and Whatley (1989) and recorded first time in India at off Tuticorin by Hussain (1998).

Species diversity

Multivariate statistical analyses have been performed using the PAST software package (version 3.0). Statistical analysis is the easiest method available, to understand the ostracod species diversity in an area (Hammer *et al.,* 2001; Rajkumar *et al.,* 2020). Species diversity includes species richness, Shannon-Weaver index, dominance, and evenness; the obtained values are given in Table-2. Species richness is often given simply as the total number of species (S) present in an area. A maximum of 41 ostracod species is recorded at station no. 2, whereas the least number of species (12 species) is recorded at station no. 9. The Shannon-Weaver index (H) is a popular diversity index used in ecological related studies and is commonly known as Shannon's diversity index. The diversity value ranges from 2.72 to 3.55 with an average value of 3.22, recorded in the study area (Fig. 7). The values of the Shannon-Weaver diversity index show that species diversity is decreasing towards deeper waters. The dominance (D) value ranges from 0.03 to 0.08, the result of dominance shows that there are no such single species that dominates the community completely. Similarly, the evenness value ranges from 0.70 to 0.89 which indicates that ostracod species are more or less evenly distributed in the study area.

Table 2 Various Species diversity indices calculated using PAST software package (version 3.0) for the present study

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Taxa_S	37	41	21	36	40	25	36	39	20	37	40	24	35	38	24
Individuals	169	203	61	171	211	71	201	208	62	184	218	73	169	180	69
Dominance_D	0.03911	0.03283	0.07713	0.04135	0.03169	0.07082	0.04275	0.03153	0.08065	0.04011	0.03253	0.07375	0.04247	0.03488	0.0754
Simpson_1-D	0.9609	0.9672	0.9229	0.9587	0.9683	0.9292	0.9573	0.9685	0.9194	0.9599	0.9675	0.9263	0.9575	0.9651	0.9246
Shannon_H	3.395	3.54	2.754	3.345	3.551	2.888	3.329	3.549	2.722	3.375	3.535	2.855	3.32	3.472	2.819
Evenness_ e^H/S	0.8061	0.8403	0.748	0.7874	0.8714	0.718	0.7753	0.8918	0.7607	0.7897	0.8573	0.7237	0.7901	0.8473	0.6983

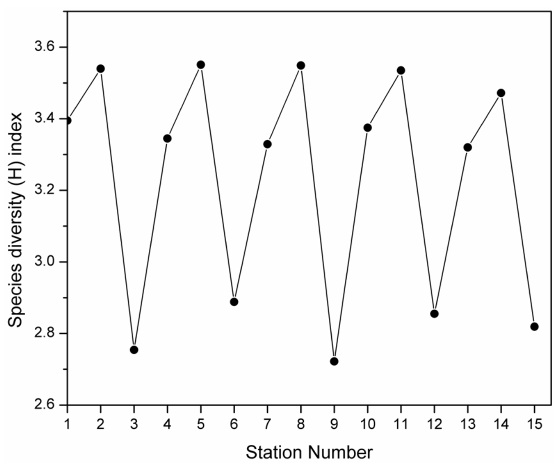


Fig. 6 Representing the variation of the dominant species in the present study

present study, 2248 ostracod shells were retrieved among those 1586 were carapace and 662 open valves indicating the rate of sedimentation estimated from the carapace to open valve ratio is rapid/faster (Fig. 8). The color of the carapace was milky white and no pyritization was observed on the Ostracod shells indicating the oxygenated environment. There are no predatory marks in the carapace.

CONCLUSIONS

Xestoleberis variegata, *Tanella gracilis,* and *Semicytherura contraria* are the abundant Ostracoda forms among the forty-one species retrieved from the study area. Granulometric study reveals that sand and silty sand are

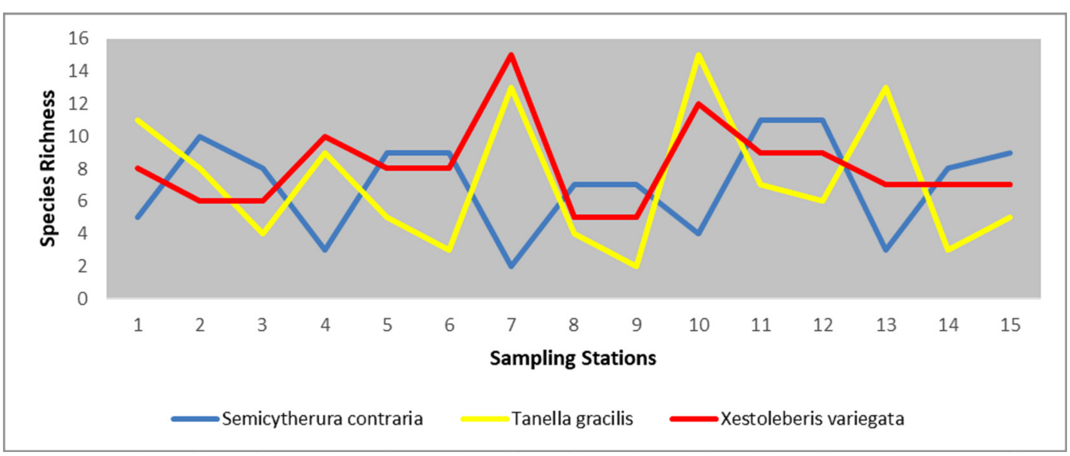


Fig. 7 Species diversity (H) index to the individual sample in the present study

Carapace-valve ratio

Oertli (1971) worked on the carapace and open valve ratio to relate the rate of sedimentation and suggested that when the ratio is high there is rapid burial with minimal disarticulation of the carapace into open valves. On studying the ostracod assemblages in the inner shelf off Tuticorin, Hussain *et al.* (2002) reported that the rate of sedimentation is rapid from the ratio of the carapace to open valves. In the

the dominant sediment texture as the result of demarcated longshore drift prevailing in this region. The ratio between the carapaces and open valves confirms the relative rate of sedimentation in the region is rapid. The distribution of the Ostracoda assemblages elucidates that the sediments are deposited in shallow, tropical, inner shelf, and oxygenated environment. Multivariate statistical analysis exhibits that the ostracod species diversity is decreasing in the deeper transect. The species diversity indicates the decrease in

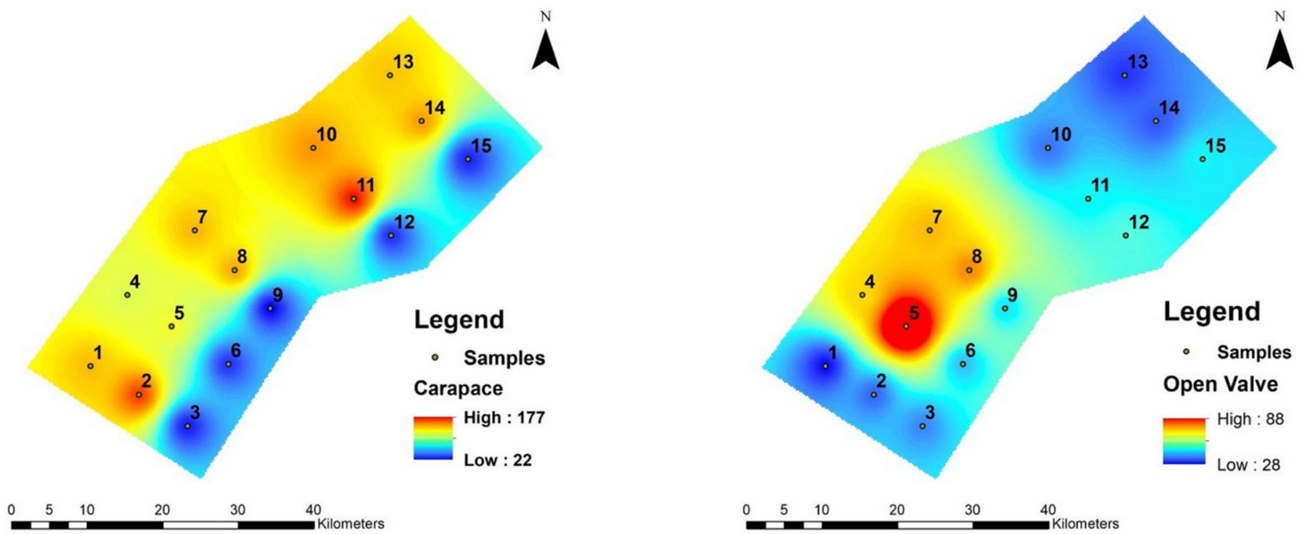


Fig. 8 Spatial distribution map of the carapace and open valve

ostracod population with increasing depth. Explicitly, the ostracod forms are related to substrate nature thus, sand and silty-sand become a congenial environment for the growth of the ostracods in this region. In the shallow water column where high $CaCO_3$, high sand percentage, low clay, and low organic matter yield maximum specimens and vice versa to the deeper water column.

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