Article

Community structure of harpacticoid copepods from the southeast continental shelf of India

K.G.M.T. Ansari, P.S. Lyla, S. Ajmal Khan, S. Manokaran, S. Raja
Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai – 608 502,Tamil Nadu, India
E-mail: ansari.cas@gmail.com

Received 1March 2013; Accepted 5 April 2013; Published online 1 June 2013

Abstract
The study is the first attempt aiming to assess the composition and number of harpacticoid copepods in the southeast continental shelf of India (Bay of Bengal). 39 putative species of copepods were identified belongings to 29 genera in 17 families. Copepod density registered gradual decrease with increase in depth and sediment was sandy to silty nature. Principal Component Analysis (PCA), clearly documents significant variability within the abiotic variables with total variation of 92.9%. Copepod assemblages differ among depths regions and between transects clearly explained by non-metric multi dimensional scaling (nMDS) and conformed by ANOSIM analysis. Diversity indices evidently registered the significant changes in harpacticoid assemblage between the depths from various transects. Considering the great significance of harpacticoid assemblages in the environmental impact assessment studies, an intensification of sampling efforts should be pursued in this region in order to improve our knowledge on pollution disturbances.

Keywords meiofauna; harpacticoid copepods; diversity; continental shelf; India.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

The Bay of Bengal influenced by tropical climate is regarded as the 64th large marine ecosystem (LME) in the world. It is moderately productive (Class II) LME with 150 to 300g of carbon produced per square meter per year from 6°N and 80° E to 22°N and 94°E (Mahapatro et al., 2011). The Bay covers an area of about 3,660,130 km^2, of which 0.49% is protected, and contains 3.63% and 0.12% of the world's coral reefs and sea mounts, respectively (Sea Around Us, 2007). The LME shows considerable spatial and temporal inconsistency of biotic and abiotic variables, because of seasonal river discharges, particularly in the surface water along the coast.

In spite of the increasing interest in the role of biodiversity in the functioning of marine ecosystems, taxonomic studies of fauna are still inadequate (Fornshell, 2012). Meiofauna has been regarded as a major metazoan component in the benthic ecosystem due to high abundance and fast turnover rates. Its production is equal or higher than macrofauna in shallow waters to deep sea (Heip et al., 1985; Coull, 1999). It constitutes a high quality food source for fishes, shrimps and larvae of mollusks (Sakthivel and Fernando, 2012; Trivedi et al., 2012; Ozcan et al., 2012). Thus it is an important component in benthic food chain (Gee, 1989). Compared to macrofauna, meiofauna is highly useful in environmental impact assessment and ecosystem health monitoring in view of its higher species richness, shorter life-cycles (3–5 generations per year) and lack of larval stages (Bongers and Ferris, 1999; Kennedy and Jacoby, 1999). In particular, they respond rapidly to changes in sediment grain size and food availability (Danovaro, 1996).

The harpacticoid copepods contain over 3000 species most of which are free-living benthic organisms (Hicks and Coull, 1983). The harpacticoid copepods contain over 3000 species most of which are free-living benthic organisms (Hicks and Coull, 1983). They are found in all salinity regimes, from the supralittoral to the abyssal zone, and in all temperatures from polar to tropical zones. Harpacticoid copepods, which are the second most abundant meiofauna taxa next only to the nematoda (Heip et al., 1985; Sajan and Damodaran, 2007; Ansari et al., 2012; Mantha et al., 2012), but they are often the dominant taxon in marine algae (Kotwicki, 2002), are flexible and well suited for shifts in their food preferences during different developmental stages, which makes it easier for them to be mass cultured, and used with different experimental designs for pollution monitoring and aquaculture (Sun and Fleeger, 1995; Chandler et al., 2004; McLachlan and Brown, 2006). Moreover, harpacticoids are more sensitive to pollutants than nematodes, which make them good indicators of pollution (Coull and Chandler, 1992; McLachlan and Brown, 2006). Therefore, harpacticoids are widely studied from the Baltic Sea (Folkers and George, 2011) and the South China Sea (Chertoprud et al., 2011). Moreover, harpacticoids are more sensitive to pollutants than nematodes, which make them good indicators of pollution (Coull and Chandler, 1992; McLachlan and Brown, 2006). Therefore, harpacticoids are widely studied from the Baltic Sea (Folkers and George, 2011) and the South China Sea (Chertoprud et al., 2011).

Information regarding the species composition of recent Indian meiofauna in general (Ansari et al., 2001; Kumar and Manivannan, 2001; Altaff et al., 2004, 2005) and of Harpacticoida in particular, is very limited (Kirshnaswamy, 1957; Wells and Rao, 1987) and recently (Mantha et al., 2012). In this backdrop, a harpacticoid copepod survey in the southeast continental shelf of India has been carried out. Currently, there is no data available on harpacticoid copepod diversity for this area. Furthermore, this coast includes the various chemical, fertilizer, PVC and other anthropogenic effective chemicals were released to this coastline (Ajmal Khan et al., 2012). Harpacticoid copepods are known as organisms which are not tolerant to anaerobic conditions (Kotwicki, 2002). Therefore the goal of the present study was to assess harpacticoid copepod diversity along this coastal area as well as to identify patterns of species distribution.

2 Materials and Methods

2.1 Study area

The study area extends from 10° 34.03' to 15° 14.48' N and from 79° 52.13' to 80° 53.87'E representing the southeast continental shelf of India, Bay of Bengal (Fig. 1). The Bay is situated at the monsoon belt and therefore receives fresh water inputs from rainfall and discharges from major river systems (Aziz et al., 1998). During northeast monsoon, an anticyclonic gyre forms in the Bay and reverses during southwest monsoon (Longhurst, 1998). Monsoon rain and flood waters produce a warm, low-salinity, nutrient and oxygen rich layer to a depth of 100 – 150m; this layer floats above a deeper, more saline, cooler layer which does not change significantly with the monsoon (Dwivedi and Choubey, 1998). Sediment samples were collected along seven transects representing thirty five stations off Karaikkal, Parangipettai, Cuddalore- SIPCOT (presence of an industrial cluster - State Industrial Promotion Corporation of Tamil Nadu), Cheyyur, Chennai, Tammenapatanam and Singarayakonda at 30-50m, 51-75m, 76-100m, 101-150m, 151-175m and above 176m depths along the continental shelf of the Bay. In Karaikkal at 76-100m depth, in Parangipettai at 151-175m depth, in Cuddalore- SIPCOT 51-75m, 76-100m, 101-150m and 151-175m and in Tammenapatanam at 51-75m depth, samples could not be collected due to hard nature of the bottom sediment.

2.2 Sampling strategy

Sediment samples were collected onboard the FORV (Fishery and Oceanographic Research Vessel) "*Sagar Sampada*" as part of the cruise 260 (December, 2008) conducted along the Bay of Bengal shelf regions in the southeast coast of India. Two grab samples were collected using a Smith McIntyre grab (having a bite area of 0.2 m^2) from each station. Immediately after grab hauling and ascertaining that the sediment was undisturbed, sub-samples were collected using a glass corer (with an internal diameter of 2.5 cm, and a length of 15 cm) from the middle of each grab sample (Platt and Warwick, 1983). The core samples were fixed in 4% buffered formalin. The replicate core samples were processed separately for downstream analyses. Hydrographical parameters [temperature, salinity, dissolved oxygen (DO) and pressure] of bottom waters were measured at each sampling station using Seabird CTD (SBE 11 deck unit and SBE 9 underwater).

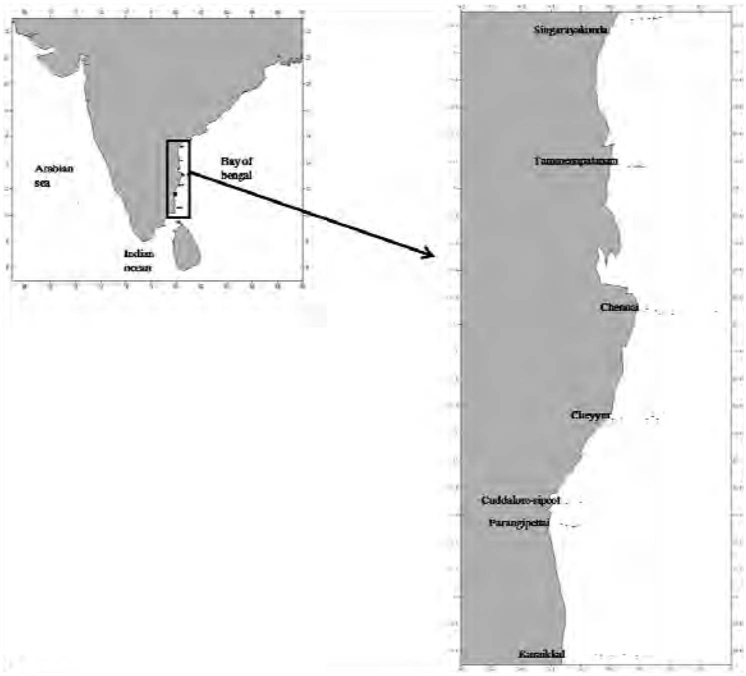

Fig. 1 Study area and study sites.

2.3 Sedimentological analysis

A sub-sample of 500g collected earlier from grab samples for each station was used for sediment texture analysis. The sediment samples were thoroughly washed and dried at 70-80º C for 24 hours in an oven. One hundred and fifty grams of dried sediment sample from each station was analysed using Retsch EasySieve shaker. The results were obtained using GRADISTAT 4.0 package (Blott and Pye, 2001). The samples which had higher clay proportion were analyzed using Marlven Particle- Master Size Analyzer 2000. The results obtained were processed statistically based on Folk and Ward (1957) method to obtain median particle diameter and nomenclature.

The surface sediment (upper 2cm) from grab for each station was sampled for organic carbon and petroleum hydrocarbons (PHC) quantification. Total Organic Carbon content (TOC) was estimated from surface sediments using chromic acid oxidation method followed by titration with ammonium ferrous sulfate (Walkley – Black method) as modified by Gaudette et al. (1974). From the values of TOC, Total Organic Matter (TOM) was calculated using a conversion factor of 1.724 following El Wakeel and Riley (1957). The sediment samples were analyzed for petroleum hydrocarbons using a Varian make Cary Eclipse Spectrofluorometer. The fluorescence of the samples was measured at 310nm excitation and at 364nm emission wavelength respectively (APHA, 1989). All the estimations were conducted in three replicates. The results were subsequently expressed in µg/g. For heavy metal analysis, dried surface sediment samples (0.5 g) from each station was subjected to metal extraction based on the acid digestion procedure (nitric acid and perchloric acid) (Walting, 1981) and subsequently concentration of the heavy metals were determined in an atomic absorption spectrophotometer.

2.4 Meiofauna and harpacticoid copepods extraction

In the laboratory, sediment samples were washed through a set of 0.5 mm and 0.063 mm sieves. The sediment retained in 0.063 mm sieve was decanted to extract meiofauna following the methods of Pfannkuche and Thiel (1988). Sorting of meiofauna from sediment was based on the flotation technique which has an efficiency of around 95% (Armenteros et al., 2008). The meiofaunal organisms were stained with Rose Bengal prior to extraction and sorting. All the harpacticoid copepods enumerated under a stereomicroscope (Meiji, Japan) and subsequently identified to lowest taxonomic level under the compound microscope (Olympus CX 41) based on standard pictorial keys. The taxonomy of harpacticoid copepods is still unresolved. Until now the monograph by Lang (1948) remains the most important identification key. Other useful works are the monographs of Sars (1911, 1921), Smirnov (1946), Lang (1965), Wells (1971), Huys et al. (1996), Seifried, (2003) and a catalogue of the new marine Harpacticoid copepods by Bodin (1997).

2.5 Statistical analysis

Univariate and multivariate analysis of harpacticoid copepod community structure were conducted using the PRIMER v6.0.2 software package (Clarke and Gorley, 2006). Univariate methods (Shannon-Wiener diversity - H′ log e; Margalef's species richness – d; Pielou's evenness - J′; Simpson dominance index – 1-Lambda′ and Hill's number - N1, N2 & N_{Inf} and multivariate analysis data were squire root transformed prior to construction of Bray-Curtis similarity matrix (Clarke et al., 2006) and two-dimensional ordinations of assemblages were subsequently created using non-metric multidimensional scaling (nMDS). The significance of differences in community structure across the scales of investigation was assessed using a serious of one-way analysis of similarities (ANOSIM). The contribution of individual species to the differences observed was calculated using similarity percentages (SIMPER) routine. Relationship between multivariate biotic patterns and environmental variables were assessed by calculating Spearman rank correlation (ρ) between a similarity matrix derived from biotic data and metrics derived from environmental data (BIO-ENV procedure). Relationships between copepod density and environmental parameters were assessed using Principal Component Analysis (PCA) were assessed based on the environmental parameters (Sediment temperature, salinity, dissolved oxygen, pressure, sand, silt/clay, TOC, Iron and Zinc). Other simple statistics (correlation, descriptive statistics and two-way ANOVA) were made using MS-Excel.

3 Results

3.1 Abiotic variables

Surface sediment temperature and dissolved oxygen showed decreasing trend with increasing depth. Bottom water salinity and pressure showed opposite trend from that of temperature and dissolved oxygen. The median particle diameter (MPD) and total organic matter (TOM) showed negative correlation with water depth, surface sediment temperature and dissolved oxygen concentration. Petroleum hydrocarbon (PHC) concentration was higher in shallower depths than in deeper depths. In case of heavy metals, almost all the concentration except zinc showed an increase in sediments with gradual increase in depth (Table 1). Inter-relationship between the environmental parameters was assessed using Principal Component Analysis (PCA), the first axis represented 73.5% and second axis explained 19.4% with the total of 92.9% in the total variability. The first axis clearly separated all the depths sampled. It was evidently demonstrated higher values of total organic carbon with silt/clay composition and high water pressure at deeper depth regions (151-175m & >176m); whereas PHC, MPD levels with sand content, water temperature, dissolved oxygen concentration was more at shallower depth regions (30-50m & 51-75m) and heavy metals like Zinc (Zn) and Iron (Fe) were maximum at the middle depth regions (76-100m & 101-150m) (Fig. 2).

Table 1 Environmental parameters recorded in the study area.

Stations	Temp.	Sal.	Pres.	DO	MPD	TOM	PHC	Sand	Silt/Clay	Co	Cu	Fe	Mn	Ni	Pb	Zn	Hg
K1	27.75	26	26.15	4.11	0.46	1.31	2.35	75.64	24.36	0.217	0.069	527.6	8.755	0.557	0.692	5.31	0.012
K2	27.9	32.67	45.26	4.06	0.2	0.28	2.84	43.33	56.67	0.16	0.084	356.4	4.541	0.389	0.516	2.139	0
K4	24.87	34.7	102.62	1.58	0.27	4.16	2.18	77.2	22.8	0.069	0.051	1.161	1.587	0.172	0.139	2.487	0
K5	19.12	34.92	147.89	0.43	0.33	5.16	1.58	78.18	21.82	0.196	0.203	413.2	3.085	0.492	0.401	4.879	0.006
K6	14.92	34.98	198.22	0.13	0.33	4.52	1.81	68.73	31.27	0.166	0.341	358.8	2.505	0.707	0.443	4.331	0.024
P1	27.66	27	26.76	4.16	0.36	1.31	2.7	76.52	23.48	0.092	0.058	138.1	1.749	0.173	0.34	3.568	0.021
P2	27.71	31.72	46.27	4.22	0.48	0.19	2.48	83.79	16.21	0.151	0.091	244.9	2.947	0.307	0.763	4.361	0
P3	27.87	32.5	66.39	4.16	0.36	4.16	2.11	76.14	23.86	0.156	0.187	230.9	4.627	0.425	0.495	1.91	0
P4	27.9	32.71	81.48	4.16	0.28	5.16	2.36	74.42	25.58	0.103	0.212	41.7	2.819	0.252	0.45	5.779	0
P6	15.78	34.96	173.05	0.13	0.15	4.64	1.97	64.64	35.36	0.306	0.454	383	4.653	0.844	0.528	2.86	0
Si1	27.26	26	26.15	4.24	0.61	0.36	2.36	88.19	11.81	0.053	0.067	92.65	1.246	0.161	0.325	7.069	0.024
Si6	16.01	34.95	152.92	0.14	0.01	0.19	2.30	65.27	34.73	0.054	0.068	88.69	1.247	0.164	0.335	7.245	0
C1	27.58	25	25.14	4.25	0.13	3.09	2.14	73.51	26.49	0.169	0.216	296.1	5.537	0.317	0.701	16.87	0
C2	27.46	30.52	42.24	4.18	0.29	2.76	2.90	73.42	26.58	0.163	0.52	366	6.864	0.468	0.576	2.248	0
C3	27.86	33.78	77.45	3.47	0.43	2.5	4.07	91.38	8.62	0.055	0.116	130.3	2.132	0.159	0.466	2.752	0
C4	25.11	33.81	98.62	2.69	0.27	6.3	2.81	86	14	0.122	0.303	70.76	4.405	0.357	0.528	6.586	0
C5	19.44	34.92	140.84	0.25	0.15	4.4	2.63	48.64	51.36	0.204	0.427	203.4	5.925	0.614	0.573	1.142	0
C6	15.03	34.97	201.24	0.11	0.13	6.66	2.36	65.78	34.22	0.156	0.294	145	3.565	0.438	0.432	1.11	0.006
Ch1	27.78	31	31.18	4.02	0.67	2.97	2.11	90.48	9.52	0.123	0.249	208.7	3.848	0.322	0.379	6.238	0
Ch2	27.93	33.39	51.3	3.71	0.45	3.33	1.85	83.61	16.39	0.168	0.206	273.4	3.903	0.357	0.423	4.559	0
Ch3	27.69	33.61	46.45	3.6	0.25	3.57	1.88	86.97	13.03	0.21	0.253	301.9	5.286	0.48	0.563	3.918	0
Ch4	24.13	34.6	96.57	0.9	0.3	5.47	1.9	70.26	29.74	0.105	1.327	291.2	7.167	0.683	0.814	6.818	0
Ch5	17.9	34.91	146.88	0.073	0.16	5.12	1.97	60.39	39.61	0.457	0.902	343.5	8.948	1.169	0.851	3.978	0
Ch6	16.76	34.98	190.16	0.076	0.02	5.35	1.80	63.98	36.02	0.438	0.935	520.5	9.004	1.336	0.609	3.415	0
T1	27.87	27	27.16	4.18	0.72	3.45	3.03	89.25	10.75	0.061	0.039	10.98	5.275	0.154	0.152	1.094	0
T3	27.51	33.72	45.26	4.01	0.52	6.9	1.75	88.18	11.82	0.127	0.286	206.6	2.984	0.513	0.42	10.53	0
T4	27.43	34.07	102.61	2.9	0.51	7.26	2.73	89.12	10.88	0.219	0.327	337.2	5.942	1.075	0.514	2.091	0
T5	18.12	34.82	148.59	0.16	0.41	7.73	2.44	75.22	24.78	0.322	0.493	273.4	3.043	0.783	0.916	3.736	0
T6	15.02	34.97	203.25	0.09	0.02	7.14	1.99	52.65	47.35	0.702	1.979	618	23.29	2.417	0.78	11.76	0
S1	27.47	27	27.16	4.21	0.47	5.01	2.87	87.6	12.4	0.113	0.198	189.1	4.747	0.246	0.346	2.368	0.012
S2	27.71	32.21	45.26	4.19	0.006	6.07	2.64	47.56	52.44	0.47	1.863	603.1	15.76	1.618	0.515	57.51	0
S3	27.74	32.29	52.3	4.18	0.004	2.38	2.93	61.81	38.19	0.786	2.433	679.6	18.35	2.143	0.528	4.047	0
S4	28.17	33.43	91.54	3.8	0.03	6.54	3.07	76.61	23.39	0.445	0.872	342.8	8.886	0.763	0.42	3.917	0
S5	17.61	34.96	141.36	0.21	0.007	4.28	2.83	66.8	33.2	0.799	2.693	665.6	29.06	2.222	0.74	8.378	0
S6	15.62	34.9	197.21	0.09	0.007	5.35	2.72	58.12	41.88	0.419	1.655	608.2	5.133	1.398	0.429	11.26	0

K – Karaikkal, P – Parangipettai, Si – SIOCOT, C – Cheyyur, Ch – Chennai, T – Tammenapatanam and S – Singarayakonda. 1 – 30-50m, 2 – 51-75m, 3 – 76-100m, 4 – 101-150m, 5 – 151-175m and 6 - >176m. Parameters: Temp. – Temperature (ºC), Sal. – Salinity (psu), Pres. – Pressure, DO – Dissolved Oxygen (ml/l), MPD – Median Particle Diameter (mm), TOM – Total Organic Matter (%), Sand (%), Silt/clay (%), heavy metals (µg/g).

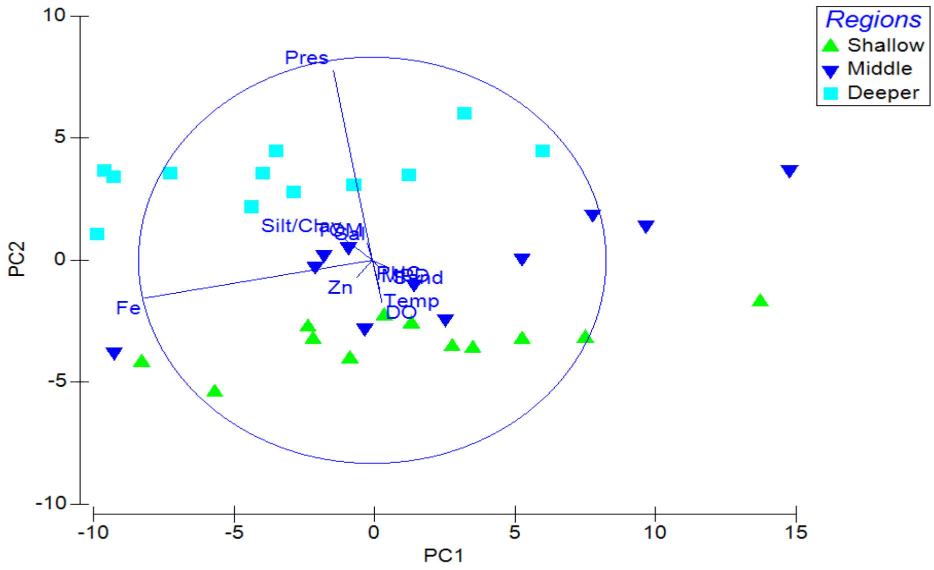

Fig. 2 Projection of the variables and sampling depths in the first plane of the Principal Component Analysis (PCA) based on environmental variables. Plot of the first two components explain 73.5% and 19.4% of the total variance.

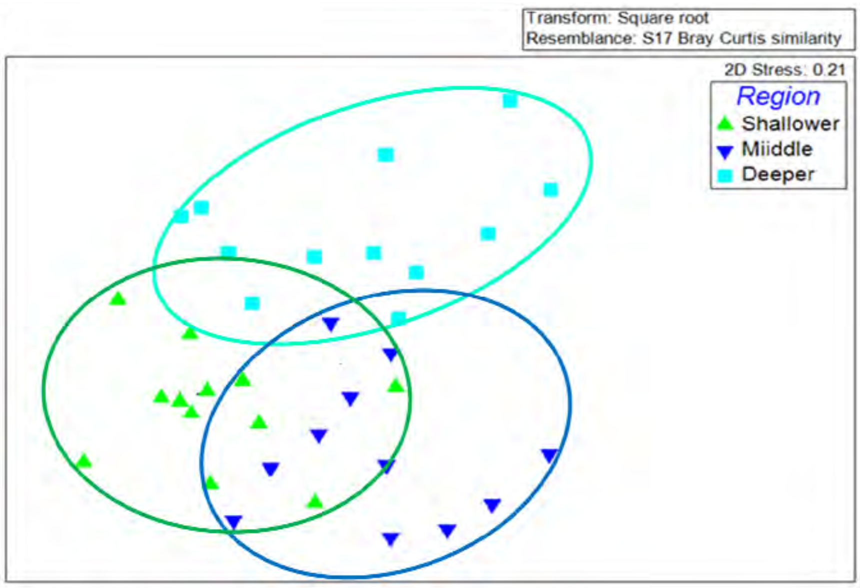

Fig. 3 nMDS plot of the harpacticoid copepod assemblages (square root transformed) at different depth regions from various transect. The sampling grouping was based on Bray-Curtis clustering.

3.2 Taxonomic composition

A total of 1259 harpacticoid copepod specimens were examined and 39 putative species belonging to 29 genera and 17 families were identified. Of the 1062 harpacticoid individuals, 84.35% were adults. The families Ectinosomatidae (21.21%), Miraciidae (16.04%), Harpaciticidae (13.58%), Aegisthidae (7.78%), Tisbidae (7.70%), Canuellidae (6.35%), Dactylopusiidae (5.56%), Paramesochridae (4.69%), Laophontidae (4.29%), Ameiridae (4.13%), Mitidae, Argestiidae, Terragonicepsidae, Cletodidae, Euterpinidae, Orthopsyllidae and

Tegastidae and were constituted (2.22%, 2.07%, 1.67%, 1.01%, 0.64%, 0.64% and 0.4% respectively) of relative abundance.

3.3 Similarity analysis

The non-metric multidimensional scaling (nMDS) ordination indicates that harpacticoid copepod assemblages differ among depths regions (shallower, middle and deeper depths) and between transects (Fig. 3). Samples are more separated according to depth regions, as conformed by two-way crossed ANOSIM (global R = 0.229, P = 0.001 among depths; global R = 0.047, P = 0.05 between transects). Average similarity among samples in terms of community composition (as indicated by SIMPER analysis) is highest for shallower depths (50.81%) and the dissimilarity between the depth regions is lowest between shallower and middle depths (57.44%) followed by middle and deeper depths (65.51%) and shallower and deeper depths (65.54%).

Table 2 Diversity indices of harpacticoid copepod assemblages in the study area.

Stations	S	N	d	J'	H'(loge)	1-Lambda'	N1	N2	N_{inf}
K1	21	66	4.774	0.9328	2.84	0.9483	17.11	15.13	9.429
K2	16	38	4.124	0.95	2.634	0.9459	13.93	12.67	9.5
K4	24	67	5.47	0.9442	3.001	0.9579	20.1	17.74	11.17
K5	11	23	3.189	0.9429	2.261	0.9249	9.592	8.672	5.75
K6	10	20	3.004	0.9472	2.181	0.9211	8.855	8	5
P1	19	46	4.701	0.9414	2.772	0.9488	15.99	13.92	7.667
P2	10	24	2.832	0.9052	2.084	0.8877	8.038	6.698	4
P3	12	32	3.174	0.9228	2.293	0.9133	9.905	8.678	5.333
P4	16	30	4.41	0.9349	2.592	0.9402	13.36	10.98	5
P6	10	16	3.246	0.9641	2.22	0.9417	9.208	8.533	5.333
Si1	24	107	4.922	0.9157	2.91	0.9408	18.36	14.7	7.133
Si6	19	57	4.452	0.9314	2.742	0.9417	15.53	13.37	8.143
C1	20	53	4.786	0.9543	2.859	0.955	17.44	15.87	10.6
C2	8	19	2.377	0.9051	1.882	0.8713	6.567	5.73	3.8
C3	8	11	2.919	0.9713	2.02	0.9455	7.537	7.118	5.5
C4	9	14	3.031	0.9587	2.107	0.9341	8.22	7.538	4.667
C5	5	7	2.056	0.963	1.55	0.9048	4.711	4.455	3.5
C6	2	2	1.443	1	0.6931	1	2	2	2
Ch1	12	26	3.376	0.9263	2.302	0.92	9.991	8.667	5.2
Ch2	9	10	3.474	0.9849	2.164	0.9778	8.706	8.333	5
Ch3	7	9	2.731	0.9708	1.889	0.9444	6.614	6.231	4.5
Ch4	4	9	1.365	0.8764	1.215	0.75	3.37	3	2.25
Ch5	10	22	2.912	0.944	2.174	0.9134	8.79	7.806	4.4
Ch6	8	11	2.919	0.9485	1.972	0.9273	7.187	6.368	3.667
T1	27	76	6.004	0.941	3.101	0.9607	22.23	19.25	10.86
T3	10	23	2.87	0.9557	2.201	0.9209	9.031	8.397	5.75
T4	10	23	2.87	0.9197	2.118	0.8972	8.311	7.053	3.833
T5	10	16	3.246	0.9641	2.22	0.9417	9.208	8.533	5.333
T6	18	47	4.415	0.9533	2.755	0.95	15.73	14.25	9.4
S1	14	42	3.478	0.945	2.494	0.9303	12.11	10.89	7
S2	9	19	2.717	0.9291	2.041	0.9006	7.701	6.811	4.75
S3	11	23	3.189	0.9524	2.284	0.9289	9.813	8.966	5.75
S4	7	21	1.971	0.8187	1.593	0.7571	4.919	3.585	2.1
S5	19	106	3.86	0.9394	2.766	0.9351	15.9	13.57	6.625
S6	21	144	4.024	0.9488	2.889	0.9427	17.97	15.66	7.2

S – Number of Species; N – Number of organisms; d - Margalef's species richness; J'- Pielou's evenness; H' loge – Shannon-Wiener diversity; 1-Lambda′ - Simpson dominance index; N1, N2, Ninf – Hills' number.

3.4 Diversity

There were significant differences in harpacticoid copepod diversity between depths as well as transects (Table 2). Diversity indices clearly explained the significant changes in harpacticoid assemblage between the depths from various transects. Shannon-Wiener index (H′log e) ranged from 0.69 (C6) to 3.10 (T1); while Pielou's evenness index (J′) from 0.82 (S4) to 1(C6). Shannon-Wiener diversity values revealed significantly lower (2.12±0.47, n=11) at the middle depth regions (ANOVA, $p<0.01$; Tukey test $p<0.05$). As expressed by indices of species richness (Margalef's richness (d), Hill's numbers (N1, N2 & N_{Inf}). However, trends were different between transects as well as depths. Margalef's richness, N1, N2 and N_{Inf} were significantly higher at the shallower depth regions (3.96±1.09; 13.18±5.07; 11.56±4.33 and 7.08±2.56 respectively, n=12) than the other depth regions (ANOVA, $p<0.05$; Tukey test $p<0.05$). Dominance index (Simpson dominance - 1-Lambda´) showed opposite to the other diversity indices.

4 Discussion

Studies on marine meiofaunal ecology and diversity have increased considerably in the last three decades. The study of this group is a major component in benthic research, subsequent to the fact that meiobenthic animals have been known since the early days of microscopy (Schratzberger, 2002). Those who pioneered meiofaunal studies considered only isolated taxa, often the exceptional species of known invertebrate groups, not the ecological relations and the community aspect. Since then the emphasis for field investigation has been biased towards the commercially more important macrofauna. Meiobenthos was earlier considered as the apex of trophic end (McIntyre and Murison, 1973). Recent studies showed their potential role in the ecology of benthic realm (Coull et al., 1995). Studies on meiobenthos pertained to only abundance of different groups and no attention was paid to the other qualitative aspects of these groups. In this backdrop quantitative attempts began to understand the potential role of meiofauna. However the history of meiofauna along the Indian coast is rather recent.

In marine benthic ecology, sediment granulometry along with environmental parameters are considered essential for determining the composition and characterization of benthic organisms (Ganesh and Raman, 2007). Depth of water plays an important role in the assemblage of benthic organisms (Austen et al., 1998) besides other environmental parameters (Gordon et al., 2002). Snelgrove and Butman (1994) concluded that the relationship was a complex interaction of the seabed flow and sediment characteristics and that no single factor could explain the distribution of organisms across all sedimentary habitats. Organisms living within the interstitial spaces are also affected, but the degree to which they are affected may vary according to their selectivity and tolerance to a particular environment (Giere, 2009).

Generally, sediment grain size varies as a function of water depth (Bennett et al., 1999) and in the present study, the finer fraction (coarse sand to fine silt) of the sediment was found to be positively correlated ($P < 0.01$) with water depth and pressure while negatively correlated with ($P < 0.05$) bottom water temperature and dissolved oxygen. Michels et al. (2003) has found that a large area of the Bay of Bengal is covered by sandy silty nature of sediments. In the present study, sandy nature of sediments contributed most of the study area (73.13±13.17, range = 43.33 - 91.38%, n = 35). Multivariate analysis showed that harpacticoid composition of the southeast continental shelf of India differs significantly from sand to silt/clay composition and did not vary with water depth. Generally, sandy nature of sediments, dissolved oxygen and salinity are commonly a major driving force, whereas in our study, it showed negative and positive trend with harpacticoid density respectively. Similar findings noted earlier by Mantha et al. (2012) on the coast of Chennai.

Harpacticoid copepods are generally the second most abundant metazoan meiofauna taxan next to the nematodes (Sajan et al., 2010) but on some tropical beaches, they outnumber nematodes (Snelgrove and

Butman, 1994). Investigation on their distribution patterns is necessary to have complete understanding of continental shelf meiofaunal composition (Thistle et al., 2007; Gheerardyn et al., 2008). Specialist relationships and tolerance to different environmental conditions favor distinct distribution patterns for many harpacticoid species, which are well established on soft bottoms (De Troch et al., 2002) and this was confirmed by the present study.

Our knowledge of the harpacticoid copepods distribution and diversity in the Indian shelf is not known except (Sajan and Damodaran, 2007). Until the present time, 49 species and 33 genera of harpacticoid copepod have been recorded from the Indian waters. In the present study, 39 species of harpacticoid copepods belonging to 30 genera and 17 families with numerical abundance of 35.97±32.06 (range = 2 – 144 ind. /10cm^2). The highest number of harpacticoid (22 species) was recorded by Eldose (2008 – Ph.D. thesis, unpublished data) from southeast continental slope of India followed by 12 species by Mantha et al. (2012) from Chennai coast, 8 species by Sajan and Damodaran (2007) from western continental shelf of India and Mondal (2010 – Ph.D. thesis, unpublished data) from Parangipettai inshore waters (Southeast coast of India). They occurred in almost all the depths, and their abundance was negatively correlated with water depth ($P<0.01$) except shallower depth. The present study sandy nature of sediment found more and the abundance of harpacticoid also higher side (59.43±26.53, range = 26 - 107 ind./10cm^2). Some of the genera that could be identified were *Leophonte, Harpacticus, Arenosetella* and *Ameira.*

Results obtained from multivariate analysis like non- metric multidimensional scaling (nMDS), confirmed that there were three different depth regions based on the numerical abundance and species composition of harpacticoid copepods. Despite the changes in harpacticoid composition across the depth regions, trends in species diversity were different. At shallower depth regions sustained a more diverse assemblage (both in terms of species richness and evenness) than middle and deeper depth regions (Fig. 3). For depth related studies indicated that an increase in sediment granulometry allows for a linier increase in harpacticoid and nematode species number and diversity. Greater interstitial space, increased resources and reduced levels of predation contribute to this relationship (Gheerardyn et al., 2008). Similarity percentages analysis (SIMPER) was used to determine the contribution from individual species to the Bray-Curtis dissimilarity between depth regions. The majority of the 39 species identified was rare, and did not contribute significantly to inter-depth dissimilarities (Mu et al., 2002).

Several studies found a significant relationship between harpacticoid community structure and oil contamination (Cross and Mortin, 1987; Gomes et al., 2000), nitrogen compounds (Nouguera and Hendrickx, 1997), sewage (TiO_2) contamination (Smol et al., 1991), heavy metals (Mu et al., 2002) and sedimentary parameters (Rubal et al., 2009). Nouguera and Hendrickx (1997) reported that the higher density of nematodes exposed to discharges of nitrogen compounds commonly used in agriculture, whereas the density of benthic harpacticoids decreases in the Southeastern Gulf of California, Mexico. Similarly the present study, the less density of harpacticoid copepods may due to the higher nematode density (Ansari et al., 2012). Carman et al. (1997) recorded higher density of *Cletocamptus deitersi* (indicator species) from more concentration of hydrocarbon whereas *Coullana* sp., *Pseudostenhelia wellsi* and *Microarthridion zittorale*. Similarly some of the indicator harpacticoid species may the reason for the higher abundance in certain stations of the present study area. Smol et al. (1991) recorded the higher percentage of nematodes within the sewage disposal (TiO_2) dumping area of Dutch coast is totally compensated by a lower percentage of harpacticoids, supporting the hypothesis that copepods are more sensitive to environmental stress than the nematodes.

5 Conclusion

Benthic harpacticoid copepods are known to be sensitive to sediment metal concentration (Somerfield et al., 1994), oil contamination (Moore and Somerfield, 1997), but none of the anthropogenic inputs damage the harpacticoid copepods assemblages, because there is no available data (harpacticoid numerical abundance and species composition) in this region. Diversity studies aim to incorporate the species composition and the conclusion of data that signify a global benefit. Therefore, the present study 39 species of harpacticoid copepods reported from the southeast coast of India are very important as they are able to present the trend of distribution seaward as well as along the coast from south to north of the study area. This shows the necessity of intensifying sampling efforts in this region to recover the present knowledge of harpacticoid copepods distribution and community structure. In order to determine the effects of anthropogenic disturbance resulting from oil exploration, pollution, aquaculture, and so on, survey designs appropriate in scale for the effects being studied should be employed. In this concern, further studies such as ecotaxicology, impact assessment, nematode/copepods index will useful to ecological quality assessment in this region.

Acknowledgements

The authors are thankful to Prof. K. Kathiresan, Director, for the encouragement and the University authorities for the facilities. The authors are also thankful to the Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences, Government of India, Kochi, for the financial assistance through the research project “Marine Benthos of Indian EEZ” and authors are thankful to all the crew members of FORV *Sagar Sampada*.

References

Ajmal Khan S, Ansari KGMT, Lyla PS. 2012. Organic matter content of sediments in continental shelf area of southeast of India. Environmental Monitoring and Assessment, 184: 7247-7256

Altaff K, Naveed MS, Sugumaran J. 2004. Meiofauna of Chennai coast of Bay of Bengal with special reference to sampling and extraction methods. Convergence, 6: 61-90

Altaff K, Sugumaran J, Naveed MS. 2005. Impact of tsunami on meiofauna of Madras Marina beach, Chennai, India. Current Science, 89: 34-38

Ansari ZA, Rivonkar CU, Sangodkar UMV. 2001. Population fluctuation and vertical distribution of meiofauna in a tropical mudflat at the Mandovi estuary, west coast of India. Indian Journal of Marine Sciences, 30: 237-245

Ansari KGMT, Lyla PS, Ajmal Khan S. 2012. Faunal composition of metazoan meiofauna from southeast continental shelf of India. Indian Journal of Geo-Marine Sciences, 41(5): 457-467

APHA. 1989. Standard Methods for the Examination of Water and Wastewater (17th edn). American Public Health Association, Washington DC, USA

Armenteros M, Perez-Garcıa JA, Perez-Angulo A, Williams JP. 2008. Efficiency of extraction of meiofauna from sandy and muddy marine sediments. Revista de Investigaciones Marinas, 29: 113-118

Austen MC, Widdicombe S, Villano-Pitacco N. 1998. Effects of biological disturbance on diversity and structure of meiobenthic nematodes communities. Marine Ecology Progress Series, 174: 233-246

Aziz AH, Ahmed L, Atapattu A, Chullasom S, et al. 1998. Regional stewardship for sustainable marine resources management in the Bay of Bengal. In: Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and management (Sherman K, Okemwa E, Ntiba N, eds). 369-378, Blackwell, Cambridge, MA, USA

Bennett RH, Ransom B, Kastner M, Baerwald RJ, et al. 1999. Early diagenesis: Impact of organic matter on mass physical properties and processes, California Continental Margin. Marine Geology, 159(1-4): 7-34

Blott SJ, Pye K. 2001. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, 26: 1237-1248

Bodin PH. 1997. Catalogue of the New Marine Harpacticoid Copepods. Koninklijk Belgisch Instituut voor Natuurwetenschappen. Studiedocumenten van Het K.B.I.N. Brussel, Belgium

Bongers T, Ferris H. 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends in Ecology and Evolution, 14: 224-228

Carman KR, Fleeger JW, Pomarico SM. 1997. Response of a benthic food web to hydrocarbon contamination. Limnology and Oceanography, 42(3): 561-571

Chandler GT, Cary TL, Volz TC, Walse SS, et al. 2004. Fipronil effects on the estuarine copepod (*Amphiascus tenuiremis*) development, fertility, and reproduction: a rapid life-cycle assay in 96-well microplate format. Environmental Toxicology and Chemistry, 23: 117-124

Chertoprud ES, Gheerardyn H, Gómez S. 2011. Harpacticoida (Crustacea: Copepoda) of the South China Sea: faunistic and biogeographical analysis. Hydrobiologia, 666: 45-57

Clarke KR, Gorley RN. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth, UK

Clarke KR, Somerfield PJD, Airoldi L, Warwick RM. 2006. Exploring interaction by second-stage community analysis. Journal of Experimental Marine Biology and Ecology, 338: 179-192

Coull BC, Chandler GT. 1992. Pollution and meiofauna: Field, laboratory and mesocosm studies. Oceanography and Marine Biology an Annual Review, 30: 191-271

Coull BC, Greenwood JG, Fielder DR, Coull BA. 1995. Subtropical Australian juvenile fish eat meiofauna: Experiments with Winter Whiting *Sillago maculata* and observations on other species. Marine Ecology Progress Series, 125: 13-19

Coull BC. 1999. Role of meiofauna in estuarine soft-bottom habitats. Australian Journal of Ecology, 24: 327-343

Cross WE, Martin CM. 1987. Effects of oil and chemically treated Oil on nearshore under –ice meiofauna studies *in situ.* Arctic, 40(1): 258-265

Danovaro R. 1996. Detritus-bacteria-meiofauna interactions in a seagrass bed (*Posidonia oceanica*) of the NW Mediterranean. Marine Biology, 127: 1-13

De Troch M, Fiers F, Vincx M. 2002. Niche segregation and habitat specialization of Harpacticoid copepods in a tropical seagrass bed. Marine Biology, 142: 345-355

Dwivedi SN, Choubey AK. 1998. Indian Ocean Large Marine Ecosystems: Need for national and regional framework for conservation and sustainable development. In: Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and Management (Sherman K, Okemwa E, Ntiba N, eds). 361-368, Blackwell, Cambridge, MA, USA

El-Wakeel SK, Riley JP. 1957. The determination of organic carbon in marine muds. Journal of Du Counseil International Exploration, 22: 180-183

Folk RL, Ward WC. 1957. Brazos River bar: A study in the significance of grain size parameters. Journal of Sedimentary and Petrology, 27: 3-26

Folkers C, George KH. 2011. Community analysis of sublittoral Harpacticoida (Copepoda, Crustacea) in the western Baltic Sea. Hydrobiologia, 666: 11-20

Fornshell JA. 2012. Key to marine arthropod larvae. Arthropods, 1(1): 1-12

Ganesh T, Raman AV. 2007. Macrobenthic community structure of the northeast Indian shelf, Bay of Bengal. Marine Ecology Progress Series, 341: 59-73

Gaudette HE, Wilson RF, Toner L, David WF. 1974. An inexpensive titration methods for determination of organic carbon in recent sediments. Journal of Sedimentary and Petrology, 44: 249-253

Gee JM. 1989. An ecological and economic review of meiofauna as food for fish. Zoological Journal of Linnaean Society, 96: 243-261

Gheerardyn H, De Troch M, Ndaro SGM, Raes M, et al. 2008. Community structure and microhabitat preferences of harpacticoid copepods in a trophical reef lagoon (Zanzibar Island, Tanzania). Journal of Marine Biological Association of UK, 88: 747-758

Giere O. 2009. Meiobenthology: The Microscopic Motile Fauna of Aquatic Sediments (2nd edn). Springer-Verlag, Heidelberg, Germany

Gomes AS, Oliveira EB, Gabardo IT, Carreira RS, et al. 2000. Benthic meiofauna study around an offshore oil production platform in compos basin, southeast Brazilian continental shelf. In: Proceedings of the 5th Congress on Marine Sciences. 1-14, La Habana, Cuba

Gordon AL, Claudia FG, Takahashi T, Sutherland S, et al. 2002. Bay of Bengal nutrient-rich benthic layer. Deep-Sea Research II, 49: 1411-1421

Heip C, Vincx M, Vranken G. 1985. The ecology of marine nematodes. Oceanography and Marine Biology-an Annual Review, 23: 399- 489

Hicks GRF, Coull BC. 1983. The ecology marine meiobenthic harpacticoid copepods. Oceanography and Marine Biology- an Annual Review, 21: 67-175

Huys R, Gee JM, Moore CG, Hamond R. 1996. Marine and Brackish Water Harpacticoid Copepods Part 1. Synopses of the British Fauna (Volume 51). Field Council, Shrewsbury, UK

Kennedy AD, Jacoby CA. 1999. Biological indicators of marine environmental health: meiofauna – a neglected benthic component? Environmental Monitoring and Assessment, 54: 47-68

Kirshnaswamy S. 1957. Studies on the Copepoda of Madras, India. University of Madras Press, India

Kotwicki L. 2002. Benthic Harpacticoida (Crustacea, Copepoda) from the Svalbard archipelago. Polish Polar Research, 23: 185-191

Kumar V, Manivannan V. 2001. Benthic foraminiferal responses to bottom water characteristics in the Palk Bay, off Rameswaram, southeast coast in India. Indian Journal of Marine Sciences 30: 173-179

Lang K. 1948. Monographie der Harpacticiden I & II". Håkan Ohlssons Boktryckeri, Lund, Sweden

Lang K. 1965. Copepoda:Harpacticoidea from the Californian Pacific Coast. Kungl. Svensk. Vetensk. Akad. Handl., 10(2): 1-566

Longhurst AR. 1998. Ecological Geography of the Sea. Academic Press, California, USA

Mahapatro D, Panigraphy RC, Naik S, Pati SK, et al. 2011. Macrobenthos of shelf zone off Dhamara estuary, Bay of Bengal. Journal of Oceanography and Marine Sciences, 2: 32-42

Mantha G, Moorthy MSN, Altaff K, Dahms HU, et al. 2012. Community structure of the Hapacticoida (Crustacea: Copepoda) on the coast of Chennai, India. Zoological Studies, 51: 463-475

McIntyre AD, Murison DJ. 1973. The meiofauna of a flatfish nursery ground. Journal of Marine Biological Association of UK, 50: 93-118

McLachlan A, Brown AC. 2006. The Ecology of Sandy Shores (2nd edn). Elsevier Science, Amsterdam, Netherlands

Michels KH, Suckow A, Breitzke M, Kudrass HR, et al. 2003. Sediment transport in the shelf canyon "Swatch of No Ground" (Bay of Bengal). Deep Sea Research II, 50: 1003-1022

Moore CG, Somerfield PJ. 1997. Response of the meiofaunal community to sewage sludge disposal in the Firth of Clyde, Scotland. Coastal Zone Topics, 3: 121-128

Mu FH, Somerfield PJ, Warwick RM, Zhang ZN. 2002. Large scale spatial patterns in the community structure of benthic harpacticoid copepods in the Bohai Sea, China. The Rafeles Bulletin of Zoology, 50(1): 17-26

Noguera SEG, Hendrickx ME. 1997. Distribution and abundance of meiofauna in a subtropical coastal lagoon in the southeastern Gulf of California, Mexico. Marine Pollution Bulletin, 34(7): 582-587

Ozcan T, Ozcan G, Erdogan H. 2012. Checklist of the freshwater decapod crustaceans from the Orontes River. Arthropods, 1(3): 118-120

Pfannkuche O, Thiel H. 1988. Sample processing. In: Introduction to the Study of Meiofauna (Higgins RP, Thiel H, eds). 134-145, Smithsonian Institute Press, Washington DC, USA

Platt HM, Warwick RM. 1983. Free-living Marine Nematodes Part I. British Enoplids, Synopsis of the British Fauna (Volume 28). Cambridge University Press, Cambridge, UK

Rubal M, Veiga P, Besteiro C. 2009. Nematode/Copepod index: importance of sedimentary parameters, sampling methodology and baseline values. Thalassas, 25(1): 9-18

Sajan S, Damodaran R. 2007. Faunal composition of meiobenthos from the shelf region off west coast of India. Journal of the Marine Biological Association of India, 49: 19-26

Sajan S, Joydas TV, Damodaran R. 2010. Meiofauna of the western continental shelf of India, Arabian Sea. Estuarine, Coastal and Shelf Science, 86 (4): 665-674

Sakthivel K, Fernando A. 2012. Brachyuran crabs diversity in Mudasal Odai and Nagapattinam coast of south east India. Arthropods, 1(4): 136-143

Sars GO. 1911. An Account of the Crustacea of Norway, Copepoda, Harpacticoida (Volume 5). Bergen Museum, Bergen, Norway

Sars GO. 1921. An Account of the Crustacea of Norway, Copepoda, Harpacticoida (Volume 7). Bergen Museum, Bergen, Norway

Schratzberger M, Dinmore TA, Jennings S. 2002. Impacts of trawling on the diversity, biomass and structure of meiofauna assemblages. Marine Biology, 130: 643-650

Sea Around Us. 2007. A global database on marine fisheries and ecosystems", Fisheries centre, University British Colmbia, Vancouver, Canada. http://www.seaaroundus.org/lme/Summeryinfo.aspx?LME=34

Seifried S. 2003. Phylogeny of Harpacticoida (Copepoda): Revision of Maxillipedasphalea and Exanechentera. Cuvillier Verlag, Göttingen, Germany

Smirnov SS. 1946. New species of Copepoda Harpacticoida from the Arctic Ocean. Trud. Dreif. Expedition - Glavsevmov. Ledokol. Par. "Sedov"., 3: 231-263

Smol N, Huys R, Vincx M. 1991. A 4-years' analysis of the meiofauna community of a dumping site for TiO_2 waste off the Dutch coast. Chemistry and Ecology, 5: 197-215

Snelgrove PVR, Butman CA. 1994. Animal sediment relationships revisited: Cause versus effect. Oceanography and Marine Biology an Annual Review, 32: 111-177

Somerfield PJ, Gee JM, Warwick RM. 1994. Soft sediment meiofaunal community structure in relation to a long-term heavy metal gradient in the Fal estuary system. Marine Ecology Progress Series, 105: 79-88

Sun B, Fleeger JW. 1995. Sustained mass culture of *Amphiascoides atopus*, a marine harpacticoid copepod, in a recirculated system. Aquaculture, 136: 313-321

Thistle D, Sedlaceka L, Carmanb KR, Fleegerb JW, Barryc JP. 2007. Emergence in the deep sea: Evidence from harpacticoid copepods. Deep-Sea Research I, 54: 1008-1014

Trivedi JN, Gadhavi MB, Vachhrajani KD. 2012. Diversity and habitat preference of brachyuran crabs in Gulf of Kutch, Gujarat, India. Arthropods, 1(1): 13-23

Walting RJ. 1981. A manual of methods for use in the Southern African Marine Pollution Monitoring Programme. South African National Science Program Report, 44: 1-82

Wells JBJ. 1971. A brief review of methods of sampling the meiobenthos. In: Proceedings of the First International Conference on Meiofauna (Hulings NC, ed). 32-49, Tunis, Tunisia

Wells JBJ, Rao GC. 1987. Littoral Harpacticoida (Crustacea: Copepoda) from Andaman and Nicobar Islands. Memories of Zoological Survey of India, 16: 1-385