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Community Structure of the Harpacticoida (Crustacea: Copepoda) on the Coast of Chennai, India

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Gopikrishna Mantha, Muthaiyan Suriya Narayana Moorthy, Kareem Altaff, Hans-Uwe Dahms, Kandasamy Sivakumar, and Jiang-Shiou Hwang (2012) Community structure of the Harpacticoida (Crustacea: Copepoda) on the coast of Chennai, India. *Zoological Studies* **51**(4): 463-475. Harpacticoid copepods were studied on sandy beaches of the Chennai coast of India from Jan. 2000 to Feb. 2001. This study provides the 1st quantitative account of these copepods on the southeastern coast of India. Surprisingly, harpacticoid copepod abundances more significantly differed among monthly samples than among stations. The total density of harpacticoids was $1.5 \times 10^6 \pm 5.4 \times 10^4$ individuals (ind.)/10 cm^2. The mean abundance in different months was highest in Feb. 2000 (15,182.67 ± 21,019.15 ind./10 cm^2) and was lowest in July 2000 (3951.07 ± 5271.87 ind./10 cm^2), whereas for stations it was highest at Neelangarai (25,187.33 ± 31,831.51 ind./10 cm^2) and the lowest at Besant Nagar (17,738.93 ± 21,581.63 ind./10 cm^2). The abundance of harpacticoid communities was dominated by copepodites during different months (25,256.14 ± 14,884.09 ind./10 cm^2 and at stations (72,470.40 ± 15,892.51 ind./10 cm^2). The mean highest and lowest abundance values of adult harpacticoids were for *Arenopontia indica* and *Psammastacus acuticaudatus* during different months (12,438.86 ± 8547.53 and 495.71 ± 496.88 ind./10 cm^2) and at different stations (34,828.80 ± 10,872.16 and 1388.00 ± 232.24 ind./10 cm^2), respectively. Cluster and principal coordinate analyses showed that harpacticoids were grouped into 6 categories. Ecological indices varied in different months, at different stations, and among harpacticoid species. http://zoolstud.sinica.edu.tw/Journals/51.4/463.pdf

Key words: Meiofauna, Sandy beach, Harpacticoida, Chennai coast.

Coastal ecosystems of both tropical and temperate regions are more pronounced with sandy beaches that have remarkable biodiversity (McLachlan and Brown 2006). The physicochemical, biological, and hydrodynamic characteristics of these fragile ecosystems form dynamic communities and are very vulnerable (Rodrıguez et al. 2003, Davies 1972). These communities show variations related to natural abiotic characteristics, e.g., temperature, salinity, desiccation, mean grain size of sediments, and water bottom currents (Coull and Bell 1979, McLachlan et al. 1996, Coull 1999, Corgosinho et al. 2003, Giere 2009), and also variations in biotic communities, e.g., competition and predation (Snelgrove and Butman 1994). An equilibrium state produced by intermediate morphodynamics between organic inputs and aerobic interstitial conditions (Short and Wright 1983) favors the meiofauna in intertidal habitats (Giere 2009).

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Rodrıguez et al. (2003) found that sandy beaches with different morphodynamics have the highest abundance at the dissipative end and the highest number of major taxa at the reflective end of the beach.

The highly abundant and species-rich meiofauna plays an important role in experimental ecology studies (Higgins and Thiel 1988). Harpacticoid copepods, which are the 2nd-most-abundant meiofauna taxa next only to the nematoda (Becker 1970, Hicks and Coull 1983), are flexible and well suited for shifts in their food preferences during different developmental stages and also between different seasonal and tidal changes, 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 Georges 2011) to the South China Sea (Chertoprud et al. 2011).

Very few studies have been carried out on meiofaunal communities along the coasts of India. Of the few studies, most were on the entire meiofauna community pertaining to the West Coast (Ansari and Parulekar 1981, Ansari 1984, Harkantra 1984, Harkantra and Parulekar 1989, Parulekar et al. 1993, Ingole and Parulekar 1998, Ingole et al. 1999, Ansari et al. 2001, Kumar and Manivannan 2001), with very few concentrated on the East Coast (Aiyar and Alikunhi 1944, Moorthy 2002, Altaff et al. 2004 2005). Only Krishnaswamy (1957) previously studied harpacticoids of the Chennai coast, and after a lapse of nearly 4 decades, our present study is a preliminary investigation along this coast to understand the community structure of meiobenthic harpacticoids.

Background of the study area

Chennai is one of the large, densely populated metropolitan cities of India with 6.22 million residents. It has a coastal stretch approximately 30 km long from Neelangarai in the south to Ennore Creek in the north. This coastal stretch is drained by 3 main outlets of the Adyar River (Shanmugam et al. 2007) in the south, the Cuvum River (Ramachandran 2001) in the central area, and Buckingham Canal (Sreenivasan and Franklin 1975, Jayaprakash et al. 2005) in the north, along with several small outlets for the city's drainage and sewage disposal. The northern part has a number of refineries, thermal power plants, fertilizer industries, etc. Industrial wastes along with residential wastes are discarded into the coastal waters of Chennai. Since Ennore, Cuvum, and Adyar estuaries form the predominant sewage disposal centers of this major city (Shanthi and Gajendran 2009), these places and their surroundings are constantly exposed to heavy pollutants and organic loading (Shanmugam et al. 2007). Five coastal stations were selected here on the basis of variations in hydrodynamic characteristics with the tidal action being semidiurnal and reaching a maximum height of 1.23 m during the study period.

MATERIALS AND METHODS

Description of the study sites

Neelangarai, located at the south end of the city, is one of the uninterrupted stretches of sandy beaches in and around the Chennai coast with tourist and fishing activities. Besant Nagar, situated in the southern part of the city, is very close to Adyar Creek from which domestic discharge and storm water enter the Bay of Bengal. A sand bar often forms at the river mouth. Marina, situated at the center of the city's coastal area, is one of the main tourist attractions of the city and is located very near the Coovum River, which carries the majority of treated/untreated domestic sewage from the city into the Bay of Bengal. Thiruvotriyur is located at the northern end of Chennai Port, has protecting artificial boulders on either side, and is more prone to strong wave action. Anthropogenic and industrial activities are more pronounced here with minor fishing activity. Ernavoor is located at the north end of the city and is very near Ennore Creek, which receives treated/untreated industrial effluents from the Manali industrial area and also fly ash and thermal effluents from the Ennore Thermal Power Station. More dredging activity is seen in this area with fishing and navigational activities.

Sampling

Meiofauna samples for the present study were collected monthly from Jan. 2000 to Feb. 2001, at 5 stations, situated within 12°56'33.05"-

13°12'10.45"N, 80°15'38.72"-80°19'21.19"E, along the southeastern coast of India (Fig. 1). Samples were taken from the intertidal region during low and high tide, based on the Indian Tide Tables (2003-2005). At each station, interstitial sandy sediment, from the top 15-cm layer, was sampled using plastic corers (3.57 cm in inner diameter and 30 cm long). Sandy sediment consisted of granules, coarse sand, and silt. Core samples were immediately fixed in buffered seawater formalin at a final concentration of 5% and taken to the laboratory.

Laboratory and statistical analyses

In the laboratory, harpacticoid copepods were extracted from the sediment sample using the technique described by Warwick and Buchanan (1970). Briefly, the formalin-fixed sediment sample was washed through a set of 500-63-μm sieves. The sediment retained on the 63-μm sieve was then decanted into a 250-ml graduated cylinder and filled with filtered seawater to a volume of 280 ml. The sample was placed at rest for 60 sec, allowing the larger particles to settle out. The supernatant was then passed through a 63-μm sieve, and this process was repeated 3 times. The decanted supernatant containing harpacticoid copepods was sorted under a binocular stereomicroscope (10x and 40x magnification using a Leica digital stereomicroscope, Jena, Germany). The numerical abundance (as the number of individuals (ind.)) of harpacticoid copepods was expressed as ind./10 cm^2.

Identification and quantification

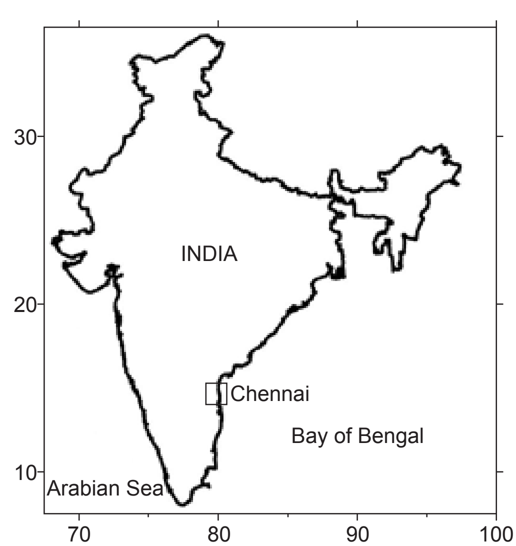
Harpacticoid copepods were identified by mounting them on microscopic slides and comparing them to descriptions by Krishnaswamy (1957), Rao (1972 1989 1993), and Wells and Rao (1987). Ovigerous females, copepodites, and nauplii were categorized into 3 different groups.

Physicochemical parameters

Physicochemical parameters such as atmospheric temperature (°C), interstitial water temperature (°C), pH, salinity (ppt), and dissolved oxygen (DO in mg/L) were recorded. Using a syringe, the interstitial water taken from the top 5 cm of the sediment surface was used to analyze pH, salinity, and DO. The interstitial temperature was recorded by inserting a mercury thermometer into the sediment column down to 5 cm deep and keeping it there for a few minutes. DO was estimated in the field using Winkler's method (Winkler, 1888), and salinity was measured with a refractometer (Radical Instruments, India).

Granulometry

A granulometric analysis was conducted following the method of Buchanan (1984). Collected sand samples were air-dried for 4-5 d and hand-sieved through a graded series



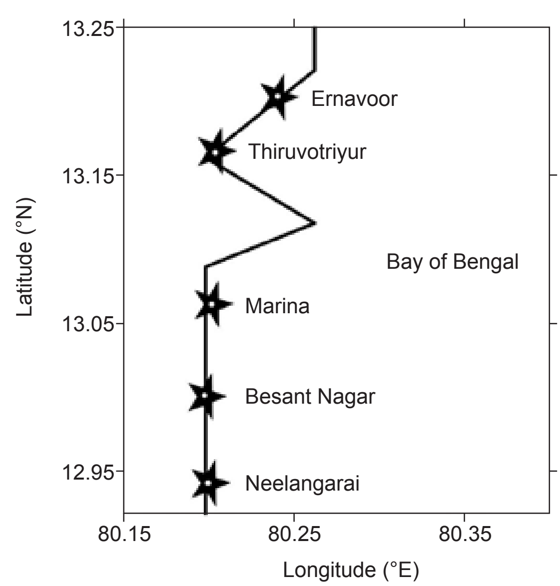


Fig. 1. Sampled stations.

of standard sieves representing intervals of the Wentworth scale (Table 1). The sieves were arranged in decreasing order of mesh sizes (2000-63 μm). Samples were placed on a stacked set of sieves. The stack was closed at the bottom end with a metal pan, closed with a cover on the top, and sieved for about 15 min. After sieving, the material on each individual sieve was weighed. The percentage composition was calculated and further analyzed.

Ecological indices

The Shannon-Wiener diversity index as H' (Shannon and Weaver 1949), Simpson's dominance index as D' (Simpson 1949), Pielou's evenness index as J' (Pielou 1969), and the species richness (SR) were determined as meiofauna taxon-based indices. These indices were computed with Palaeontological Statistics (PAST) vers. 2.09 statistical package (Hammer et al. 2001).

Statistical analysis

A parametric analysis of variance (ANOVA) was used to detect significant differences in harpacticoid copepod abundances among months and stations. After a significant ANOVA result was found, Tukey's honest significant difference (HSD) test was used for contrasts. Before the analysis, the normality of the data was checked, and when necessary, data were transformed accordingly. The homogeneity of the variance was assessed by Cochran's test. Pearson's correlation coefficient analysis was used to highlight any significant differences among major harpacticoid copepod distributions, environmental variables, and soil size. Single-linkage Bray-Curtis cluster dendograms were created to determine the similarity in the distribution and abundance among different sampling months, different stations, and harpacticoid copepod species. Scatterplot diagrams for the principle component and correspondence analyses were carried out to ascertain the groupings and to determine the contribution of harpacticoid copepods during different months and at different stations. All statistical analyses were carried out using Microsoft-EXCEL (vers. MS-Office 2007, Redmond, WA), SPSS vers. 15.0 (SPSS, Chicago, IL), and PAST vers. 2.0.

RESULTS

Physicochemical parameters

Physicochemical parameters showed similar patterns of increases and decreases at all stations except for DO. The atmospheric temperature varied 28.2-32.1°C, the interstitial temperature varied 26.4-30.2°C, salinity varied 29.7-33.7 ppt, the pH varied 7.9-8.7, and the DO varied 4.2-5.8 mg/L (Fig. 2).

Monthly distributions

The monthly mean of total harpacticoid abundance was highest in Feb. 2000 (15,182.66 ±

Table 1. Mean contributions of different-sized sand grains at different sampling stations (St.). %WS, percentage of wet sand (g/10 cm^2); PC%, percentage composition of each soil size; ^{m}, minimum; and ^{x}, maximum

St. no.	Sand grain size(mm)	Neelangarai	Marina	Besant Nagar	Thiruvottriyur	Ernavoor	PC%
1	> 2.000	1.07 ± 0.43^m	1.90 ± 0.52^m	0.58 ± 0.11^m	0.13 ± 0.77^m	2.15 ± 0.33^m	0.83^m
2	1.680	1.90 ± 0.86	2.22 ± 0.69	1.61 ± 0.68	2.84 ± 0.86	3.05 ± 0.87	1.65
3	0.542	31.28 ± 4.97	36.87 ± 4.47	23.97 ± 3.17	28.46 ± 3.51	42.24 ± 2.85^x	23.06
4	0.425	37.92 ± 2.68^x	37.64 ± 3.15^x	33.32 ± 2.68^x	34.24 ± 3.14^x	38.48 ± 4.11	25.72^x
5	0.300	17.13 ± 1.39	19.63 ± 1.79	17.74 ± 2.66	15.71 ± 1.84	18.00 ± 1.95	12.49
6	0.275	23.58 ± 1.71	25.25 ± 2.14	27.77 ± 2.54	24.65 ± 2.89	21.25 ± 1.72	17.35
7	0.147	23.69 ± 3.17	20.33 ± 2.51	30.12 ± 3.74	29.21 ± 3.07	13.77 ± 1.54	16.59
8	0.042	2.80 ± 0.67	2.32 ± 0.75	3.89 ± 1.33	5.07 ± 0.81	2.24 ± 0.76	2.31
	Total	139.37 ± 17.42	146.16 ± 18.27	139.00 ± 17.37	140.31 ± 17.53	141.18 ± 17.64	100
	%WS	19.74	20.70^x	19.69^m	19.87	20.00	100

21,019.15 ind./10 cm^2) and was lowest in July 2000 (3951.06 ± 5271.86 ind./10 cm^2). The relative percent composition was the highest in Feb. 2000 (14.87%), followed by Jan. 2001 (13.38%), with the lowest composition found in Mar. 2000 (3.99%) (Table 2).

The highest dominance, and the least diversity and evenness were observed in Sept. 2000. The least dominance, and the highest diversity and evenness were observed in Aug. 2000. Species richness was lowest in July 2000 (Table 2).

Station distributions

The highest mean total harpacticoid abundance was observed at Neelangarai (25,187.33 ± 31,831.51 ind./10 cm^2), and the lowest was observed at Ernavoor (17,116.80 ± 20,219.27 ind./10 cm^2). The relative percentage composition was the highest at Neelangari (24.67%) and the lowest at Ernavoor (16.77%) (Table 3).

The highest dominance, and the lowest diversity and evenness were observed at Thiruvotriyur. The lowest dominance, and the

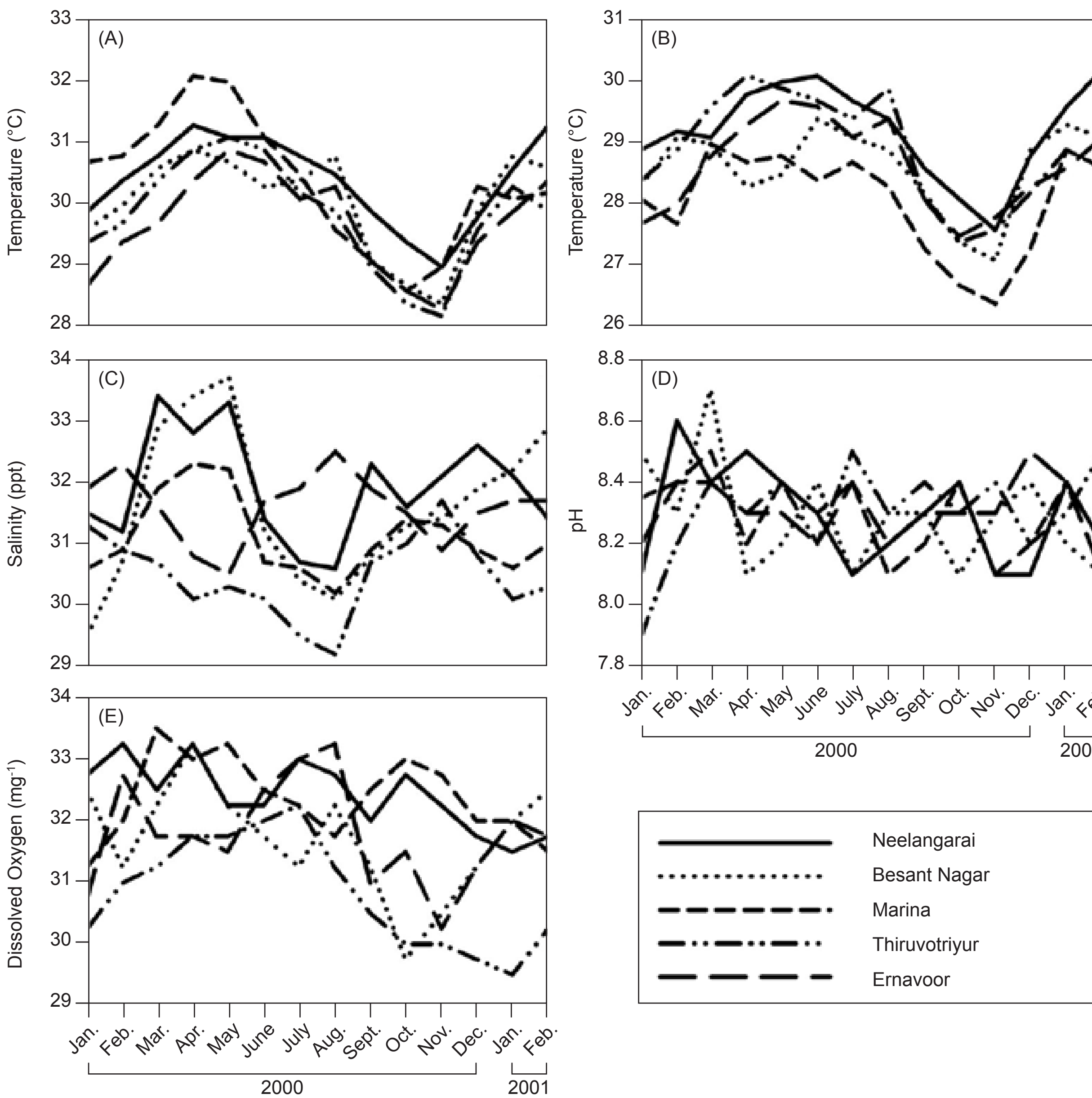


Fig. 2. Monthly physicochemical parameters at 5 stations from Jan. 2000 to Feb. 2001.

highest diversity and evenness were observed at Ernavoor (Table 3). Even though Thiruvotriyur contributed to the 2nd-highest abundance, next only to Neelangari, it showed the highest dominance index, being less evenly distributed throughout the sampling period (Fig. 3).

Harpacticoid copepod species distributions

Twelve species of harpacticoid copepods were identified. Among different stages, copepodites dominated the overall abundance with 25,882.28 ± 26,077.52 ind./10 cm^2, followed by nauplii (25,256.14 ± 14,884.08 ind./10 cm^2) and ovigerous females (18,214.71 ± 10,881.37 ind./10 cm^2). Among species, the highest abundance was contributed by *Arenopontia indica* (Rao, 1967) (12,438.85 ± 8547.52 ind./10 cm^2), and the lowest was contributed by *Parapseudoleptomesochra trisetosa* (Krishnaswamy, 1957) (514.85 ± 599.82 ind./10 cm^2) (Table 4).

The highest dominance and lowest diversity and evenness indices were shown by *Apodopsyllus madrasensis* (Krishnaswamy, 1951), and the lowest dominance and highest diversity and evenness were shown by *Psammastacus acuticaudatus* (Krishnaswamy, 1957). *Apodopsyllus camptus* (Wells, 1971) showed the lowest species richness at all sampling sites (Table 4).

The single-linkage Bray-Curtis cluster

Table 2. Mean abundances (indivuduals/10 cm^2) and ecological indices of harpacticoid copepod distributions during different months at all sampling stations. RA, relative abundance (%); S, species richness; D', Simpson's dominance index; H, Shannon's diversity index; J', Pileou's evenness index; ^{m}, minimum; ^{x}, maximum

	Mean ± S.D.	S	D'	H'	J'	RA
Jan. 2000	3973.60 ± 5008.94	14	0.1655	1.9920	0.5233	3.89
Feb. 2000	15,182.66 ± 21,019.15^x	15	0.1859	1.8790	0.4365	14.87^x
Mar. 2000	5012.53 ± 6997.39	14	0.1879	1.8940	0.4746	4.91
Apr. 2000	6251.60 ± 8509.15	14	0.1819	1.9620	0.5079	6.12
May 2000	4562.13 ± 6180.27	15	0.1809	1.9270	0.4577	4.47
June 2000	8670.00 ± 9539.03	13	0.1420	2.1110	0.6351	8.49
July 2000	3951.06 ± 5271.86^m	12^m	0.1774	1.9800	0.6034	3.87^m
Aug. 2000	7603.86 ± 7336.57	15	0.1246^m	2.2350^x	0.6229^x	7.45
Sept. 2000	5985.60 ± 9275.07	15	0.2161^x	1.8050^m	0.4053^m	5.86
Oct. 2000	4385.60 ± 5253.98	15	0.1560	2.1010	0.5448	4.30
Nov. 2000	5016.53 ± 6484.90	15	0.1706	2.0750	0.5310	4.91
Dec. 2000	6618.13 ± 8520.61	15	0.1698	2.0270	0.5061	6.48
Jan. 2001	13,657.06 ± 18,478.74	15	0.1806	1.9070	0.4490	13.38
Feb. 2001	11,210.40 ± 16,965.45	15	0.2092	1.9040	0.4476	10.98
Total	1,531,212.00 ± 54,532.08					100

Table 3. Mean abundances (individuals/10 cm^2) and ecological indices of harpacticoid copepod distributions at 5 stations in all sampled months. RA, relative abundance (%); S, species richness; D', Simpson's dominance index; H', Shannon's diversity index; J', Pileou's evenness index; ^{m}, minimum; ^{x}, maximum

	Mean ± S.D.	S	D'	H'	J'	RA
Neelangarai	25,187.33 ± 31,831.51^x	15	0.1660	2.0310	0.5082	24.67^x
Marina	18,610.80 ± 23,548.18	15	0.1663	1.9910	0.4880	18.23
Besant Nagar	17,738.93 ± 21,581.62	15	0.1588	2.0830	0.5352	17.38
Thiruvottriyur	23,426.93 ± 31,710.85	15	0.1807^x	1.9840^m	0.4846^m	22.95
Ernavoor	17,116.80 ± 20,219.27^m	15	0.1535^m	2.1160^x	0.5530^x	16.77^m
Total	1,531,212.00 ± 54,673.66					100

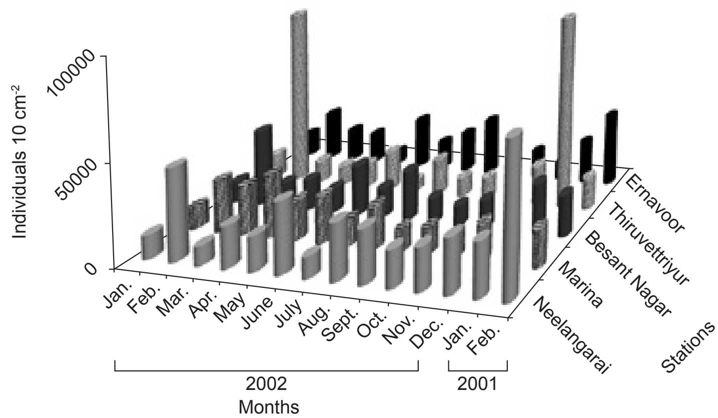


Fig. 3. 3D histogram showing the mean monthly abundances (ind./10 cm^2) of harpacticoid copepods at each station during different sampling months.

Table 4. Harpacticoid copepod abundances (individuals/ 10 cm^2) and ecological indices during months and at stations. RA, relative abundance (%); S, species richness; D', Simpson's dominance index; H', Shannon's diversity index; J', Pileou's evenness index; ^{m}, minimum; ^{x}, maximum

	By month				
	Mean ± S.D.	S	D'	H'	J'
Arenosetella indica	10,544.14 ± 5334.46	14	0.0884^{m}	2.5310^{x}	0.8971^{x}
Arenosetella germanica	2005.42 ± 1610.80	14	0.1142	2.3460	0.7456
Hastigerella leptoderma	1163.42 ± 911.96	13	0.1122	2.3040	0.7701
Arenopontia indica	12,438.85 ± 8547.52^{x}	14	0.1027	2.4400	0.8196
Arenopontia subterranean	1309.71 ± 1062.90	14	0.1151	2.3310	0.7345
Psammastacus acuticaudatus	495.71 ± 496.88^{m}	13^{m}	0.1381	2.1760	0.6776
Apodopsyllus camptus	802.85 ± 706.58	12^{m}	0.1228	2.2390	0.7817
Apodopsyllus madrasensis	2085.71 ± 2509.43	14	0.1674^{x}	2.1340	0.6033^{m}
Parapseudoleptomesochra trisetosa	514.85 ± 599.82	11	0.1615	1.9780^{m}	0.6573
Ameira parvula	820.57 ± 694.29	13^{m}	0.1189	2.2920	0.7611
Leptastacus euryhalinus	2680.57 ± 2699.74	14	0.1387	2.1790	0.6316
Sewellina reductus	5157.28 ± 4335.77	14	0.1183	2.3450	0.7451
Ovigerous	18,214.71 ± 10,881.37	14	0.0951	2.4880	0.8595
Copepodites	25,882.28 ± 16,077.52^{x}	14	0.0970	2.4800	0.8529
Nauplii	25,256.14 ± 14,884.08	14	0.0945	2.4840	0.8567
Total	1,531,212.00 ± 127,161.95				

	By station					
	Mean ± S.D.	S	D'	H'	J'	RA
Arenosetella indica	29,523.60 ± 11,020.67	14	0.2223	1.5550	0.9475	9.64
Arenosetella germanica	5615.20 ± 2019.58	14	0.2207	1.5610	0.9525	1.83
Hastigerella leptoderma	3257.60 ± 986.65	13^{m}	0.2147	1.5770	0.9676	1.06
Arenopontia indica	34,828.80 ± 10,872.16^{x}	14	0.2156	1.5700	0.9614	11.37^{x}
Arenopontia subterranean	3667.20 ± 689.40	14	0.2057	1.5960	0.9864	1.20
Psammastacus acuticaudatus	1388.00 ± 232.24^{m}	13^{m}	0.2045^{m}	1.5980^{x}	0.9886^{x}	0.45^{m}
Apodopsyllus camptus	2248.00 ± 675.91	12^{m}	0.2145	1.5670	0.9588	0.73
Apodopsyllus madrasensis	5840.00 ± 5287.71	14	0.3312^{x}	1.3170^{m}	0.7467^{m}	1.91
Parapseudoleptomesochra trisetosa	1441.60 ± 1224.07	11^{m}	0.3154	1.3570	0.7771	0.47
Ameira parvula	2297.60 ± 1620.86	13^{m}	0.2796	1.4160	0.8238	0.75
Leptastacus euryhalinus	7505.60 ± 1880.92	14	0.2100	1.5830	0.9738	2.45
Sewellina reductus	14,440.40 ± 5163.92	14	0.2205	1.5560	0.9479	4.72
Ovigerous	51,001.20 ± 9217.53	14	0.2052	1.5970	0.9873	16.65
Copepodites	72,470.40 ± 15,892.51^{x}	14	0.2077	1.5910	0.9814	23.66^{x}
Nauplii	70,717.20 ± 17,389.26	14	0.2097	1.5860	0.9768	23.09
Total						100

analysis of different months (Fig. 4A) showed 5 major groups. Likewise at different stations (Fig. 4B), the analysis showed 2 major groups, and meiofauna groups (Fig. 4C) showed 6 major groups according to similarities in contributions to the total meiofauna abundance.

In our study, we used 8 different types of metal sieves for our soil sediment samples (Table 1), which showed variations in their distribution at different places during different sampling periods. Overall, 0.425-mm sand grains (25.72%) were dominant at the stations, and the least was observed with > 2-mm sand grains, whereas Marina (20.7%) was found to have the highest and Besant Nagar (19.69%) the lowest percentage of wet sand in g/10 cm^2.

Pearson's 2-tailed correlations among the different-sized grades of soil with harpacticoid copepods and groups showed that *Apd. camptus* and *Apd. madrasensis* were significantly (p < 0.05) correlated with each other, and with 0.542- and 0.147-, and 0.3-mm sand grains, respectively.

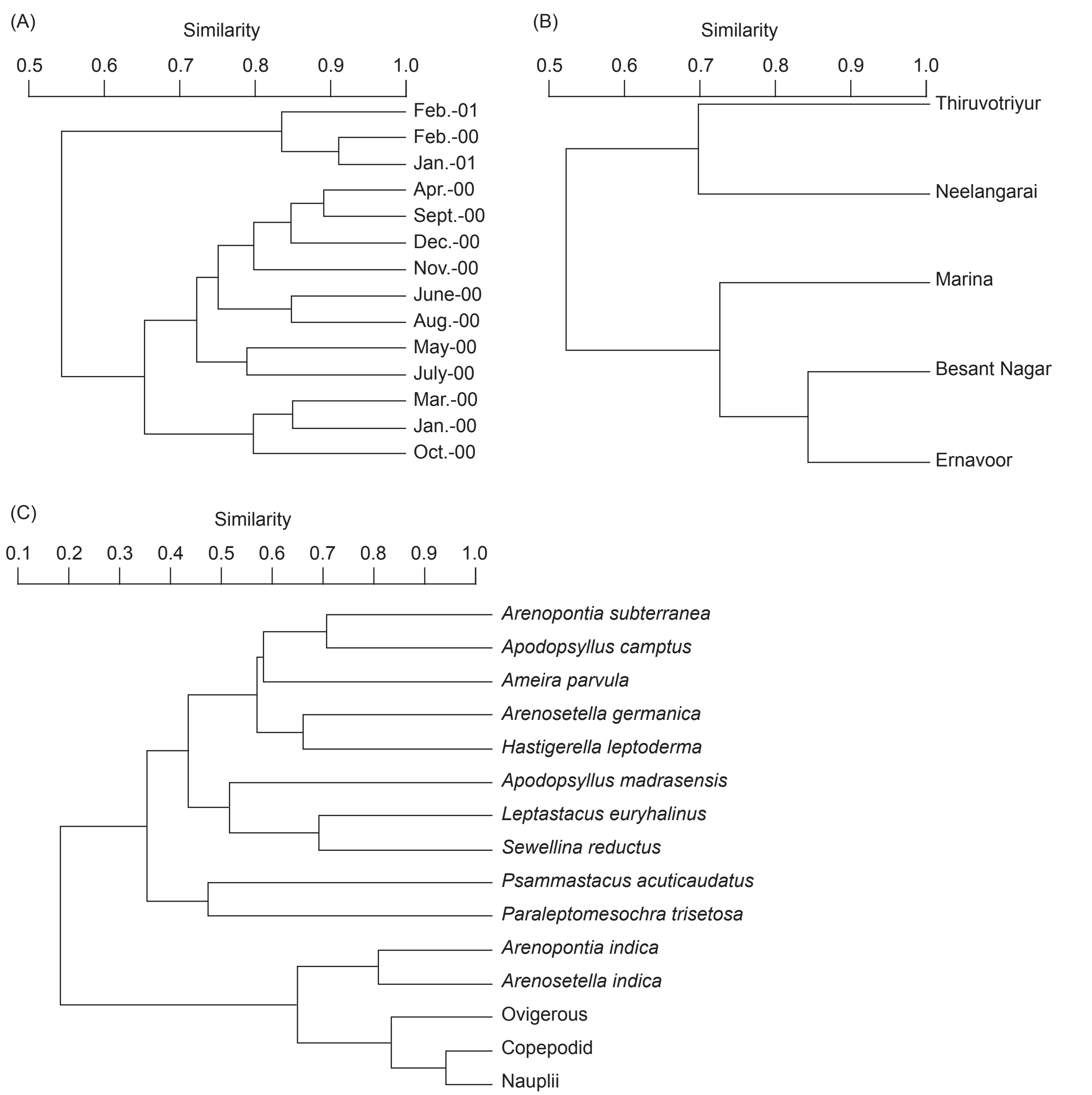


Fig. 4. Cluster dendogram of harpacticoid copepod abundances in different months (Jan. 2000 to Feb. 2001) (A), at different stations (B), and among different species, ovigerous animals, and developmental stages (C).

Pearson's 2-tailed correlations of harpacticoid copepods with physicochemical parameters showed that *Arenosetella germanica* (Kunz, 1937), was positively correlated with atmospheric and interstitial temperatures at $p < 0.01$, and *Leptastacus euryhalinus* (Krishnaswamy, 1957) was significantly correlated with atmospheric temperature and salinity at $p < 0.05$ and with interstitial temperature at $p < 0.01$. *Apodopsyllus madrasensis* and *Par. trisetosa* showed significant negative correlations with DO at $p < 0.05$. *Sewellina reductus* (Krishnaswamy, 1956) showed a significant positive correlation with interstitial temperature at $p < 0.05$. Among harpacticoid groups, only copepodites showed positive correlations with atmospheric and interstitial temperatures at $p < 0.05$.

One-way ANOVA of harpacticoid copepods showed that *Arenosetella indica* (Krishnaswamy, 1957), *Arns. germanica*, *Hastigerella leptoderma* (Klie, 1929), *Arenopontia subterranea* (Kunz, 1937), *Arnp. indica*, *Apd. camptus*, *Ameira parvula* (Claus, 1866), *Lep. euryhalinus*, and *S. reductus*, significantly ($p < 0.05$) differed in different months, and *Arns. indica*, *Par. trisetosa*, and *Am. parvula* significantly ($p < 0.05$) differed at different stations.

DISCUSSION

Coastal sandy shores are most vulnerable to hydrodynamics, tidal changes, wind, erosion of sand and nutrients during the monsoon, abiotic factors, and nutrient enrichment via sewage disposal (McIntyre 1968, Coull and Bell 1979, McLachlan et al. 1996, Rodrıguez et al. 2003, Shanmugam et al. 2007). Animals 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).

On sandy shores, DO is commonly a major driving force, whereas in our study, it showed negative trends with *Apd. madrasensis* and *Par. trisetosa*. Copepodites showed positive trends with both atmospheric and interstitial temperatures, whereas *Lep. euryhalinus* showed a positive trend with salinity. Almost all of the species and both copepodites and ovigerous harpacticoids were significantly correlated with monthly distributions, rather than with stations. Moreover, on sandy shores, grain size is the main component determining the distribution of organisms; other factors, such as the level of pollution, the organic load, and food availability, also influence their availability (Giere 2009).

In general, tropical regions are known to support a richer variety of meiobenthic fauna than temperate regions, including major groups such as nematodes, copepods, turbellarians, annelids, and gastrotrichs (Rao 1975). Specialist relationships and tolerance to different physicochemical conditions favor distinct distribution patterns for many harpacticoid species, which are well established on tidal soft bottoms (Coull et al. 1979, De Troch et al. 2002), and this was confirmed by our study. Apart from food availability, variations in temperature (McIntyre 1969, Huys et al. 1986) play an important role in determining hatching and growth of the various developmental stages; DO (Grainger 1991) determines their occurrence in the upper sediment layers which favors an epibenthic life, such as with *Arns. indica* and *Arnp. indica*, which were the dominant species in our study.

Harpacticoid copepods are usually the 2nd-most-abundant meiofauna taxon next to nematodes (Platt and Warwick 1980, Heip et al. 1982, Hicks and Coull 1983), but on some tropical beaches, they outnumber nematodes (Giere 2009), for which Nicholls (1935) coined the term "interstitial fauna", as a substitute for meiofauna, after he observed the striking species richness of this small, but slender and dominant meiofauna group on British sandy beaches. Even in our study, we observed a total abundance of harpacticoid copepods of $1.5 \times 10^6 \pm 1.27 \times 10^5$ ind./10 cm^2.

Our study area might be more density dependent, as was shown for other tidal flats (Sach and van Bernem 1996), where harpacticoid copepods were most abundant in shallow flats and lagoons with muddy, detrital sands reaching up to several 1000 ind./10 cm^2. Such a trend was also clear in the present study.

Results obtained from a single-linkage Bray-Curtis cluster dendogram were compared to scatterplot diagrams of the principal component ordination. This confirmed that there were 6 major harpacticoid groups which contributed to the total abundance at different stations and in different months (Fig. 5). Scatterplot diagram of the correspondence analysis showed the degree of contribution of different harpacticoid species, and ovigerous and developmental stages in different months (Fig. 6A) and at different stations (Fig. 6B).

Thus, harpacticoid copepods being dominant during the study period showed that even though the sandy shores of the Chennai coast are vulnerable to several hydrodynamic, physical, biological disturbances and pollution, their faunal diversity and abundance are well-balanced with variations and modifications in the species diversity. The highest abundance was for copepodites, followed by nauplii and ovigerous females, which suggests that neither top-down (predation) nor bottom-up (food quantity) control plays a significant role in limiting the population size, as these harpacticoid populations are always rapidly reproducing (McLachlan and Brown 2006). This might also be an adaptive strategy to overcome the harsh mechanical disturbances which occur here.

In conclusion, the high abundance of harpacticoid copepods, particularly copepodites, nauplii and ovigerous females showed that these meiobenthic copepods are always reproductively active, and the highest abundances of *Arnp. indica* and *Arns. indica* showed that these 2 species are well suited to this climatic regime with their tolerant and adaptive natures. It was also concluded that even though the DO along with other abiotic factors somewhat varied, interstitial spaces and nutrients within the sand grains were replenished and nourished by the tidal action of these sandy beaches. Furthermore, long-term mesocosm experimental studies could provide more information on the nature and stability of these meiofauna assemblages with high reproductive and developmental strategies.

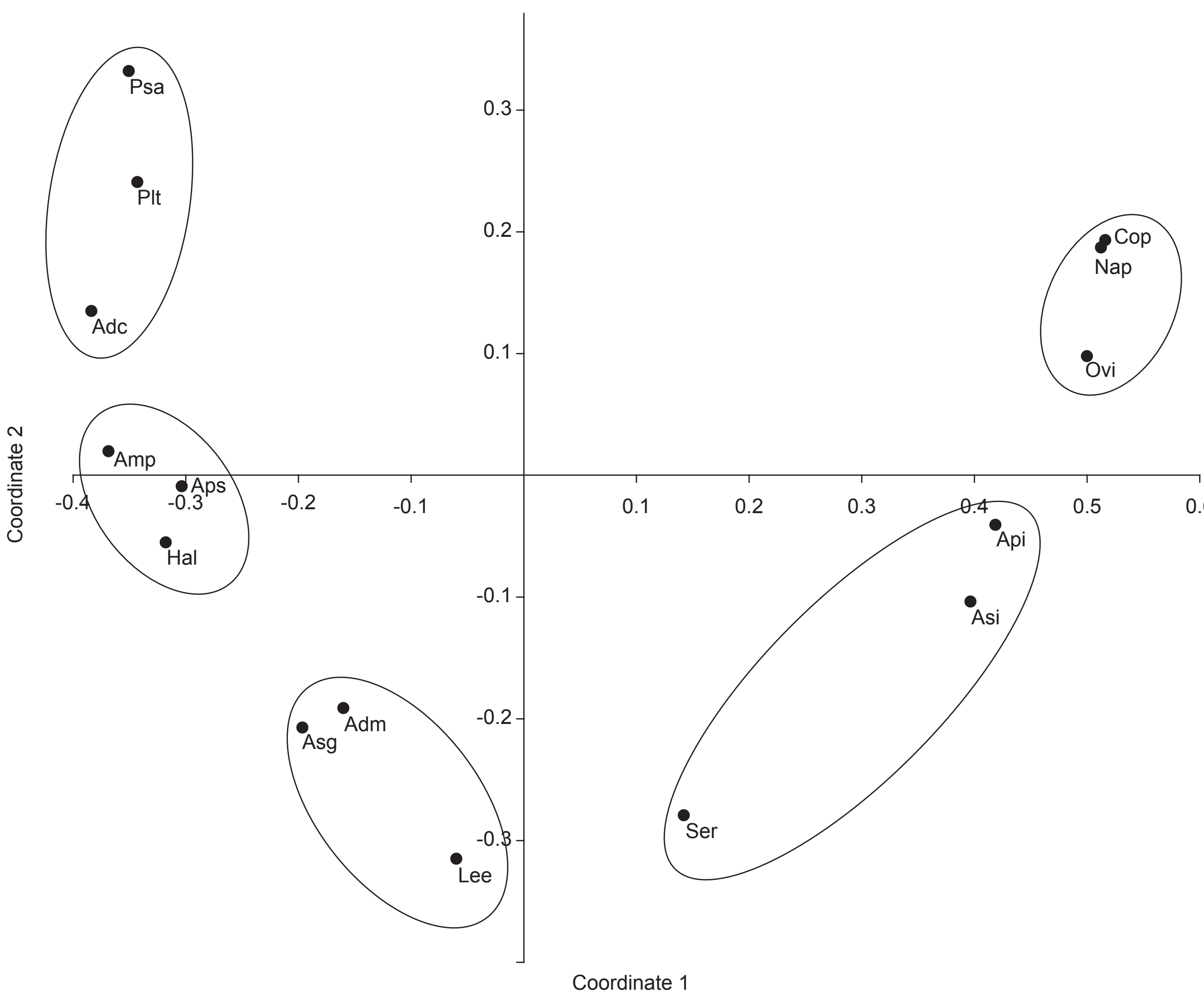


Fig. 5. Principal component ordination of harpacticoid copepod abundances. Asi, *Arenosetella indica*; Asg, *Arenosetella germanica*; Hal, *Hastigerella leptoderma*; Api, *Arenopontia indica*; Aps, *Arenopontia subterranea*; Psa, *Psammastacus acuticaudatus*; Adc, *Apodopsyllus camptus*; Adm, *Apodopsyllus madrasensis*; Plt, *Parapseudoleptomesochra trisetosa*; Amp, *Ameira parvula*; Lee, *Leptastacus euryhalinus*; Ser, *Sewellina reductus*; Ovi, ovigerous; Cop, copepodites; and Nap, nauplii.

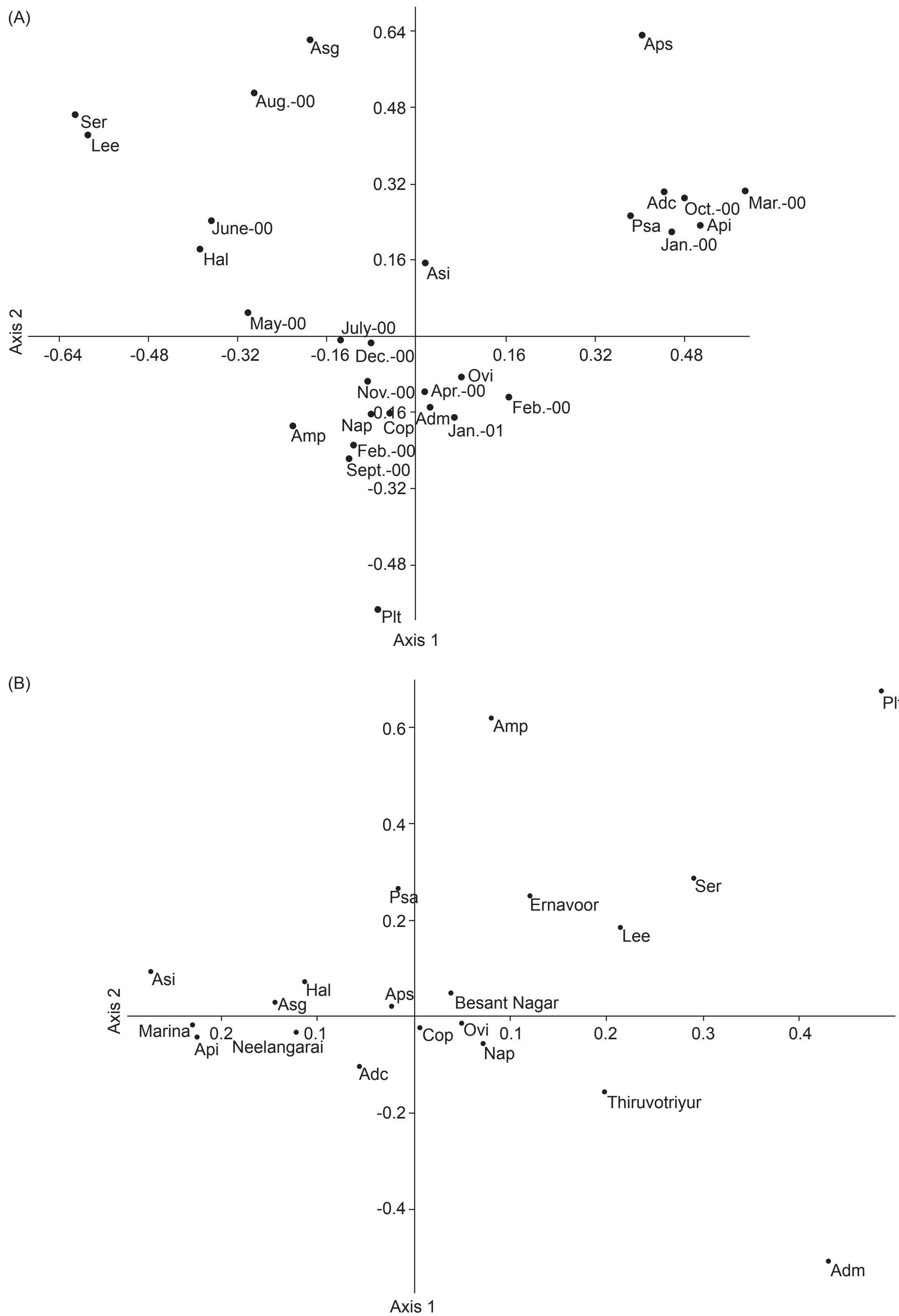


Fig. 6. Correspondence analysis showing the contribution of harpacticoid copepods towards abundances during different months (A) and at different stations (B). Abbreviations are defined in the legend to figure 5.

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