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Benthos in the nearshore waters off Visakhapatnam

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ABSTRACT

The faunal composition, population density, biomass, volume of benthos in relation to sediment, depth range and lat.-long squares off Visakhapatnam were studied. The population density varied from 112 m^{-2} to 6656 m^{-2} with an average of 1712 m^{-2} (±1311.88). Biomass ranged between 0.72g m^{-2} and 42.84g m^{-2} with an average of 13.43g m^{-2} (± 9.85). Volume, on the other hand, ranged from 2.81 ml m^{-2} to 54.77 ml m^{-2} with an average of 19.76 ml m^{-2} (±13.55). Polychaeta (63 %) was the dominant group of fauna followed by Amphipoda (17 %). Various indices of spatial pattern, richness, diversity, association etc. have been worked out.

Introduction

The bottom fauna or benthos form an important link in the food web in sea. Bottom dwelling fishes and crustaceans feed mainly on the benthic organisms. Hence the abundance of benthic fauna is a major factor deciding the demersal fishery potential of a given region of sea. Therefore, study of the qualitative and quantitative aspects of benthos is very important in applied fisheries research.

Studies on benthos of seas and estuaries of India have a history of more than five decades. Samuel (1944) who described the animal communities of the sea bottom off Madras is credited to be the initiator of benthic studies in India. Along the east coast of India, many workers studied the benthos of estuaries (Chandran *et al*., 1982), river mouths (Ansari *et al*., 1982), and Kakinada Bay environment (Radhakrishna and Ganapati, 1969; Bhavanarayana, 1975 and Raut, 1997). Ganapati and Rao (1959), Sokolova and Pasternak (1964), Neyman *et al*. (1973), Rodrigues *et al*. (1982) and Harkantra *et al*. (1982) made studies covering a wider area of the Bay of Bengal and east coast of India. Parulekar *et al*. (1982) attempted to assess the demersal fishery resource potential of Indian seas based on benthic production.

Studies related to benthos in and around Visakhapatnam were conducted earlier by Radhakrishna (1964), Ganapati and Raman (1976), Raman (1980) and Subba Rao and Venkateswara Rao (1980). An attempt to study the benthos off Visakhapatnam in relation to the demersal fisheries was made by Sudarsan (1983). Adiseshasai (1992) made a time-scale study on the littoral macrobenthos off Visakhapatnam from fixed transects. However, most of this information is available in 'gray literature'. There were no serious attempts to study the benthic fauna and food habits of demersal fishes simultaneously. The present paper is a part of the study conducted to assess the qualitative and quantitative aspects of benthic fauna in relation to the food of demersal fishes off Visakhapatnam.

Materials and methods

Sampling was carried out onboard the Institute's research vessel R V Cadalmin V during October 1987 to November 1989. Fifty-seven samples were taken between latitudes 17°.15' and 17° 44' N in the depth range of 22 to 55 m (Fig.1). The methodology of collection, preservation and analysis of benthos is as detailed by Holme (1964) and Birket and McIntyre (1971). A Petersen grab with sampling area of 0.07 m^2 was used for collection of benthic samples. The sediment temperature was recorded immediately after the grab was taken onboard. A sub-sample of the sediment was removed and percentage composition of major components, namely sand, silt and clay were estimated as per the procedure given by Krumbein and Pettijohn (1938). The sediment sample was emptied into a bucket and then washed through a series of three sieves of mesh sizes 4000 μm (BSS-4), 1000 μm (BSS-16) and 500 μm (BSS-30) in that order. The benthic organisms retained in each sieve were collected in three different bottles and preserved with 10 percent formalin. A few drops of Rose Bengal stain (1:500) were added to this sample to facilitate sorting of the organisms from other components of the soil. The benthic macrofauna were isolated and collected in a dish. The wet weight of the segregated organisms was measured to the nearest milligram after removing the moisture using a filter paper. A conversion factor was worked out averaging dry weights of six pre-weighed wet samples dried at about 90° C till constant weight. Displacement volume of total of organisms in each sample was measured to the nearest 0.1 ml. The animals were segregated under a dissection microscope into different taxa such as Polychaeta, Amphipoda etc. and their numbers enumerated.

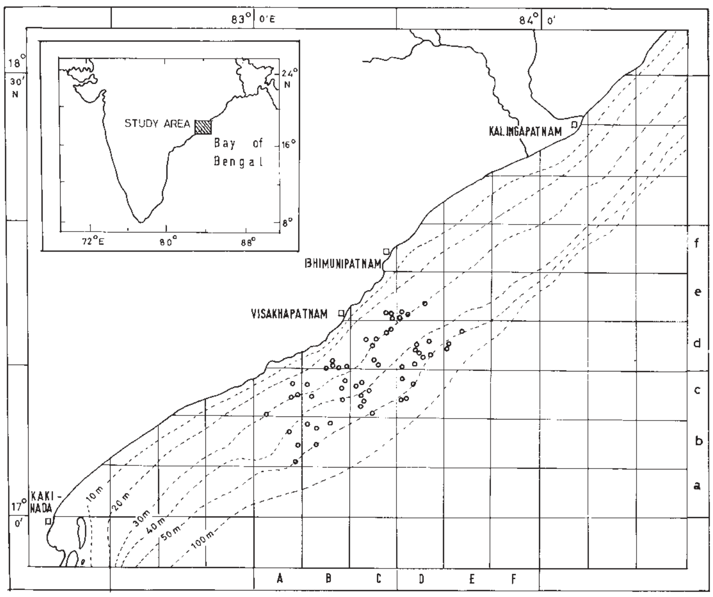

Fig. 1. Map showing location of sampling stations.

The stations were categorized based on three factors and the distribution of different animal groups as well as various indices was worked out. Under the first categorization, stations falling within each of the 12 sequentially numbered 10' (minutes) latitude-longitude squares were grouped together to assess the averages for the respective squares. Similarly stations were categorized according to depth range and also based on sediment character in order to study the pattern and abundance of distribution of fauna influenced by these factors. The different indices of spatial pattern, richness, evenness, diversity and association were worked out as detailed in Ludwig and Reynolds (1988). Index of affinity (trellis diagram method) was worked out as detailed in Wieser (1960) and Sanders (1960).

Results and discussion

Sediment characteristics

The sediment characteristics showed a general transition from sand through silt to clay as the depth increased. However, some deviations in this general tendency were observed at few stations. While the percentage of sand showed a significant negative relation with depth, that of clay showed a significant positive relation. The silt component showed an increasing trend with depth, though not as significant as the sand or clay. Linear regression of percentage of the three major sediment components on depth gave the following regression lines.

Sand (%) = 104.0602 – 1.811190 Depth (r^2 =0.64332, $P < 0.001$)

Silt (%) = 7.408315 + 0.813507 Depth (r^2 =0.31818, $P < 0.001$)

Clay (%) = -12.90580 +1.000940 Depth (r^2 =0.54001, $P < 0.001$)

Sudarsan (1983) also observed such general progression of sand to clay with increasing depth. Noticing similar anomalies in the general pattern, he suggested that the frequent dredging operations being done in these areas are responsible for those deviations.

Size composition of the fauna

A set of three sieves mentioned earlier were used to study the size composition of the faunal groups. The percentage of volume and biomass retained was maximum in sieve No.16 whereas, the percentage of number of animals was maximum in sieve No. 30 (Fig. 2a). Out of the more than 40 different animal groups identified, sieve No.4 retained 16

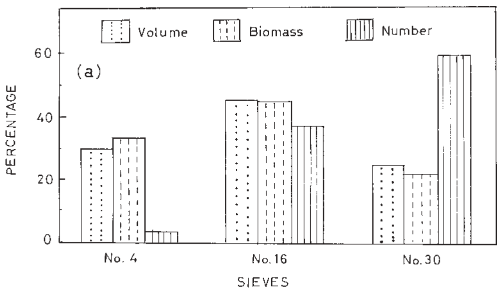

Fig. 2a. Percentage of population biomass and volume retained in different size sieves.

groups while 35 and 30 different animal groups were retained in sieves Nos.16 and 30 respectively. Cirripidea (Barnacles) and Alima larvae were present only in sieve No.4. Penaeid prawns, fish larvae, Anomura (hermit crab), eel larva, Hydrozoa, Scyphozoa and Megalopa larvae were retained only in sieve No.16. Foraminifera, Pteropoda, Pycnogonida, oyster spat and Isopoda were observed only in sieve No.30. The other groups were present in either two or three of the sieves. The percentage of some selected animal groups retained in the three different sieves is depicted in Fig. 2b.

Similar to the situation encountered by Sanders (1956 and 1960) earlier, the larger animals are less abundant than smaller ones and the presence of rare randomly distributed large animals effectively determine the biomass (and vol-

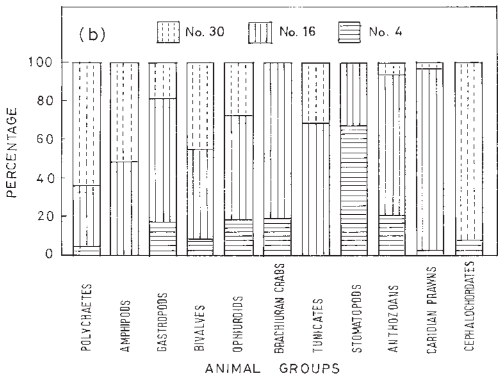

Fig. 2b. Percentage of number of different animal groups retained in different size sieves.

ume) of the sample. Therefore, as Sanders (1960) had pointed out, the number of animals could be a more reliable measurement than biomass (and volume). The number of groups retained in the 4000µm mesh sieve more than doubled as the mesh size decreased to 1000µm and slightly decreased in the 500µm. The distribution of number of animal taxa over the size range could have been clearer if more sieves were used and the animals were identified up to species level.

Faunal composition and prevalence

The benthic fauna showed great diversity even at the group level, with more than forty different groups. Polychaetes were the most dominant group of the benthic fauna accounting for an average 62.5 % of the total population followed by Amphipods with an average of 17 %. Tunicates (4.8 %), Copepoda (1.5 %), Cephalochordata (1.4 %), Caridean prawns (1.3 %), Bivalvia (1.3 %), Tanaidacea (1.2 %), Cumacea (1.0 %), Foraminifera (1.0 %), Ophiuroidea (0.9 %), Gastropoda (0.7 %) and Isopoda (0.5 %), Brachyuran crabs (0.5 %) were the other important groups which individually contributed to > 0.5 % of the total population. The remaining 6.0 percent of the population was constituted by Sipuncula, Callinassidae, Penaeidae, Nematoda, Asteroidea, Anomuran crabs, Pteropoda, Solenogasters, Pycnogonida, Stomatopoda, Mysidacea, Bryozoa, Hydrozoa, Anthozoa, Scyphozoa, Sergestidae, Scapopoda, Ostracoda, Echinoidea, Echiurida fish and crustacean larvae, eggs and a few unidentified organisms. Megalopa, Zoea and Alima were the important crustacean larvae. Tunicates (Doliolidae and Salpidae) were present in unusual numbers in two of the four samples, thus claiming a significant share of the total population. Details of the average number of different organisms, their percentage, prevalence, and spatial pattern indices are given in Table 1.

Both Polychaeta and Amphipoda recorded the maximum prevalence of 98 % each. Caridea (60 %), Bivalvia (55 %), Tanaidacea (51 %), Ophiuroidea (44 %) Brachyura (42 %) Copepoda (42 %), Cumacea (40 %) Sipuncula (33 %) and Gastropoda (28 %) were the other important groups prevalent in more than 25 % of the samples. Tunicates, which represented about 5 % of the total population, had a low prevalence of about 7 %, indicating its sporadic occurrence. Thus prevalence can be used as a check for misleading figures of percentage, caused by occurrence of any animal group in large numbers in one or two samples.

Among the Polychaeta, representatives of the families Spionidae, Capitellidae, Terebellidae, Nephtyidae, Eunicidae, Cirratulidae, Ampharetidae, Nereidae, Sternapsidae, Syllidae, Serpulidae, Sabellidae, Aphroditidae Amphinomidae, Phyllodocidae, Hesionidae, Spionidae, Magelonidae, Orbiniidae, Paraonidae, Maldanidae, Flabelligeridae and, Opheliidae were noticeable. Among the Amphipods, members of the families Hyperiidae,

TABLE 1. *The Average density (no m^{-2}), Percentage, Prevalence, Index of Dispersion (ID), Green Index (GI) and Morisita' Index (I_d) of different benthic animal groups off Visakhapatnam.*

Animal Group	Average	Percentage	Prevalence	Indx Disp	Green Indx	Morisita-I_d
Foraminifera	17.23	1.01	20	174.59	0.18	11.09
Hydrozoa	0.49	0.03	4	13.75	0.47	27.95
Scyphozoa	0.25	0.01	2	14	1	58.08
Anthozoa	3.93	0.23	16	35.19	0.15	9.74
Nematoda	3.05	0.18	18	16.24	0.09	6.03
Chaetognatha	5.67	0.33	11	80.61	0.25	15.09
Bryozoa	0.25	0.01	2	14	1	58.08
Solenogasters	1.96	0.11	9	22.94	0.2	12.27
Gastropoda	12.05	0.7	28	226.73	0.33	19.76
Pteropoda	0.74	0.04	5	13.5	0.3	18.4
Scaphopoda	0.49	0.03	2	28	1	58.04
Bivalvia	22.47	1.31	55	43.47	0.03	2.89
Polychaeta	1070.61	62.51	98	791.01	0.01	1.74
Sipuncula	11.33	0.66	33	51.99	0.08	5.51
Echiurida	4.67	0.27	12	74	0.28	16.71
Pycnogonida	0.74	0.04	5	13.5	0.3	18.4
Ostracoda	1.23	0.07	9	13	0.17	10.93
Copepoda	25.63	1.5	42	501.53	0.34	20.54
Cirripedia	0.25	0.01	2	14	1	58.08
Stomatopoda	1.47	0.09	11	12.75	0.14	9.08
Cumacea	16.88	0.99	40	50	0.05	3.91
Tanaidacea	20.19	1.18	51	36.39	0.03	2.76
Isopoda	7.96	0.47	19	46.71	0.11	6.75
Amphipoda	290.74	16.98	98	303.42	0.02	2.04
Mysidacea	5.4	0.32	18	37.25	0.12	7.73
Penaeidae	0.98	0.06	4	34.62	0.61	35.87
Sergestidae	3.68	0.22	11	58	0.27	16.55
Caridea	21.72	1.27	60	22.85	0.02	2.01
Anomura	0.74	0.04	4	23	0.54	31.61
Callianassidae	1.47	0.09	9	17.5	0.2	12.34
Brachyura	9.33	0.54	42	18.25	0.03	2.85
Echinoidea	5.16	0.3	16	67.36	0.23	13.91
Asteroidea	1.47	0.09	9	17.5	0.2	12.34
Ophiuroidea	15.63	0.91	44	34.76	0.04	3.16
Tunicates	82.3	4.81	7	3929.66	0.84	48.75
Cephalochordata	23.58	1.38	18	362.1	0.27	16.33
Eggs	2.89	0.17	9	42.59	0.25	15.46
Crustacean larvae	3.44	0.2	22	14.82	0.07	5.045
Fish larvae	1.72	0.1	11	16.57	0.16	10.16
Unidentified organisms	12.6	0.74	13	422.85	0.59	34.54

Ampeliscidae, Aoridae, Corophiidae, Gammaridae, Haustoriidae, Lilljborigiidae, Oedicerotidae, Photidae, Phoxocephalidae, Podoceridae and Caperellidae could be identified.

Earlier workers (Harkantra *et al.*, 1982, Sudarsan, 1983) observed the domination of Polychaeta and Amphipoda in the fauna. However, the relative abundance of these groups were different. The percentages of Polychaeta and Amphipoda observed by Harkantra *et al.* (1982) were 68 and 7 % respectively, whereas Sudarsan recorded 39.14 %

Polychaeta, 32.15 % Amphipoda and 8 % Pelicypoda from this area. The prevalence of Polychaeta (77 %), Amphipoda (29 %), Bivalvia (24 %), Alpheidae and Ophiuroidea (9 % each) that was reported by Harkantra *et al.* (1982) was much different from those in the present study. The sampling area in the present study being a only a subset of former's study area, variations in the abundance and spatial patterns are likely to occur due to clubbing of stations from various depth and locations.

Spatial Pattern

Three indices of spatial pattern were calculated for each animal group for understanding their distribution in space (Table 1). The choice of Index of Dispersion (ID) was used as a statistical test for assessing the agreement of the data to the Poisson series and Green Index (GI) was used as a reliable measure of clumping useful for comparison. Morisitas' Index (I_d) was chosen as a reliable Index of Patchiness, unaffected by changes in density due to random thinning.

In the case of Index of Dispersion (ID), the highest values were recorded by Tunicates, followed by Polychaeta, Copepoda, Cephalochordata, Amphipoda, Gastropoda and Foraminifera in the decreasing order. Green Index (GI) was highest (maximum 1) for animals represented in only one sample. Naturally the lowest GI was obtained for Polychaeta (0.01) followed by Amphipoda (0.02), Caridea (0.02), Brachyura (0.03), Bivalvia (0.03), Cumacea (0.05) and Tanaidacea (0.05), in increasing order. Morisita's Index (I_d), on the other hand, was lowest for Polychaeta, (1.96) followed by Caridea (2.01), Amphipoda (2.05), Tanaidacea (2.76), Brachyura (2.85), Bivalvia (2.94), Cumacea (3.91) and Ophiuroidea (3.16) in the increasing order.

Index of Dispersion (ID) varies between 0 for maximum uniformity through 1 for randomness and 'n', the total number of individuals in sample, for maximum clumping. Green index (GI) on the other hand, assumes value –n/(n-1) for maximum uniformity, 0 for randomness and 1 for maximum clumping (Ludwig and Reynolds, 1988). The high values of ID and low values of GI for most of the faunal groups indicated their clumping pattern of distribution. Incidentally the 'd' statistic calculated for different groups were all greater (27.253 > d < 653.912) than the critical value 1.96. Therefore, the distribution of none of the animal groups followed a Poisson series.

Density, biomass and volume

The density of benthic population showed wide variation from 112 m^{-2} at St. 4 to 6656 m^{-2} at St. 48 with an average of 1712 (±1311.88) for the entire study area (Fig.3a). Biomass ranged between 0.72g m^{-2} at St. 4 and 42.84g m^{-2} at St. 48 with an average of 13.43g m^{-2} (± 9.85) in the study area (Fig.3b). Volume on the other hand varied between 2.81 ml m^{-2} at St.

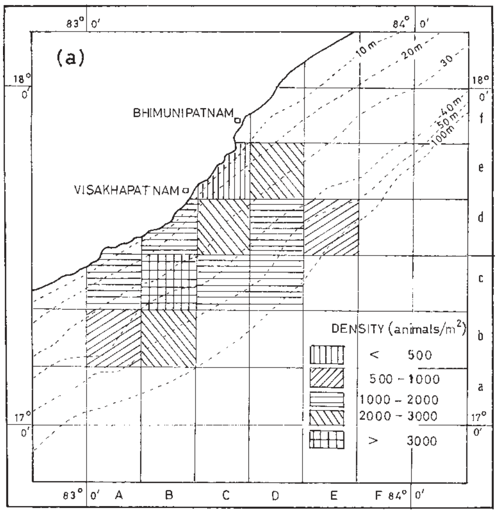

Fig. 3a. Distribution of benthic population in different lat.-long. squares off Visakhapatnam.

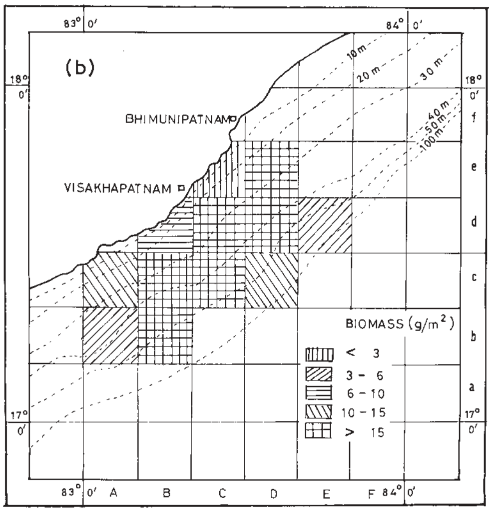

Fig. 3b. Distribution of benthic biomass in different lat.-long. squares off Visakhapatnam.

52 and 54.77 ml m^{-2} at St. 48 with an average of 19.76 ml m^{-2} (±13.55).

The average population density of 1712 m^{-2} is significantly higher than the average of 931 m^{-2} derived from Harkantra *et al.* (1982) for region up to 60m depth. However, in spite of the difference in the sampling locations, the average (wet weight) biomass of 13.79 g m^{-2} up to 60 m depth in the former study is very close to the present finding of 13.43g m^{-2}. The difference in mean density is probably due to unusual abundance of certain groups in a few samples, which incidentally contributed little to the biomass, in the present study.

The wet weight biomass of 13.43g m^{-2} when converted into to dry weight at an average rate of 0.18 would yield average standing crop of 2.42g m^{-2}. This in turn would yield an annual production of 4.84g m^{-2} yr^{-1} (Sanders, 1956). Assuming a conservative ecological efficiency of 10 % (Slobdokin, 1962, Damodaran, 1973), the organic carbon equivalent of 48.4 g C m^{-2} yr^{-1} is expected to be produced in theses waters. Vijayakumaran *et al.* (1996) estimated an average primary surface production of 26.96mg C m^{-3} d^{-1} for the present study area for more or less same period. Added to the column production and production by benthic diatoms and microbes, this level of primary production would be sufficient to sustain the benthic production estimated in the present study.

Faunal distribution in relation to sediments

Sandy sediments had the lowest average population density of 402 m^{-2} (Table 2). Polychaeta and Amphipoda were represented nearly equally, accounting for 34 and 36 % respectively of the total. Cumacea and Cephalochordata each accounted for nearly 7 % in sandy sediment population. Silt-sand sediments had 39 % Polychaeta and 28 % Amphipoda. Cephalochordata (6 %) Copepoda (5 %), Gastropoda (3 %) and Bivalvia (3 %) were the other important organisms. Sandy-silt had 65 % Polychaeta and 24 % Amphipoda followed by Tanaidacea (3 %), Caridea and Ophiuroidea (2 %) and Copepoda (1 %).

The sandy-silt-clay sediment had the highest average population density of 2334 m^{-2}. Polychaeta accounted for 70 % of the fauna followed by Amphipoda (11 %), Tunicates (9 %) and several other organisms accounting for about 1 %. Clay-silt sediment fauna had 70 % Polychaeta, and 15 % Amphipoda. Foraminifera, Caridea, and Copepoda each accounted for 2 % of the population. Silt-clay had 67 % Polychaeta and 23 % Amphipoda followed by 2 % each of Cumacea, Tanaidacea, Caridea, and a few other organisms. Clay-sand had 46 % Polychaeta and 41 % Amphipoda followed by Caridea (3 %), Ophiuroida (4 %) Solenogaster (2 %) and a few other organisms accounting for 1 %.

TABLE 2. *Faunal distribution in different types of sediments off Visakhapatnam*

ANIMAL GROUP	SAND	SILT-SAND	SAND- SILT	SAND-SILT-CLAY	CLAY-SILT	SILT- CLAY	CLAY-SAND
	AVE (%)	AVE (%)	AVE (%)	AVE (%)	AVE (%)	AVE (%)	AVE (%)
Foraminifera		4.31(0.3)		29.32(1.3)	24.27(2.4)	2.8(0.2)	
Hydrozoa		1.08(0.1)		0.64			
Scyphozoa	4.67(1.2)						
Anthozoa	4.67(1.2)	7.54(0.5)		5.09(0.2)			
Nematoda		4(0.3)		3(0.1)	2.55(0.2)	5.6(0.3)	
Chaetognatha		19(1.2)			6.91(0.7)		
Bryozoa	4.67(1.2)						
Solenogasters					5.09(0.5)	5.6(0.3)	28(1.8)
Gastropoda	4.67(1.2)	37.77(2.5)	7(0.4)	5.09(0.2)	5.09		
Pteropoda		1.077(0.1)		0.64			14(0.9
Scaphopoda		2.15(0.1)					
Bivalvia	4.67(1.2)	39.54(2.6)	7(0.4)	27.86(1.2)	10.18(1.0)	2.8(0.2)	
Polychaeta	135.7(33.7)	600(39.2)	1022.59(65.1)	1659.36(71.1)	719.91(70.3)	1123.6(65.5)	730(45.6)
Sipuncula		7.54(0.5)		19.73(0.8)	9.09(0.9)		14(0.9)
Echiurida		9.69(0.6)		2.55(0.1)		16.8(1)	
Pycnogonida		1.08(0.1)		1.27(0.1)			
Ostracoda	4.67(1.2)	3.23(0.2)		0.64			
Copepoda	4.67(1.2)	72.38(4.7)	14(0.9)	10.64(0.5)	15.81(1.5)	11.2(0.7)	14(0.9)
Cirripedia				0.64			
Stomatopoda		2.15(0.1)		1.91(0.1)		2.8(0.2)	
Cumacea	28(7)	18(1.2)	14(0.9)	19.09(0.8)	5.09(0.5)	28(1.7)	
Tanaidacea		22.38(1.5)	49(3.1)	22.55(1)	12.73(1.2)	25.2(1.5)	
Isopoda	9.33(2.3)	19.85(1.3)		5.73(0.2)	1.27(0.1)	5.6(0.3)	
Amphipoda	145(36.1)	430.31(28.1)	373(23.8)	253.36(10.9)	149(14.5)	384.8(22.8)	660(41.3)
Mysidacea		8.62(0.6)		5.09(0.2)	7.64(0.7)		
Penaeidae		1.08(0.1)		1.91(0.1)			
Sergestidae	4.67(1.2)	10.77(0.7)		1.27(0.1)		5.6(0.3)	
Caridea		16.62(1.1)	38(2.4)	26.64(1.1)	16.18(1.6)	28(1.7)	42(2.6)
Anomura		1.08(0.1)		1.27(0.1)			
Callianassidae				1.91(0.1)		8.4(0.5)	
Brachyura		11.85(0.8)	7(0.4)	10.82(0.5)	3.81(0.4)	14(0.8)	14(0.9)
Echinoidea	4.67(1.2)	17.23(1.1)	7(0.4)	1.27(0.1)	1.27(0.1)		
Asteroidea		4.31(0.3)		0.64		2.8(0.2)	
Ophiuroidea		15.15(1)	24(1.5)	22.55(1)	7.27(0.7)		70(4.4)
Tunicates		1.08(0.1)		212.59(9.1)			
Cephalochordata		28 (7)	89.38(5.8)		0.64	7.64(0.7)	
Eggs				5.77(0.2)	3.45(0.3)		
Crustacean larvae		14(3.5)	6.46(0.4)	7(0.4)	1.27(0.1)	8.4(0.5)	
Fish larvae		1.077(0.1)		0.64	3.45(0.3)	5.6(0.3)	14(0.9)
Unidentified		42.15(2.8)		4.27(0.2)	5.64(0.6)	2.8(0.2)	
Total	402	1529.92	2162	2366.36	1024.636	1690.4	1600

The relative abundance of Amphipoda, Cumacea, Cephalochordata, etc. in sand -silt dominated sediments and that of Polychaeta, Caridea, Ophiuroida, Tanaidacea etc. in clay silt dominated sediments could be clearly seen in the present study. This is an indication of the animal-sediment relationship determined by the feeding habits of animals and other factors. Earlier workers (Sanders, 1956 and 1958; Harkantra, 1982) have observed that filter feeders numerically dominate in sand while deposit feeders prefer mud.

Faunal distribution in relation to depth

The average population density at different depth ranges varied between 941 m^{-2} (50-59 m) and 2043 m^{-2} (40-49 m). The relative abundance of Polychaeta as

TABLE 3. *Distribution of benthic animals at different depth strata off Visakhapatnam*

DEPTH STRATUM	20-29 m		30-39 m		40-49 m		50-59 m	
ANIMAL GROUP	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Foraminifera	10.18	0.65	28.06	1.37	21.83	1.09		
Hydrozoa	1.27	0.08			0.78	0.04		
Scyphozoa	1.27	0.08						
Anthozoa	6.36	0.41	2.47	0.12	6.22	0.31		
Nematoda	2.55	0.16	3.65	0.18	2.33	0.12	4.2	0.46
Chaetognatha	5.09	0.33	11.24	0.55	0	0	7.6	0.82
Bryozoa	1.27	0.08						
Solenogasters					1.56	0.08	8.4	0.91
Gastropoda	42.09	2.7	6.59	0.32	5.44	0.27	1.4	0.15
Pteropoda	1.27	0.08			0.78	0.04	1.4	0.15
Scaphopoda	0	0	1.65	0.08	0	0	0	0
Bivalvia	34.36	2.21	30.06	1.47	20.22	1.01	0	0
Polychaeta	1112.09	71.44	1148.33	59.26	1209.06	60.43	635.9	68.95
Sipuncula	6.36	0.41	15.65	0.76	10.89	0.54	11.4	1.24
Echiurida	2.55	0.16	7.41	0.36	4.67	0.23	1.4	0.15
Pycnogonida	1.27	0.08	0.82	0.04	0.78	0.04	0	0
Ostracoda	2.55	0.16	2.47	0.12	0	0	0	0
Copepoda	11.45	0.74	56.18	2.74	7	0.35	21.2	2.3
Cirripedia					0.78	0.04	0	0
Stomatopoda	1.27	0.08	1.65	0.08	2.33	0.12	0	0
Cumacea	20.36	1.31	19.53	0.95	16.33	0.82	1.4	0.15
Tanaidacea	17.82	1.14	22.65	1.1	28	1.4	5.2	0.56
Isopoda	2.55	0.16	15.18	0.74	9.33	0.47	0	0
Amphipoda	172.09	11.05	398.44	20.56	318.17	15.9	178	19.3
Mysidacea	6.36	0.41	6.59	0.32	5.44	0.27	1.4	0.15
Penaeidae	0	0	3.29	0.16	0	0	0	0
Sergestidae	2.55	0.16	8.24	0.4	2.33	0.12	0	0
Caridea	8.91	0.57	22.47	1.1	26.44	1.32	18.4	2
Anomura	1.27	0.08			1.56	0.08	0	0
Callianassidae	1.27	0.08			3.11	0.16	1.4	0.15
Brachyura	10.18	0.65	10.71	0.52	10.89	0.54	1.4	0.15
Echinoidea	8.91	0.57	9.88	0.48	0.79	0.04	0	0
Asteroidea	3.82	0.25	1.65	0.08	0	0	1.4	0.15
Ophiuroidea	5.09	0.33	20.53	1	21.56	1.08	7	0.76
Tunicates	35.73	2.3	0	0	238.78	11.93	0	0
Cephalochordata	8.91	0.57	67.53	3.29	5.44	0.27	0	0
Eggs					5.22	0.26	7.1	0.77
Crustacean larvae	7.64	0.49	3.29	0.16	2.33	0.12	1.4	0.15
Fish larvae			0.82	0.04	3.89	0.19	1.4	0.15
Unidentified organisms			33.65	1.64	6	0.3	3.8	0.41
Total	1582.89	100	1898.765	100	2042.778	99.97	940.61	100

percentage of the total fauna varied between 59 % (30-39 m) and 71 % (20-29 m). Abundance of Amphipoda, on the other hand, varied between 11 % (20-29m) and 21 % (30-39 m) and seemed to compensate, at least partially, for the decrease in number of Polychaeta at different depths (Table 3). Out of the more than 40 groups of organisms identified, 33 were recorded in 20-29 m depth range and 40-49 m depth, 30 were observed from 30 –39 m depth and 22 were represented in 50 – 59 m depth.

Faunal distribution in Lat.-long. Squares.

The population density and biomass distribution in different 10' Lat.-Long. squares is depicted in Fig. 3a and 3b. The lowest mean population density (382 m^{-2}), biomass (1.26 g m^{-2}) and volume (3.23-ml m^{-2}) were observed at sq. Ce. The maximum average population density (3052 m^{-2}), biomass (17.5g m^{-2}) and volume (33.57ml m^{-2}) were observed at sq. Bc. Nine animal groups were represented in sq. Ab, whereas sq. Ed and sq. Ce had 11 groups each. There were 26 groups represented in sq. Cd and sq. De followed by sq. Dc (23), Bc and Cc (22 each), and Dd and Bb each with a representation of 20 groups.

Except in sq. Ce, Polychaeta were most dominant in all squares accounting for 33.8 % (sq. De) to 78.6 % (Sq. Ab). In sq. Ce Polychaeta (17.4 %) was the second dominant group while amphipods accounted for 49.2 %. Amphipods were the second dominant group ranging from 8.5 % (sq. Bd) to 31.4 % (sq. De) of the population. Cephalochordata were a dominant component (1.8 to 3.3 %) in sq. Cd, Ce and De. Caridea were an important component (1.3 to 1.8 %) in sq. Ab, Bb, Cc, Dc and Dd. Chaetognatha were notably present (3.5 to 12.5 %) in sq. Ed and Ce. Tanaidacea was present significantly (1.3 to 1.7 %) in sq. Ab, Bb and Dc. Tunicates accounted for 42.9 % and 2.5 % respectively in sq. Bb and Bc. Foraminifera were present in notable quantities (1.3 to 2.2 %) in sq. Ac, Bc and Bd. Bivalves were the important group (1.6 to 3.7 %) in sq. Ac, Cc and Ce. Copepods were an important group in sq. Ed (5.5 %) and sq. De (10.4 %), whereas the presence of Cumacea was notable in sq. Cd (1.5 %) and sq Ce (3.3 %). Among other important groups, Ophiuroidea (1.7 %) and Gastropoda (9.2 %) were notable in sq. Ac, eggs (3.2 %) fish larvae (1.3 %) were noted in sq. Ab and Sipuncula (2.2 %) was notable in sq. Bd.

Richness, diversity and evenness

In spite of the limitation with respect to the underlying conditions, two Richness Indices namely Margalef Index (R1) and Menhinick Index (R2) were calculated (Table 4). It is indicated that among the depth zones, 20-29 m was the richest followed by 40-49 m depth zone in fauna and 50-59 m depth zone was the poorest. Among the sediment class, silty-sand hosted richest fauna followed by sandy-silty-caly, clayey-silt and silty-clay in that order. Sand and sandy-silt were poorer in fauna, whereas clayey-sand was the poorest in fauna. Among the lat.-long. squares sq. Cd and De were the richest followed by sq. Dc, Bc and, Cc. Squares Ed and Ce were poorer while sq. Ab was poorest in fauna.

Diversity Indices namely Shannon's Index (H'), Simpson's Index (λ) and Hill's diversity numbers N1 and N2 were calculated (Table 4). The Simpson's Index (λ) will be nearer to 1 for low level of diversity and near zero for high level of diversity. Shannon's Index (H'), on the other hand, assumes value zero when there is only one species in the sample and assumes maximum value when all the S species are represented by same

TABLE 4. *Average Density, Biomass, Volume and Indices of Richness, Diversity and Evenness arrived at for different depth strata, sediment strata and lat.-long. squares.*

CLASS (No. of Samples)	AVERAGES			RICHNESS INDICES		DIVERSITY INDICES				DIVERSITY INDICES	
	Density *No m*$^{-2}$	Volume *ml m*$^{-2}$	Biomass *g m*$^{-2}$	R1	R2	H'	λ	N1	N2	E4	E5
Overall (57)	1712	19.76	13.43	39.91	39.00	1.51	0.42	4.53	2.36	0.52	0.38
DEPTH STRATUM											
20-29 m (11)	1683	15.19	10.97	32.70	32.99	1.30	0.52	3.65	1.90	0.52	0.34
30-39 m (18)	1899	22.98	11.92	28.90	28.99	1.52	0.40	4.57	1.49	0.22	0.15
40-49 m (18)	2042	23.63	17.83	31.90	31.99	1.43	0.41	4.17	2.47	0.59	0.46
50-59 m (10)	940	11.83	6.33	21.89	21.98	1.13	0.51	3.08	1.94	0.63	0.45
SEDIMENT											
Sand (3)	402	7.26	4.55	14.86	14.97	1.65	0.26	5.25	3.90	0.74	0.68
Silty-sand (13)	1530	17.93	13.15	33.90	33.99	2.01	0.24	7.44	4.14	0.55	0.48
Sandy-silt (2)	2162	22.16	11.20	11.88	11.98	1.00	0.48	2.71	2.07	0.76	0.62
Sandy-silty-clay (22)	2366	24.97	16.77	27.91	28.00	0.98	0.53	2.66	1.90	0.71	0.54
Clayey-silt (11)	1025	14.19	9.90	22.89	22.99	0.98	0.52	2.65	1.94	0.73	0.54
Silty-clay (5)	1690	24.16	16.97	19.89	19.99	1.10	0.49	3.01	2.02	0.67	0.51
Clayey-sand (1)	1600	23.88	12.50	9.86	9.98	1.23	0.38	3.44	2.62	0.76	0.67
LAT.-LONG .SQUARE											
Sq. Ab (3)	990	13.69	5.08	8.87	8.98	0.82	0.63	2.24	1.59	0.77	0.48
Sq. Bb (4)	2496	22.36	15.35	19.89	19.99	1.41	0.33	4.11	3.08	0.75	0.67
Sq. Ac (4)	1073	17.57	11.77	16.88	16.98	1.32	0.44	3.73	2.27	0.61	0.46
Sq. Bc(5)	3052	33.57	17.50	21.90	21.99	1.05	0.59	2.86	1.70	0.59	0.38
Sq. Cc (7)	1661	19.56	16.80	21.89	21.99	1.04	0.57	2.82	1.76	0.62	0.42
Sq. Dc (5)	1119	15.94	12.59	22.88	22.97	1.24	0.45	3.80	2.20	0.58	0.43
Sq. Bd (5)	1780	12.28	8.12	19.89	19.99	1.06	0.60	2.89	1.65	0.57	0.35
Sq. Cd (7)	1930	24.38	16.68	25.89	25.99	1.45	0.40	4.28	2.50	0.59	0.47
Sq. Dd (7)	1802	24.78	18.71	19.89	19.99	1.11	0.51	3.04	1.95	0.64	0.46
Sq. Ed (3)	716	9.12	5.76	10.87	10.98	1.25	0.42	3.49	2.36	0.67	0.54
Sq. Ce (3)	382	3.23	1.26	10.86	10.97	1.59	0.29	4.92	3.42	0.70	0.62
Sq. De (4)	2205	23.90	16.13	25.89	25.99	1.95	0.23	7.00	4.36	0.62	0.56

number of individuals. Highest diversity was indicated in 30-39 m depth zone followed by 40-49 m depth zone, the 20-29 m depth zone being the lowest in diversity. The sandy-silt and sandy sediments supported high diversity followed by clayey-sand sediment. Among the lat.-long. squares, sq. Ce and De had high diversity and sq. Bd the lowest.

Hill's Diversity Numbers N1 and N2 indicated the number of abundant and very abundant species (groups here). It could be seen that the 40-49 m and 30-39 m depth zones had more number of abundant species compared to the other two zones. Among the sediment classes, silty-sand and sand had maximum number of abundant species as well as very abundant species. Among the lat.-long squares, square De had maximum number of abundant species followed by sq. Cd, Ce and Bb. Squares Ac, Dc, and Ed were more or less similar in number of abundant species. Other squares had comparatively less number of abundant species.

Two evenness indices namely Hill's Ratio (E4) and Modified Hill's Ratio (E5) were calculated for different classifications (Table 4). The Modified Hill's Ratio

(E5) approaches value zero (in contrast E4 approaches value 1), as a single species becomes more and more dominant. Among the depth zones, It could be seen that 30-39 m zone was more even and depth zone 40-49 m was less even in faunal distribution compared to the other zones. Excepting perhaps silty-sand and silty-clay, almost all types of sediments have a high degree of uneven distribution of fauna. Among the lat.-long. squares, distribution is more even at sq. Bd, Bc, Cd and Dc, whereas sq. Bb, Ce and Bb had high degree of uneven distribution and other squares had moderate unevenness.

It is obvious that the area under study showed high diversity and great richness with regard to fauna even at the group level. Though all the indices presented here may not be of great significance for interpreting the faunal abundance and patterns of distribution, they would serve for comparison when similar studies are undertaken in future in the same area.

Association among species (groups)

Schluter's (1984) Variance Ratio (VR) was used to test the significance of association among multiple species (groups). The VR index of association was arrived at from the presence-absence data and the statistic W derived was tested for significant departure from the expected value of 'no association' where W approximates a chi-square distribution. An extremely high value of VR = 24.85582 and W = 1416.782 indicated very close association between the faunal groups in the study area. If the association is not significant the value of W should lie between 40.6465 and 75.623 ($\chi^2_{0.05,57} < W < \chi^2_{0.95,57}$).

In order to examine the relation between abundance of one group with that of another group, simple regression of pairs was attempted. Ten pairs of animal groups showed significant ($p<0.01$) coefficient of regression. Three types of indices of association, namely Ochiai Index, Dice Index and Jaccard Index (Ludwig and Reynolds, 1988), worked out for those 10 pairs also indicate the degree of their association (Table 5).

Degree of uniformity in faunal distribution

To ascertain the extent to which the animals living in the study area represent a homogeneous population, the index of affinity was calculated for all the possible pairs of samples as per methods adopted by earlier workers (Sanders; 1960, Wieser; 1960; Harkantra *et al.*, 1982). Though the convention is to de-

TABLE 5. *Regression products and three different indices relevant to the association between 10 pairs of animal groups.*

Animal pair		Ochiai index	Dice Index	Jaccard index
Polychaeta	Bivalvia	0.732	0.698	0.536
Polychaeta	Caridia	0.779	0.756	0.607
Amphipoda	Cumacea	0.641	0.582	0.411
Amphipoda	Tanaidacea	0.720	0.682	0.518
Amphipoda	Copepoda	0.655	0.600	0.429
Amphipoda	Isopoda	0.443	0.328	0.196
Bivalvia	Brachyura	0.596	0.593	0.421
Cumacea	Tunicates	0.209	0.148	0.080
Tanaidacea	Caridea	0.701	0.698	0.537
Tanaidacea	Tunicates	0.279	0.182	0.100

pict the results in the form of a trellis diagram, it was not done here due to the likelihood of ambiguity, which might result from the large number (1624) of sample pairs. However, a simplified overall picture is summarized in Fig. 4. The indices of affinity ranged from zero (Sample pair 14 & 51) to 100 (Sample pairs 3 & 44, 3 & 47). As obvious from the figure, more than 60 % of the station pairs exhibited similarity in nearly 60 % of the fauna. This is further indicated by the average index of affinity for all stations, which worked out to be 59.6559. Sanders (1960) recorded an overall index of affinity of 56.6 for 276 sample pairs in his study of benthos of Buzzards Bay. Thus it would be reasonable to assume that the distribution of fauna showed moderately high degree of homogeneity.

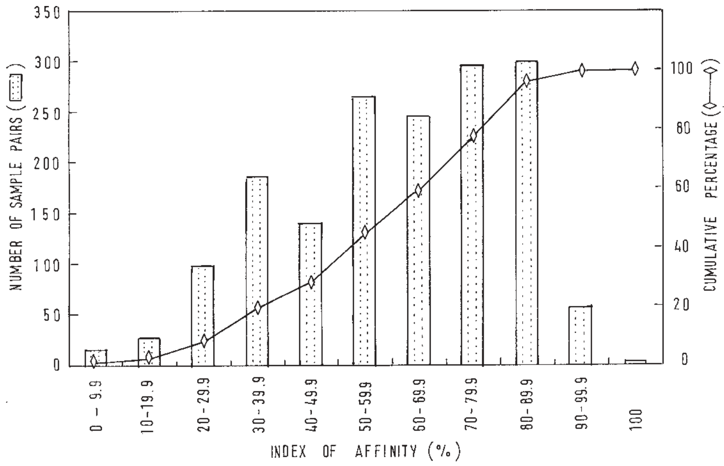

Fig. 4. Frequency distribution of index of affinity between pairs (summarized from Trellis Diagram method) of benthic sampling stations off Visakhapatanm.

The benthic population off Visakhapatnam in general exhibited highly diverse, extremely clumped and more or less homogeneous pattern of distribution. The domination of polychaetes and relative abundance of amphipods in the benthic community off Visakhapatnam has been well established. However, there seems to be variations in the relative abundance of other groups in different studies. This could be due to the minor spatial differences in sampling or temporal changes in the population due to various environmental changes.

Bottom trawling operations are carried out generally off to the southwest and northeast parts of the harbour transect and only part of the present study area comes under area of trawling. The present results are insufficient to assess any impact of possible effect of trawling. Therefore, in future it is necessary to take up further studies on the effect of trawling on benthos in these waters, covering a wider area.

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References

Adiseshasai, K. 1992. *Littoral macrobenthos off Visakhapatnam, India*. Ph.D. Thesis, Andhra University, Visakhapatnam.

Ansari, Z.A., C.L. Rodrigues, A. Chatterji and A. H. Parulekar 1982.Distribution of meiobenthos and macrobenthos at the mouth of some rivers of the east coast of India. *Indian J. Mar. Sci*., **11**: 341-343.

Bhavanarayana, P.V. 1975. Some observations on the benthic faunal distribution in the Kakinada Bay. In: R Natarajan (Ed.), *Estuarine Biology,* P. 146 –150.

Birkett, L and A. D. McIntyre 1971. *Methods for the Study of Marine Benthos*, 157pp.

Chandran, R., G.S. Thangaraj, V. Sivakumar, Shri Krishnadas and K. Ramamurty 1982. Ecology of macrobenthos in Vellar estuary. *Indian J. Mar. Sci.,* **11**: 122-127.

Krumbein, W.C. and E.J. Pettijohn 1938. *Manual of Sedimentary Petrography,* 549pp.

Damodaran, R. 1973. Studies on the benthos of the mud banks of Kerala coast. *Bull. Dept. Mar. Sci., Univ. Cochin*, **6**: 1-126.

Ganapathi, P.N. and M.V.L. Rao 1959. Preliminary observation on the bottom fauna of the continental shelf of the northeast coast of India. *Proc. 1st All India Congress on Zoology, Part-III* : 6-13.

Ganapathi, P.N. and A.V. Raman 1976. *Capitella capitella* (Fabricius, 1780) (Polychaeta, Capitellidae) -–An indicator of pollution in Visakhapatnam harbour. *Indian J. Mar. Sci.,* **5**: 251.

Harkantra, S.N. 1982. Studies on sublittoral macrobenthic fauna of the Inner Swansea Bay. *Indian J. Mar. Sci*., **11**:75-78.

Harkantra, S.N., C.L. Rodrigues and A.H. Parulekar 1982. Macrobenthos of the shelf of northeastern Bay of Bengal. *Indian J. Mar. Sci*., **11**: 115 –121.

Holme, N.A. 1964. Methods of sampling Benthos. *Adv. Mar. Biol*., **2**:171-269.

Ludwig, J.A. and J.F. Reynolds 1988. *Statistical Ecology, a Primer on Methods and Computing.* 337pp.

Neyman, A.A., M.K.Sokolova, N.C. Vinogradeov and F.A. Pasternal 1973. Some patterns of the distribution of bottom fauna in the Indian Ocean. In: B. Zeitzchel (Ed.), *The Biology of the Indian Ocean*, 1167-1173.

Parulekar, A.H., S.N. Harkantra and Z.A. Anzari 1982. Benthic production and assessment of demersal fisheries resources of the Indian seas. *Indian J. Mar. Sci.,* **11**: 107-114.

Radhakrishna, Y. 1964.*The systematics and ecology of bottom fauna*, Ph.D. Thesis, Andhra University, Visakhapatnam.

Radhakrishna, Y and P. N. Ganapati 1969. Fauna of Kakinada Bay. *Proc. Nat. Inst. Sci. India*, **38**: 688-699.

Raman 1980. *Ecology of pollution in Visakhapatnam Harbour*, Ph.D. Thesis, Andhra University, Visakhapatnam.

Raut, Dipti 1997. *Benthic macrofauna of mangrove waterways and the bay environment of Kakinada, east coast of India*. Ph.D. Thesis, Andhra University, Visakhapatnam.

Rodrigues, C.L., S.N. Harkantra, and A.H. Parulekar 1982. Sublittoral meiobenthos of northeastern Bay of Bengal. *Indian J. Mar. Sci*., **11**: 239 –242.

Samuel, M. 1944. Preliminary observations on the animal communities of the level sea bottom of Madras coast. *J. Madras Univ*., **15**: 45-71.

Sanders, H.L. 1956. Oceanography of the Long Island Sound, 1952-1954. X Biology of marine bottom communities. *Bull. Bingham Oceanogr. Coll*., **15**: 345-414.

Sanders, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal Sediment relationships. *Limnol. Oceanogr.,* **3**: 245-258.

Sanders, H. L. 1960. Benthic studies in Buzzards Bay III, the structure of the soft bottom community. *Limnol. Oceanogr.*, **5**: 138-153.

Schluter, D. 1984. A variance test for detecting species associations with some example applications. *Ecology,* **65**: 998-1005

Sokolova, M.A. and F.A. Pasternak 1964. Quantitative distribution and tropic zonation of the bottom fauna in the Bay of Bengal and the Andaman Sea. *Trudy Inst. Okeonol. Moskova*, **66**: 271-296.

Slobdokin, L B. 1962. *Growth and Regulation of Animal Population*. Holt Rinehart & Winneston, New York, 184pp.

Sudarsan, D. 1983. *Studies on demersal and trawl fisheries of Visakhapatnam*. Ph.D. Thesis, Andhra University, Visakhapatnam.

Subba Rao, B.V.S.S.R. and Venkateswara Rao 1980. Aquatic oligochaetes as indicators of organic pollution in Visakhapatnam harbour. *Indian J. Mar. Sci.,* **9**: 222-223.

Vijayakumaran, K., B. Naryana Rao and K. Radhakrishna 1996. Surface productivity and related hydrography off Visakhapatanm during pre-monsoon and winter months of 1987-89. *Indian J. Mar Sci.,* **25**: 29-34.

Wieser, W. 1960. Benthic studies in Buzzards Bay – II, The meiofauna. *Limnol. Oceanogr*., **5**(2): 121-137.