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BIODIVERSITY OF MACROBENTHOS ON THE INTERTIDAL FLATS OF SUNDERBAN ESTUARINE REGION, INDIA

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INTRODUCTION

Estuaries are highly dynamic and interesting ecosystem where strong transition between sea and freshwater exists (Mclusky, 1971). The mixing of fresh and marine water produces complex effects on the entire abiotic and biotic conditions of the ecosystem including sedimentation, salinity, nutrients-level, productivity and diversity and abundance of fauna. The tidal nature of estuaries exposes periodically vast areas of intertidal flats, during low tides, which harbour a specialised community of macrobenthic invertebrates. Because of their great importance, both in trophic dynamics of the ecosystem and as indicator of the quality of environment, these communities have gained considerable attention both in India (Panikker and Aiyer, 1937; Balssubramaniyam, 1960; McIntyre, 1964; Maclachlan, 1971; Ansel *et al.*, 1972, 1978; Ajmal Khan *et al.*, 1975; Parulekar *et al.*, 1975; Dwivedi *et al.*, 1975; Bhunia and Choudhury, 1981; Govindan *et al.*, 1983; Choudhury *et al.*, 1984 and Fernando, 1987) and elsewhere (Spooner and Moore, 1940; Brady, 1943; Holme, 1949; Carriker, 1967; Dawn, 1971; Wolff, 1973; Sasekumar, 1974; Khayrulla and Jones, 1975; Wildish and Kristmanson, 1979; Maurer and Lathern, 1979; Andrew *et al.*, 1980; Alongi, 1987 and Elliot and Kingston, 1987). However, barring a few, most of the studies were mainly carried out from the viewpoint of density or productivity, without making much efforts to analyse the specific structure of the community. It is only during the last few years that serious attempts have been made in this direction in different parts of the world (Elliot and Kingston, 1987; Barr *et al.*, 1990; Attrill *et al.*, 1996). However, from the Indian estuaries not many reports are yet available, more so from the most important and largest estuarine complex–the Hugly-Matla, which is formed by the major Indian river, Ganga. The lower zone of this system on the delta forms Sunderban estuarine and mangrove region.

Therefore, the present investigations were undertaken to study the benthic macroinvertebrates-occurrence, abundance and diversity on intertidal flats of Sunderban estuarine region, specially from the view point of assessing the spatial variations in biodiversity patterns between different areas and zones associated with major contributing estuaries. In order to make proper comparison, areas situated in mid-estuarine zone of the Major River Hugly have also been included.

DESCRIPTION OF THE STUDY AREA

Indian Sunderban estuarine region, which is only one third of total Sunderban delta (two-third in Bangladesh), covers the lower portion of Hugly-Matla estuarine system and is mainly formed by an offshoot of major river Ganga in the districts of North and South 24 Parganas of West Bengal State, near Bay of Bengal, between latitudes 21°31' N and 23°30' N and longitudes 87°45' E and 88°45' E. Several other smaller tributaries like Roopnarayan and Haldi also join the system. The main estuary Hugly is highly tidal and this limit extends to 295 km from the mouth. Estuarine complex in lower zone, forming main Sunderban region, is criss-crossed with a large number of smaller distributaries and their creeks and channels (Khals), forming a number of islands where dense luxurient mangrove forests grow. Vast areas of mud flats and a few patches of sand flats (near sea face) appear around these islands during low tides which occur twice a day. The important estuaries contributing to the system are Hugly, Muriganga, Saptamukhi, Thakuran (Jamira), Matla, Harinbhanga-Raimangal etc. (Fig. 1). Details of the physiography has already been described (Khan, 1995a, 1995b).

MATERIALS AND METHODS

A. Study Zones and Stations

For the purpose of present study, the entire area was divided into four major zones, and samples were collected from different stations, numbering one to three in each zone. These zones and stations were :

ZONE–1, HUGLY MIDDLE ZONE

This zone was demarcated in almost middle region of 295 Km tidal stretch of main feeding river and samples were drawn from following stations.

Station 1, Achipur : Approximately 135 Km from the mouth. The river at this point passes through Calcutta Metropolitan District with large human settlements along both the banks. The intertidal flats were small and the substrate muddy but not very soft.

Station II, Nurpur. Approximately 115 Km from the mouth. The river in this region passes through comparatively thinly populated area. The sizes of the exposed flats were comparatively larger than station 1.

ZONE–2, HUGLY LOWER ZONE MUDFLATS

This zone was located in lower region of the estuarine system in Sunderban proper on the western side. This included areas west of the River Saptamukhi to the western boundary of Sunderban. Most the intertidal flats in upper and middle portions of this zone were muddy but at the mouth these were replaced by sand flats. Sampling was done from the following stations :

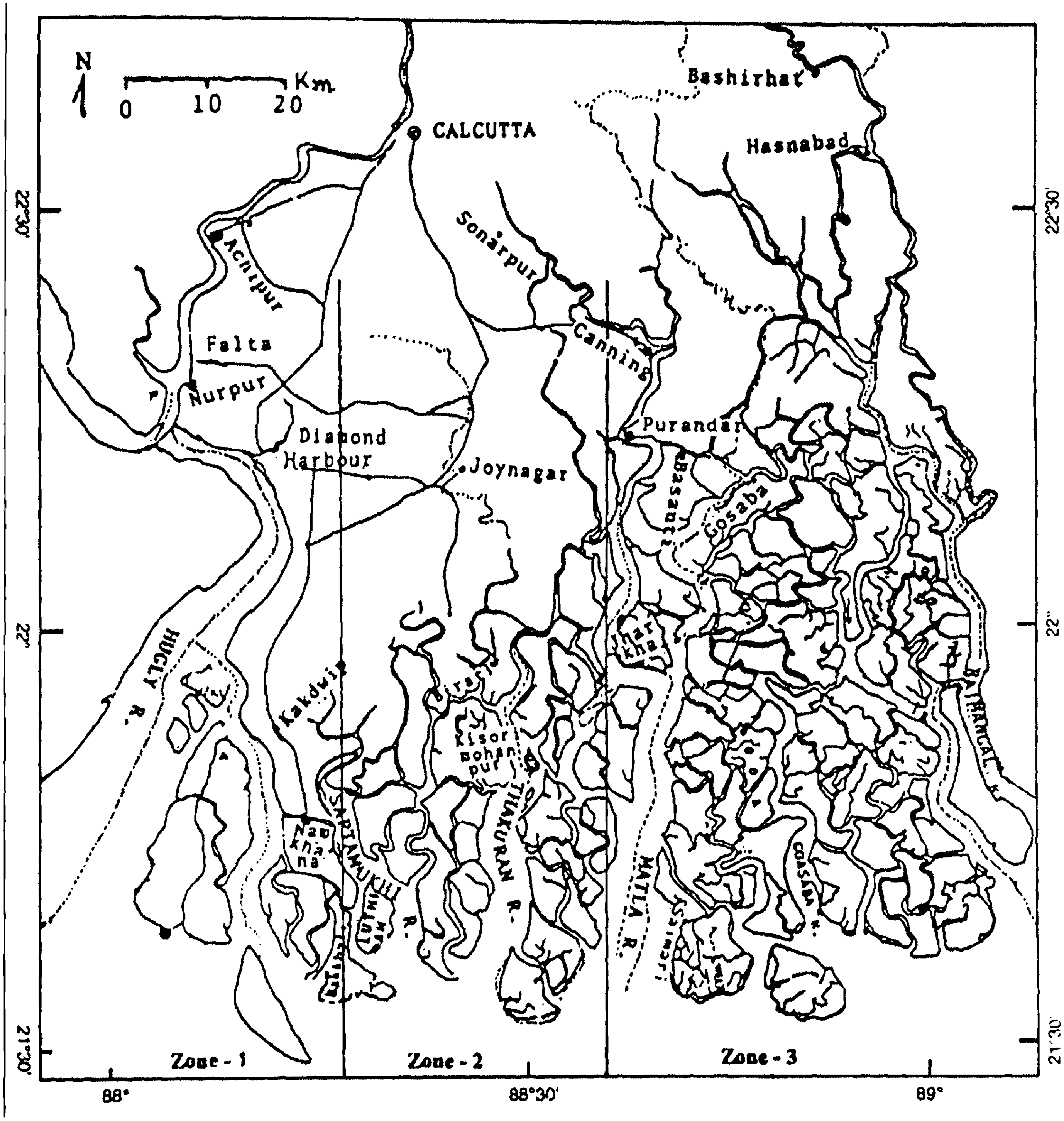


Fig. 1. Sunderban Estuarine Zone of Hughly-Matla System.

Station III, Kakdwip : This station was situated nearly 25 Km from the mouth, with muddy flats.

Station IV, Namkhana : This station was located about 19 Km from the mouth, with considerably larger exposure of soft muddy flats.

Station V, Printice island : This station was nearly 10 Km from sea face. The island was uninhabited and full of mangrove forest. The mudflats were formed by very soft mud.

ZONE–3, THAKURAN-MATLA ZONE MUD FLATS

This zone covered the areas situated east of River Saptamukhi to west of river Goasaba covering major distributaries, namely Thakuran and Matla. This was the biggest zone, covering main area of the system. The entire zone was characterized by extremely soft muddy substrate near low tide marks and not very hard substrate at highest of high tide marks during any time of lunar month. It included almost virgin areas of mangrove forests. Most of the area is under Tiger Reserve where the entry is extremely restricted. This zone was covered from the following stations.

Station VI, Kishori Mohanpur : This station was situated on a small island, most of which gets submerged during high tide. The intertidal flats were mainly comprised of extremely soft muddy substrate. It was situated nearly 45 km from the mouth in Thakuran estuarine area.

Station VII. Jharkhali : This station was almost in the middle of Matla estuary, nearly 60 Km from the mouth. The island has a small population of mainly fisherfolk. The substrate around the island was muddy and soft.

Station VIII, Purandar (Canning) : This was situated in the upper portion of Matla River. This river has lost its freshwater connection due to reclamation in upper reaches and resembles almost backwater. Except during monsoon period, this river does not receive any freshwater discharge.

ZONE–4, MATLA SAND FLATS

Almost all areas near the sea face contain sandy flats that are located around certain islands. Only one sand flat was surveyed :

Station IX, Saimari : This station was situated about 8 km from sea-face on the western side of the island and was comprised of vast beach of sand flats.

Survey and Collection

Macrobenthic fauna were collected from different stations during the years 1989-92. As monsoon plays an important role in the dynamics of seasons of this region of the country, the annual cycle was divided into three major seasons viz. Premonsoon (March–June), Monsoon (July–October) and Postmonsoon (November–February). Each season was subdivided into two parts, the early (1), covering first two months, and late (II) comprising of last two months.

From each station a set of 4 samples along a transect, from low water mark to high water mark, were collected by placing a wooden quadrate of 0.5 X 0.5 m to a depth of 15 cm. The epifauna from the demarcated area were first picked up or trapped quickly (crabs) and then entire soil was taken and washed through a sieve of 0.5 mm mesh-size. Macro fauna retained on the sieve were picked up with the help of a magnifying glass and the remaining contents were washed in small amount of water. The smaller animals were gently picked up with the help of a sable hairbrush or a wide-mouth pipett. All macrobenthos were sorted live. Samples were first narcotized by adding a few drops of menthol in water containing the animals and then preserved after sometime in 8%

formalin. Special care was taken for polychaetes for narcotisation and whenever possible they were fixed in 70% alcohol. The identification of taxa, counting, measurement and biomass-determination were carried out in laboratory. The dry weight biomass was determined by keeping the animals in an oven at 65°C for a few days.

Species diversity and similarity indices

In order to assess the diversity, several indices of diversity were applied to macro-benthic community which are :

1. Menthinik Index (Menhinik, 1964).. S/In
2. Index of Diversity (Margalef, 1951).. $\frac{S-1}{\log_e N}$
3. Shannon-Weiner Index of diversity (Wilhm, 1972)............... $H = -\sum ni/N \log_e ni/N$
4. Simpson/s index.. $D = 1 - \sum \frac{nj(nj-1)}{N(N-1)}$
5. Evenness (Pielow 1959).. J = H/Hmax where Hmax is equal to $\log_2 S$

Where S = No. of species in the sample

N = total number (density) of all individuals of all groups in the sample

Ni, nj = number of individuals (density) of species i or j in the sample.

Similarity Analysis

Similarity between different zones were determined based on percentage similarity index, which chiefly represented the qualitative structure of fauna (Greig-Smith, 1964) as :

$$S = (c \times 100)\ a + b - c$$

Where a is the number of species present in first sample, b is the number of species in second sample and c is the number of species present in both samples.

The similarities between zones with respect to quantitative structure of fauna were determined as per the formula of Romaniszyn (1970)

$$S = \frac{W}{a + b + c}$$

Where W is the sum of densities minima of different taxa occurring at site A or B, irrespective of sites, and a and b are sum of densities of all taxa occurring at site A or B.

Soil samples were analysed for the grain size as per the methods of Krumbein and Pettijhon (1938). Organic carbon was estimated as per the methods of El-Wakeel and Riley (1956). Dissolved oxygen of interstitial water was determined by Winkler's modified method. Temperature was measured with the help of a soil thermometer. Salinity was measured argimetrically.

RESULTS

A. Physico-chemical nature of soil

The general features of physico-chemical nature of soil of all zones during different seasons are given in Table 1. Salinity increased steadily from Zone-1 (Hugly middle zone) to Zones 2, 3 and 4. In Zone-1, drastic reduction in salinity occurred during monsoon months when the surface runoff and river discharges were highest. The impact of huge dilution was also evident during post-monsoon months when salinity was not very high. However, during premonsoon season the salinity increased considerably to nearly 15 times of the lowest value observed during monsoon period. In Zones 2 (Hugly mudflats) and 3 (Matla mudflats) the salinity as a whole was considerably high throughout the year, though the seasonal variations were of the same order as in Zone-1, lowest in monsoon and highest in premonsoon. Mean salinity values in Zone-3 were always slightly higher than in Zone-2. The values varied between 10.0 and 27.0 ppt in Zone-2 and 16.0 to 29.0 ppt in Zone-3. Mean soil temperature did not vary much in different zones. The seasonal variations were also not very pronounced during major part of the year when mean monthly temperature fluctuated around 30°C. A moderate drop in temperature was noted during the latter part of postmonsoon season but that was for a brief period. Dissolved oxygen contents of interstitial water were also moderate in all zones during all seasons, which varied between 3.01 mg/l (Zone-1, PRM-1) and 5.2 mg/l (Zone-4, POM-11). Organic carbon values were also quite moderate in all the zones during all seasons, except in Zone-1 during premonsoon.

Sediment composition was dominated by silt followed by clay in Zones 1, 2 and 3. Sand particles contributed very little during all seasons. The case was reverse in Zone-4 where, sand particles formed nearly 88% of the sediment particles.

Table 1. Physico-chemical nature of the soil of mud and sand flats at different zones.

Parameters	Zone 1			Zone 2			Zone 3			Zone 4		
	PRM	MON	POM	PRM	MON	POM	PRM	MON	POM	PRM	MON	POM
Salinity (ppt)	15.0	1.0	5.2	27.0	10.0	14.0	29.0	16.0	18.0	32.0	18.0	26.6
Organic carbon (mgC/g)	3.57	1.2	1.0	1.2	2.9	1.7	1.3	2.6	1.5	1.1	1.5	1.0
Temperature (°C)	30.5	30.5	22.5	30.0	29.6	22.0	30.5	29.8	21.9	30.5	30.5	21.2
Dissolved oxygen (mg/l)	3.01	3.0	4.0	4.0	4.1	4.9	4.1	4.4	4.9	4.6	4.8	5.2
Sediment Composition (%)												
Sand	20.7	16.6	18.3	5.6	4.0	5.5	4.3	6.2	5.1	92.6	84.3	88.5
Caly	22.3	20.9	20.2	21.5	26.0	22.2	22.2	25.5	24.9	4.2	8.5	6.8
Silt	57.9	62.5	61.5	73.5	70.0	72.3	73.3	68.3	70.0	3.8	7.2	4.7

PRM–Premonsoon, MON–Monsoon, POM–Postmonsoon.

B. Total recorded species

Altogether 83 taxa were recorded during quantitative sampling from different zones of the estuarine system over the length of survey (Fig 2). Macrobenthic fauna of both mud and sand flats belonged mainly to Gastropoda (24 taxa), Bivalvia (12 taxa), Polychaeta (14 taxa), Brachyura (17 taxa) Anomura (3 taxa) and Asteroidea (3 taxa). Other groups like Actinaria, Nemartina, Bryozoa, Oligochaeta, Echiura, Sipuncula, Macrura (Crustacea), Ophiuroidea and Chironomidae were represented by one or two taxa each (Table 2).

Most of the taxa were common to two or more zones. Maximum number of taxa was recorded from Zone-3 (Thakuran-Matla mud flats), comprising Stations 6, 7 and 8. This zone was represented by 58 taxa. This was followed by Zone 2 from where a total of 48 taxa were recorded. Minimum number of taxa was found in Zone-1 (Hugly middle zone) where only 22 taxa occurred over the entire duration of survey. The sand flats of Zone-4 (Takuan-Matla sand flats) contained altogether 39 species. These species were recorded from the quantitative samples only (Fig. 2). Not many differences were noticed between different stations in each zone (Fig 3, Table 2).

Groupwise analysis revealed the dominance of gastropods in all zones which were represented by 12, 14, 18 and 9 taxa, constituting 54%, 34%, 31% and 25% of the total macro-invertibrate fauna in Zones 1, 2, 3 and 4 respectively (Fig 4, Table 3). Polychaetes contributed between 13% and 18% of the total taxa in different zones, with number of species varying between 3 and 9. Bivalves were represented by maximum number of species in Zone-4. While only few species of brachyuran crabs were recorded from Zone-1 (3 species, 13%), their strength reached to the maximum in Zone-3 (12 species, 20%). The oligochaetes were the inhabitants of Zone-1 only and were not able to tolerate higher salinity values. Contrary to this, taxa belonging to most of the other groups were only confined to higher salinity zones.

C. Numerically abundant species

Out of these only 9-12 taxa were abundant in different zones and formed the major portion of benthic macroinvertebrate density (Table 4). Among the gastropods, *Assiminea brevicola*, *Cerithidea (C) cingulata* and *Telescopium (T) telescopium* were very common on the mud flats and these together contributed more than 30% of total macrobenthos in Zones 2 and 3. Next in importance were hermit crabs of the species *Cliobanarius padaensis* is Zones 2 and 3. In Zone-4, gastropod, *Septaria lineata*, bivalve, *Macoma birmanica* and *Solen brevis*, anomura, *Coenobita cavipes* and brachyuran *Ocypoda macrocera* were most abundant species. In Zone-1, gastropod, *Stenothyara deltae*, *Assiminea francesiae*, polychaete, *Neanthes cihingrigattensis etc.* were most abundant species.

D. Density (abundance)

The numerical density of major groups as individuals/m^2 and their relative composition in different zones are shown in Fig. 5 and stationwise listing is done in Table 5. The mean density

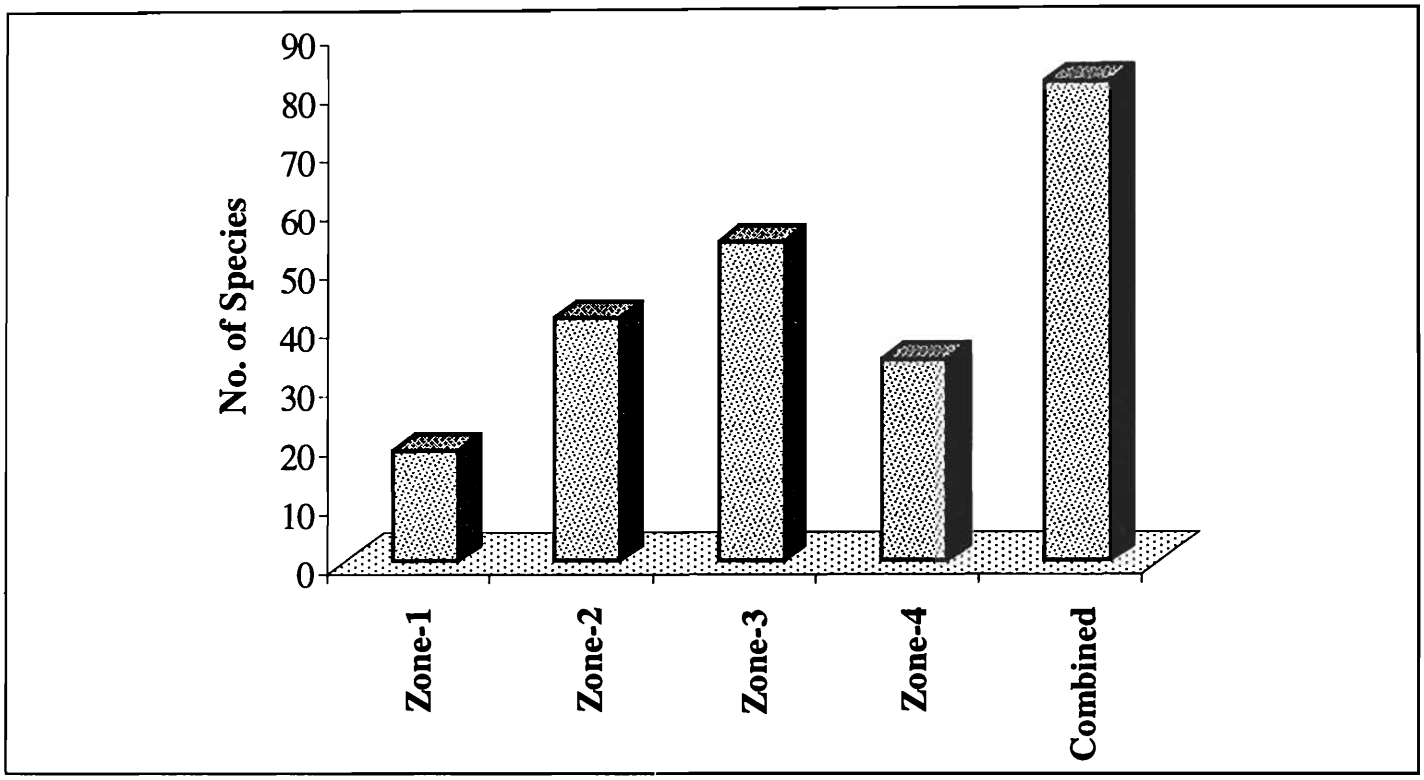


Fig. 2. Number of species recorded from each zone and all zones combined.

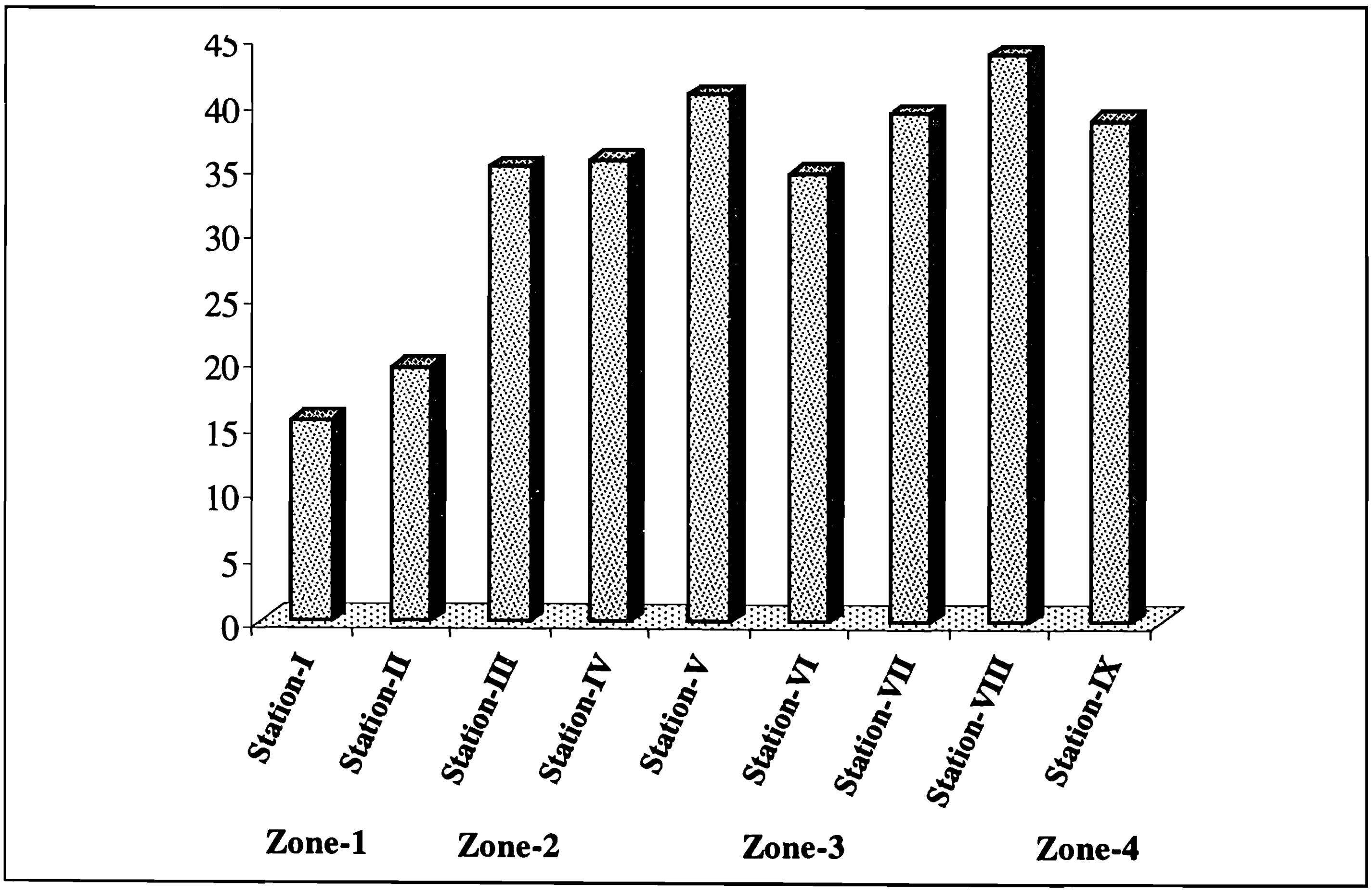


Fig. 3. Number of species recorded from each station.

Table 2. The occurrence of macrobenthic invertebrates in different zones.

Taxa	Zone 1	Zone 2	Zone 3	Zone 4
CNIDARIA – ACTINARIA				
1. *Edwardsia jonesii* Sheshya & Cuttress	–	+	+	–
2. *Pelocoetes exul* (Annandale)		–	+	–
BRYOZOA				
3. *Victorella sp*	–	+	+	–
MOLLUSCA-GASTROPODA				
4. *Potamacmaea fluviatills* (Blandford)	–	–	+	–
5. *Tubiola microscopia* Adams	–	–	+	–
6. *Nerita articulata* (Gould)		+	+	–
7. *Neritina (Dostia) violacea* (Gmelin)	+	–	–	–
8. *Pseudonerita sulculosa* (Von Martens)	+	+	+	–
9. *Septaria lineata* (Lamarck)	+	+	–	+
10. *Littorina (Palustorina) melanostoma* Gray	–	–	+	–
11. *Littorina (Littorinopsis) scabra* (Linnaeus)	+	+	–	–
12. *Stenothyra deltae* (Bensen)	+	+	+	+
13. *Stenothyra blanfordiana* Nevil	–	+	+	+
14. *Assiminea beddomeana* Nevil	–	+	+	+
15. *Assiminea brevicola* (Pfeiffer)	–	+	+	+
16. *Assiminea francesiae* (wood)	+	–	–	–
17. *Thiara (Thiara) scabra* (Muller)	+	–	–	–
18. *Telescopium (T) telescopium* (Linnaeus)	+	+	+	+
19. *Cerithidea (Cerithideopsilla) cingulata* (Gmelin)	+	+	+	+
20. *Natica tigrina* (Roeding)	–	–	+	+
21. *Nassarius stolatus* (Gmelin)	–	+	+	–
22. *Pugilina cochlidium* (Linnaeus)	–	–	+	+
23. *Ellobium (Auricula) gangeticum* (Pfeiffer)	–	+	+	+
24. *Ellobium aurisjudae* (Linnaeus)	+	+	–	–
25. *Melampus pulchella* Petit	+	–	+	–
26. *Pythia plicata* (Gray)	+	+	+	–
27. *Onchidium tigrinum* Stoliczska	–	+	+	–
MOLLUSCA-BIVALVIA				
28. *Scaphula deltae* Blanford	–	+	–	–
29. *Anadora granosa* (Linnaeus)	–	–	+	–
30. *Modiolus striatulus* (Hanley)	–	–	+	–

Table 2. (*Contd.*)

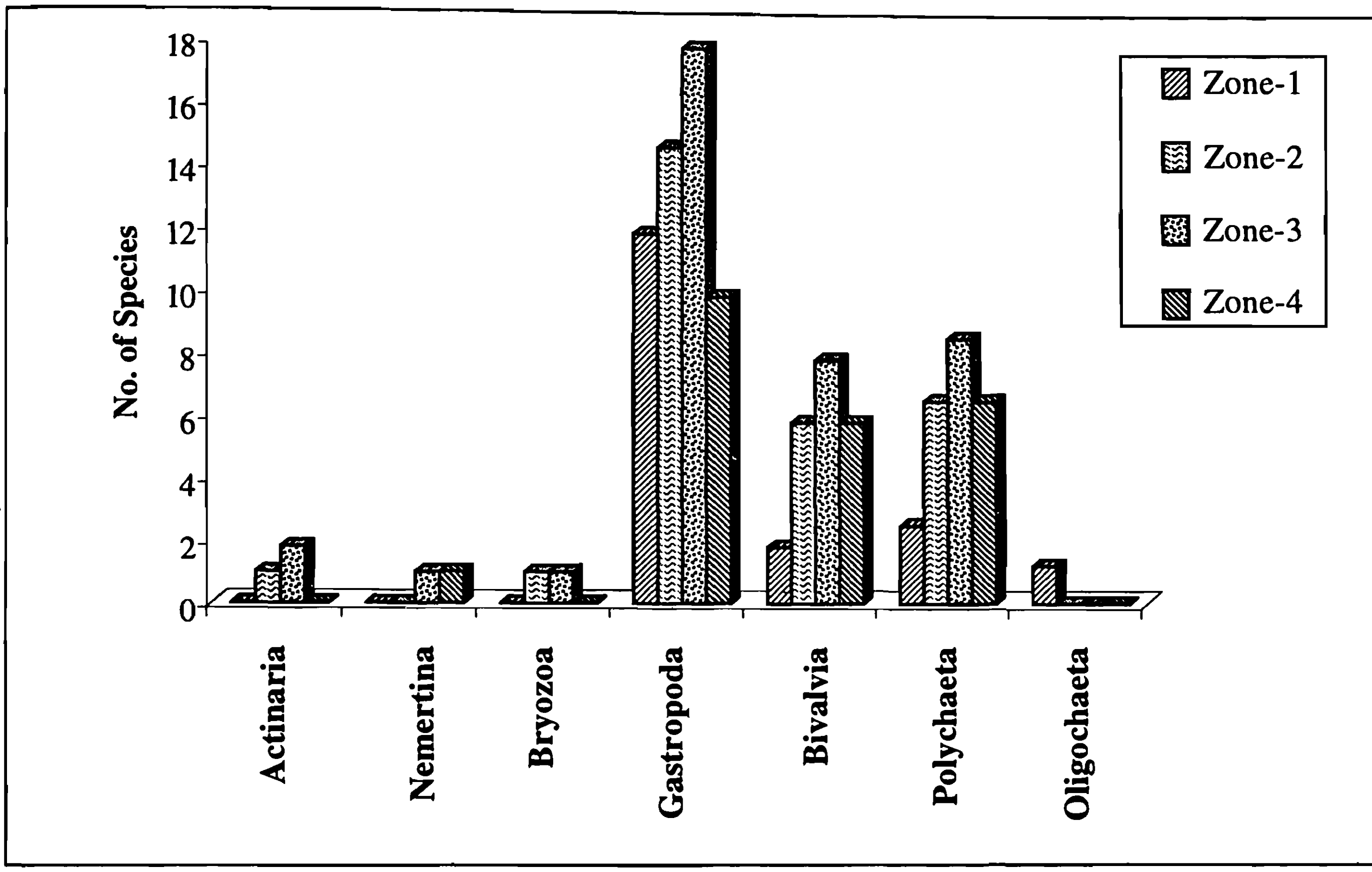
Taxa	Zone 1	Zone 2	Zone 3	Zone 4
31. *Crassostrea gryphoides* Newton & Smith	–	–	+	+
32. *Meretrix meretrix* Lennaeus	+	+	+	+
33. *Pelcyora trigona* (Reeve)	–	+	–	–
34. *Donax incarnatus* Schroter	–	–	+	+
35. *Macoma birmanica* (Philippi)	–	–	+	+
36. *Solen brevis* Gray	–	+	+	+
37. *Silqua albida* Dunker	–	+	–	+
38. *Corbicula striatella* Deshayes	+	–	–	–
39. *Tellina sp.*	–	+	+	+
ANNELIDA-POLYCHAETA				
40. *Lepidonotus tenuisetosus* (Gravier)	–	–	–	+
41. *Anaitides madeirensis* (Langerhans)	–	+	–	–
42. *Sigambra constricta* (Southern)	–	–	–	+
43. *Talehsapia annandalei* Fauvel	–	+	+	–
44. *Dendronereides heteropoda* Southern	+	+	+	+
45. *Namalycastis indica* (Southern)	–	+	–	–
46. *Neanthes chingrighattensis* (Fauvel)	+	+	–	–
47. *Glycera sp.*	–	–	+	–
48. *Eunice aphroditois* (Pallas)	–	–	+	–
49. *Diopatra cuprea* (Bosc)	–	–	+	+
50. *Lumbrineris polydesma* (Southern)	–	+	+	
51. *Polydora* sp.	–	–	+	–
52. *Poletamilla leptochaeta* Southern	+	–	–	–
53. *Nepthys polybranchia* Southern	–	+	+	+
ANNELIDA-OLOGOCHAETA				
54. *Limnodrillus* sp.	+	–	–	–
ECHIURA				
55. *Anelassorhynchus microrhynchus* (Prashad)	–	+	+	+
56. *Anelassorhynchus branchiorhynchus* (Annadale & Kemp)	–	+	+	+
SIPUNCULA				
57. *Phascolosoma arcuatum* (Gray)	–	+	+	+
MACRURA-ALPHEIDAE				
58. *Alphaeus paludicola* Kemp	–	+	+	+

Table 2. (*Contd.*)

Taxa	Zone 1	Zone 2	Zone 3	Zone 4
ANOMURA				
59. *Clibanarius padavensis* de Man	–	+	+	–
60. *Diogenes* sp.	–	–	–	+
61. *Coenobita cavipes* Stimpson	–	–	–	+
BRACHYURA				
62. *Euricarcinus* sp.	–	+	+	+
63. *Sesarma biddens* (De Haan)	–	+	+	–
64. *Sesarma tetragona* (Fabricius)	–	–	+	+
65. *Sesarma edwardsi* de Man	+	–	–	–
66. *Metapograpsus messor* (Forskal)	–	+	+	+
67. *Metapograpsus maculatus* H. M. Edwards	–	–	+	+
68. *Metaplax intermedia* de Man	+	–	–	–
69. *Metaplax dentipes* (Heller)	–	+	+	–
70. *Scylla serrata* (Forskal)	+	–	–	–
71. *Ocypoda macrocera* H. Milne-Edwards	–	–	–	+
72. *Uca (Deltuca) dussumieiri* Spinata	–	–	+	–
73. *Uca (Deltuca) rosea* (Tweedie)	–	–	+	+
74. *Uca (Celuca) triangularis* Crane	–	–	+	+
75. *Dotillopsis brevitarsis* (de Man)	–	–	+	–
76. *Dotilla blanfordi* Alcock	–	+	–	–
77. *Tympanomerus gangeticus* Kemp	–	–	+	–
78. *Macrophthalmus* sp.	–	–	+	–
ASTEROIDEA				
79. *Astropecten indicus* Doederlein	–	+	+	+
OPHIUROIDEA				
80. *Amphioplus tenuis* (H. L. Clark)	–	+	–	+
81. *Ophiactis delagoa* Balinsky	–	–	–	+
INSECTA; DIPTERA; CHIRONOMIDAE				
82. *Chironomus* sp.	+	+	+	–
NEMERTINA				
83. *sp. n. det*	–	–	+	+
TOTAL NUMBER OF TAXA	**22**	**44**	**58**	**39**

Table 3. Number of macrobenthic taxa of major groups recorded from different Stations and Zones (Combined). Figures in parentheses indicate approximate percentage composition.

Macrobenthic groups	Number of species											
	Zone-1			**Zone-2**				**Zone-3**				**Zone-4**
	Station-I	Station-II	**Combined**	Station-III	Station-IV	Station-V	**Combined**	Station-VI	Station-VII	Station-VIII	**Combined**	Station-IX
Actinaria	–	–	**–**	–	1(2.8)	1(2.4)	**1(2.3)**	2(5.7)	1(2.5)	1(2.2)	**2(3.4)**	–
Nemertina	–	–	**–**	–	–	–	**–**	1(2.8)	1(2.5)	–	**1(1.7)**	**1(2.5)**
Bryozoa	–	–	**–**	1 (2.8)	–	1(2.4)	**1(2.3)**	–	1(2.5)	1(2.2)	**1(1.7)**	–
Gastropoda	8(50)	10(50)	**12(54)**	12(34.3)	14(39)	14(34.1)	**15(34)**	14(40)	10(26)	15(34)	**18(31)**	**10(25)**
Bivalvia	1(6.2)	2(10)	**2(11)**	4(11.4)	4(11.1)	5(12.2)	**6(14)**	3(8)	4(10)	5(11)	**8(14)**	**6(15.4)**
Polychaeta	3(18.7)	2(10)	**3(13.6)**	7(20)	6(16.6)	7(17.1)	**7(15.9)**	4(11.4)	6(15.4)	8(18.2)	**9(15.5)**	**7(17.9)**
Oligochaeta	1((6.2)	1(5)	**1(5.5)**	–	–	–	**–**	–	–	–	**–**	–
Echiura	–	–	**–**	2(5.7)	1(2.7)	2(20.5)	**2(4.5)**	1(2.8)	1(2.6)	2(4.5)	**2(3.4)**	**1(2.5)**
Sipuncula	–	–	**–**	1 (2.8)	1(2.8)	1(2.4)	**1(2.3)**	–	1(2.5)	1(2.2)	**1(1.7)**	**1(2.5)**
Macrura	–	–	**–**	–	1(2.8)	1(2.4)	**1(2.3)**	1(2.8)	1(2.5)	1(2.2)	**1(1.7)**	**1(2.5)**
Anomura				1 (2.8)	1(2.8)	1(2.4)	**1(2.3)**	1(2.8)	1(2.5)	1(2.2)	**1(1.7)**	**2(5)**
Brachyura	2(12.4)	3(15)	**3(13.6)**	6(17.1)	513.9)	6(13.6)	**6(13.6)**	7(20)	11(28.2)	6(13.6)	**12(20)**	**7(18)**
Astroidea-Ophiuroidea	–	–	**–**	–	1(2.8)	2(4.9)	**2(4.5)**	1(2.8)	1(2.5)	2(4.5)	**1(1.7)**	**3(7.7)**
Chironomidae	1(6.2)	1(5)	**1(5.5)**	1 (2.8)	1(2.8)	–	**1(2.3)**	–	–	1(2.2)	**1(1.7)**	–
TOTAL	16	20	**22**	35	36	41	**44**	35	39	44	**58**	**39**



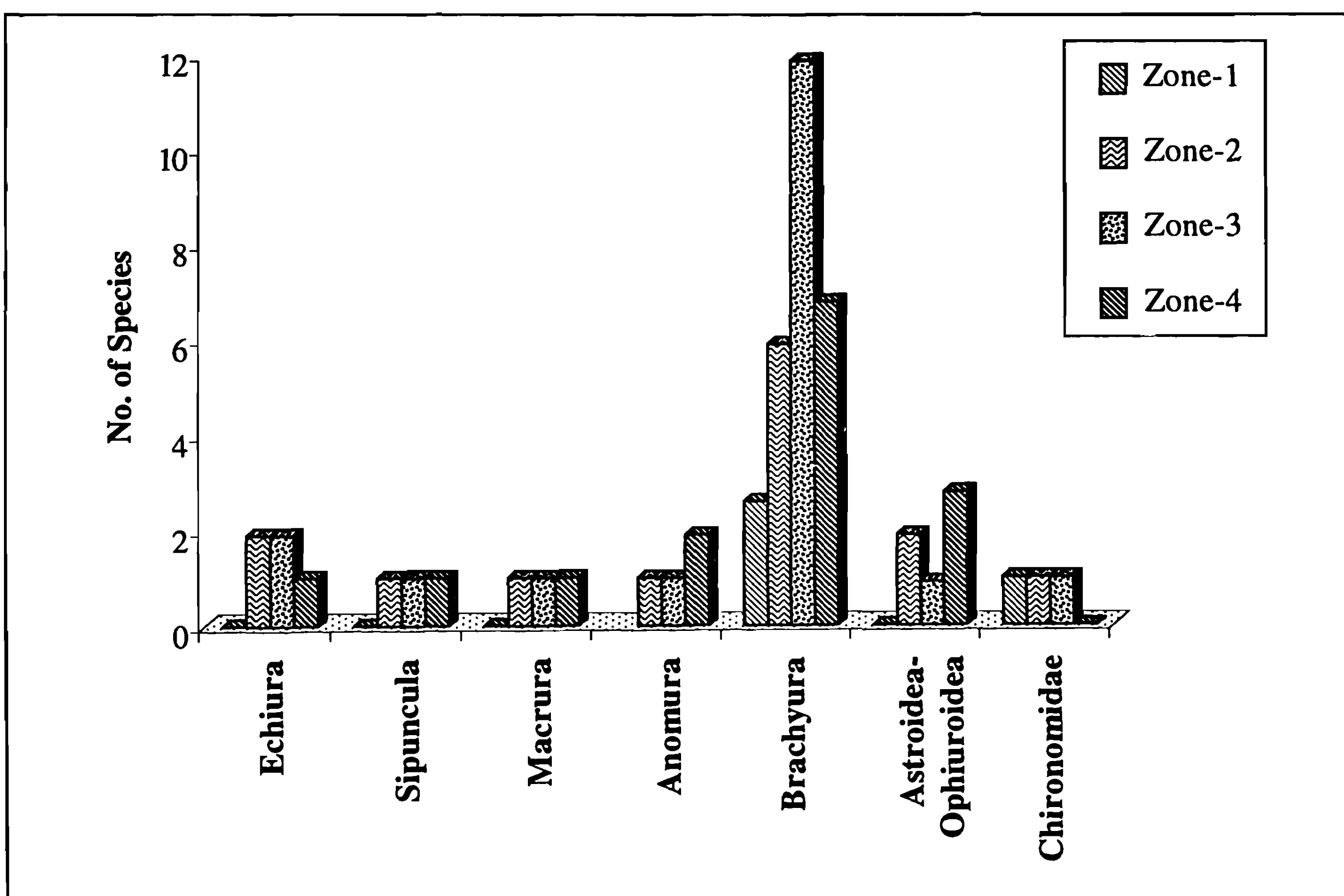


Fig. 4. Number of Species of different macrobenthic groups recorded from different zones.

Table 4. Numerically abundant taxa in different zones.

ZONE-1
Littorina (Littorinopsis) scabra (Linnaeus)
Stenothyra deltae (Bensen)
Assiminea francesiae (Wood)
Thiara (Thiara) Scabra (Muller)
Telescopium (T) telescopium (Linnaeus)
Cerithidea (Cerithidepsilla) cingulata (Gemlin)
Neanthes chingrighattensis Fauvel
Tubifex sp
Metaplax intermedia de Man

ZONE-3
Assiminea brevicola (Pfeiffer)
Telescopium (T) telescopium (Linnaeus)
Cerithidea (Cerithideopsilla) cingulata (Gmelin)
Pythia plicata (Gray)
Anadora granosa (Linnaeus)
Meretrix meretrix Linnaeus
Talehsapia annandalei Fauvel
Glycera sp
*Diopatra cuprea (*Bosc)
Clibanarius padvensis de Man
Sesarma tetragona Fabricius
Metapograpsus messor(Forskal)

ZONE-2
Assiminea brevicola (Pfeiffer)
Telescopium (T) telescopium (Linnaeus)
Cerithidea (Cerithideopsilla) cingulata (Gmelin)
Meretrix meretrix Linnaeus
Silqua albida Dunker
Talehsapia annandalei Fauvel
Dendronereides heteropoda Southern
Euricarcinus sp
Sesarma biddens (De Haan)

ZONE-4
Assiminea brevicola (Pfeiffer)
Anadora granosa (Linnaeus)
Meretrix meretrix Linnaeus
Donax incarnatus Schroter
Solen brevis Gray
Coenobita cavipes Stimpson
Diogenes sp
Metapograpsus messor (Forskal)
Ocypoda macrocera H. Milne-Edwards

varied between $65/m^2$ in Zone-1 and $126/m^2$ in Zone 3. The density in Zones 2 and 4 were also moderate, with values as $94/m^2$ and $74/m^2$ respectively. Density-wise too, the most abundant macrofaunal group was gastropod in all zones, contributing 41% to 67.0% in Zones 1, 2 and 3. Their contribution in Zone-4 was comparatively lesser (34%) due to considerable increase in the abundance of bivalves, which contributed nearly 19.46% as against their contribution of approximately 6%, 5.3% and 5.5% in Zones 1, 2 and 3 respectively. Polychaetes were almost

Table 5. Variation in density (No/m²) of major macrobenthic groups at different stations and Zones (Combined). Figures in parentheses indicate approximate percentage composition.

Macrobenthic groups	Number of species										
	Zone-1			Zone-2				Zone-3				Zone-4
	Station-I	Station-II	Combined	Station-III	Station-IV	Station-V	Combined	Station-VI	Station-VII	Station-VIII	Combined	Station-IX
Actinaria	–	–	–	–	2.5	6.5	**4.5(4.8)**	3	6.5	4	**4.5(3.5)**	–
Nemertina	–	–	–	–	–	–	–	1	0.5	–	**0.5(.4)**	**1(1.3)**
Bryozoa	–	–	–	0.5	0.5	0.5	**0.5(.5)**	–	1.5	–	**0.5(.4)**	–
Gastropoda	32	50	**41((63)**	38.5	48.5	65.4	**50.8(54)**	70.5	65	67	**67.5(53)**	**26(34)**
Bivalvia	3.5	4.5	**4(6.1)**	6.2	5.3	3.5	**5(5.3)**	4.8	10.7	5.5	**7(5.5)**	**14.5(19)**
Polychaeta	8.5	9.5	**9(13.8)**	13.5	9.8	18.5	**13.9(15)**	14.5	12.7	26.8	**18(14.3)**	**6.5(8.5)**
Oligochaeta	6	2	**4(6.1)**	–	–	–	–	–	–	–	–	–
Echiura	–	–	–	0.5	0.5	0.5	**0.5(.5)**	1	1	–	**0.7(.55)**	**0.5(.65)**
Sipuncula	–	–	–	–	1	0.5	**0.5(.5)**	–	1	0.5	**0.5(.4)**	**0.5(.65)**
Macrura	–	–	–	–	2.4	1	**0.9(.9)**	0.5	1.2	0.8	**0.8(.63)**	**0.5(.65)**
Anomura	–	–	–	2.2	6.5	9.3	**6(6.4)**	5.5	7	14.5	**9(7.1)**	**9(11.7)**
Brachyura	3.5	6.5	**5(7.7)**	7.7	8.2	14.5	**10.1(10)**	9	18	10.5	**12.5(9.9)**	**13(17)**
Astroidea-Ophiuroidea	–	–	–	–	–	1.5	**0.5(.5)**	7	5	–	**4(3.1)**	**5(6.5)**
Chironomidae	3	1	**2(3.1)**	1	0.5	–	**0.5(.5)**	–	–	1.5	**0.6(.48)**	–
TOTAL	56.5	73.5	**65**	70.1	85.7	121.7	**93.7**	116.8	130.1	131.1	**126.1**	**76.5**

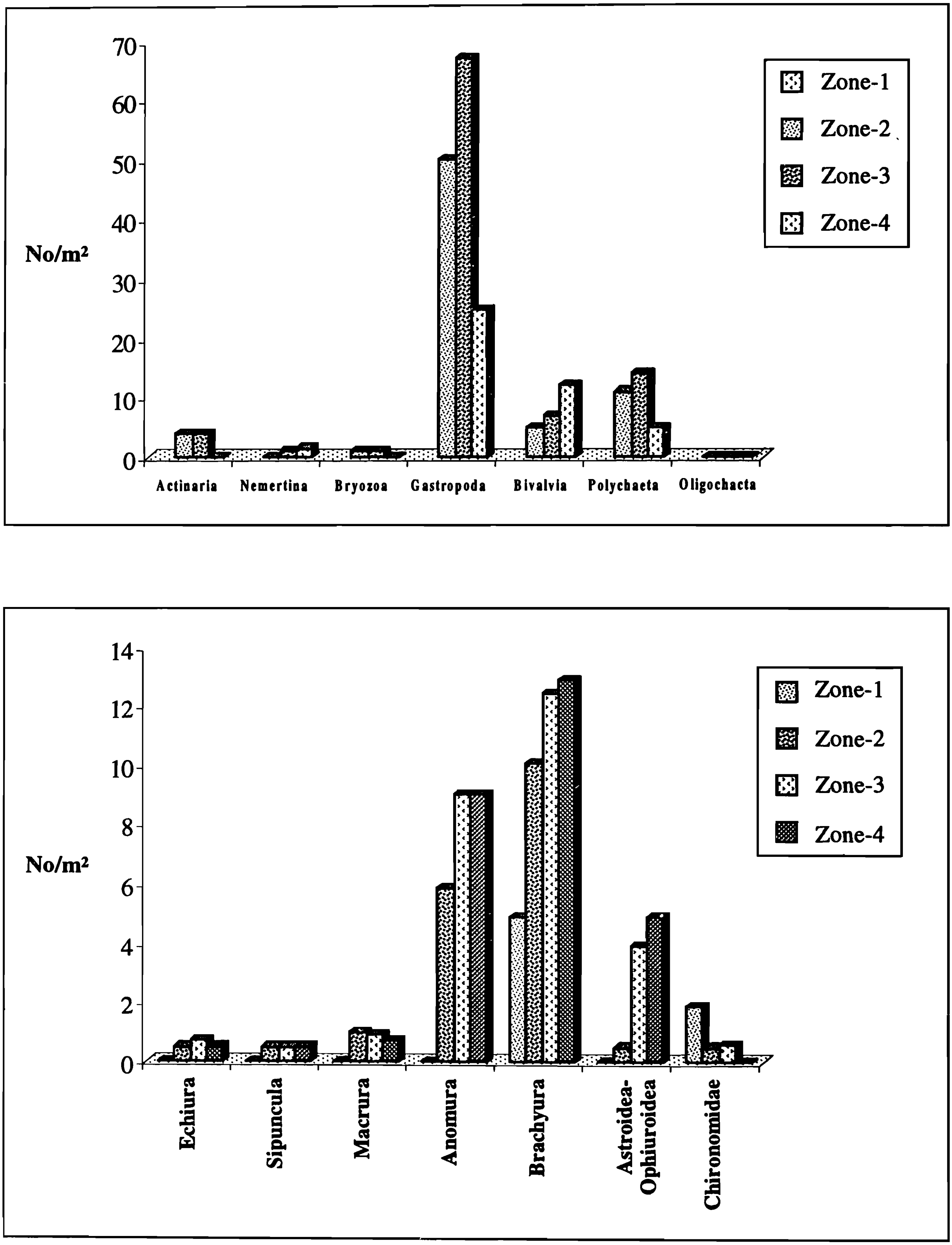


Fig. 5. Variations in mean density of major macrobenthic groups in different zones.

uniformly distributed in Zones 1 to 3, contributing between 14 to 18%. In Zone 4, their contribution was only 8.5%. Because of the occurrence of ocypod crabs in comparatively higher numbers, the contribution of total brachyuran crabs in Zone-4 was slightly higher (17%), as compared to other zones. The hermit crabs contributed significantly in Zones 2, 3, and 4 and the densities varied between 6.4–11.7%, highest in Zone-4 where two species of sand flat replaced the mud flat species *Clibanarius padvensis*. The contribution of all other groups, except Echinoderms– Asteroidea and Ophiuroidea, were very low.

Biomass

Biomass values of some important groups of macrobenthos are shown zonewise in Figs. 6 and detailed stationwise data are given in Table 6. Like abundance, highest biomass values were recorded from Zone-3 (29.2 g/m^2). While gastropods contributed maximum to biomass in Zones 1 to 3, the biomass contribution of bivalves was higher in Zone-3 (6.9 g/m^2), as compared to gastropods (2.9 g/m^2), which was mainly due to occurrence of large-sized bivalves on sand flats. Polychaetes and brachyuran crabs contributed almost equally in Zones 1 to 3 but the contribution of the latter in Zone 4 was comparatively higher. The ocypod crabs were responsible for the higher biomass in Zone-4.

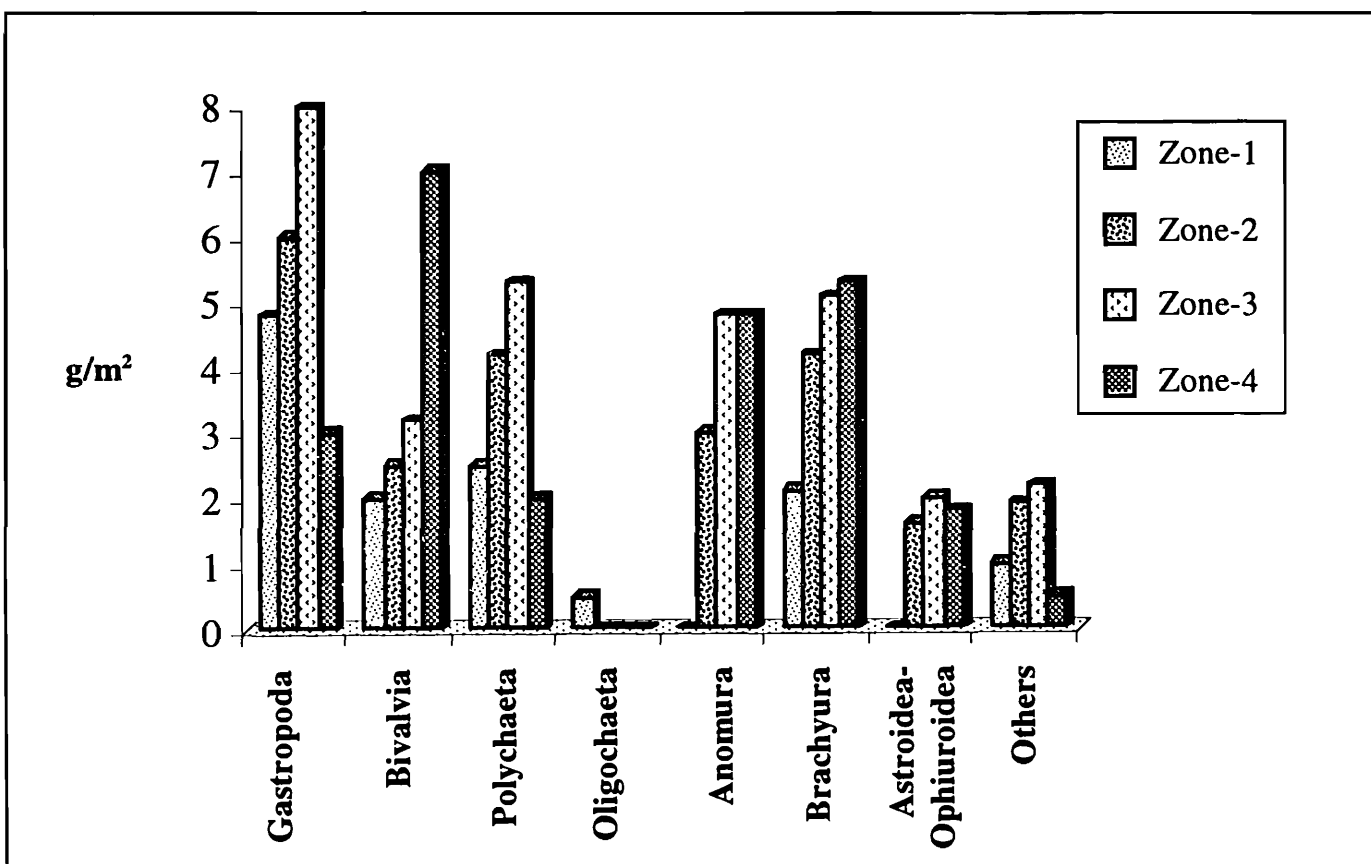


Fig. 6. Variation in mean biomass (g/m^2) of some important groups.

Table 6. Variation in biomass (g/m^2) of some important macrobenthic groups at different stations and Zones (combined). Figures in parentheses indicate approximate percentage composition.

Macrobenthic groups	**Number of species**											
	Zone-1			**Zone-2**				**Zone-3**				**Zone-4**
	Station-I	Station-II	**Combined**	Station-III	Station-IV	Station-V	**Combined**	Station-VI	Station-VII	Station-VIII	**Combined**	Station-IX
Gastropoda	4	5.2	**4.6(37)**	4.1	5.8	7.2	**5.7(26)**	8.4	6.7	7.6	**7.6(26)**	**2.9(12)**
Bivalvia	1.6	2.2	**1.9(15)**	3.1	2.8	1.3	**2.4(11)**	2.3	5.1	2.7	**3.4(11)**	**7(30)**
Polychaeta	2.2	3	**2.6(21)**	2.7	3.6	6.2	**4.2(19)**	4.4	3.3	8.2	**5.2(18)**	**1.9(8)**
Oligochaeta	0.6	0.2	**0.4(3.2)**	–	–	–	–	–	–	–	–	–
Anomura	–	–	–	1	3	4.2	**2.7(12)**	2.8	4.6	5.8	**4.4(15)**	**4.4(19)**
Brachyura	1	3	**2(16)**	3.4	2.2	6.4	**4(18)**	3	7.5	4.5	**5(17)**	**5.2(22)**
Astroidea-Ophiuroidea	–	–	–	–	–	3.3	**1.1(5)**	3	1.8	–	**1.6(5)**	**1.3(5)**
Others	1.3	0.6	**0.9(7.2)**	1.6	1.8	1.5	**1.6(7)**	2.1	1.7	2.2	**2(7)**	**0.5(2)**
TOTAL	10.7	14.2	**12.4**	15.9	19.2	30.1	**21.7**	26	30.7	31	**29.2**	**23.2**

E. Species diversity and Evenness

Almost all the indices applied (Table 7) revealed high diversity in Zones 2 to 4 and Zone 1 was characterised by lowest diversity. The Menhinik index values ranged between 2.728 and 5.167, Margalef's, between 5.031 and 11.785, Simposon's, between 0.4206 and 0.8958, and Shanon-Weiner's, between 2.118 and 4.560, highest in Zone 3 and lowest in Zone 1. The order of ranking was Zone 3, Zone 2, Zone 4 and Zone 1 in descending order, excepting Simpson's, which interchanged the position of Zones 4 and 3. The evenness values were 0.47, 0.61, 0.71 and 0.58 in Zones 1, 2, 3 and 4 respectively following the same ranking order. The values of Shannon-Wiener index was above three in all zones excepting Zone-1.

F. Similarity

Table 8 gives the values of similarity analysis of both indices, the qualitative of Greig-Smith and quantitative of Romaniszyn between the pairs of different zones. While qualitative index revealed higher similarity between Zones 2 and 3; 3 and 4 and 2 and 4, the quantitative index placed only Zones 2 and 3 close together. However, both indices gave almost similar highest values of similarity between Zones 2 and 3.

Table 7. Species diversity values.

Indices	Zone 1	Zone 2	Zone 3	Zone 4
Species richness (s)	22	44	58	39
Meenhinick Index of Diversity	2.728	4.538	5.176	4.518
Simpson's Diverity Index (D)	0.4206	0.7228	0.8958	0.8330
Shannon-Weeiner Diversity Index (H)	2.118	3.346	4.560	3.086
Pielow Evenness Index (J)	0.470	0.610	0.710	0.580

Table 8. Index of Similarity between Zones.

Pair of zones	Similarity indices	
	Qualitative (Grieg-Smith)	Quantitative (Romaniszyn
Zone-1 and 2	15.8	18.2
Zones 1 and 3	11.1	12.2
Zones 1 and 4	12.9	10.7
Zones 2 and 3	41.6	41.2
Zones 2 and 4	33.8	12.0
Zone 3 and 4	39.9	16.7

DISCUSSION

The total number of macrobenthic invertebrate taxa recorded during present investigations from Sunderban region of Hugly-Matla estuarine system is very low as compared to number of species recorded by taxonomists. A recent report (Subba Rao, 1995) summerises the number of species recorded from the estuarine system till date. This includes more than 300 species of only those macrobenthic groups that are considered during present study. Although this cumulative figure is based on detailed taxonomic surveys and collections spanning over a century, the currently recorded number of species are also considerably high (Anon, 1995). Such a large discrepancy could be related to two factors. Firstly, the present report is based on quantitative samples collected from very specific measured areas of few randomly selected spots at fixed depth without getting biased to animals occurring outside the demarcated area. Contrary to this, taxonomist made a thorough search of all possible habitats repeatedly including those available in water or attached to mangrove plants and even macrovegetations, over a very large space and for quite a long time, and also collecting those species which are important from taxonomic viewpoints like rare species etc. Further each worker was specialist of a particular group. Such efforts by a very large number of taxonomists are bound to yield considerably higher number of species. Secondly, during the present investigation too, not many efforts were made to take into consideration rarely occurring species, which were not important from general ecological viewpoints.

Even 83 species are taken into consideration, the number is sufficiently large as compared to several earlier reports on this estuary and also on many others. The earlier report from one part of the estuarine system (Bhunia and Choudhury, 1981; Choudhury *et al.,* 1984) lists less than 30 species. A general faunistic survey carried out by Misra and Barua (1987) revealed the existence of 70 species. It appears that many of the species reported earlier (Subba Rao, 1995) are either rare or do not occur in the areas surveyed during present investigations.

Comparatively high species richness and diversity of Sunderban estuarine system is exceptional, as estuaries in general have been reported to be low biodiversity areas because of their quickly changing nature and physically stressful conditions (Mclusky, 1971; Wildish and Kristmanson, 1979; Warwick and Uncle, 1980). However, there are several other estuaries where species richness was considerably high. Elliot and Kingston (1987) reported very high macrobenthic faunal species richness from Fourth estuary (East U.K. Coasts) with 87 species from just two grabs, and Barr *et al.,* (1990) found a total of 78 species from Humber estuary. Recently, Attrill *et al.,* (1996) recorded 200 species of benthic invertebrates (93 macrobenthic and 107 mieobenthic) from Chapman Buoy area of Thames Estuary. All these figures are very close to the number of macrobenthic species recorded from Sunderban estuarine system.

The species richness on the mud flats increased progressively from Zone-1 to Zone-3. The lowest number of species was recorded from upper zone of the estuary which was expected, as environmental stress was comparatively greater in this zone as compared to nearly stable conditions of other zones. As a general rule, species richness increases progressively from upper zone towards the mouths as conditions become more suitable, specially salinity.

Among the factors directly governing such increase in species richness and density, salinity and substrate have been reported to be of utmost importance (Carriker, 1967; Wildish, 1977; Paruleker and Dwivedi, 1977; Warwick and Uncle, 1980). It is clear from the physical composition of benthic sediments of mud-flats that composition changed considerably from Zone-1 to Zones 3 and 4. The high composition of silt in the sediments of lower zone was almost constant during different parts of the year but such changes in the composition of sediments in Zone-2 were quite pronounced. The high species richness in Zones 2 and 3. The high species richness in Zones 2 & 3, where the sediment composition was not very heterogeneous, is also a feature of this estuarine system, as high species richness of benthic fauna is generally associated with sediments of heterogeneous composition. However, the richness of sand flat could be related to such sediment heterogeneity. Increase in faunal diversity and abundance with increasing level of salinity was quite evident and such relationships in estuaries are well known.

Groupwise analysis revealed the dominance of gastropods both in terms of species richness and abundance followed by polychaetes. This important characteristic of Sunderban estuaries is not observed in most of other Indian estuaries. Generally macrobenthos of the estuaries are either dominated by polychaetes followed by bivalves (Purulekar *et al.*, 1975) or vice-versa (Paruleker and Dwivedi, 1974) or polychaetes followed by crustaceans (Untawale and Paruleker, 1976). In Vellar estuary, McIntyre (1967) reported the dominance of crustaceans. The dominance of polychaetes over gastropods have also been reported from other countries too (Atrill *et al.*, 1996). Similar dominance of gastropods on the intertidal flats of this estuarine system has also been observed by earlier workers (Choudhury *et al.*, 1984), Nandi and Choudhury, 1985).

Biotic indices based on quantitative diversity have been widely used in communities of benthic macroinvertebrates in order to assess the biodiversity patterns (Abele and Walters 1974, Clarke and Warwick, 1984). All the indices applied to benthic macroinvertebrates of Sunderban intertidal flats revealed comparatively very high diversity except in Zone-1. Higest diversity was observed in Zone-3. This result tallied well with all other biotic parameters that separated Zone 3.

The similarity analyses very clearly separated Zone-1 from rest of the zones, as the values were lowest in all sets where Zone-1 was involved. Secondly, it showed very high similarity between Zones 3 and 4. Considering the similarity of physico-chemical and biological conditions of these two zones, it was quite expected. The differences in the results obtained by the two types of indices were also evident. While qualitative index of Gerig-Smith gave higher values in several pairs, the quantitative one showed closeness of only one pair. It was probably due to the fact that the latter index also takes into consideration the density, besides species number. There were many species that were common to different zones but their densities differed considerably.

SUMMARY

Benthic macroinvertebrate biodiversity on intertidal flats of Sunderban estuarine region of Hugly-Matla estuarine system was studied between the period 1989 and 1993. Species composition, density and biomass of different groups were determined based on quantitative sampling.

For the purpose of spatial comparison, entire region was divided into four ecologically different zones viz. Mid-estuarine zone of main river Hugly (Zone-1), Hugly lower zone and flats (Zone-2), Thakuran-Matla mud flats (Zone-3) and Matla sand flats (Zone-4).

Quantitative collection over the length of survey revealed the occurrence of 83 taxa from all zones belonging mainly to four major groups, Gastropoda, Bivalvia, Polychaeta and Brachyura. Other groups were represented by a few taxa only. The maximum species richness was recorded from Zone-3 followed by Zone-2, both mud flats in lower zone, and minimum from Zone-1. However, maximum abundance and biomass was contributed by a few numerically abundant species in each zone.

Both abundance and biomass were high on mud flats and least values were obtained from mid estuary. Sand flats reflected a slightly different picture where biomass was higher in comparison to their numerical density. Gastropods dominated both in species richness and abundance in all zones.

To assess the macrobenthic species diversity, several quantitative and qualitative biotic indices were applied. All these indices pointed to high species diversity in all zones except Zone-1. The lower diversity of Zone-1 was related to great environmental stress due to continuously fluctuating tides and lower salinity level and higher diversity of mud flats in lower zone was due to stability of benthic sediments and higher salinity levels.

Both qualitative and quantitative indices of similarities were applied to find out the affinities between different zones. The indices separated clearly Zone-1 from others as most dissimilar. Highest similarity was recorded in case of Zones 2 and 3, both mud flats in lower estuarine zone.

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