

Benthic Studies in Goa Estuaries : Part III—Annual Cycle of Macrofaunal Distribution, Production & Trophic Relations

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Macrobenthos in Mandovi, Cumbarjua canal and Zuari estuaries, a physically interconnected tropical estuarine system which undergoes large seasonal changes in salinity distribution due to heavy monsoonal precipitation, is very rich (111 species) and varied. Fauna is most contiguously distributed showing high degree of aggregation, less affinity, lowest degree of association and high diversity. Six faunal assemblages based on dominant species and faunal associates are identified. Polychaetes and bivalves together contribute 70% of the macrofauna, by number and weight. Biomass production, inspite of large temporal and spatial variations, is high (54.17 g m^{-2}) with proportionately high organic matter production of $4.08 \text{ g C m}^{-2} \text{ y}^{-1}$. Estimated annual benthic production, based on standing stock measurements, is 49.95 g m^{-2} or 5 tonnes km^{-2} .

Earlier investigations¹⁻³ on the benthos of Goa estuaries relate to faunal distribution in relation to salinity incursion and sediment distribution. The present communication covers the annual cycle of environmental and biotic factors in relation to distribution, production, trophic relations and other relevant aspects of benthic macrofauna in the Mandovi, Cumbarjua canal and Zuari estuarine system of Goa.

Materials and Methods

Sampling for bottom fauna and temperature, salinity, dissolved oxygen and organic carbon of sediments, was done at fortnightly intervals, over 2 yr (1971-73) at 14 stations (Fig. 1). Macrobenthos samples in replicate were collected by a van Veen grab (0.04 m^{-2} surface coverage and 10 cm penetration) and sieved through a 0.5 mm mesh screen. Processing and analysis of benthic samples were done by the same technique as reported earlier⁴ and biomass values calculated on wet weight basis. Standard procedures were followed for the analysis of environmental factors.

Results and Discussion

Depth at different sampling points varied within a modest range, depending on the tidal phase and seasonal flooding. Variations were also due to time lag in tidal incursion, from mouth to the head of the estuary. In general, the average depth (m) in different sections of the estuarine system, was 6.01 ± 1.43 (Mandovi), 4.88 ± 0.88 (Cumbarjua canal) and 4.36 ± 1.01 (Zuari).

Temperature of the bottom waters (0.3 m above the sediment surface) showed variations (Table 1) of a modest magnitude. Range of temperature was of

almost similar order in all the 3 sections. High annual average value at sts 6 - 8 in the Cumbarjua Canal probably acts as a thermal intermediate zone between the 2 estuaries.

As assessed from the per cent coefficient values (Table 1), the magnitude of variations in salinity was more pronounced in the upper reaches of Mandovi (especially at sts 4 and 5) and gradually decreased towards Zuari with intermediate value in the Cumbarjua Canal.

Dissolved oxygen showed a decreasing trend downstream with minimum saturation at the river

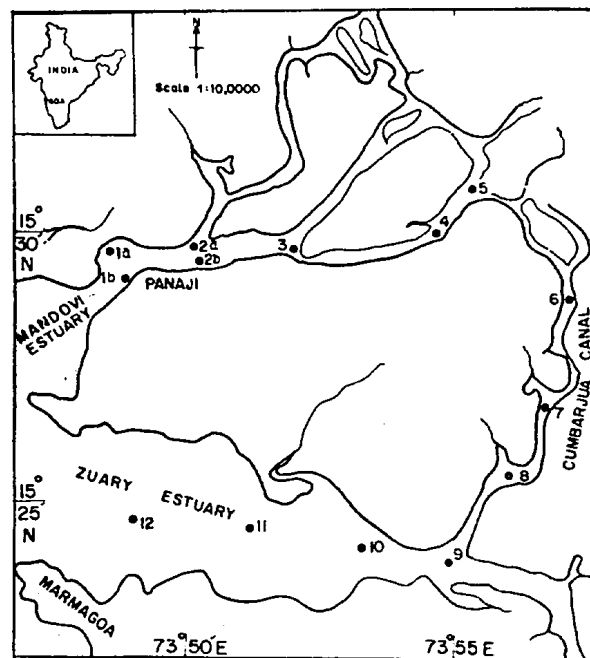


Fig. —Sampling stations

mouth (Table 1). Values < 1 ml/litre were recorded at sts 1 b and 12, when the temperature of bottom waters at these stations was also low.

Grain size distribution, for all stations along with animal sediment relationship has been reported¹⁻³ and therefore, only the broad substratum type along with the range of grain size is listed (Table 1).

Organic carbon in the bottom deposits showed wide fluctuations as indicated by high values of per cent coefficient of variations (Table 1). Except st 12 all the stations in the lower reaches had higher values than those in the upper reaches.

Fauna - distribution, abundance and composition—In all 111 species were identified (Table 2). At sts 11 and 12 chaetognaths, mysids, copepods and siphonophores were recorded in grab samples in July, but due to stray occurrence and insignificant numbers they have not been considered in final analysis.

Number of species and individuals, showed wide seasonal variations (Table 3). During monsoon, there was a considerable decrease in the population size. At st 1a, there was > 30 times depletion in the faunal abundance in monsoon. Number of species decreased from 50% at most of the stations to 95% at a few stations (st 9). Correspondingly, the population density also showed very low counts during monsoon followed

by gradual increase in the succeeding season. Seasonal qualitative and quantitative changes in the benthic macrofauna were more pronounced in the Mandovi, moderate in the Cumbarjua canal and less intense in the Zuari (Table 2).

Polychaetes and molluscs, especially bivalves, dominated the bottom fauna. At most of the stations, these 2 faunal groups constituted > 70% of the total fauna. Numerically dominant species (Table 2) were *Modiolus metcalfei* (st 1a), *Mytilus viridis* (st 1a), *Diopatra neapolitana* (sts 1 b, 2 a, 2 b and 8), *Meretrix casta* (sts 3 to 6 and 10), *Paphia malabarica* (st 9), *Cerithidea fluviatilis* (st 7), *Diogenes custus* (st 7) and *Glycera alba* (sts 11 and 12). Bivalves were dominant in Mandovi, polychaetes in Zuari and gastropod-polychaete combination in Cumbarjua canal. Most of these species were in large assemblages (population count of > 4000/m²) resulting in the formation of commercial beds of mussels (st 1a) or clams (sts 3, 6, 9 and 10). All the dominant species showed a seasonal pattern of abundance. *M. casta*, *D. neapolitana* and *G. alba* had maximum abundance in premonsoon season, whereas in other species (*M. metcalfei*, *M. viridis*, *P. malabarica* and *C. fluviatilis*), high population counts were generally encountered in the postmonsoon.

Dominant species also exhibited spatial variations

Table 1—Range; Mean and Per Cent Coefficient of Variation (in parenthesis) in Environmental Factors at Different Stations

St	Temp. °C	Sat. ‰	Dissolved oxygen ml/l	Organic carbon %	Type of substratum (mean size, mm)
1a	23.5-30.4;26.95 (100)	1.49-35.67;29.64 (105)	1.36-5.92;4.07 (104)	0.28-2.72;1.43 (113)	Hard-boulders with coarse sand (> 2)
1b	24 -30.6;26.86 (100)	4.18-35.98;30 (103)	0.9 -5.26;3.9 (109)	0.21-3.49;1.33 (119)	Sandy mud (0.25-0.125)
2a	24.5-30.6;26.95 (99)	0.27-35.89;26.1 (108)	2.12-5.49;4.27 (101)	0.11-2.51;1.24 (116)	Silty-clay (0.03-0.125)
2b	25 -30.4;26.98 (100)	0.27-35.97;27.76 (106)	1.36-6.29;4.22 (102)	0.14-2.92;1.22 (125)	Silty clay (0.03-0.125)
3	24.9-30.5;27.11 (100)	0.12-35.55;24.88 (109)	2.41-5.39;4.25 (101)	0.11-2.55;0.78 (144)	Sandy (0.5-0.25)
4	24.9-31.2;27.8 (100)	0.12-33.86;18.7 (120)	3.51-5.4;4.72 (100)	0.11-1.51;0.58 (120)	do
5	25.1-31.5;27.8 (100)	0.04-33.05;16.92 (124)	3.51-6.5;4.88 (101)	0.11-2.07;0.88 (123)	do
6	25 -32 ;28.44 (100)	0.12-37.78;19.24 (123)	3.71-5.93;4.51 (100)	0.24-1.8 ;1 (114)	Muddy sand (0.25-0.125)
7	25.6-31.8;28.37 (100)	0.12-36.09;21.92 (117)	3.51-5.59;4.3 (104)	0.14-2.93;0.84 (152)	Hard-cobble & coarse sand (> 2)
8	25.7-31.9;28.27 (100)	0.21-36.8 ;23.23 (118)	3.64-5.92;4.52 (100)	0.66-2.18;1.31 (108)	Clayey sand (0.125-0.025)
9	25.7-31.8;28.13 (98)	1.23-36.72;25.15 (115)	3.35-6.04;4.38 (101)	1.52-2.59;1.85 (110)	Silty clay (0.03-0.125)
10	25.2-31.2;27.98 (100)	3.15-36.35;27.36 (106)	1.48-5.17;4.09 (102)	0.79-3.15;2.09 (106)	Silty clay (0.03-0.125)
11	25.5-31.3;27.63 (100)	3.53-36.35;26.32 (105)	1.17-5.26;4.09 (104)	0.22-2.83;1.42 (119)	Sandy mud (0.25-0.125)
12	22.1-31.1;27.34 (100)	5.63-36.34;31.11 (102)	0.71-5.15;3.77 (106)	0.17-1.96;0.7 (122)	Sandy (0.5-0.25)

Table 2—Distribution of Macrobenthic Species at Different Stations in the Mandovi-Cumbarjua Canal-Zuari Estuarine System of Goa

Species	Stations														
	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12	
<i>Ammonia beccarii</i> (Linne)	---	2700a	---	182b	662b	7b	3b	5b	---	---	---	452a	---	1535a	
<i>Pteroides esperi</i> (Gray)	---	12b	---	---	---	---	---	---	---	---	---	---	290b	458b	
<i>Cavernularia orientalis</i> Thompson & Simpson	---	418b	---	---	---	---	---	---	---	---	---	---	212b	108b	
<i>Virgularia rumphii</i> , Kolliker	---	---	---	---	---	---	---	---	---	---	---	---	---	7b	
<i>Spongodes</i> sp.	---	---	---	---	---	---	---	---	1b	2b	---	---	---	1b	
<i>Anemonia indicus</i> , Parulekar	6b	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Cribrinopsis robertii</i> , Parulekar	73b	---	---	---	---	---	---	---	---	---	1a	30a	---	---	
<i>Pelocoeetes exul</i> (Annandale)	---	---	---	28a	---	---	---	---	---	---	2a	100a	---	---	
<i>Phycoetes gangeticus</i> (Annandale)	---	---	---	5	---	---	---	---	---	---	---	---	---	---	
<i>Metapeachia tropica</i> (Panikkar)	---	6b	---	---	---	---	2b	---	---	---	---	---	2b	8b	
<i>Edwardsia tinctoria</i> Annandale	---	---	---	1b	---	---	---	---	---	---	---	---	1b	---	
<i>Paraconylactis indicus</i> , Dave	---	---	1b	---	---	---	---	---	---	---	---	---	---	---	
Annelida-Polychaeta															
<i>Lepidonotus carinulatus</i> , Grube	---	587a	---	---	201a	123b	26b	3b	---	---	---	---	---	---	
<i>Gattyana deludens</i> , Fauvel	139a	437a	---	98b	24b	1b	6b	2b	---	---	---	5b	27b	105a	
<i>Panthalis oerstedii</i> , Kinberg	4a	3b	---	---	---	---	---	---	1b	---	---	---	28b	1b	
<i>Eurythoe complanata</i> , (Pallas)	11a	---	---	---	---	---	---	---	8b	---	---	---	---	---	
<i>E. parvecarunculata</i> , Horst	---	---	---	---	---	1b	---	2b	---	---	---	---	86b	13b	
<i>Leocrates claparedii</i> , (Costa)	---	85a	---	1b	1b	1b	---	---	---	---	---	---	6a	---	
<i>Syllis closterobranchia</i> , Schmarda	---	---	---	---	---	---	---	---	---	---	94b	239b	187a	102a	
<i>Nereis capensis</i> , Grube	4a	266a	---	81b	27b	---	---	1b	---	---	---	7b	5a	---	
<i>N. mirabilis</i> , Kinberg	8a	190a	3b	57b	6b	1b	---	---	---	---	---	---	---	3a	
<i>N. zonata</i> , Fauvel	---	18a	---	---	---	---	---	---	---	---	---	---	1b	---	
<i>N. burmensis</i> , Monro	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Leptonereis</i> sp.	---	---	4a	---	---	---	---	---	---	---	---	---	---	---	
<i>Perinereis nigropunctata</i> Horst	---	---	1b	---	1b	---	2b	---	3b	---	---	---	---	18a	
<i>P. nuntia</i> , (Savigny)	---	43b	---	---	---	---	---	---	---	---	---	---	---	9a	
<i>P. aibuhitensis</i> , (Ehlers)	28a	119a	47a	3a	1b	1b	---	---	---	---	---	---	1b	---	
<i>P. cultrifera</i> , Grube	---	---	---	---	---	---	---	---	1b	---	---	---	---	---	
<i>Dendronereis arborifera</i> , Fauvel	1b	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>D. aestroma</i> , Fauvel	---	---	2b	---	---	---	3b	---	---	---	---	---	---	---	
<i>Lumbriconereis heteropoda</i> , Marenzeller	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>L. pseudobifilaris</i> , Fauvel	---	6a	---	---	---	---	---	---	---	---	---	---	30a	7a	
<i>Phyllodoce tenuissima</i> , (Savigny)	---	4a	---	---	---	---	---	---	---	---	---	---	3a	---	
<i>Mercierella enigmatica</i> , Ehlers	5a	23a	---	---	1b	---	---	---	---	---	---	1b	1b	7a	

Table 2—Distribution of Macrobenthic Species at Different Stations in the Mandovi-Cumbarjua Canal-Zuari Estuarine System of Goa—Contd

Species	Stations													
	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12
<i>Glycera alba</i> , Rathke			384a	8a		40b	68b			288a	409a		1384a	867a
<i>G. longipinnis</i> , Rathke			101a			2b				7a	9a		54a	12a
<i>Sthenalais boa</i> , (Johnston)		6b			8b									1b
<i>Prionospio cirrifera</i> , Wiren			991a	124a			183b			849a	551a	400a		
<i>P. pinnata</i> , Ehlers			311a	494a						133a	783a	209a	87a	
<i>Diopatra neapolitana</i> , Delle chiaje			789a	909a	86a	417a		162a	10a	6882a	453a	608a	329a	89a
<i>Terebella ehrenbergi</i> , Grube		3b												
<i>Marphysa sanguinea</i> , Montagu	5b	33b		9b	2b								28b	
<i>M. mossambica</i> , Peters		3b										244b	387b	
<i>Sabellaria cementarium</i> , Moore	764a				18a	21a	5a	3a			2b	34a	183a	84a
			Echiuroidea											
<i>Thalassema</i> sp.			579a	9a		7a				93a	67a		237a	103a
			Mollusca											
<i>Dentalium octangulatum</i> , Donovan														2b
<i>Crepidula walshi</i> , Herrmann										17a				
<i>Natica tigrina</i> , (Roding)					18a	4a	3a	188a			206a			
<i>Cerithidea fluviatilis</i> , (Poteez & Michoud)			1359a			752a	84a	12a	49a	2810a				
<i>Turritella attenuata</i> , Reeve		48b											2b	48b
<i>Thais ruguosa</i> , (Lamarck)	248a													
<i>Telescopium telescopium</i> , (Linne)						11a				44a				
<i>Terebralia palustris</i> , (Linne)						4a				7a				
<i>Neritina depressa</i> , Benson						2a				3a				
<i>Onchidium verruculatum</i> , Cuvier						1b				3b				
<i>Meretrix casta</i> , (Chemnitz)		103a		68a	9010a	893a	924a	6834a				2391a	625a	287a
<i>Paphia malabarica</i> , (Chemnitz)	398a			187a						218a	2467a	1658a	710a	18a
<i>P. textile</i> , (Gmelin)	10a			6a							23a	4a	4a	3a
<i>Sunetta solandri</i> , Gray		18a												
<i>Donax incarnatus</i> , Linne		269a												
<i>D. apperitus</i> , Linne		9a												
<i>Nucula semiramisensis</i> , Reeve													1b	
<i>Martesia striata</i> , (Linne)	4a													
<i>Siliqua albida</i> (Monothya)			43a									70b	22b	
<i>Pholas orientalis</i> , Gmelin										24a				
<i>Anomia acheus</i> , (Linne)										249a				
<i>Tellina</i> sp.	31a					46a	10a							
<i>Dossinia modesta</i> , (Sowerby)	2a												326b	481b
<i>D. trigona</i> (Reeve)													28b	130b
<i>Gafrarium</i> sp.	4b				18b	1b		12b				16b		

Contd

Table 2—Distribution of Macrobenthic Species at Different Stations in the Mandovi-Cumbarjua Canal-Zuari Estuarine System of Goa—Contd

Species	Stations														
	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12	
<i>Mytilus viridis</i> , Linne	800a	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Modiolus metcalfei</i> (Hanley)	2358a	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Modiolus</i> sp.	9a	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Anadara granosa</i> , Lam.	—	—	187a	—	—	—	41b	—	—	—	24a	19a	20a	—	
<i>Fossularia symmetrica</i> , Brug.	—	—	5a	—	—	—	—	—	—	—	244a	13a	3a	—	
<i>Placenta placenta</i> , (Linne)	—	—	—	—	—	—	—	—	—	—	20a	183a	—	—	
<i>Solen truncatus</i> (Sowerby)	—	—	—	—	—	—	—	—	—	—	56a	106a	—	—	
<i>Crassostrea bicolor</i> , Hanley	4a	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>C. madrasensis</i> , Preston	—	—	—	—	314a	—	—	—	—	—	—	—	—	—	
<i>C. cucullata</i> , Born	481a	—	—	—	600a	—	—	—	—	—	—	—	255a	—	
<i>Lingula</i> sp.	—	—	—	—	—	—	—	—	—	—	3a	—	—	—	
Brachiopoda															
Arthropoda - Crustacea															
<i>Balanus amphitrite</i> , Darwin	37a	—	—	—	12a	—	—	—	—	—	—	—	—	118a	
<i>Sphaeroma annandalei</i> , Stebbings	—	1b	—	—	4b	2b	—	—	—	13b	—	—	—	—	
<i>Limnoria</i> sp.	—	—	—	—	249a	5b	1b	—	—	—	—	—	—	—	
<i>Corophium</i> sp.	—	162a	57a	310a	203a	203a	61a	28a	3a	486a	—	157a	264a	—	
<i>Eurydice</i> sp.	—	438a	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Alpheus malabaricus</i> , Fabricius	—	—	16b	—	—	2b	—	—	—	4b	—	1b	—	—	
<i>Alpheus</i> sp.	—	—	2b	—	—	—	—	—	—	—	—	—	—	—	
<i>Metapenaeus monoceros</i> , Fabricius	—	—	—	—	—	—	6a	4a	21a	—	—	—	1b	—	
<i>Caridina</i> sp.	—	—	—	—	—	—	—	—	—	—	—	3b	26b	5b	
<i>Dorippe astuta</i> , (Fabricius)	—	—	—	—	—	—	—	—	—	—	—	—	1b	—	
<i>Matuta victor</i> , (Fabricius)	—	2b	—	—	—	—	—	—	—	—	—	—	—	—	
<i>M. lunaris</i> , (Forsk.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Calappa hepatica</i> , (Linnaeus)	—	—	21b	9b	—	—	2b	—	—	—	—	3b	33b	8b	
<i>Charybdis cruciata</i> , (Herbst)	—	—	—	—	—	—	—	—	—	—	—	7b	—	—	
<i>Scylla serrata</i> , (Forsk.)	—	—	—	—	10a	18a	304a	48a	—	—	—	2b	414b	183b	
<i>Portunus pelagicus</i> (Linnaeus)	—	—	—	—	—	—	—	—	—	—	—	19b	47b	31b	
<i>P. sanguinolentus</i> (Hebst)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Marcophthalmus sulcatus</i> , (Milne-Edwards)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Dotilla myctiroides</i> , (Milne Edwards)	—	39b	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Sesarma oceanica</i> , de Man	—	13b	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Diogenes custus</i> , (Fabricius)	6a	40a	3a	—	5a	—	—	—	53a	87a	3a	1a	46a	7a	
<i>Clibanarius padavensis</i> , de Man	4a	5a	19a	—	—	—	—	—	2a	2a	6a	—	3a	—	
<i>Pinnotheres</i> sp.	—	—	1b	—	—	—	—	—	—	26b	—	1b	—	—	
<i>Petrolisthes boscii</i> , (Audouin)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Contd

Table 2—Distribution of Macrobenthic Species at Different Stations in the Mandovi-Cumbarjua Canal-Zuari Estuarine System of Goa —Contd

Species	Stations													
	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12
Echinodermata														
<i>Astropecten indica</i> , Smith		4b											1b	2b
<i>Temnopleura toreumaticus</i> , (Klein)		3b											12b	31b
<i>Ophiactis savignyi</i> , Muller & Troschel				2b										
<i>Synapta</i> sp.			1b									1b		
Pisces														
<i>Glossogobius giuris</i> (Hamilton-Buchanan)						4a				14a				
<i>Boleophthalmus dussimieri</i> , Cuv. & Val.						26a				67a				

a = Present throughout the year; b = Not present in the monsoon season

Table 3—Number of Species and Population Counts at Different Stations

St	No. of species		Population count (m ⁻²)	
	Total	Monsoonal	Total	Monsoonal
1a	27	6	3901	121
1b	35	16	1169	192
2a	25	11	1861	512
2b	22	10	492	356
3	23	13	1176	990
4	29	14	1087	846
5	20	12	2242	244
6	15	8	4382	2120
7	13	6	523	93
8	24	6	502	125
9	20	1	1350	484
10	32	16	1851	246
11	45	25	1401	810
12	37	18	1201	250

in their distribution. Bivalve species were conspicuous on sandy and hard substrates. Polychaeta sedentaria were abundant in silty or silty-clay substrates, whereas the errant polychaetes were most common in the sandy or sandy-mud deposits. Most of the crustacean species being epifaunal in habit, showed little substrate preference. Some of the species grouped under miscellaneous displayed substrate specificity. At st 7, where the bottom deposits were heavily covered with mining refuse, there was a considerable impoverishment in animal life. No single species, inspite of its numerical abundance, showed a continuous distribution in time and space in the estuarine system of Goa (Table 2).

Spatial dispersion, faunal similarity, association and diversity—Patchiness or discontinuous distribution was investigated by computing the index of dispersion and testing this against the poisson distribution⁵. These indices were calculated separately, for total fauna as well as for polychaete and bivalve fractions which together account for > 70% of the total. The index values for total fauna at different stations (Table 4) were always > 1 indicating contiguous distribution. Similarly, the dispersion patterns for polychaetes (except at st 10 where regular distribution prevailed) and bivalves were also highly contiguous. Departures from randomness (values > or < 1) were found significant (P < 0.05). Distribution patterns showed maximum (3.2) and minimum (2.6) contiguity in Mandovi and Zuari respectively. Similarly, bivalves which dominated the benthic macrofauna in Mandovi were more (3.17) aggregated than polychaetes (1.98).

The patchiness in the faunal distribution was further investigated by measuring the coefficient of association

(T) between 2 stations⁶. Using 2 × 2 contingency table, coefficients were computed for all possible combinations of station pairs, taking into account the presence or absence of the 111 species (Table 2). The values (Table 5) showed very low degree of association between different sets of stations. Similarity indices⁷ based on species composition at different stations were also calculated.

Maximum similarity was > 15% between st 1 b and st 2 b whereas between all the other sets of stations, it was < 11% (Fig. 2). These and the coefficient of association values (Table 5) clearly indicate that the macrofauna in different parts of this estuarine system is very much diverse. Therefore, for understanding the magnitude of faunal diversity, indices were also calculated, separately, for individual stations⁸ and between sets of stations⁹.

The value \bar{d} (index of diversity) showed large temporal and spatial variations (Table 6). A gradual decrease in faunal diversity was observed from the

Mandovi to the Zuari with intermediate values in the Cumbarjua canal.

Diversity between the stations⁹ and the measure of diversity¹⁰ at respective stations (Fig. 4) indicate that the fauna at st 7 was least diverse, whereas at sts 1 a, 3 and 6 it was highly diverse. Similarly, fauna at st 12 compared with that at st 3 showed high diversity (3.11), while at st 8 in relation to that at sts 1 b and 2 b it had the lowest diversity or in other words, more affinity.

Standing stock and production estimates—Macrobenthic biomass production (wet weight, excluding skeletal parts) showed large seasonal variations (Table 7). At all locations, except at st 9, lowest biomass values were recorded during monsoon. High biomass production was either in postmonsoon (sts 1 b, 2 b, 4 to 7 and 11) or premonsoon (sts 1 a, 2 a, 3, 8, 10 and 12) season. Seasonal biomass production varied by more than 100 times at most of the stations, with the highest degree of variation of 800% or more at st 1 a, 1 b and 6.

Table 4—Index of Dispersion of Total Fauna, Polychaetes and Bivalves at Different Stations

St	Total Fauna	Polychaetes	Bivalves
1a	4.9	1.2	3.4
1b	2.1	2.7	2.2
2a	2.5	2.5	4
2b	1.6	1.5	1.5
3	1.8	2.3	1.8
4	2.7	2.6	4.4
5	6.8	3.9	8.8
6	3.8	1.7	3.9
7	3.1	1.7	4.6
8	2.2	2.3	1.2
9	1.7	1.9	1.9
10	5	0.28	2.4
11	1.4	1.6	1.5
12	2.3	1.6	2.8

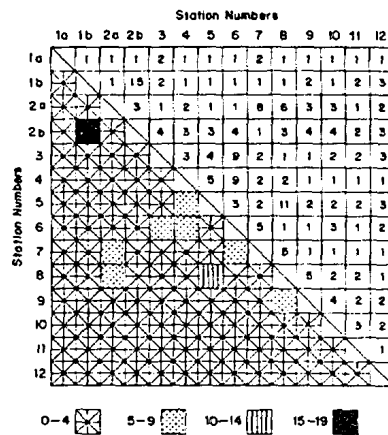


Fig. 2—Per cent faunal similarity in macrofauna (benthos) between different stations in Mandovi-Cumbarjua Canal-Zuari Estuarine System

Table 5—Coefficient (\bar{T}_{ab}) of Faunal Association Between Different Stations

	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12
1a	—	0.06	0.10	0.08	0.16	0.09	0.15	0.02	0.02	0.06	0.03	0.01	0.002	0.001
1b	—	—	0.04	0.05	0.25	0.05	0.03	0.01	0.005	0.16	0.19	0.04	0.26	0.34
2a	—	—	—	0.21	0.03	0.17	0.08	0.02	0.54	0.45	0.27	0.27	0.12	0.01
2b	—	—	—	—	0.34	0.27	0.29	0.33	0.02	0.24	0.31	0.33	0.23	0.27
3	—	—	—	—	—	0.33	0.32	0.56	0.14	0.09	0.06	0.19	0.1	0.27
4	—	—	—	—	—	—	0.41	0.54	0.10	0.1	0.14	0.1	0.32	0.2
5	—	—	—	—	—	—	—	0.22	0.12	0.5	0.17	0.11	0.09	0.21
6	—	—	—	—	—	—	—	—	0.34	0.06	0.06	0.21	0.04	0.16
7	—	—	—	—	—	—	—	—	—	0.32	0.02	0.04	0.07	0.01
8	—	—	—	—	—	—	—	—	—	—	0.37	0.07	0.07	0.03
9	—	—	—	—	—	—	—	—	—	—	—	0.33	0.14	0.07
10	—	—	—	—	—	—	—	—	—	—	—	—	0.28	0.14
11	—	—	—	—	—	—	—	—	—	—	—	—	—	0.46

Table 6—Index of Diversity (\bar{d}) at Different Stations and in Different Months

Month	Stations													
	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12
June	3.41	5.57	2.86	3.7	1.37	0.71	1.35	1.35	1.17	4	2.11	1.95	0.55	0.53
July	1.43	2.53	4.9	2.57	2.04	1.17	0.95	0.62	0.58	5.36	0.68	1.45	1.62	0.71
Aug.	3.19	3.56	3.19	1.63	1.11	1.74	1.97	0.85	1	1.87	1.32	1.95	1	0.58
Sept.	2.22	2	3.61	2.91	3.04	3.16	3.53	1.75	0.91	1.37	2.04	0.63	0.89	—
Oct.	2.08	4.77	4.35	4.31	2.16	3.4	2.31	2.03	4.26	3.43	3.15	1.24	1.22	0.91
Nov.	2.79	5.3	4.27	5.48	1.88	3.64	3.66	4.4	3.07	4.86	1.27	2.33	3.05	2.35
Dec.	5.72	7.44	6.17	6.61	3.4	4.4	4.59	2.41	2.94	3.22	2.29	1.71	2.58	—
Jan.	5.8	6.56	6.44	5.66	4.98	5.75	4.44	2.16	2.48	5.07	1.68	2.66	2.33	4.8
Feb.	4.89	8.65	5.49	4.55	3.77	4.54	5.41	4.7	2.54	2.94	0.7	1.9	2.97	1.83
March	4.87	12.86	5.14	3.96	1.59	2.42	3.44	3.57	0.75	3.03	1.21	3.51	0.53	4.48
April	5.11	9.51	5.56	3.22	3.85	3.56	3.05	2.6	1.5	3.96	1.87	4.09	0.99	2.58
May	3.67	8.78	5.72	5.05	4.26	2.09	2.49	3.21	0.53	3.52	3.14	4.1	1.18	3.41
Mean	3.76	6.46	4.80	4.13	2.78	3.04	3.09	2.47	1.81	3.55	1.78	2.29	1.57	2.21
SE(±)	1.42	3.02	1.1	1.37	1.2	1.26	1.28	1.24	1.15	1.15	0.78	1.0	0.87	1.76

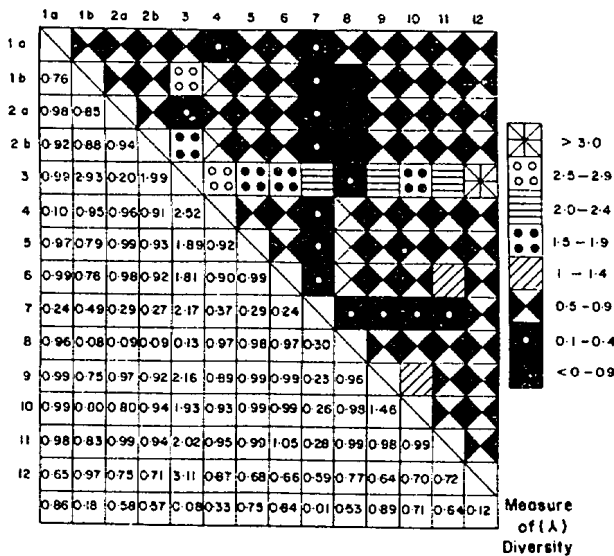


Fig. 3—Measure and index of faunal diversity in macrobenthos at and between different stations in Mandovi-Cumbarjua Canal - Zuari Estuarine System

Spatial variations were mainly due to difference in the type of bottom deposits, as evidenced by high annual averages of $> 100 \text{ g m}^{-2}$ at certain stations (1 a, 3 and 6) dominated by mussels and/or clams flourishing in hard or sandy bottom deposits. For the estuarine system as a whole, the annual average was 54.17 g m^{-2} with sectional values of 70.55 (Mandovi), 61.9 (Cumbarjua canal) and 22.23 (Zuari).

The wet weights of all the major taxonomic groups were determined separately and the data converted into dry organic matter using the conversion factors derived from the actual observations on wet weight/organic matter relationships for the numerically important species. For polychaetes, molluscs, crustaceans and miscellaneous faunal groups, the

mean conversion factors were 0.119, 0.062, 0.141 and 0.09 respectively.

Comparison of per cent dry organic matter content with the percentage composition of respective faunal groups at different stations indicates (Table 8) that though the molluscs (46.75%) formed the dominant group, the polychaetes contributed maximum (43.82%) to the total organic matter. In crustaceans and miscellaneous groups, there was a direct relationship between faunal abundance and dry organic matter production. The differences in organic matter values in respect of different faunal groups are also due to the varying degree of water content in molluscs (75-80%) and polychaetes (62-65%). Based on organic matter values attempts have been made to compute the total standing crop at different stations in order to estimate the annual production of benthic macrofauna.

Annual mean production (Table 8) for the estuarine system as a whole was $4.08 \text{ g C m}^{-2} \text{ y}^{-1}$ with sectional mean values of 5.19 (Mandovi), 4.80 (Cumbarjua canal) and 1.98 (Zuari). These values are in accordance with the observed biomass (wet weight) at different stations.

A rough estimate of the macrobenthic production at different stations for June 1971 - May 1973, was attempted by the method of Crisp¹¹. Biomass values, growth progression and age-composition of some of the dominant species like *Meretrix casta*¹², *Paphia malabarica*¹³, *Mytilus viridis*¹⁴ and *Modiolus metcalfei*¹⁵ indicate that with a few exceptions, all individuals were 1 yr or less in age and hence the data obtained are comparable¹¹ for production estimates. At times, between the 2 successive samplings, a negative value for weight increment was observed and therefore, necessary corrections were applied¹⁶. The negative values are also theoretically possible, because of either lack of new settlement of planktonic larvae or due to

Table 7—Seasonal Biomass (g m^{-2}) Variation at Different Stations
[Values are range with mean in parentheses]

St	Monsoon (June-September)	Postmonsoon (October-January)	Premonsoon (Feb-May)
1a	0.09-2.24 (0.62)	11.7-772.8 (243.77)	0.3-524.7 (266.17)
1b	0.08-17.37 (3.87)	0.74-855.6 (128.29)	0.14-6.9 (1.34)
2a	0.05-19.84 (3.83)	2.16-108.32 (25.03)	2.1 -153.6 (43.98)
2b	0.06-60.51 (12.86)	1.68-108.3 (26.05)	0.32-33.6 (6.83)
3	0.34-198.15 (34.74)	9.03-659.4 (169.01)	0.48-584.4 (302.42)
4	0.01-11.38 (2.11)	4.36-140.7 (37.24)	1.1 -87.9 (28.6)
5	0.05-1.02 (0.38)	3.6 -312. (79.22)	0.26-117.9 (22.58)
6	0.3 -227 (31.01)	22.5 -876.9 (314.02)	0.42-195.6 (69.48)
7	0.11-4.16 (1.20)	00.9-146.7 (30.04)	0.26-74.4 (22.67)
8	0.19-15.25 (5.23)	4.5 -40.95 (17.85)	0.24-336.3 (66.97)
9	0.01-78.77 (18.22)	2.64-26.4 (12.54)	1.08-18 (6.96)
10	0.04-44.85 (7.54)	1.83-112.04 (33.75)	5.1-111.97 (34.3)
11	0.02-0.6 (0.14)	0.36-229.2 (41.83)	1.15-36.9 (9.46)
12	0.01-2.8 (0.94)	0.36-79.8 (17.06)	0.54-220.5 (68.02)

Table 8—Standing Stock of Benthic Macrofauna and Contribution by Different Faunal Groups

St	Faunal composition (%)				Total standing stock (g C m^{-2})	Mean standing stock (g C m^{-2})
	Polychaetes	Molluscs	Crustaceans	Miscellaneous		
		Dry organic matter (%)				
1a	17.79	79.88	0.86	1.46	231.97	12.2
	33.7	62.8	1.8	1.7		
1b	37.86	6.47	10.12	45.54		
	46.51	3.28	14.04	36.17	114.64	5.45
2a	72.87	18.84	1.42	6.86		
	84.09	8.97	1.83	5.11	68.06	2.83
2b	68.77	10.06	12.41	8.75		
	74.32	4.48	15.11	6.09	40.17	1.91
3	3.62	87.38	2.61	6.38		
	7.72	77.18	6.28	8.82	233.79	10.16
4	23.27	66.08	8.87	1.68		
	37.66	44.22	16.36	1.76	42.4	1.92
5	20.12	72.88	6.65	0.34		
	34.69	51.99	12.94	0.37	53.43	2.54
6	2.28	93.18	4.45	0.06		
	4.96	84.01	10.93	0.08	198.11	8.61
7	11.44	24.37	63.69	0.49		
	12.23	10.75	76.69	0.33	41.37	2.17
8	69.95	27.22	1.32	1.5		
	83.62	13.45	1.77	1.65	63.26	3.01
9	42.47	66.02	0.16	1.34		
	63.7	34.76	0.27	1.26	26.15	1.13
10	23.92	60.94	7.15	7.98		
	38.37	40.42	12.92	8.28	46.65	2.12
11	45.06	31.3	11.6	12.03		
	57.15	16.42	16.57	9.86	41.15	1.95
12	26.26	19.69	12.49	41.55		
	34.84	10.79	18.69	35.67	44.63	3.18

non-feeding period of certain species. Other possibility is that a great many of the larvae that settle between 2 successive sampling dates, are either eaten or lost due to natural mortality.

Estimated annual production (Table 9) values were tested by a chi-square and the calculated χ^2 (6.302) was less than the table χ^2 (22.36) value, which substantiates the reliability of the estimated production. The estimated production in unit area for the whole estuarine system works out to be $49.95 \text{ g m}^{-2} \text{ y}^{-1}$ which is not very much different ($< 10\%$) from the observed biomass value of 54.17 g m^{-2} .

Taking $49.95 \text{ g m}^{-2} \text{ y}^{-1}$ as a representative figure of annual production, the estimated annual macrobenthic biomass production for the investigated area of 40 km^2 would be about 199.87, roughly 200 tonnes. Taking dry weight to be about 22% of the wet weight, and the carbon content to be 34.5% of the dry weight, the annual organic carbon production would be 14.5 tonnes, which is very high as compared to earlier reports¹⁶⁻¹⁹.

Trophic relations—The macrobenthic infauna is dominated by polychaete-bivalve combination, which are filter-feeders and therefore, mainly subsist on the particulate organic matter in the water column.

Productivity of benthos is presumably related to the primary productivity of the overlying water column¹⁹. In this estuarine system, the annual primary production is $205 \text{ g C m}^{-2} \text{ y}^{-1}$ (ref. 20), while the zooplankton production is reported²¹ to be $7.81 \text{ g C m}^{-2} \text{ y}^{-1}$. Observed macrobenthic standing stock is $4.08 \text{ g C m}^{-2} \text{ y}^{-1}$, which is mainly derived from organisms like polychaete-bivalves, for which Sanders¹⁸ suggests annual production to be about twice the standing stock and therefore, the estimated

Table 9—Production Estimates ($\text{g m}^{-2} \text{y}^{-1}$) of Benthic Macrofaunal Biomass at Different Stations

St	Observed	Estimated
1a	174.06	253.72
1b	50.42	53
2a	24.28	13.19
2b	15.53	9.96
3	163.22	92.81
4	23.32	14.94
5	33	26
6	141.16	113
7	17.47	15.1
8	27.07	24.87
9	12.82	7.98
10	25.58	20.83
11	18.68	14.9
12	31.81	32.06

biomass production will be about $8.16 \text{ g C m}^{-2} \text{y}^{-1}$.

Slobodkin²² has defined the ecological efficiency as the ratio of yield in one trophic level to the next trophic level, only if the yield is a constant fraction of production. The computed ratio for the transfer coefficient for the area under study varies²³ from 1.7 - 39.9%. Assuming 10% ecological efficiency, the secondary production would be $20.5 \text{ g C m}^{-2} \text{y}^{-1}$, whereas from the data of the present investigation, it works out to be $15.98 \text{ g C m}^{-2} \text{y}^{-1}$ (7.82 zooplankton + 8.16 macrobenthos). The difference of $4.52 \text{ g C m}^{-2} \text{y}^{-1}$ can be attributed to the meiobenthic production, which on this part of the west coast of India, accounts for almost 50% of the total benthic standing stock²⁴. It is necessary to note here that the zooplankton production value of $7.82 \text{ g C m}^{-2} \text{y}^{-1}$ is derived from day time collections only and hence is subjected to discrepancy.

The trophic relationship arrived at is based on the primary productivity of the water column, which is one of the 3 major sources of organic inputs for benthic population in a shallow and well mixed estuarine system, under the present investigation. In the absence of relevant data on the supply of organic matter to benthic life, from the other 2 sources, namely primary production of the substratum and the organic matter derived from the rich fringing mangrove vegetation, bordering this estuarine system, the computations attempted here can very well be an underestimate.

Discussion

The estuarine system of Goa, subject to the monsoonal gyre and receiving about 3000 mm of annual rainfall, undergoes wide temporal and spatial variations in the salinity values, thus resulting in

considerable decrease in the qualitative and quantitative distribution of the macrobenthic fauna.

A multi-regressional analysis of environmental parameters in relation to population count as assessed from r^2 (coefficient of determination) values, indicate (Table 10) that there are well demarcated temporal and spatial variations in the effectiveness of any single environmental factor in the distribution of benthic macrofauna. While at most of the stations in the Mandovi and Cumbarjua Canal salinity largely regulates the distribution, in Zuari it is the combination of more than a single environmental parameter which is effective. The importance of sediment types in the distribution of macrofauna¹³ and foraminifera²⁵ in this estuarine system is well established.

Panikkar²⁶ postulated the concept of partial or complete destruction of tropical estuarine fauna, during SW monsoon, followed by an annual repopulation of the estuaries and backwaters in postmonsoon. Such changes have been ascribed to heavy run off of freshwater during the monsoon, followed by the gradual build-up of saline regime in the postmonsoon period. Thus the tropics, as compared to mid latitudes, are regions of high physiological stresses²⁷ wherein the estuaries are characterized by high water temperature with a small seasonal range; lower salinities with a high seasonal range and small tidal ranges with large ratio of spring to neap. Such large stresses result in distinct seasonal changes in the distribution of dominant species, characterized by a near total depletion during the SW monsoon; initial colonization during postmonsoon followed by secondary colonization; growth and structural development of benthic communities in the premonsoon season. Faunal depletion that occurs during each monsoon season, causes the cycle to repeat annually. Similar observations have been reported for Cochin backwaters²⁸ and Vembanad lake²⁹, both tropical estuaries. Holland *et al.*³⁰ have reported similar annual cycle in the mesohaline benthic communities in upper Chesapeake Bay.

Estuarine benthic fauna contain a mosaic of animal assemblages, occupying large or small areas where boundaries may be well or poorly defined³¹. The macrobenthic fauna in the present investigation, are characterized by a highly variable species composition. Some of the species undergo large spatial and temporal variations in local abundance while other members of the same faunal assemblages change only a little^{1,3}.

Such differences in the distribution and abundance of benthic macrofauna can be explained in terms of 2 different adaptive strategies - opportunistic and equilibristic³². The relative opportunism is mostly related to mobility and feeding position in relation to

Table 10—Coefficient of Determination (r^2) Between Environmental parameters and Faunal Abundance at Different Stations

Parameters	1a	1b	2a	2b	3	4	5	6	7	8	9	10	11	12
T & PC	0.0099	0.3185	0.1739	0.0313	0.2767	0.1866	0.0022	0.0099	0.0782	0.0104	0.0681	0.19	0.1554	0.1297
S & PC	0.2292	0.0203	0.0377	0.0097	0.2257	0.1754	0.1015	0.2081	0.2169	0.4671	0.0003	0.199	0.0942	0.0549
DO & PC	0.2247	0.0051	0.1345	0.0016	0.0013	0.0010	0.5481	0.0238	0.0889	0.3261	0.000057	0.000057	0.000017	0.3201
OC & PC	0.0164	0.2405	0.2104	0.0028	0.0102	0.0039	0.0772	0.0141	0.0242	0.0030	0.0005	0.00065	0.0259	0.0003
T & S	0.0267	0.0928	0.1618	0.1885	0.3139	0.2023	0.2318	0.2439	0.1941	0.2029	0.1195	0.0115	0.016	0.0097
T & DO	0.014	0.0573	0.1102	0.0146	0.0153	0.0013	0.0678	0.00008	0.0057	0.0180	0.1601	0.3492	0.2794	0.1364
T & OC	0.0041	0.0726	0.1513	0.403	0.0185	0.4202	0.0139	0.2357	0.1600	0.0260	0.5312	0.0353	0.3054	0.049
S & DO	0.005	0.0183	0.0251	0.0114	0.0461	0.2785	0.0608	0.0015	0.0326	0.1976	0.1234	0.0046	0.000007	0.0092
S & OC	0.1096	0.1394	0.0234	0.4295	0.0209	0.1522	0.0005	0.0126	0.0214	0.0562	0.0299	0.0755	0.1584	0.3697
DO & OC	0.386	0.1316	0.0563	0.0167	0.0076	0.0058	0.0144	0.1713	0.0076	0.0480	0.0864	0.1580	0.1972	0.1076

T = temperature, PC = population count, S = salinity, DO = dissolved oxygen, OC = per cent organic carbon

bottom deposits. Sedentary animals and those living or feeding close to sediment - water interface are more likely to be opportunistic and, hence, less predictable in space and time. Mobile organisms, and also those living or retreating deep into the sediment are more likely to be equilibristic and generally tend to have populations that are most predictable in space and time³².

Distribution of most of the benthic invertebrates show an aggregated spatial pattern³³. Dense assemblages of infaunal organisms as observed are burrowing deposit feeders, suspension feeders and tube builders. Such assemblages are discrete, often age-class dominated and have sharp boundaries with neighbouring assemblages. These sharp boundaries are due to interaction between the established infaunal individuals and settling planktonic larvae³⁴. There are many barriers which the pelagic larvae of macrobenthic animals have to cross, before they finally settle on the bottom, and that each type of bottom deposit will attract a very limited and selected set of species³⁵. Such biotic interactions coupled with the extreme variability of environmental factors, resulted in the evolution of a most diverse benthic fauna in the tropical estuaries. Faunal diversity, in such environments, is not due to the dominance of a few species, but mainly because of the numerical abundance of few species. The population density and standing stock of the community which are high can well be attributed to protracted breeding season, fast growth rate and short life span in tropical environments. Sanders³⁶ who observed high infaunal diversity in the benthos of Vellar estuary, ascribed the probable reason for the greater diversity in tropical estuaries to the fact that it is easier to tolerate low salinities at high temperatures, than at low temperatures. As a result, more marine forms are able to flourish in tropical estuaries than in higher latitudes³⁷.

In spite of the most diversified benthic macrofauna, this estuarine system is characterized by a large number of euryhaline species with prolonged breeding season, high fecundity and fast growth rate. Earlier studies¹²⁻¹⁵, have clearly indicated that many of these species give very high yields under (within habitate) aquaculture practices. Similarly, a number of marine and freshwater species of fish and prawn, use this estuarine system for breeding and early development³⁸. Even by traditional methods, fish farming is highly profitable³⁹ in this estuarine system. Recent investigation⁴⁰ clearly indicates that this estuarine system is completely free of any type of pollution and thus, this high productivity ecosystem holds vast potentials for large-scale cultivation of a variety of finfishes and shell fishes.

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