

Impact of Eco-restoration on the Biodiversity of Sundarbans Mangrove Ecosystem, India

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Abstract A comprehensive study on biodiversity and environmental characteristics of three different selected study sites located on different estuarine networks viz. Matla, Saptamukhi, and Hooghly on eastern, central, and western regions, having different environmental features of Sundarbans Mangrove Ecosystem, India, a World Heritage Site, was conducted through six seasons of consecutive 2 years. The different sites under study have shown variable species composition. Special emphasis was made to record the population structure of benthic fauna, which exhibited maximum density during pre-monsoon followed by monsoon and post-monsoon. Physicochemical parameters displayed a wide range of fluctuation through different seasons and also revealed differences among different study sites. Biotic community structures of different study sites have been analyzed using different community indices like similarity index, dominance index, diversity index, and evenness index. Moreover, in order to evaluate the environmental stress on the environmental health of this dynamic mangrove ecosystem of global importance, species pollution value and community pollution value have been deduced as a new model of biotic indices based on the distribution patterns of both zooplanktons and benthic fauna. Canonical correspondence analysis revealed the cumulative influence of a group of environmental parameters

on the abundance of different components of biodiversity. The study site II (Saptamukhi), encircled by undisturbed mangrove islands, revealed the least pollution stress and higher biological diversity followed by Jharkhali (study site I), which is in the process of eco-restoration and Bokkhali (study site III), which has been under anthropogenic stress especially from ecotourism.

Keywords Biodiversity · Eco-restoration · Mangrove Ecosystem · Sundarbans

1 Introduction

Mangrove ecosystem represents one of the most productive natural wetlands found in the intertidal zone of tropical and subtropical regions of the world (Chaudhuri and Choudhury 1994). This specialized ecosystem, dominated by intertidal salt tolerant halophytic vegetation and enjoying the influences of two high and two low tides a day, offers a unique environment for bioresource development on one hand and maintains ecological balance through the protection of coastal line on the other (Chakraborty 1995).

The present research work was carried out from November 2001 to October 2003 to compare the biodiversity and environmental status of three contrasting habitats of Sundarbans mangrove ecosystem of West Bengal, India, with the help of some biotic indices and also to assess the impact of eco-restoration, if any, on the functioning of this ecosystem.

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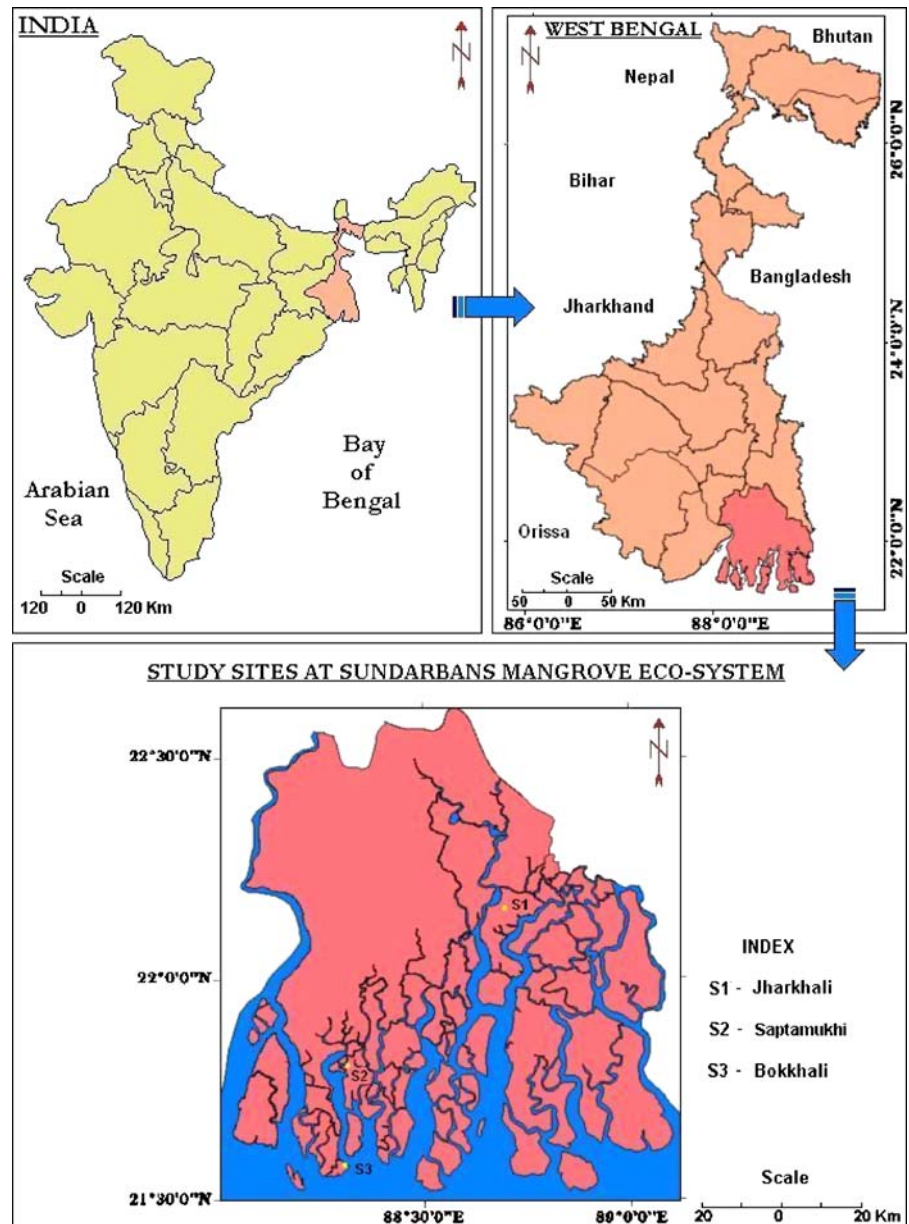
2 Material and Methods

2.1 Physiography of the Study Sites

The Indian Sundarbans is located between 21°32'–22°40' North and 88°85'–89°00' East in the district of 24 Parganas of the state of West Bengal (Fig. 1).

Three study sites located on three estuaries of Sundarbans viz. Matla, Saptamukhi, and Hoogly estuary were selected for the present study. Out of these three study sites, Jharkhali, (study site I) on Matla estuary, is in the process of eco-restoration because of the large-scale successful afforestation program; Sushnir Chara, located on Saptamukhi estuary (study site II), is in an almost stable condition

Fig. 1 Map showing location of study sites



because of least anthropogenic interactions, and Bokkhali on Hoogli estuary (study site III) is facing eco-degradation because of ecotourism, salinity invasion, erosion, and changing patterns of water flow coupled with unwanted accretion.

2.1.1 Different Tidal Levels of the Study Sites

Three subzones in the intertidal zones of selected study sites, viz. high-tide level (HTL), low-tide level (LTL), and mid-tide level (MTL), were identified in the study sites as per the conventional guidelines. (Chandra and Chakraborty 2008)

2.2 Analysis of Physicochemical Parameters of Soil and Water

Monthly samplings of soil and interstitial water were made from different tidal levels of three study sites to analyze different physicochemical parameters of soil and interstitial water following standard methods (APHA 2000) and with the help of water quality checker (TOA, model No. WQC22A, Japan.).

2.3 Procedure for Biological Sampling

Floral and faunal components were collected and subsequently identified with the help of standard literatures (Blasco 1975; George et al. 2005). For the quantitative estimation of macrobenthic fauna, random samplings were made in a monthly interval from three transects lying on three tidal levels of intertidal belts, i.e., LTL, MTL, and HTL from three contrasting study sites with the help of a quadrat having 0.5 m² area. Five such subsamples (0.5 m²) from each transect were collected. Macrobenthic fauna residing within each quadrat were sorted out initially by hand and subsequently by a sieve having a mesh size of 0.5 mm, for assessing population density and was expressed in No./m² (Chakraborty and Choudhury 1994).

2.4 Community Structure Analysis of Different Macrobenthic Fauna

Community structure analysis, by computing relative abundance, index of dominance (Simpson 1949), species richness or variety index (Menhinick 1964), species diversity index (Shannon and Weiner 1949),

evenness index (Pielou 1966), and index of similarity (Sorensen 1984), was done following standard publications (Chakraborty and Choudhury 1994; Khalua et al. 2008; Chandra and Chakraborty 2008.)

Relative abundance (RA) = $n_i/N \times 100$

Where,

n_i total number of individuals of i th species

N total number of individuals of all the species

Index of dominance (C) = $\sum (n_i/N)^2$

Where,

n_i importance value for each species (number of individual)

N total of importance value

Species richness or variety index (d) = S/\sqrt{N}
(or $d = S - 1/\ln N$)

Where,

S number of species

N total number of all species

Species diversity index – $\bar{H} = -\sum P_i \log P_i$
= $-\sum (n_i/N) \log (n_i/N)$

Where,

n_i importance value for each species

N total of importance values

$P_i (n_i/N)$ importance probability for each species

Evenness index (e) = $\bar{H}/\log S$

Where,

\bar{H} diversity index

S number of species

Index of similarity (S in %) = $\frac{2C}{A+B} \times 100$

Where,

A number of species in one study site

B number of species in another study site

C number of species common to both study sites

2.5 Deduction of Species Pollution Value and Community Pollution Value

Species pollution value (SPV) of different species and community pollution value (CPV) were calculated following the method suggested by Jiang and Shen (2003).

$$Pb = \sum_{i=1}^n Pi \quad [Pi = Cd/Co]$$

where: Pb is the comprehensive chemical pollution index, Pi is the chemical pollution index for a single chemical parameter, Cd is the concentration of the measured chemical parameter at the sampling site; Co is the upper limit of the concentration of the chemical parameter, n is the number of contributing parameters (here, $n = 12$). According to the abovementioned formula, each study site's Pb was calculated. In the case of dissolved oxygen (DO), Pi was calculated as Co/Cd because oxygen decreases in response to pollution. The SPV of each species was calculated by:

$$SPV = \frac{\sum_{i=1}^n (\ln^{10Pb}/n)i}{N}$$

Where SPV is the species pollution value; Pb is the comprehensive pollution value; n is the number of chemical parameters; and N is the number of sampling sites. CPV, or the biotic index, used to evaluate the pollution degree of each study site, was calculated by:

$$CPV = \frac{\sum_{i=1}^n SPV_i}{n}$$

Where CPV is the community pollution value; and n is the number of species in a community.

Here, an attempt was made to estimate the rate of change in species occurrence with respect to the CPV in order to derive the impact of pollution on the species occurrence. As the species occurrence takes place in binary form, to estimate the intensity of factor on this kind of variable, logistic regression was performed. If D is the occurrence and nonoccurrence of species, and CPV is the

pollution index, the relationship can be depicted as the following:

$$D = \alpha + \beta CPV \quad (1)$$

“ D ” represents “Dummy variable”

Where $D=1$ for species occurrence; $D=0$ for non-species occurrence

Since D being binary value requires logistic transformation, which can be written as following logistic form of equation

$$\ln\left(\frac{D}{1-D}\right) = \alpha + \beta CPV$$

$$\ln L = \alpha + \beta CPV \quad (2)$$

Here, β represents the rate of changes of species occurrence for a change in CPV. Following logistic regression method, α and β have been estimated.

2.6 Statistical Analysis

Statistical analyses were made to determine the relationship between different biological parameters with that of ecological ones. Canonical Correspondence Analysis (CCA) using the program Multivariate Statistical Package version 3.1 was done.

3 Results

3.1 Distribution of Different Floral and Faunal Components

The flora and fauna of the studied sites varied in distribution as is shown in Table 1.

Out of the true mangrove plant species occurring in the study sites, special mention may be made of *Rhizophora apiculata*, *Sonneratia apetala*, *Avicennia marina*, *Excoecaria agallocha*, *Bruguiera cylindrica*, *Acanthus ilicifolius*, etc. The mangrove-associated plants are represented by species such as *Sarcobolus carinatus*, *Suaeda maritima*, *Pandanus tectorius*, etc. Some examples of the mesophytic bioinvasive plants occurring in the three study sites are *Casuarina equisetifolia*, *Alternanthera* sp., etc. Important phytoplankton species include *Nitzschia* sp., *Peridinium* sp., *Ceratium* sp., etc. The commonly occurring zooplankton orders are copepoda (25 species), rotifera

Table 1 Distribution of different floral & faunal components at the three study sites

Serial no:	Name of the floral/faunal component	Total number of family/genera/species	Number occurring in		
			SI	SII	SIII
1	True Mangrove Plants	24 species	24	16	17
2	Mangrove Associated Mesophytic Plants	33 species	21	8	19
3	Mesophytic Bioinvasive Plants	10 species	9	–	10
4	Phytoplankton	23 genera	17	21	19
5	Zooplankton	42 species	32	29	16
6	Ichthyoplankton	18 families	17	15	18
7	Macrobenthos	79 species	50	54	55

SI Study Site I, SII Study Site II, SIII Study Site III

(four species), chaetognatha (four species), and cladocera (six species). Important ichthyoplanktons identified here belonged to the families Clupeidae, Engraulidae, Megalopidae, etc. Seventy-nine species of macrobenthos were recorded from different study sites, among which major faunal groups were *Edwardsia jonesii* and *Paracondylactis indica*, representing Phylum Cnidaria; *Mastobranchas* sp., *Glycera* spp., *Perinereis* sp., and *Lumbriconereis* sp., representing class Polychaeta; *Scylla* sp., *Dotilla* sp., *Uca* spp., *Ocypoda* sp., etc., representing class Crustacea, and *Littorina* sp., *Nerita* sp., etc., representing phylum mollusca. A total of 24 species of shrimps and 118 species of fin fishes (commonly occurring are *Liza*, *Harpodon*, *Tenualosa*, *Chanos*, *Plotosus*, *Anguilla*, etc.), 10 species of reptiles (identified families include Varanidae, Colubridae, Crocodylidae, Chelonidae, and Emididae), 45 species of avi-fauna (including Cormorant, Heron, Egret, Kingfisher, Stork, etc.), and 20 species of mammals represented by Chiroptera, Rhesus Macaque, Indian Pangolin, Bengal Fox, Civet, Jungle cat, Wild Boar, etc. have been recorded from different study sites (Annon 2003).

3.2 Population Density of Macrobenthic Fauna

The population density of macrobenthic fauna (No/m²) at different study sites were recorded through 24 months and six seasons of two consecutive years, and it was found out that the abundance of macrobenthic fauna fluctuated from season to season as well as in between different tidal levels and different study sites. Out of 79 species of macrobenthos documented from the three selected study sites, it was revealed that polychaetes were the most abundant faunal group

(46.44%), followed by mollusks (37.39%), brachyuran crabs (12.62%), actinarians (3.48%), and others miscellaneous macrobenthic fauna (0.07%; Fig. 2)

Twenty macrobenthic species were selected for detailed studies on their distribution, zonation pattern, seasonal population dynamics, and impact of prevailing ecological parameters on them. These macrobenthos included two species of actinarians, eight species of polychaetes, three species of brachyuran crabs, and seven species of mollusks. The selection was based on their proportionate contribution towards total macrobenthic density, diversity, and distribution, as revealed from the analysis of their relative abundance (Table 2).

3.3 Population Density of Different Groups of Zooplankton

Among different groups of zooplankton recorded from three selected study sites, copepoda was found to be the most abundant faunal group (57%), followed by cladocera (9%), decapoda larvae (9%), molluscan larvae (8%), polychaete larvae (4%), sergestidae

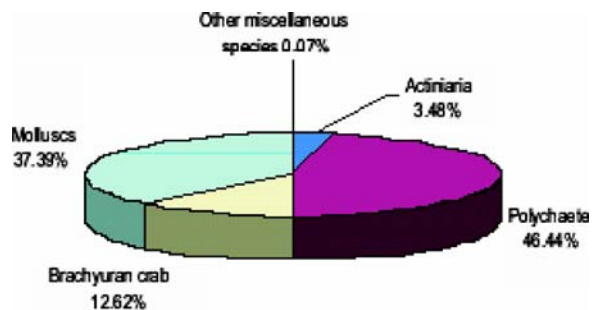


Fig. 2 Percentage-wise representation (average of three study sites) of different groups of macrobenthic fauna

Table 2 Range and average (in parenthesis) of population density (No/m²), Relative abundance (%), Rank and SPV value of different macrobenthic species at different study sites

Sl. no	Species	SI			SII			SIII			SPV
		Range and average	RA	Rank	Range and average	RA	Rank	Range and average	RA	Rank	
1	<i>Edwardsia jonesii</i>	5.06–13.33 (8.01)	2.05	22	4.82–19.2 (9.20)	2.31	17	0.27–4.27 (1.41)	0.36	43	4.18
2	<i>Paracondylactis indica</i>	2.67–11.47 (4.89)	1.24	28	4.27–13.87 (7.87)	1.98	20	0.8–6.13 (2.26)	0.58	39	4.18
3	<i>Talehsapia amandalei</i>	6.67–18.33 (13.8)	3.50	5	10.93–21.6 (17.2)	4.34	5	–	0.00	–	2.83
4	<i>Neanthes chingrighattensis</i>	–	0.00	–	4.33–21.2 (14.1)	3.55	7	6.33–18.33 (13.38)	3.45	7	2.78
5	<i>Perinereis cultrifera</i>	2.6–15.87 (10.73)	2.71	11	4.6–15.33 (11.53)	0.00	–	–	0.00	–	1.39
6	<i>Perinereis nigropunctata</i>	7.82–15.8 (12.67)	3.20	8	4.26–17.8 (13.07)	3.29	8	0.00	0.00	–	2.83
7	<i>Diopatra cuprea cuprea</i>	8.06–16.2 (12.64)	3.20	8	–	3.29	8	9.46–22.93 (18.15)	4.68	3	2.73
8	<i>Mastobranchas indicus</i>	16.6–27.4 (23.25)	5.88	2	7.37–23.2 (17.68)	4.44	4	18.53–31.4 (27.31)	7.03	1	4.18
9	<i>Perheteromastus tenuis</i>	–	0.00	–	2.53–18.67 (13.07)	3.29	8	12–64.9 (22.79)	5.41	2	2.78
10	<i>Owenia fusiformes</i>	1.93–9.06 (6.33)	2.68	12	5.73–20.6 (15.53)	3.91	6	8.8–22.07 (17.12)	4.41	4	4.18
11	<i>Uca acuta acuta</i>	11.26–15.93 (14.03)	3.39	6	6.63–13.33 (9.70)	2.44	15	5.6–9.26 (8.04)	2.07	18	4.18
12	<i>Uca triangularis bengali</i>	6.33–11.93 (9.74)	2.36	17	3.07–5.07 (4.43)	1.12	28	2.73–4.93 (4.11)	1.63	23	4.18
13	<i>Metaplax intermedia</i>	7–10.87 (9.37)	3.12	9	5.13–7.13 (6.09)	2.79	13	–	1.65	22	4.18
14	<i>Nerita articulata</i>	7.3–14.1 (11.01)	2.79	10	3.8–9.5 (7.4)	1.87	21	2.1–7.2 (4.8)	1.66	21	4.18
15	<i>Littorina melanostoma</i>	7.9–18.4 (13.0)	3.29	7	6.2–15.1 (10.9)	2.75	14	2.8–8.87 (6.56)	1.69	20	4.18
16	<i>Assimineae brevicula</i>	10.8–24.7 (17.33)	4.38	3	12.8–26.6 (20.05)	5.05	3	7.03–13.4 (10.93)	2.82	14	4.18
17	<i>Assimineae francesiae</i>	13.8–34.6 (23.8)	6.02	1	15.8–39.7 (27.4)	6.90	1	7.76–21.2 (14.46)	3.72	5	4.18
18	<i>Telescopium telescopium</i>	10.1–19.6 (14.19)	3.59	4	7.06–15 (11.11)	2.80	12	5.93–11.93 (9.04)	2.33	17	4.18
19	<i>Cerithidea cingulata</i>	15–33.9 (23.8)	6.02	1	12.2–25.8 (20.42)	5.14	2	7.6–19.8 (13.7)	3.52	6	4.18
20	<i>Nassarius foveolatus</i>	6–14.73 (10.59)	2.68	12	6.06–11.6 (9.11)	2.29	19	4.8–10 (7.53)	1.94	19	4.18
21	<i>Maldane sarsi</i>	5.2–12.87 (10.34)	2.62	14	3.8–19.28 (14.05)	3.00	9	5–15.07 (10.73)	2.76	16	4.18
22	<i>Eteone barantollae</i>	–	0.00	–	–	2.96	10	7.87–26.4 (20.38)	3.18	10	2.78
23	<i>Glycera tessellata</i>	–	0.00	–	5.53–16.33 (11.78)	2.94	11	–	0.00	–	1.44
24	<i>Nemalycastis indica</i>	3.27–13.47 (9.67)	2.45	16	3.13–12.8 (9.31)	2.34	16	13.1–27.2 (21.62)	3.34	9	4.18
25	<i>Lumbriconereis heteropoda</i>	–	0.00	–	6.85–22.67 (16.7)	2.30	18	0.6–1.46 (0.58)	0.00	–	1.44
26	<i>Cerithidea obtusa</i>	7.6–14 (10.47)	2.65	13	8.26–12.66 (10.37)	1.81	22	4.6–8.1 (5.91)	1.52	26	4.18
27	<i>Littorina undulata</i>	6.4–14.6 (10.01)	2.53	15	5.4–12.6 (9.26)	1.78	23	2.4–7.73 (5.14)	1.33	28	4.18
29	<i>Anadara granosa</i>	2.8–6.53 (4.3)	1.11	29	4–6.7 (5.2)	1.32	25	2.93–4.53 (3.6)	0.93	33	4.18
30	<i>Polydora normalis</i>	0–0.27 (0.04)	0.00	–	2.6–7.6 (5.02)	1.26	26	–	0.00	–	1.44
31	<i>Nassarius stolatus</i>	3.73–6.86 (5.14)	1.30	27	3.86–5.93 (4.87)	1.23	27	–	0.00	–	2.83
32	<i>Dotilla blanfordi</i>	–	0.00	–	1.2–10.2 (5.54)	1.12	28	6.4–11.27 (9.33)	1.49	27	2.78
33	<i>Pelocoetes exul</i>	1.6–8.53 (3.6)	0.91	33	0.8–12.53 (4.39)	1.11	29	0.8–1.07 (0.23)	0.03	50	4.18
34	<i>Uca lactea annulipes</i>	–	0.00	–	4.13–7.6 (6.07)	1.10	30	2.47–4 (3.44)	0.84	35	2.78
35	<i>Metaplax crenulata</i>	0–1.77 (0.885)	1.64	25	0–1.14 (0.57)	1.06	31	–	0.00	–	2.83
36	<i>Sesarma chironantes bidens</i>	6.07–9.8 (8.58)	1.82	24	3.3–6 (4.2)	1.05	32	3.8–7.13 (5.76)	1.06	29	4.18
37	<i>Capitella capitata</i>	0.7–6.4 (4.02)	1.02	30	3.8–6.6 (3.66)	0.92	33	–	0.00	–	–
38	<i>Neritina violacea</i>	1.2–3.53 (2.35)	0.60	38	1.6–4.13 (3.05)	0.77	34	–	0.00	–	2.83
39	<i>Neritina smithi</i>	2.6–8.6 (5.9)	1.50	26	1.3–4.2 (2.9)	0.74	35	–	0.00	–	2.83
40	<i>Natica tigrina</i>	2.13–3.73 (2.96)	0.75	34	1.53–3.67 (2.36)	0.60	36	1.2–1.8 (1.47)	0.38	42	4.18
41	<i>Scopimera globosa</i>	1.6–3.47 (2.81)	0.71	35	0.26–3.13 (1.74)	0.56	37	–	0.00	–	2.83
42	<i>Natica vitellus</i>	1.06–2.6 (1.85)	0.47	39	0.73–4.2 (1.9)	0.48	38	0.6–1.07 (0.29)	0.07	48	4.18
43	<i>Littorina scabra scabra</i>	1.4–5.4 (3.72)	0.94	32	0.73–2.5 (1.7)	0.44	39	–	0.00	–	2.83
44	<i>Dotillopsis brevitarsis</i>	1.6–3.46 (2.8)	0.71	35	1.06–2.93 (1.61)	0.44	39	2.07–3.4 (2.67)	0.70	36	4.18
45	<i>Macrophthalmus pectinipes</i>	3.06–5.63 (4.29)	0.98	31	1.13–3.33 (1.3)	0.41	40	1.93–3.53 (2.73)	0.69	37	4.18
46	<i>Architectonica perspectiva</i>	0.13–0.8 (0.38)	0.10	43	0.6–2.8 (1.57)	0.39	41	–	0.00	–	2.83
47	<i>Metaplax distincta</i>	–	0.00	–	1.73–3 (2.23)	0.33	42	1.8–2.9 (2.18)	0.26	45	2.78

Table 2 (continued)

Sl. no	Species	SI			SII			SIII			SPV
		Range and average	RA	Rank	Range and average	RA	Rank	Range and average	RA	Rank	
48	<i>Sesarma pictum</i>	–	0.00		1.33–2.2 (1.18)	0.17	43	0.26–0.93 (0.2)	0.05	49	2.78
49	<i>Umbonium vastiarum</i>		0.00			0.10	44		0.00		1.44
50	<i>Uca dussumieri dussumieri</i>	–	0.00		6.46–9.43 (8.21)	0.08	45	3.8–5.6 (4.78)	0.32	44	2.78
51	<i>Sesarma taeniolatum</i>	2.53–9.33 (4.28)	0.05	44	6–8.6 (7.44)	0.05	46	–	0.00		2.83
52	<i>Modiolus striatulus</i>	0.8–1.33 (0.36)	0.00		0.4–0.73 (0.18)	0.05	46	0.26–0.86 (0.56)	0.15	47	2.78
53	<i>Acrilla acumunata</i>	1.3–4.2 (2.78)	0.70	36	0.3–0.6 (0.16)	0.04	47	–	0.00		2.83
54	<i>Sesarma longipes</i>	–	0.00		2.53–8 (5.68)	0.03	48	–	0.00		1.44
55	<i>Scylla serrata</i>	5.27–11.33 (9.12)	0.02	45	6.7–9.93 (8.34)	0.03	48	1.86–3.8 (2.56)	0.01	52	4.18
56	<i>Saccoglossus</i> sp.	–	0.00		0–0.02 (0.01)	0.02	49	–	0.00		1.44
57	<i>Carcinoscorpius rotundicauda</i>	0–0.01 (0.005)	0.01	46	0–0.01 (0.005)	0.01	50	–	0.00		2.83
58	<i>Onchidium tigrinum</i>	0.53–2.6 (1.14)	0.29	41	0–0.26 (0.04)	0.01	50	0.86–3.33 (2.28)	0.59	38	2.73
59	<i>Lumbriconereis polydesma</i>	3.33–12.4 (9.17)	2.20	20	–	0.00		0–4.67 (0.77)	0.00		1.39
60	<i>Glycera alba</i>	–	0.00		–	0.00		7.13–16.8 (13.37)	3.44	8	1.34
62	<i>Nemlycastis fauveli</i>	3.27–10.07 (7.48)	1.89	23	–	0.00		5.93–14.2 (10.86)	2.80	15	2.73
63	<i>Dendronereides gangetica</i>	–	2.29	18	–	0.00		6.26–15.53 (12.47)	3.04	12	1.34
64	<i>Dendronereides heteropoda</i>	–	0.00		–	0.00		12.33–22.03 (18.37)	0.00		1.34
65	<i>Dendronereis aestuarina</i>	4.73–12.4 (9.06)	0.00		–	0.00		–	0.00		1.39
66	<i>Glauconome sculpta</i>	–	0.00		–	0.00		5.4–12.8 (9.08)	1.59	25	1.34
67	<i>Nemartean-sp1.</i>		0.00			0.00			0.02	51	1.34
68	<i>Solen brevis</i>	4.8–11.9 (8.82)	2.23	19	–	0.00		–	0.00		1.39
69	<i>Crassostrea gryphoides</i>	2.4–5.4 (3.73)	0.94	32	–	0.00		1.8–5.6 (3.64)	0.94	32	2.73
70	<i>Phytocoetopsis ramunii</i>	1.6–4.27 (2.53)	0.64	37	–	0.00		–	0.00		1.39
71	<i>Diadumene schilleriana</i>	0.27–3.47 (1.39)	0.35	40	–	0.00		0.53–4.27 (1.87)	0.48	40	2.73
72	<i>Saccostrea cucullata</i>	0.26–1.47 (1.0)	2.25	42	–	0.00		0.4–1.13 (0.26)	0.07	48	2.73
73	<i>Eteone ornata</i>	–	0.00		–	0.00		7.87–26.4 (19.38)	3.11	11	1.34
74	<i>Ocyropa macrocera</i>	–	0.00		–	0.00		4–8.5 (6.93)	0.98	30	1.34
75	<i>Ocyropa ceratophthalma</i>	–	0.00		–	0.00		3.07–4.86 (4.36)	0.89	34	1.34
76	<i>Amalda ampla</i>	–	0.00		–	0.00		0.13–1.46 (0.85)	0.22	46	1.34
77	<i>Ellobium gangeticum</i>	–	0.00		–	0.00		0–0.46 (0.18)	0.05	49	1.34
78	<i>Donax incarnatus</i>	–	0.00		–	0.00		3.8–8.2 (6.31)	1.60	24	1.34
79	<i>Phascolasoma</i> sp.	–	0.00		–	0.00		0–0.02 (0.015)	0.02	51	1.34

CPV values have been found to be 3.35, 3.30, and 3.01 at study sites I, II, and III, respectively

(4%), chaetognatha (4%), and other miscellaneous groups (5%; Fig. 3)

3.4 Relative Abundance (%) of Macrobenthic Fauna

Relative abundance of different groups of macrobenthic fauna revealed highest relative abundance of mollusks, especially the gastropod species. *Assimonia francesiae* and *Cerithidea cingulata* followed by polychaetes, brachyuran crabs, actinarians, and others at study site I. At study site II, highest relative abundance was shown by *A. francesiae*, a mollusk, followed by polychaetes,

brachyuran crabs, actinarians, and others, but at study site III, results of relative abundance revealed highest values for a polychaete, *Mastobranchus indicus*, followed by mollusks, brachyuran crabs, actinarians, and others (Table 2).

3.5 Community Indices

3.5.1 Similarity Index (%)

On the basis of the occurrence of mangrove and associated plant species, the highest value of 66% was

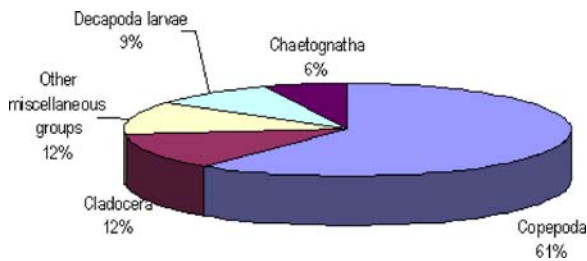


Fig. 3 Percentage-wise representation (average of three study sites) of different groups of zooplankton

found in between study sites I and III, followed by 61.53% between study sites I and II, and 45.71% between study sites II and III. This index was 68.85% between study sites I and II, 57.78% between study sites II and III, and 45.83% between study sites I and III on the basis of occurrence of zooplankton. The similarity index (based on the abundance of phytoplankton species) revealed that highest similarity was found in between study sites II and III (85%) followed by 78.95% between study sites I and II, and 77.78% between study sites I and III. On the basis of occurrence of ichthyoplankton species, the highest similarity was recorded as 97.14% between study sites I and III, followed by 90.91% between study sites II and III, and 87.5% between study sites I and II. On the basis of the macrobenthic faunal abundance, the highest value of similarity index was estimated as 75% between study sites I and II, followed by 66.06% between study sites II and III, and 62.86% between study sites I and III (Table 3).

3.5.2 Species Dominance Index, Diversity Index, Richness Index, and Evenness Index

Community analysis through the deduction of different biotic indices showed that dominance index was maximum at study site III followed by study sites I and II for low-tide level. For mid-tide level, this index was maximum at study site III, followed by study sites II and I. For high-tide level, this index was maximum at study site I, followed by study sites III and II. Highest species diversity index was recorded at study site III, followed by study sites I and II at low-tide level. It was highest at study site II, followed by study sites I and III for mid-tide level. For high-tide level, the diversity index was highest at study site I, followed by study sites II and III. The richness index was found to be maximum

at study site II followed by study sites I and III for low-tide level. It was highest at study site II followed by study sites III and I for mid-tide level. At high-tide level, the highest value of richness index was recorded from study site II followed by study sites I and III. Results of evenness index showed maximum value at study site III followed by study sites II and I for low-tide level. For mid-tide level, the highest value of this index was recorded from study site I followed by study sites II and III. There existed definite seasonal trends with regard to all those indices (Table 4).

3.5.3 Species Pollution Value and Community Pollution Value

Among the zooplanktons, the highest SPV was recorded as 4.18 (*Euchaeta marina*, *Centropages dorsipinatus*, *Centropages alcocki*, *Eucalanus elongatus*, *Lapidocera pectinata*, *Macrosetella gracilis*, Zoea larva, Nauplius larva, and Megalopa larva) and the lowest SPV was recorded as 1.34 (*Paracalanus dubia*) (Table 5). The highest and lowest SPV were

Table 3 Similarity indices different floral and faunal communities of three study sites

	S-I	S-II	S-III
On the basis of occurrence of mangrove plants			
S-I	–	61.53	66
S-II	–	–	45.71
S-III	–	–	–
B. On the basis of occurrence of Zooplankton			
S-I	–	68.86	45.83
S-II	–	–	57.78
S-III	–	–	–
C. On the basis of occurrence of phytoplankton			
S-I	–	78.95	77.78
S-II	–	–	85
S-III	–	–	–
D. On the basis of occurrence of Ichthyoplankton			
S-I	–	87.5	97.14
S-II	–	–	90.91
S-III	–	–	–
E. On the basis of occurrence of macrobenthic fauna			
S-I	–	75	62.86
S-II	–	–	66.06
S-III	–	–	–

Table 4 Seasonal variation of different community indices at three study sites during post-monsoon 2001 to monsoon 2003 (November 2001 to October 2003)

Indices	2002–2003																	
	2001–2002				MON				POM				PRM					
	LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL
Study site I																		
DI	0.13	0.064	0.136	0.11	0.064	0.082	0.11	0.062	0.803	0.121	0.062	0.123	0.108	0.063	0.078	0.109	0.062	0.079
SDI	-0.93	-0.80	-0.926	-1.028	-1.222	-1.114	-1.026	-1.229	-1.118	-0.995	-1.228	-0.995	-1.034	-1.229	-1.141	-1.026	-1.229	-1.124
RI	1.16	0.971	1.114	0.974	0.728	1.189	1.134	0.787	1.423	1.437	1.011	1.722	1.054	0.748	1.327	1.105	0.777	1.389
EI	-0.87	-0.64	-0.926	-0.897	-0.974	-1.0002	-0.921	-0.979	-0.976	-0.868	-0.979	-0.893	-0.902	-0.979	-0.969	-0.921	-0.979	-0.981
Study site II																		
DI	0.13	0.064	0.154	0.104	0.065	0.109	0.093	0.067	0.106	0.104	0.062	0.14	0.095	0.065	0.105	0.093	0.067	0.106
SDI	-0.90	-1.22	-0.907	-0.938	-1.219	-1.001	-0.965	-1.209	-1.012	-0.937	-1.231	-0.942	-0.977	-1.219	-1.014	-0.97	-1.208	-1.02
RI	1.06	0.996	1.46	0.997	0.719	1.258	0.974	0.75	1.473	1.406	1.058	1.839	1.005	0.738	1.224	0.947	0.74	1.422
EI	-0.90	-0.97	-0.871	-0.842	-0.971	-0.898	-0.894	-0.963	-0.909	-0.841	-0.98	-0.873	-0.877	-0.971	-0.94	-0.899	-0.962	-0.916
Study site III																		
DI	0.14	0.079	0.235	0.1	0.083	0.258	0.118	0.085	0.379	0.138	0.081	0.203	0.284	0.085	0.229	0.115	0.083	0.391
SDI	-0.975	-1.141	-0.648	-1.082	-1.121	-0.625	-1.05	-1.118	-0.467	-0.995	-1.135	-0.725	-0.825	-1.121	-0.691	-1.053	-1.131	-0.442
RI	0.313	0.992	1.266	0.246	0.691	1.112	0.261	0.711	1.006	0.384	1.018	1.809	0.193	0.749	1.335	0.254	0.742	0.719
EI	-0.875	-0.948	-0.926	-0.92	-0.953	-0.895	-0.893	-0.95	-0.776	-0.846	-0.942	-0.931	-0.702	-0.931	-0.888	-0.896	-0.939	-0.927

LTL Low tide level, *MTL* Mid tide level, *HTL* High tide level, *POM* Post-monsoon, *PRM* Pre-monsoon, *MON* Monsoon, *DI* Dominance Index, *SDI* Species Diversity Index, *RI* Richness Index, *EI* Evenness Index

Table 5 Occurrence of zooplankton species and their respective SPV in three study sites

No.	Species	S I	S II	S III	SPV
1	<i>Euchaeta marina</i> Prestandrea (Giesbrecht)	+	+	+	4.18
2	<i>Centropages dorsipinatus</i> Thompson & Scott	+	+	+	4.18
3	<i>Centropages alcocki</i> Sewell	+	+	+	4.18
4	<i>Canthocalanus pauper</i> (Giesbrecht)	–	+	+	2.78
5	<i>Eucalanus elongatus</i> Dana	+	+	+	4.18
6	<i>E. subcrassus</i> Giesbrecht	+	+	–	2.83
7	<i>Paracalanus parvus</i> Giesbrecht	–	+	–	1.44
8	<i>P. dubia</i> Sewell	–	–	+	1.34
9	<i>Acrocalanus intermis</i> Sewell	+	+	–	2.83
10	<i>A. similis</i> Sewell	–	+	–	1.44
11	<i>Pseudodiaptomus serricaudatus</i> (T. Scott)	+	+	–	2.83
12	<i>P. binghami</i> Sewell	+	–	–	1.39
13	<i>P. annandalei</i> Sewell	+	+	–	2.83
14	<i>P. aurivilli</i> Cleve	+	+	–	2.83
15	<i>P. tollingerae</i> Sewell	+	–	–	1.39
16	<i>Temora turbinata</i> (Dana)	–	+	+	2.78
17	<i>Lapidocera minuta</i> Geisbrecht	+	+	–	2.83
18	<i>L. acuta</i> (Dana)	–	+	–	1.44
19	<i>L. pectinata</i> Thompson & Scott	+	+	+	4.18
20	<i>Calanopia elliptica</i> (Dana)	+	–	–	1.39
21	<i>Pontella andersoni</i> Sewell	–	+	+	2.78
22	<i>Tortanus gracilis</i> (Brady)	+	+	–	2.83
23	<i>Acartia (Odontacartia) spinicauda</i> Geisbrecht	+	+	–	2.83
24	<i>Microsetella rosea</i> (Dana)	+	–	+	2.73
25	<i>Macrosetella gracilis</i> (Dana)	+	+	+	4.18
26	<i>Sagitta bedoti</i>	+	+	–	2.83
27	<i>S. emflata</i>	+	–	–	1.39
28	<i>S. pulchra</i>	–	+	+	2.78
29	<i>Krohnitta pacifica</i>	+	–	+	2.73
30	<i>Keratella</i> sp.	+	–	–	1.39
31	<i>Brachionus</i> sp.	+	+	–	2.83
32	<i>Filinia</i> sp.	+	–	–	1.39
33	<i>Asplanchna</i> sp.	+	–	–	1.39
34	<i>Diaphanosoma</i> sp.	–	+	–	1.44
35	<i>Daphnia</i> sp.	+	–	–	1.39
36	<i>Ceriodaphnia</i> sp.	+	+	–	2.83
37	<i>Moina</i> sp.	+	–	–	1.39
38	<i>Alona</i> sp.	+	+	–	2.83
39	Zoea larva	+	+	+	4.18
40	Nauplius larva	+	+	+	4.18
41	Megalopa larva	+	+	+	4.18
		32	29	16	
	CPV	2.80	3.05	3.47	

Table 6 Range and average (in parenthesis) of physicochemical parameters of water at different tidal levels of three study sites

Sl. Parameters No.	SI			SII			SIII						
	IW			IW			IW						
	LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL				
1	Temperature °C	19.8–30.6 (25.67)	19.3–31.8 (26.49)	19.2–31.8 (26.77)	21.2–30.5 (25.7)	18.2–32.1 (24.38)	18.8–29.5 (23.58)	18.4–30.6 (24.55)	20.9–31.2 (25.2)	16.8–30.8 (24.50)	19.2–31.5 (25.70)	18.9–32.6 (25.63)	21.1–31.6 (25.8)
2	pH	7.1–7.8 (7.49)	7.3–7.84 (7.59)	7.36–8.0 (7.65)	7.2–7.9 (7.68)	6.9–7.9 (7.52)	6.4–8.0 (7.52)	6.8–8.0 (7.67)	7.1–7.6 (7.4)	6.3–8.1 (7.55)	7.0–8.5 (7.87)	7.5–8.21 (7.94)	7.2–7.9 (7.72)
3	Salinity (‰)	9.4–17.05 (13.49)	10.24–17.41 (14.28)	12.17–17.33 (14.70)	11.0–16.5 (13.65)	5.0–17.23 (11.85)	7.1–18.03 (13.14)	6.86–19.2 (13.42)	6.6–18.1 (12.86)	14.5–28.86 (19.44)	14.9–30.8 (20.08)	15.2–31.5 (21.19)	17.05–28.1 (18.79)
4	D.O. (mg/L)	4.43–6.29 (5.37)	4.08–6.08 (4.89)	1.62–4.86 (3.04)	5.2–7.9 (5.62)	4.49–6.08 (5.34)	4.28–6.08 (5.60)	1.18–4.05 (2.69)	6.1–7.2 (5.48)	4.28–6.7 (5.96)	3.16–5.98 (5.35)	1.05–5.68 (3.39)	5.2–6.9 (5.94)
5	B.O.D (mg/L)	1.22–3.65 (2.38)	1.21–3.65 (2.30)	0.31–2.93 (1.24)	0.41–3.95 (2.42)	1.21–3.83 (2.29)	1.62–3.43 (2.27)	0.4–1.62 (1.14)	0.6–4.1 (2.65)	1.32–3.45 (2.42)	0.87–3.66 (2.32)	0.79–2.03 (1.34)	0.7–3.25 (2.01)
6	Turbidity	130–380 (299.58)	192–357 (284.54)	148–365 (309.40)	62–258 (212.00)	291–564 (404.13)	229–548 (399.88)	256–550 (379.71)	95–345 (198.26)	151–470 (207.54)	140–251 (183.42)	144–257 (168.96)	125–365 (192.25)
7	Conductivity	2.17–3.02 (2.68)	1.45–3.04 (2.63)	2.1–2.96 (2.70)	2.31–2.79 (2.54)	1.13–2.95 (2.42)	2.01–3.24 (2.70)	1.12–3.23 (2.65)	2.12–2.92 (2.51)	2.23–3.84 (3.12)	1.12–3.88 (3.09)	2.7–4.2 (3.42)	2.36–3.12 (3.42)
8	Silicate (ppm)	10.2–15.5 (12.88)	11.2–15.8 (13.25)	12.0–16.4 (14.14)	10.2–15.5 (12.64)	12.5–16.2 (14.23)	12.6–16.7 (14.65)	13.2–16.8 (15.52)	9.5–14.2 (11.33)	14.2–18.5 (16.87)	14.6–22.01 (18.79)	13.0–21.5 (19.21)	10.2–19.2 (15.62)
9	Phosphate (ppm)	0.10–0.80 (0.40)	0.20–1.4 (0.54)	0.6–1.4 (0.86)	0.14–0.46 (0.39)	0.18–1.42 (0.62)	0.12–1.82 (0.69)	0.22–1.9 (0.74)	0.17–2.1 (0.74)	0.28–0.98 (0.61)	0.24–1.18 (0.69)	0.18–1.5 (0.67)	0.17–1.21 (0.72)
10	Nitrate Nitrogen (ppm)	1.64–3.01 (2.14)	1.12–2.08 (1.63)	1.82–3.6 (2.57)	1.05–2.82 (1.75)	1.28–3.01 (1.96)	1.61–3.8 (2.12)	1.06–4.31 (2.14)	1.51–4.65 (2.58)	0.34–1.98 (1.07)	0.42–2.5 (1.19)	0.76–2.87 (1.42)	0.56–3.1 (1.84)
11	Ammonical Nitrogen (ppm)	1.15–3.2 (1.68)	1.02–3.9 (2.14)	2.28–3.8 (2.69)	1.21–2.9 (1.55)	1.04–4.1 (2.04)	1.64–3.86 (2.15)	1.34–4.62 (2.25)	1.65–4.92 (2.38)	0.44–3.42 (1.21)	0.4–2.09 (1.16)	0.78–2.68 (1.48)	0.65–3.25 (2.03)
12	Nitrite Nitrogen (ppm)	0.84–1.46 (1.15)	0.96–1.85 (1.25)	1.18–1.75 (1.42)	0.84–2.24 (1.34)	0.92–1.46 (1.06)	0.94–1.82 (1.15)	0.92–1.75 (1.22)	0.87–2.20 (1.56)	0.24–1.26 (0.56)	0.28–0.95 (0.55)	0.42–1.02 (0.67)	0.56–1.72 (0.85)

LTL low-tide level, MTL mid-tide level, HTL high-tide level, IW interstitial water, SW surface water

also found as 4.18 and 1.34 in case of different macrobenthic species (Table 2).

The highest CPV of zooplanktons was recorded as 3.47 at study site III followed by 3.05 and 2.80 at study sites II and I, respectively (Table 5). The CPV of macrobenthic species revealed that study site I possessed the highest value (3.35), which was followed by study sites II (3.30) and III (3.01) (Table 2).

3.5.4 Physicochemical Parameters

Different physicochemical parameters displayed a wide range of temporal and spatial variation. Water temperature, salinity, pH, conductivity, turbidity, dissolved oxygen (DO), and biochemical oxygen demand (BOD) were found to be higher during pre-monsoon, while, silicate, phosphate phosphorous, nitrite nitrogen, ammonical nitrogen, and nitrate nitrogen were maximum during monsoon. The post-monsoon season was characterized in having lowest temperature, moderate salinity, and other parameters (Table 6). Soil temperature, salinity, organic carbon, and sand content were found to be higher during pre-monsoon, while available potassium, available nitrogen, and available phosphorous were maximum during monsoon. The post-monsoon season was characterized in having lowest temperature, available phosphorous, available potassium, available nitrogen, and moderate level of other parameters (Table 7).

3.5.5 Statistical Analysis

CCA involving 12 environmental parameters of water viz. temperature, pH, salinity, turbidity, conductivity, dissolved oxygen, biochemical oxygen demand, silicate, phosphate phosphorous (W PO₄), nitrate nitrogen (W NO₃), ammonical nitrogen (W NH₃), nitrite nitrogen (W NO₂), and 10 environmental parameters of soil viz. temperature, pH, organic carbon, salinity, available potassium, available phosphorous, available nitrogen, and textural components (sand, silt, and clay) revealed interrelationships among different macrozoobenthic species in terms of their different ecological parameters on one hand and also recorded cumulative influence of a group of ecological parameters on the abundance of macrozoobenthic population on the other.

Data were plotted against four quadrants through multidimensional scaling. These plots enabled to

Table 7 Range and average (in parenthesis) of physicochemical parameters of soil at different tidal levels of three study sites

Sl. No.	Parameters	SI			SII			SIII		
		LTL	MTL	HTL	LTL	MTL	HTL	LTL	MTL	HTL
1	Temperature °C	19.8–26.0 (25.65)	20.1–30.8 (25.99)	20.6–31.4 (26.46)	21.0–30.5 (25.63)	21.4–30.8 (25.98)	21.9–30.9 (26.24)	21.1–30.6 (26.26)	21.3–31.0 (26.69)	21.6–31.4 (26.99)
2	pH	6.61–7.96 (7.36)	6.62–7.8 (7.32)	6.6–7.91 (7.37)	6.64–7.66 (7.16)	6.94–7.69 (7.20)	6.64–7.7 (7.24)	7.09–7.96 (7.54)	7.02–8.1 (7.57)	7.1–8.1 (7.60)
3	Salinity (‰)	9.12–17.86 (13.31)	9.16–17.56 (13.68)	10.22–17.88 (14.07)	3.17–19.12 (12.40)	3.24–19.1 (12.63)	3.2–19.38 (12.79)	6.08–29.86 (19.53)	6.18–30.17 (19.69)	6.65–30.45 (20.02)
4	Organic Carbon (%)	0.42–1.06 (0.64)	0.56–1.28 (0.79)	0.48–1.2 (0.70)	0.37–1.42 (0.74)	0.41–1.49 (0.83)	0.33–1.46 (0.78)	0.74–1.52 (1.04)	0.87–1.64 (1.20)	0.88–1.56 (1.13)
5	Available Potassium (mg/100 gm)	0.21–0.71 (0.49)	0.19–0.78 (2.96)	0.28–0.79 (0.55)	0.16–0.81 (0.55)	0.26–0.84 (0.59)	0.3–0.85 (0.61)	0.16–0.56 (0.36)	0.16–0.49 (0.34)	0.14–0.47 (1.92)
6	Available Phosphorus (mg/10 gm)	0.54–3.6 (1.90)	0.66–4.3 (2.20)	0.75–4.8 (2.45)	0.2–3.7 (2.16)	0.4–3.8 (2.34)	0.5–4.2 (2.50)	0.17–0.78 (0.42)	0.17–0.83 (0.47)	0.2–0.85 (0.54)
7	Available Nitrogen (mg/10 gm)	4.21–29.5 (14.67)	5.23–28.46 (15.39)	6.75–29.35 (16.21)	7.3–30.6 (17.39)	7.9–31.24 (18.18)	8.2–31.6 (18.53)	2.63–7.68 (4.85)	2.6–8.8 (4.97)	2.06–6.77 (4.10)
8	Soil Texture (%)									
	Sand	8.6–19.5 (14.33)	10.4–21.8 (16.72)	11.6–22.6 (17.84)	1.3–19.22 (13.97)	3.8–21.38 (16.86)	4.9–23.3 (17.97)	50.0–80.0 (64.15)	58.6–85.2 (71.39)	63.7–87.8 (74.85)
	Silt	44.3–59.3 (52.89)	45.2–59.0 (53.20)	48.7–62.2 (56.40)	45.8–65.41 (55.66)	45.2–64.25 (54.86)	48.5–66.3 (57.88)	13.9–43.5 (29.64)	10.8–38.2 (24.26)	9.2–33.6 (21.61)
	Clay	24.5–42.2 (32.78)	21.9–39.6 (30.10)	17.3–35.6 (25.76)	21.7–47.8 (30.37)	20.5–45.4 (28.28)	15.2–41.8 (24.15)	2.7–11.5 (6.22)	1.2–9.0 (4.35)	1.0–7.5 (3.54)

LTL low-tide level, MTL mid-tide level, HTL high-tide level

enumerate the correlations between population density of different macrozoobenthic species and environmental parameters of soil and water. The interrelationships among the species at three tidal levels (LTL, MTL, and HTL) of three study sites (study sites I, II, and III) can also be evaluated by this representation. The eigenvalues and percentage in different axes, cumulative percentage, cumulative constant percentage, and species–environmental correlations were derived from CCA analysis in three axes (axis 1, axis 2, and axis 3) for all the study sites are shown in Table 8. Each and every plot is described herein.

3.5.6 At Study Site I (Jharkhali)

Four macrobenthic species (sp 6, 13, 15, and 18) were found to be quite independent of all the environmental parameters at LTL of study site I. Temperature, silicate, nitrate nitrogen, ammonical nitrogen, nitrite nitrogen of water, and available potassium, sand, and silt contents of soil were found to independently govern the distribution of four macrobenthic fauna (sp 1, 3, 5, and 8), while pH, DO, BOD, salinity of water

and pH, and salinity of soil influenced the distribution of five other macrobenthic species (sp 2, 14, 16, 17, and 19) at LTL of study site I. This result also suggested that six species (sp 1, 2, 14, 16, 17, and 19) showed close relation among themselves whereas, three other species of macrobenthos (sp 3, 5, and 8) displayed inverse relation with other three species (sp 13, 15, and 18; Fig. 4).

At MTL of study site I, environmental parameters exhibited clubbed appearance and showed significant relation with the abundance of macrobenthic species. This result also suggested that six species (sp 3, 5, 6, 7, 8, and 10) enjoyed close relationship among themselves while, other 10 species (sp 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20) could be clubbed based on their intimate relationship (Fig. 4).

At HTL of study site I, four macrobenthic species (sp 11, 14, 15, and 19) were found to be quite independent in their distribution to all the environmental parameters. This result also suggested that four species (sp 5, 8, 10, and 17) showed intimate relationships among themselves while population density of two other species (sp 8 and 10) revealed contrasting results

Table 8 Results of Canonical correspondence analysis (CCA) between environmental parameters with macrobenthic faunal density at different study sites

	LTL			MTL			HTL		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
S I									
Eigenvalues	0.01	0.009	0.001	0.055	0.01	0.004	0.008	0.006	0.001
Percentage	38.253	32.883	5.122	58.694	10.442	4.691	38.187	29.859	6.53
Cumulative %	38.253	71.136	76.258	58.694	69.136	73.828	38.187	68.045	74.576
Cumulative Constant %	42.482	84.58	90.67	74.892	88.215	94.201	45.409	80.916	88.681
Species–environmental correlations	0.888	0.974	0.905	0.871	0.951	0.883	0.943	0.95	0.906
S II									
Eigenvalues	0.009	0.005	0.002	0.012	0.006	0.002	0.012	0.005	0.001
Percentage	37.673	23.353	8.152	48.12	22.798	7.119	45.559	18.105	5.35
Cumulative %	37.673	61.027	69.178	48.12	70.917	78.036	45.559	63.664	69.014
Cumulative Constant %	47.729	77.351	87.643	53.583	78.969	86.895	58.985	82.426	89.352
Species–environmental correlations	0.905	0.954	0.873	0.96	0.991	0.912	0.941	0.928	0.825
S III									
Eigenvalues	0.016	0.008	0.003	0.009	0.007	0.003	0.044	0.006	0.004
Percentage	36.089	17.609	6.623	32.777	23.07	11.303	43.14	5.45	3.776
Cumulative %	36.089	53.698	60.321	32.777	55.847	67.15	43.14	48.589	52.365
Cumulative Constant %	52.996	78.885	88.581	41.784	71.193	85.601	79.269	89.283	96.221
Species–environmental correlations	0.78	0.952	0.853	0.91	0.949	0.799	0.774	0.702	0.681

with the population density of sp 11. Similar trend of inverse relationship was also recorded between sp 14 and 15 with sp 19 (Fig. 4).

3.5.7 At Study Site II (*Susnirchara*)

Environmental parameters did not impart their impact much on the distribution and abundance of 12 macrobenthic species (sp 1, 2, 3, 4, 6, 8, 9, 16, 17, 18, 19, and 20) at LTL of study site II. However, sp 14 displayed

significant relation with salinity of soil and sp 15 exhibited significant relation with pH of both water and soil and also showed significant relation with dissolved oxygen of water. This result also revealed that sp 1, 2, and 3; sp 8 and 18; and sp 17 and 20 could be clubbed based on their interrelationships, whereas seven species (sp 1, 2, 3, 4, 6, 9, and 19) of macrozoobenthos displayed inverse relation with other two species (sp 14 and 15; Fig. 5).

At MTL of study site II, most of the environmental parameters did not exhibit significant impact on the

Fig. 4 CCA for environmental parameters vs. macrobenthic faunal population density at study site I

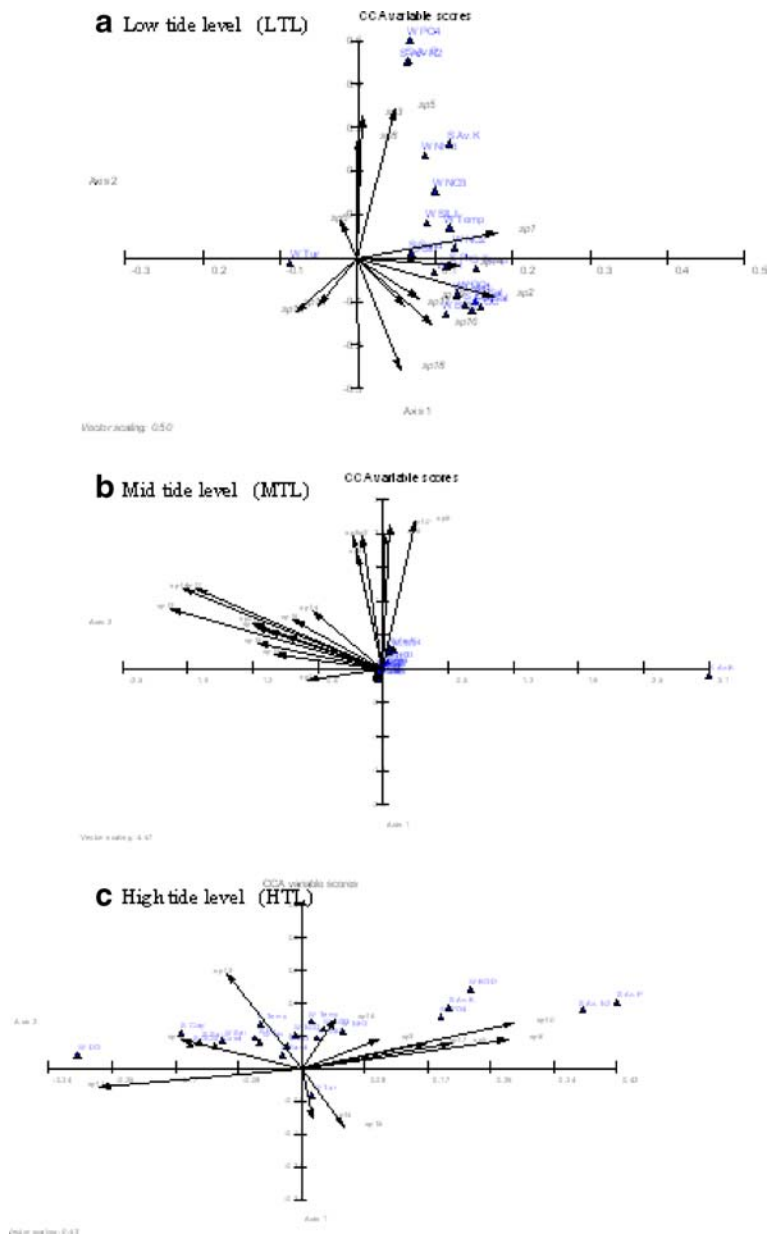
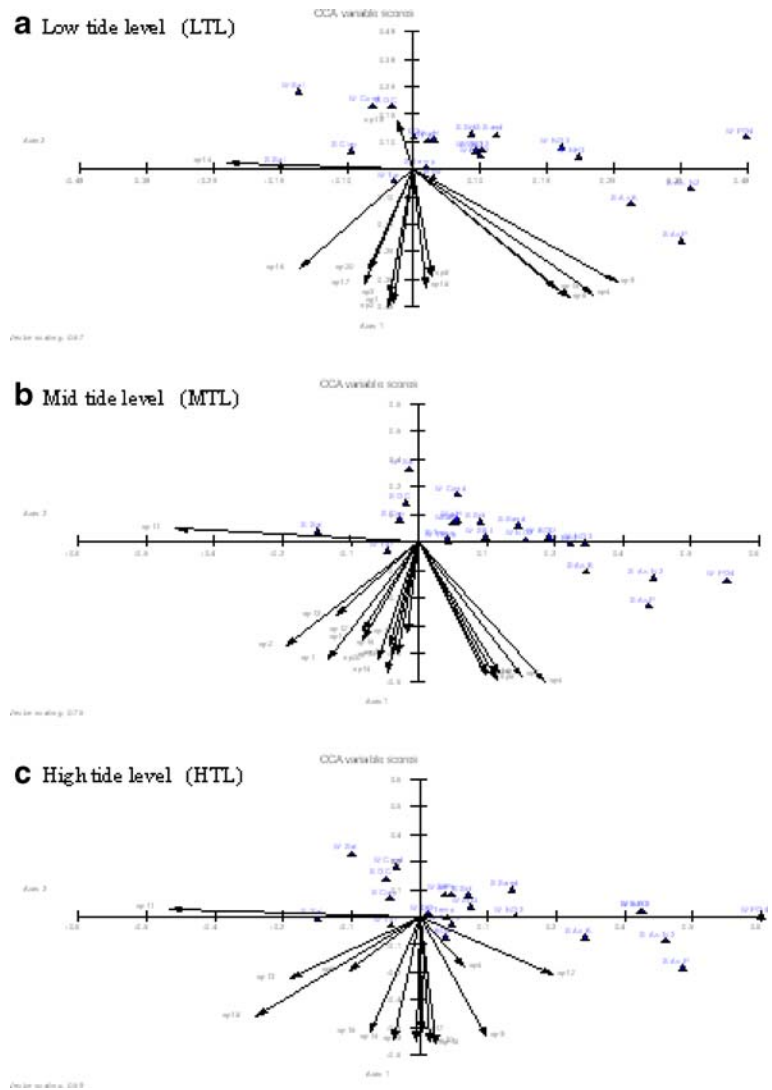


Fig. 5 CCA for environmental parameters vs. macrobenthic faunal population density at study site II



abundance of macrobenthic species. Only salinity of soil showed significant relation with the abundance of sp 11. This result also suggested that 12 species (sp 1, 2, 6, 12, 13, 14, 15, 16, 17, 18, 19 and 20) enjoyed close relation with each other while, 5 other species (sp 3, 4, 8, 9 and 10) could be clubbed based on their intimate relationships [Fig. 5].

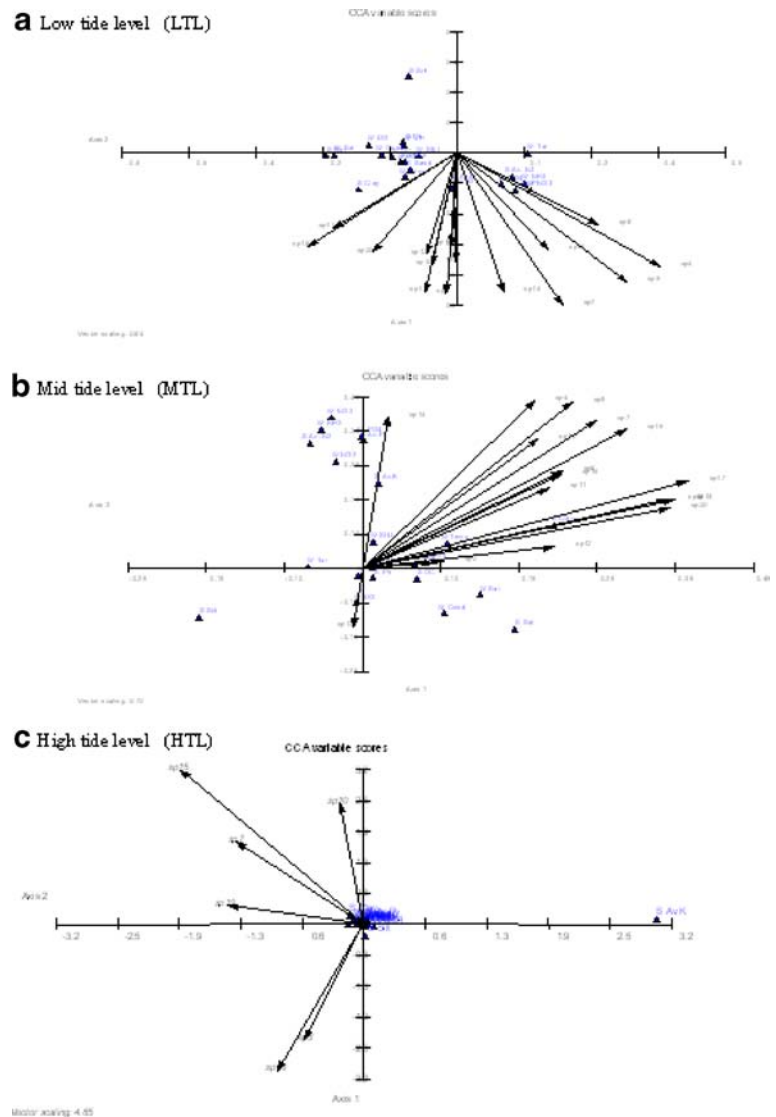
At HTL of study site II, 10 macrobenthic species (sp 6, 9, 10, 12, 14, 15, 16, 17, 18 and 19) were found to be quite independent in their distribution to the environmental parameters. The salinity of soil displayed significant relation with the abundance of sp 11 while turbidity and BOD of water showed significant relation with sp 13 and sp 4 respectively [Fig. 5].

3.5.8 At Study Site III (Bokkhali)

Temperature, nitrate nitrogen, ammonical nitrogen, nitrite nitrogen and phosphate phosphorus of water and available potassium, available nitrogen and available phosphorous of soil were found to independently govern the distribution of different macrobenthic fauna at LTL of study site III. This result also revealed that 2 species (sp 11 and 18) of macrobenthic fauna enjoyed intimate relation to each other and 6 other species (sp 1, 2, 10, 12, 17 and 19) could be clubbed based on their close relationship [Fig. 6].

At MTL of study site III, 8 macrobenthic species (sp 4, 6, 7, 9, 10, 11, 15 and 16) were found to be quite independent in their distribution to the environmental

Fig. 6 CCA for environmental parameters vs. macrobenthic faunal population density at study site III



parameters whereas 4 species (sp 17, 18, 19 and 20) enjoyed significant relation with temperature of water and clay content of soil, 2 species (sp 2 and 12) showed significant relation with temperature and pH of water and pH of soil but sp 14 showed significant relation with silicate of water and available potassium of soil. This result also revealed that sp 2 and 12, sp 6 and 16 and sp 18 and 19 enjoyed intimate relation to each other respectively [Fig. 6].

At HTL of study site III, environmental parameters showed clumping distribution and expressed significant relation with the macrobenthic faunal abundance. This result also revealed that 2 species (sp 8 and 18) could be clubbed based on their intimate relationship [Fig. 6].

Species–environmental correlation deduced from eigenvalues and their percentage, cumulative percentage and cumulative constant percentage revealed different results in respect to different study sites and tidal levels. The study site II displayed highest values in all tidal levels followed by S-I and S-II (Table 8).

4 Discussion

Ecological restoration is the process of assessing the recovery of an ecosystem that has been degraded or damaged and also represent an intentional activity that

initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. In order for an ecosystem to be well adapted to local site conditions and to display resilience in response to a stressful or changing environment, the species population that comprise it, must possess genetic fitness. An ecosystem containing genetically fit populations is one that is not only adapted to the current environmental regime, but possess some “genetic redundancy”, whereby the gene pool contains a diversity of all alleles that may be selected in response to environmental change. The present study has highlighted the distributional pattern of different biotic communities in three contrasting ecozones of Sundarbans Mangrove Ecosystem, a World Heritage Site. One ecorestorated site (S-I), one almost free from anthropogenic stress (S-II) and the other having both natural environmental and anthropogenic stress. The intertidal regions in the present communication were characterized by a wide range of faunal diversity and their peak abundance was observed during pre-monsoon followed by post-monsoon and moonsoon. Display of different zonation patterns by different groups of macrozoobenthos have been found to be initially associated with the dynamics of estuarine mangrove ecosystem enjoying diurnal and seasonal variations and tidal interplays which reflect their adaptation to different degrees of hydrodynamics of this environment (Chakraborty and Choudhury 1992). Present investigation revealed that mid-tide level harboured the maximum number of macrobenthic species followed by low-tide level and high-tide level. These observations were supported by the previous records (Chakraborty and Choudhury 1994). Present investigation highlighted similarity indices between different study sites on the basis of different groups of faunal abundance. Diversity index, richness index, evenness index and dominance index showed both temporal and spatial variation. SPV and CPV categorically highlighted the pollution status of different study sites. Different statistical analysis revealed positive and negative association between different groups of fauna and ecological parameters. CCA in the present investigation revealed that different ecological parameters of both water and soil have different intensity of impact on macrobenthic faunal distribution and abundance. The results also highlighted species assemblage structure at different tidal levels (LTL, MTL and HTL) of the three study sites.

CPV deducted from the distributional pattern of macrobenthic fauna revealed gross pollution in all three study sites while the same biotic index calculated based on the results of zooplankton diversity highlighted least pollution in the ecorestorated study site-I followed by study site-II and study site-III. It was found that environmental health in respect to faunal and floral assemblages, physical and chemical properties of water and soil of study site –II was most conducive for biodiversity enhancement followed by study site II while study site III represented an ecodegraded mangrove-estuarine habitat. Quantification of dynamic complexity of mangrove- estuarine ecosystem based on base line information appeared to be an imperative for development of eco-restoration strategy for the restoration of damaged ecosystems and conservation of biodiversity.

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