

Spatial variations in zooplankton diversity in waters contaminated with composite effluents

Subhra Kumar MUKHOPADHYAY¹), Buddhadeb CHATTOPADHYAY, Abhishek Roy GOSWAMI* and Asitava CHATTERJEE²)

Government College of Engineering and Leather Technology, Block- LB Sector III, Salt Lake City Kolkata-700098

¹) Durgapur Government College, J.N Avenue Durgapur 713214, India

²) Directorate of Forest, Govt. of West Bengal, Kolkata, India

*e-mail corresponding author: rg.abhishek@gmail.com

ABSTRACT

Zooplankton species are cosmopolitan in their clean freshwater habitat and are also found in industrial and municipal wastewaters. The present study records for the first time the aspects of zooplankton diversity in relation to physico-chemical environment of five selected sites of the East Calcutta wetlands, a Ramsar site of Kolkata city, India, heavily contaminated by industrial and municipal wastewaters. The study revealed the occurrence of 22 species of zooplankton, among these 3 species of Cladocera, 2 species of Copepoda, 15 species of Rotifera, and 2 species of Ostracoda were recorded. The copepod *Mesocyclops leuckarti* was found in all the five sites, rotifers *Asplanchna brightwelli*, *Brachionus angularis*, *B. calyciflorus* and Cladocera *Ceriodaphnia cornuta* were found in four sites; *Moina micrura* and *Diaphanosoma sarsi* were found at three sites. Site wise variation in dominance, diversity, evenness and richness were calculated. Site 1, a fish-pond that stabilized composite wastewater, showed the maximum species richness having 17 species, while Site 2, SWF wastewater carrying canal, showed only 4 species. The calculated Jack 1 values of Sites 1 to 5 were 21.78, 3.77, 18.63, 12.5 and 16.95 respectively. Shannon-Wiener species diversity index (H') values were almost similar for all the three relatively less polluted sites viz., Site 1 (1.959), Site 4 (2.010), Site 5 (2.047). However, at highly polluted sites viz., 2 and 3, H' value of 1.336 and 0.984 respectively, were calculated. Simpson's Dominance index (D_{simp}) value was highest at Site 3 (0.618) indicating maximum dominance, whereas at Site 5 dominance was lowest (0.1680) and diversity was highest. We discuss the role of zooplankton in the amelioration of wastewater.

Keywords: East Calcutta wetland, Ramsar site, zooplankton, wastewater-fed fishponds, diversity indices

1. INTRODUCTION

Zooplankton species are cosmopolitan in nature and they inhabit all freshwater habitats of the world, including polluted industrial and municipal wastewaters. Zooplankton are not only useful as bioindicators to help us detect pollution load, but are also helpful for ameliorating polluted waters. Comparisons of size structure, fecundity, and reproductive strategies of zooplankters can indicate the nature and extent of pollutant loads (Sarma 1996; Mukhopadhyay *et al.* 2000). The eastern fringe of Kolkata (formerly Calcutta), has the largest urban wetland, the East Calcutta Wetlands (ECW), a Ramsar site (No. 1208), that covers around 12,500 ha. The area includes 286 wastewater-fed fishponds spread over 3,832.27 ha (over 30% of the total wetland area) that produce nearly 10,915 metric tonnes of fish annually (Chattopadhyay *et al.* 1999). It receives effluents from about 6000 small-scale industrial establishments like tanneries, rubber industries, electroplating industries, pigment manufacturing units, potteries, and battery manufacturing plants. Composite industrial effluent together with municipal wastewater flow down through a web of canals traversing the ECW ecosystem and are finally discharged in Kultigong River, nearly 40 kilome-

ters from Kolkata city. A number of vast shallow water bodies receive the bulk of polluted wastewater and are used in pisciculture. ECW ecosystem modifies and traps a broad spectrum of contaminants. From the source to the discharge site the wastewater exhibits substantial reductions in Total Suspended Solids (TSS), Total Dissolved Solids (TDS), total hardness, chloride content, Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) (Chattopadhyay *et al.* 2004). Interesting dynamics in the community structure of zooplankton, thriving in wastewater and contaminated waters, have been recently reported from India. The present study is the first attempt to record the changes in the community structure of zooplankton, in a stabilization pond and in wastewater carrying canals along the gradient from the source points down to the confluence site in response to the changing physico-chemical environment.

2. MATERIALS AND METHODS

The areas under investigation were located between Dhapa and Kultigong in the ECW (lat. 22° 33' – 22° 40' N; long. 88° 25' – 88° 33' E), India. The first sampling station (Site 1) was a fishpond fed by tannery effluent,

around 1 km away from the source point of the canal that carried raw composite tannery effluent from Tangra tannery agglomerate, Kolkata. The second station (Site 2) was located at Chowbaga, which is 8 km from the source point, where the composite tannery effluent was siphoned into the Storm Water Flow (SWF) canal, that is being mixed with the municipal sewage through Ballygunge Drainage Pumping System which carries the bulk effluent load from two other tannery agglomerates (Topsia and Tiljala) and other small-scale industries. The third sampling station (Site 3) was on the SWF canal, near the proposed Calcutta Leather Complex at Karaidanga, around 15 km away from the source point. Site 4 was located on the same canal near Kultigong lock gate around 40 km away from the source point. Here SWF meets with the Dry Weather Flow (DWF) canal that principally carries the municipal sewage about 200 metres upstream of Kultigong river. Site 5 was on the DWF at Ghoshpur, 1km upstream from Kultigong lock gate. Sampling was done monthly for two years (24 months) between 11.00 and 16.00 hours.

From each sampling station 35 l of surface water was slowly filtered through a No. 25 bolting silk cloth plankton net for quantitative estimation of plankters. Phytoplankters and Nanozooplankters were studied in live condition. All plankton samples were analysed using Leica DM LB2 microscope fitted with Leica DFC320 camera. Narcotization, preservation and identification of plankters were made using standard references (Ahlstorm 1940; Sharma 1979a; Sharma 1979b;

Michael & Sharma 1988; Edmondson 1992; Battish 1992).

The chemical parameters of water, including Chloride, Acidity, Alkalinity, Total Hardness, Carbonate hardness, were analyzed on the spot by using EMERCK (Germany) Aquamerck/ Aquaquont water testing kits. COD, BOD, TSS, phosphate (PO_4^{3-}), nitrate (NO_3^-), sulphide (S^{2-}) and metals were analyzed following Eaton *et al.* 1995. pH, conductivity, TDS and Dissolved Oxygen (DO) were measured potentiometrically on the spot using Multiline P4 (WTW, Germany). Air and water temperature were measured by using multi-user digital thermometer. For statistical computation and community structure analyses, statistical computer software (*Statistica* for Windows, Version 5.1A, Statsoft Inc., 1996), SPSS (SPSS for Windows, Release 10.0.1 SV, SPSS Inc., 1999) and Community Analysis Package (IRC, UK, 2000) were used.

3. RESULTS AND DISCUSSION

Tables 1 and 2 show the mean values (and standard deviation) of different physico-chemical conditions and metal loads recorded from the four sites on the wastewater-carrying canal and from the tannery wastewater fed fishpond. Most of these values, even in the relatively cleaner sites of the wastewater carrying canal and the tannery wastewater-fed fishpond, were much different from those reported from uncontaminated ponds of West Bengal (Sharma 1992; Michael 1968). Zooplankters

Tab. 1. Mean and standard deviation (N = 24) of the physicochemical parameters measured at the study sites.

	Site 1		Site 2		Site 3		Site 4		Site 5	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Air Temp. (°C)	32.4	2.7	32.6	2.8	32.3	3.0	32.2	2.9	33.1	3.4
Water Temp. (°C)	31.3	4.0	30.8	4.0	30.8	3.2	30.9	3.0	29.8	3.5
pH	7.9	0.7	7.6	0.6	7.3	0.6	7.4	0.6	7.5	0.7
DO (mg l ⁻¹)	6.0	1.6	0.1	0.2	0.4	0.6	4.2	2.0	4.5	1.5
TDS (mg l ⁻¹)	1451	686	2386	1830	958	358	2307	2194	1753	1563
Conductivity (mS)	2.9	1.4	4.8	3.6	1.9	0.6	4.8	4.5	3.6	3.2
TSS (mg l ⁻¹)	542	378	344	144	499	319	96	36	243	98
Tot. Acidity (mmol l ⁻¹)	6.3	4.1	6.3	2.7	8.1	7.9	9.7	5.4	9.0	1.8
Tot. Alkalinity (mmol l ⁻¹)	26.7	25.6	63.6	68.5	21.7	18.6	20.6	22.5	18.6	18.6
CO ₃ Hardness (mg l ⁻¹ CaCO ₃)	449	397	528	433	407	417	430	410	315	206
Tot. Hardness (mg l ⁻¹ CaCO ₃)	754	825	693	648	641	616	944	890	667	422
Cl ⁻ (mg l ⁻¹)	988	695	1621	1195	726	444	1627	1698	1082	858
PO ₄ ³⁻ (mg l ⁻¹)	0.9	0.7	1.8	1.2	3.3	1.1	2.4	1.6	2.4	1.1
NO ₃ ⁻ (mg l ⁻¹)	43.6	29.0	41.0	31.9	34.6	31.5	36.9	28.2	41.5	26.7
NO ₂ ⁻ (mg l ⁻¹)	9.9	7.9	4.4	0.4	4.4	0.4	4.7	0.4	7.4	2.4
S ²⁻ (mg l ⁻¹)	128.4	100.5	77.6	79.1	141.9	39.6	85.3	40.3	121.1	55.1
BOD ₅ (mg l ⁻¹)	149	77	264	171	95	40	86	37	122	79
COD (mg l ⁻¹)	4740	4408	5602	3968	3979	3785	2241	2105	1642	1312
Chlorophyll <i>a</i> (mg l ⁻¹)	38.6	0.0	18.5	6.6	8.6	3.8	12.7	3.0	21.2	6.8

Tab. 2. Mean and standard deviation (N = 24) of the total metal content of the wastewater measured at the study sites.

	Site 1		Site 2		Site 3		Site 4		Site 5	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Chromium (mg l ⁻¹)	0.014	0.031	0.263	0.372	0.067	0.188	0.029	0.062	0.058	0.125
Lead (mg l ⁻¹)	0.463	0.124	0.408	0.088	0.336	0.105	0.359	0.101	0.281	0.097
Copper (mg l ⁻¹)	0.661	0.338	0.211	0.025	0.834	0.631	0.897	0.439	1.262	1.091
Zinc (mg l ⁻¹)	0.112	0.058	0.215	0.035	0.136	0.035	0.194	0.026	0.267	0.050
Manganese (mg l ⁻¹)	2.358	1.651	1.142	0.114	1.814	1.237	2.654	1.657	1.925	0.765
Magnesium (mg l ⁻¹)	83.55	20.53	103.4	4.17	152.2	52.69	50.89	38.97	177.6	94.61
Iron (mg l ⁻¹)	2.162	0.756	1.978	0.999	2.500	1.317	1.800	0.673	2.305	1.272

were represented by fifteen rotifers, two copepods, three cladocerans and two ostracoda species. Tables 3 demonstrates the succession of zooplankters along the study sites starting from the source down to final discharge point. The successional sequence was as follows: sessile Rotifera (Site 2) → pelagic Rotifera (Site 3) → pelagic Rotifera and Microcrustaceans (Site 4 and 5). Wetzel (2001) pointed out that rotifers commonly appear early in the succession of zooplankton communities and are succeeded by microcrustaceans. Rotifers were usually suppressed by cladocerans through exploitative competition for shared, limiting food resources. In cleaner water, the abundance and diversity of organisms with complex life history strategies increased.

3.1. Rotifers: Nature's water purifiers

Rotifers, the tiny wheel animalcules, are considered nature's water purifiers because they perform an important cleanup service in the still or slow-moving waters they inhabit. Sharma (1992) made a detailed account of the systematics and ecology of freshwater rotifers of West Bengal, but investigations on rotifers inhabiting industrial or municipal wastewater of India are scant (Arora 1961; Chandra & Krishna 1983; Patil & Harshey 1983; Sharma 1986; Saksena & Kulkarni 1986; Das & Dutta 1998). As an age-old practice, raw composite tannery effluents are stabilised in a number of tanks for the purpose of pisciculture in the ECW ecosystem. Rotifers are present in such tanks and in the wastewater carrying canal and perform the excellent function of combating organic debris load.

The presence of fifteen-rotifer species in waters with a high chloride concentration (725–1627 mg l⁻¹) indicates their euryhaline nature. Interestingly, these rotifers were also observed to grow when the pH was in the range of 7.3–7.9. Species that reached large population sizes in the slightly acidic or near-neutral waters included: *Asplanchna intermedia*, *A. brightwelli*, *Brachionus calyciflorus dorcas* and *Filinia longiseta*. Sharma (1992) also records the occurrence of *A. priodonta*, *A. brightwelli* and *B. calyciflorus* in acidic and neutral

waters. *B. calyciflorus dorcas* f. *spinosa* flourished in both acidic (pH 6.9) and alkaline (pH 8.6) conditions in the present study, thus exhibiting a wide range of pH tolerance. DO (0.1 to 6.0 mg l⁻¹) showed little effect on the rotiferan community. Both illoricate rotifers and rotifers as a whole exhibited significant (P < 0.05) positive correlation with DO (r = 0.80 and 0.81 respectively), NO₂⁻ (r = 0.90 and 0.89 respectively) and S²⁻ (r = 0.84 and 0.83 respectively) and significant (P < 0.05) negative correlation with conductivity (r = -0.98 in both cases) and Chloride (r = -0.90 and -0.88 respectively). Correlation coefficient values are given in Table 4.

The significant positive correlation between rotifers and S²⁻ in the present study is interesting. The reduction of sulphate (SO₄²⁻) to S²⁻, some of which is lost to the sediment as insoluble metallic sulphides, and the oxidation of H₂S to SO₄²⁻ both play a significant role in the modification of conditions for wastewater that is contaminated with proteinaceous material. A number of sulphate-reducing bacteria are heterotrophic and anaerobic and use the sulphur compounds during oxidative metabolism. Sulphur-reducing bacteria on the other hand, are obligate anaerobes and produce oxygen from sulphate. These two kinds of bacteria, along with sulphur-oxidising bacteria, grow abundantly in wastewater that is rich in tannery effluent (van Groenestijn *et al.* 1999) and encourage the growth of both protozoa and rotifers along the food chain.

Freshwater aquaculture ponds of the state of West Bengal are known to harbor a variety of rotiferan species. In a fishpond at Barrackpore, West Bengal, as many as 30 species were recorded (Michael 1968), and in a similar pond 18 species were reported (Sharma 1992). In contrast, throughout the present study period, the presence of only 7-9 species, at low densities in the component populations, categorically indicates the presence of significant toxicants that limit species diversity and density. Even in such adverse physico-chemical environment, three brachionids, viz., *Brachionus caudatus personatus* (density 13.2 ± 12.311 nos. l⁻¹), *B. calyciflorus dorcas* f. *spinosa* (density 72.6 ± 32.650 nos. l⁻¹) and *B. quadridentatus cluniorbicularis* (density 114.5 ±

Tab. 3. Abundance of zooplanktonic organisms in the sampling sites (Number of organisms $\times 1^{\pm} \pm \text{sd}$). In parenthesis are the minimum and maximum value.

	Site 1	Site 2	Site 3	Site 4	Site 5
ROTIFERA					
<i>Asplanchna intermedia</i>	9.4 \pm 5.9 (0.0 – 18.4)	-	0.7 \pm 2.1 (0.0 – 9.6)	-	19.9 \pm 21.4 (1.5 – 86.1)
<i>A. brightwelli</i>	42.1 \pm 55.2 (0.0 – 163)	-	0.3 \pm 1.3 (0.0 – 6.2)	1.8 \pm 4.3 (0.0 – 15.3)	4.6 \pm 5.8 (0.1 – 18.7)
<i>Brachionus candatus personatus</i>	13.2 \pm 12.3 (0.0 – 40.2)	-	2.8 \pm 4.2 (0.0 – 13.5)	2.2 \pm 5.6 (0.0 – 24.7)	-
<i>B. angularis</i>	0.8 \pm 0.76 (0.0 – 2.2)	-	1.8 \pm 4.2 (0.0 – 15.1)	1.6 \pm 2.7 (0.0 – 11.6)	3.1 \pm 5.2 (0.0 – 18.3)
<i>B. calyciflorus dorcas f. spinosa</i>	72.6 \pm 32.6 (2.6 – 122)	-	126 \pm 90.8 (12.5 – 318)	3.0 \pm 3.8 (0.0 – 16.1)	62.4 \pm 55.4 (7.1 – 182.6)
<i>B. quadridentatus cluniorbicularis</i>	114 \pm 101 (0.0 – 274)	-	-	-	8.3 \pm 16.6 (0.0 – 67.1)
<i>B. plicatilis</i>	0.2 \pm 0.4 (0.0 – 1.4)	-	1.8 \pm 4.9 (0.0 – 18.1)	0.9 \pm 2.2 (0.0 – 10.3)	-
<i>B. bidentata</i>	-	-	2.2 \pm 5.3 (0.0 – 25.2)	6.6 \pm 7.9 (0.2 – 28.1)	-
<i>B. rubens</i>	-	-	4.7 \pm 11.5 (0.0 – 48.2)	-	-
<i>B. falcatus</i>	7.1 \pm 17.5 (0.0 – 82.5)	-	-	-	11.5 \pm 17.2 (0.0 – 53.2)
<i>Keratella tropica</i>	0.6 \pm 0.8 (0.0 – 2.4)	1.1 – 2.2 (0.0 – 8.2)	1.0 – 2.6 (0.0 – 2.6)	-	1.0 – 1.7 (0.0 – 5.1)
<i>Filinia opoliensis</i>	21.4 \pm 38.1 (0.0 – 132)	-	1.4 \pm 2.2 (0.0 – 7.0)	-	9.1 \pm 15.6 (0.0 – 47.3)
<i>F. longiseta</i>	-	-	-	-	3.3 \pm 3.7 (0.0 – 11.8)
<i>Philodina citrina</i>	-	1.2 \pm 3.6 (0.0 – 14.2)	-	-	-
<i>Scardium longicaudum</i>	0.2 \pm 0.8 (0.0 – 4.1)	0.8 \pm 2.1 (0.0 – 8.5)	-	-	0.5 \pm 1.2 (0.0 – 4.6)
COPEPODA					
<i>Mesocyclops leuckarti</i>	6.6 \pm 16.2 (0.0 – 66.2)	0.5 \pm 1.2 (0.0 – 3.4)	2.1 \pm 3.9 (0.0 – 13.2)	14.5 \pm 8.7 (2.0 – 31.9)	93.6 \pm 64.1 (6.5 – 191.3)
<i>M. hyalinus</i>	3.1 \pm 4.5 (0.0 – 12.7)	-	-	-	1.9 \pm 3.5 (0.0 – 12.4)
CLADOCERA					
<i>Moina micrura</i>	1.1 \pm 18.2 (0.0 – 69.1)	-	-	5.4 \pm 4.4 (0.2 – 13.5)	36.9 \pm 40 (1.5 – 133)
<i>Ceriodaphnia cornuta</i>	1.9 \pm 5.7 (0.0 – 26.5)	-	0.2 \pm 0.4 (0.0 – 1.2)	1.1 \pm 1.8 (0.0 – 6.8)	6.1 \pm 11 (0.0 – 41.7)
<i>Diaphanosoma sarsii</i>	0.4 \pm 1.1 (0.0 – 3.9)	-	0.5 \pm 0.9 (0.0 – 2.8)	-	12.4 \pm 14.3 (0.0 – 55.9)
OSTRACODA					
<i>Cyclocypris globosa</i>	-	-	13.7 \pm 14.2 (0.2 – 45.1)	0.8 \pm 0.7 (0.0 – 1.9)	-
<i>Cyprinotus dentatus</i>	79.2 \pm 77.6 (0.0 – 210)	-	-	6.4 \pm 7.6 (0.2 – 29.6)	38.2 \pm 28.2 (6.6 – 99.0)

100.656 nos. l⁻¹) thrived in large numbers in the waste-water fed fish pond (Site 1). Thus, these species could be considered very tolerant species, as far as the present ecotoxicants were concerned. *B. calyciflorus dorcas* f. *spinosa* also appeared in even larger numbers in the more troubled waters of Site 3 (density 126.1 ± 90.791 nos. l⁻¹). Two illoricate forms, viz., *A. intermedia* and *A. brightwelli*, thrived in larger numbers at Sites 1 and 5, which share a much more similar physico-chemical regime. Several toxicants in the environment are known to induce rapid parthenogenetic development while reduced sexual development in different rotifer species, even at low concentrations (Snell *et al.* 1999). Parthenogenetic swarms of brachionids and, at times, of *A. brightwelli* corroborate such findings in the stabilisation ponds fed by tannery wastewater in the present study.

Forbes (1999) pointed out that parthenogenetically reproducing clones of cladocerans and rotifers offer several advantages, the most important of which is the identification and quantification of the role of genetic factors in controlling responses to toxicants, under stressful situations. Snell *et al.* (1999) reported a toxicant-induced reduction in rotiferan population growth rate. It was observed that the most serious consequence of such reduced population growth rate was a reduction in resting egg production.

Rotifers were common in the samples collected from Sites 1, 3, 4 and 5. Three rotifer species, viz., *Keratella tropica*, *Philodina citrina* and *Scaridium longicaudum* appeared in small number in the samples collected from Site 2. A very small population of *Scaridium longicaudum* was also noted from Sites 1 and 5 (Tab. 3). Dominant rotifer species were *Asplanchna intermedia*, *A. brightwelli*, *B. calyciflorus dorcas* f. *spinosa* and *B. quadridentatus cluniorbicularis*. Occurrence of these clean-water species in high abundance in wastewater indicates their tolerance to a wide range physico-chemical factors. Sharma (1992) reported the alkaline preference of *B. angularis*, *B. caudatus* and *B. calyciflorus*, but in the present study they grew in the mean pH range of 7.32 ± 0.586 – 7.91 ± 0.690.

3.2. Micro crustaceans: grazing – predation – detritivory

Six microcrustacean species, comprising of two predatory Copepods, three grazer Cladocerans and two detritivore Ostracods appeared in the wastewater (Tab. 3). *Mesocyclops leuckarti* was the only copepod present in all the sampling stations. In sites 1 and 5 *M. hyalinus* also appeared along with *M. leuckarti*. Collections from these sites also contained 3 cladoceran species; of these, *Moina micrura* was the most abundant. The other two species, *Ceriodaphnia cornuta* and *Diaphanosoma sarsi* were present in small numbers at Sites 1 and 5. *C. cornuta* was also present at low abundance in Site 4 while a similarly low density of *D. sarsi* was noted from site 3. Two species of ostracoda, viz., *Cyclocypris globosa*

and *Cyprinotus dentatus* were observed in the collected samples. Ostracods are omnivorous and feed on bacteria, algae, detritus and other microorganisms by means of filtration (Edmondson 1992). They are mostly active on the surface of the sediment and as their population flourished, the species appeared in the littoral samples. *Cyclocypris globosa* was present at Sites 3 and 4 whereas *Cyprinotus dentatus* was present Sites 1, 4 and 5. Important physico-chemical factors influenced the microcrustacean population fluctuation, including DO, conductivity, chloride, nitrite (NO₂⁻), S²⁻, COD, Cu and Mg. Significant negative correlations were observed between ostracods and conductivity ($r = -0.98$; $P < 0.05$) and chloride ($r = -0.89$; $P < 0.05$). Significant positive correlations were observed between ostracods and NO₂⁻ ($r = 0.90$; $P < 0.05$) and S²⁻ ($r = 0.89$; $P < 0.05$). Total copepods and cladocerans exhibited a significant negative correlation with COD ($r = -0.78$ and -0.74 respectively; $P < 0.05$) but positive correlations with Cu ($r = 0.84$ for both cases; $P < 0.05$) and Mg ($r = 0.75$ and 0.73 respectively; $P < 0.05$). Both correlations and multiple regression analyses are given in Table 4.

3.3. Zooplankton community structure analysis

Site-wise variations in dominance, diversity, evenness, richness and other indices of community structure are given in Tables 5 and 6. Estimating the total or real number of species, i.e., species richness, including those that were not sampled, in a community is a crucial task, especially when the habitat is in a stressful situation. For this purpose, first-order *Jack Knife Estimate (JACK1)* of species richness was employed to resample the observed species and to relate the estimated species richness to a higher sample size. *JACK1* values calculated for the five sites were as follows: Site 1 - 21.78, Site 2- 3.77 Site 3- 18.63 and Site 4- 12.5 and Site 5- 16.95. Therefore, the value was lowest for the most polluted sampling station (Site 2) and highest for the stabilized fishpond (Site 1). Shannon–Wiener species diversity index (H'), based mainly on the proportional species abundance, was almost similar for all the three sites, viz., Site 1 (1.959), Site 4 (2.010) and Site 5 (2.047). In Site 2 and Site 4 the calculated values were 1.336 and 0.984 respectively. At the most stressful site (site 2), H' value was slightly higher than Site 3, though only four species occurred at the former site. Pielou's index of evenness (J') was highest in Site 2 (0.964) followed by Site 4 (0.838), Site 5 (0.738) and Site 1 (0.691) while the lowest was recorded in Site 3 (0.363). Therefore, except Site 3, the J' values for all other sites were within a comparable range.

Simpson's dominance index (D_{SIMP}), which is also based on proportional abundance like H' , showed quite contrasting values to those for H' . D_{SIMP} value was highest for Site 3 (0.618) indicating maximum dominance at the site with minimum diversity, as reflected by the H' value. In contrast, dominance was lowest at Site 5

Tab. 4. Correlation coefficients (significant at $P < 0.05$) between the zooplankton communities and the physicochemical environment of their habitat (*marked correlations were significant).

	D.O	Cond	Cl	NO ₂ ⁻	S ²⁻	COD	Cu	Mg
Illoricate Rotifera	0.80*	-0.98*	-0.90*	0.90*	0.84*	-0.14	0.37	0.12
Total Rotifera	0.81*	-0.98*	-0.88*	0.89*	0.83*	-0.14	0.38	0.07
Copepoda	0.49	-0.46	-0.59	0.42	0.57	-0.78*	0.83*	0.74*
Cladocera	0.58	-0.59	-0.69	0.53	0.67	-0.74*	0.83*	0.73*
Ostracoda	0.84*	-0.98*	-0.89*	0.90*	0.84*	-0.20	0.43	0.09
Total Zooplankton	0.85*	-0.98*	-0.95*	0.90*	0.89*	-0.39	0.60	0.31

Tab. 5. Different indices to comment on the community structure of the study sites.

Diversity indices	Site-1	Site-2	Site-3	Site-4	Site-5
Species Number Estimate [$Jack1 = OS + r_j(n-1)/n$]	21.78	3.77	18.63	12.5	16.95
Shannon-Wiener Species Diversity Index [$H' = -\sum_{i=1}^{OS} p_i \ln p_i$]	1.959	1.336	0.984	2.010	2.047
Pielou's Evenness Index [$J = \frac{H'}{\ln OS}$]	0.691	0.964	0.363	0.838	0.738
Margalef's Richness Index [$D_{MARG} = \frac{OS-1}{\ln N}$]	2.688	2.342	2.757	2.638	2.611
Simpson's Dominance Index [$H_{SIMP} = \sum_{i=1}^{OS} (p_i)^2$]	0.185	0.273	0.618	0.176	0.168

Where OS = observed number of species; P_i = Proportional abundance of species i ; n = number of individuals per species; N = total number of individuals per sample; r_j = occurrence of species with minimum density.

(0.168) where diversity was maximum (2.047). Although both Shannon measures and Simpson's index consider the proportional abundance of species, H' is more sensitive to rare species and D_{SIMP} puts more emphasis on the common species. Therefore, these indices point out the occurrence of many rare species in

Sites 1, 4 and 5, but not at Site 3. Margalef's richness index (D_{MARG}), which considers both abundance and species numbers, varied between 2.342 and 2.757. The highest D_{MARG} value of 2.757 was calculated at Site 3, followed by Site 1 (2.688), Site 4 (2.638) and Site 5 (2.611) (Tab. 5). All these sites harboured a good number of

Tab. 6. Different similarity indices to compare the community structure of the study sites

	Site-2		Site-3		Site-4		Site-5	
	S_J	S_M	S_J	S_M	S_J	S_M	S_J	S_M
Site-1	0.286	0.0003	0.750	0.426	0.642	0.071	0.910	0.467
Site-2			0.210	0.0003	0.132	0.0005	0.300	0.006
Site-3					0.692	0.054	0.646	0.500
Site-4							0.518	0.240

Jaccard Similarity Index

$$[S_J = \frac{2a}{OStot}]$$

Morisita's Similarity Index

$$[S_M = \frac{2_i \cdot x_{i1}x_{i2}}{x_{i1}^2 + x_{i2}^2}]$$

Where x_{i1} , x_{i2} = densities of species I at sites 1 & 2; a = co-occurring species; $OStot$ = total number species in both sites, i was the species of i^{th} kind.

zooplankton species. When comparison between sites was made by using quantitative presence-absence type, Jaccard similarity index (S_J) (Tab. 6), Site 1 and Site 5 showed maximum similarity ($S_J = 0.910$) whereas low similarity ($S_J = 0.132$) was calculated between site 2 and Site 4. S_J values were also fairly high for the comparisons between Site 1 and Site 3 ($S_J = 0.750$) and between Site 3 and Site 4 communities ($S_J = 0.692$). Morisita's similarity index (S_M), based on meristic data (i.e., counts of individuals referring quantitative indices), showed high values for the comparison between Site 1 and Site 5 ($S_M = 0.467$) and low values for the comparison between Site 1 and Site 2 ($S_M = 0.0003$) and between Site 2 and Site 3 ($S_M = 0.0003$). Therefore, from the qualitative standpoint, tannery wastewater stabilisation pond was much similar to the sites located at farthest stations on SWF and DWF canals but quantitatively speaking, communities at all the sites, except the Site 2 with much toxic load, were much more similar.

Index of dominance dropped from 0.618 at Site 3 to 0.168 at Site 5 indicating lower environmental stress at the later site. In fact, Sites 1, 4 and 5 all showed considerably lower values (than in the remaining sites) indicating a less stressful situation. Likewise, Shannon index of general diversity more than doubled from Site 3 (0.984) to Site 5 (2.047). Evenness and richness indices also showed the same trend, indicating a gradual improvement of the abiotic environment from Site 2 through to Site 4. However, density and diversity of the planktonic organisms, even at distant sites of 4 and 5, were significantly lower compared to the reports from clean uncontaminated waters (Michael 1968; Sharma 1992). This definitely indicated the presence of stressful physico-chemical environment even at the final dis-

charge site of the canal (Sites 4 and 5) where there was considerable natural abatement of most of the toxicants. Hierarchical cluster analysis of the study sites was done on the basis of the different limnochemical conditions (Fig 1). Dendrograms constructed using nearest neighbour method showed that the Site 2 was quite separate from the two different clusters composed of Site 1-Site 3 and Site 4-Site 5 indicating their comparable physico-chemical ambience. Hierarchical cluster analysis of the study sites made based on the abundance of the zooplankton species in the study sites (Fig. 2) revealed a comparable picture. As Site 2 carried the highest loads of contaminants, it was farthest from all the clusters in the dendrogram. Sites 1, 3 and 5 were comparatively cleaner, and harbored zooplankton at comparable densities and richness.

Correlation coefficient values (significant at $P < 0.05$) between the diversity indices and metal content in the ambient environment are presented in Table 7. Interestingly, Cr and Zn showed significant negative correlation with Species Number Estimate ($Jack1$) and Margalef's richness index while significant positive correlation with Pielou's evenness index indicating that these metals, when abundant in ambient water, had a negative impact on the zooplanktonic diversity and only the tolerant opportunists grew in contaminated waters. Pb also exhibited similar result, although not significant at $P < 0.05$. Contrastingly, Cu and Mn showed significant positive correlation with $Jack1$ and Margalef indices and a weak negative correlation with Pielou's evenness index. Mg and Fe also exhibited similar results, although the correlation coefficient values were insignificant in all cases. Although most of the trace metal micronutrients like Cu, Zn, Fe, and Mn were in

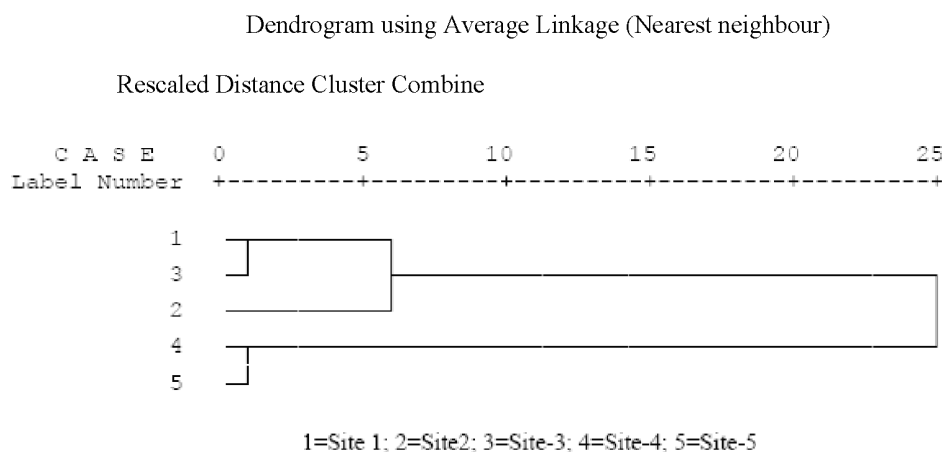


Fig. 1. Hierarchical cluster analysis of the selected study sites depending on the limnochemical conditions.

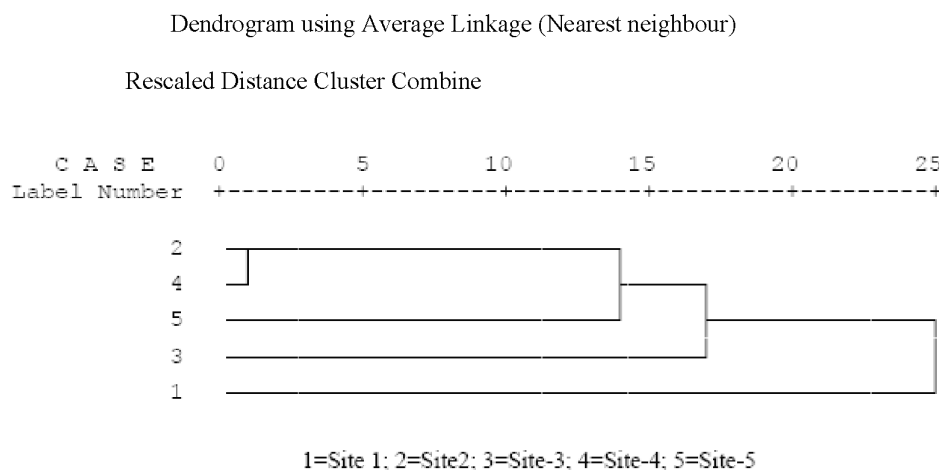


Fig. 2. Hierarchical cluster analysis of the sites depending on the richness and abundance of zooplankton species in the study sites.

organic complexes, a large fraction of Zn usually remained in ionic form or weak complexes (Wetzel 2001). Thereby, a difference between Zn and other bioactive trace elements were observed to influence the zooplankton community structure differently. Most Pb was also reported to be adsorbed to particle surfaces and thereby exhibited weak correlations as compared to Cr and Zn in the present study. Wetzel (2001) reviewed the effects of trace metals on plankton community and it was important to note that the relative concentrations of trace elements had a significant effect on the competitive abilities of the plankton.

4. CONCLUSION

The ECW is able to transform and trap a wide range of contaminants. The present study records the remarkable decrease in TSS (72 %), TDS (59 %) and chlorides

(55 %) between the wastewater source point (Site 2) and the final discharge site (Site 4). DO profile increased dramatically from 0.10 mg l⁻¹ at Site 2 to 4.24 mg l⁻¹ at Site 4. Site 1, the wastewater-fed fish pond, had normal DO level (6.01 mg l⁻¹) for fish development, while Site 4 and Site 5 attained DO values 4.24 and 4.53 mg l⁻¹ respectively, the limit of the fish tolerance by natural processes of stabilization. Decreases in BOD and COD values were 67 % and 60 % respectively. Such changes definitely indicate the cost-effective ameliorative role of the wetland ecosystem proving the excellent efficiency of the natural stabilization of wastewater. At about 30 km down the source point, we noticed a number of water dependent avifauna around the study sites. From these regions different oligosaprobic fauna like, dragonflies, their nyaads, bloodworms and aquatic beetles were also found. Plankters played a major role in the amelioration processes through degradation of the suspended solids

Tab. 7. Correlation coefficients (significant at $P < 0.05$) between the diversity indices and metal content in the ambient environment (*marked correlations were significant).

	Jack1 Estimate	Shannon Index	Pielou's Index	Margalef's Index	Simpson's Index
Cr	-0.87*	-0.50*	0.49*	-0.90*	0.11
Pb	-0.03	0.001	0.25	-0.19	-0.18
Cu	0.60*	0.46*	-0.38	0.64*	-0.11
Zn	-0.50*	0.31	0.53*	-0.52*	-0.42
Mn	0.59*	0.64*	-0.15	0.68*	-0.34
Mg	0.23	-0.29	-0.47*	0.13	0.39
Fe	0.58*	-0.46*	-0.84*	0.51*	0.66*

and progressive utilization and transformation of the nutrients. Rotifers, both sessile and pelagic species, degraded TSS, releasing nutrient in one hand and increasing light penetration on the other and thereby augmented phytoplankton productivity and consequently improved DO profile. Such series of changes are important in amelioration processes operating in the wastewater carrying canal (Koteswari & Ramanibai 2004). Despite the presence of high nutrient load, different other chemical factors might have been responsible to check the excess growth of autotrophs, leading to eutrophication. In addition to the remarkable ameliorative capacity of the ECW, treating about 1/3 of the Kolkata city's wastewater (estimated at 68 million liters/day), agriculture and pisciculture in these regions produce 150 tons of fresh vegetables and 40 tons of fish daily providing an employment opportunity of 2 persons per hectare. Tiny microbes and plankton are instrumental in turning wastes into wealth, with the support of the strong solar radiation, and a myriad of physico-chemical interactions and transformations.

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REFERENCES

- Ahlstorm, E.H. 1940. Revision of Rotatoria, Genus *Brachionus* and *Platyas* with descriptions of one new species and two new varieties.
- Arora, H.C. 1961. Rotifera as indicators of pollution, *Bull. CPHERI Nagpur*, 3&4: 24-26.
- Battish, S.K. 1992. *Freshwater Zooplankton of India*, Oxford and IBH publishing CO, Pvt, Ltd. Delhi.

- Chandra, S. & G. Krishna. 1983. Effect of tannery waste disposal on the quality of the river Ganges in Kanpur. *Poll. Res.*, 2: 63-64.
- Chattopadhyay, B., R. Gupta, A. Chatterjee & S.K. Mukhopadhyay. 1999. Characterisation and ecotoxicity of tannery wastes envisaging environmental impact assessment, *J.Amer.Leather Chem. Assoc.*, 94 (9): 337-346.
- Chattopadhyay, B., S. Chatterjee & S.K Mukhopadhyay. 2004. Seasonality in Physico Chemical; Parameters of Tannery Wastewater Passing Through The East Calcutta Wetland Ecosystem. *J. Soc. Leather Technol. Chem.*, 88: 27-36.
- Das, N.K. & N.C. Datta. 2000. Seasonal variation in diversity indices of periphytic community of wastewater-fed pond, 2000, *Waste recycling and resource management in the developing world*, University of Kalyani and International ecological engineering society, Kalyani: 10-11.
- Eaton, A.D., L.S. Clesceri, A.E. Greenberg. 1995. *Standard Methods of the Examination of Water and Wastewater*. 19th Edn. APHA, Washington D.C.
- Edmondson, W.T. *Fresh water Biology (Ward & Whipple)*. 1992. International Books & Periodicals Supply Service, 2nd ed.
- Forbes, V.E. 1999. Genetics and Ecotoxicology-Insight from the Interface. In: V.E. Forbes (Ed.), *Genetics and Ecotoxicology*. Taylor & Francis, U.S.A: 1-8.
- Koteswari, Y.N. & R. Ramanibai. 2004. Evaluation of toxicity of tannery effluent on plankton community structure: a multispecies microcosm study II. *Turk J Biol.*, 28: 55-63.
- Michael, P. 1984. *Ecological methods for Field and Laboratory Investigation*. Tata McGraw Hill Publication Ltd, New Delhi.
- Michael, R.G. 1968. Studies on the Zooplankton of a tropical fishpond. *Hydrobiol.*, 32: 47-68.
- Mishra, S.R. & D.N. Saksena. 1992. Eds., *Aquatic Ecology*, Asish Publication House, Delhi: 231-273.
- Mukhopadhyay, S.K., A. Chatterjee, R. Gupta & B. Chattopadhyay. 2000. Rotiferan community structure of a tannery effluent stabilisation pond in east Calcutta wetland ecosystem. *Chem. Env. Res.*, 9 (1 & 2): 85-91.
- Patil, S.G. & D.K. Harshey. 1983. Impact of gelatine factory effluent on the water quality and biota of a stream near Jabbalpur, *J. Environ. Biol.*, 7: 61-65.
- Saksena, D.N. & N. Kulkarni. 1986. On the rotifer fauna of two sewage channels of Gwalior. *Limnologica (Berlin)*, 17: 139-148.
- Sarma, S.S.S. 1996. Some relationships between size structure and fertility of rotifer populations. In: B.L. Kaul (Ed.), *Advances in Fish Wildlife Ecology and Biology*. Daya Publishing House, Delhi, 1: 37-50.

- Snell, S.W., M. Serra & M.J. Carmona. 1999. Toxicity and sexual reproduction in Rotifers: Reduced resting egg production and heterozygosity loss, In: V.E. Forbes (Ed.), *Genetics and Ecotoxicology*, Taylor & Francis, U.S.A., 169-185.
- Sharma, B.K. 1979a. Rotifers of West Bengal III, *Hydrobiol.*, 64: 239-250.
- Sharma, B.K. 1979b. Rotifers of West Bengal IV, *Hydrobiol.*, 65: 39-47.
- Sharma, B.K. 1986. Assessment of pollution indicators in Indian rotifera, *J. Meghalaya Sci. Soc.*, 9: 47-49.
- Sharma, B.K. 1992. Systematics, distribution and ecology of fresh water rotifer of West Bengal. In: S.R. Mishra and D.N. Saksena (Eds), *Aquatic Ecology*, Asish Publishing House, Delhi: 231-237.
- Sharma, D.C., P.C. Srivastava, B.N. Johri & P. Chandra. 1996. Environmental Impact of Tannery Effluents on Heavy Metal Phytotoxicity and Health Hazards. *J. Indust. Poll. Cont.*, 12(2): 137-142.
- van Groenestijn, J.W., E. Ravindranath & J.S.A. Langerwerf. 1999. Sulphur recovery from tannery wastewater, *Proc. XXVI IULTCS Congress*, Central Leather Research Institute, Madras: 428-433.
- Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems*, 3rd Ed. Academic Press, New York: 181-186.

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