Zooplankton assemblages along the longitudinal gradient of the River Yamuna floodplains in Delhi

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Abstract
Zooplankton communities along the River Yamuna in Delhi stretch showed considerable spatio-temporal variations. A gradual shift from a zooplankton assemblage dominated by Cladocera and Copepoda to a community dominated by Rotifers and a drastic decrease in biotic index values were observed along the longitudinal gradient. Relatively cleaner sites supported larger zooplankton assemblages compared to those subjected to sewage outfalls and industrial effluents. Species elimination was observed mainly in the mid-stretch and downstream of Okhla subjected to high loads of pollution. The study highlighted the role of inundated floodplain habitats in structuring the zooplankton community at upstream of Okhla barrage which supported the diverse community in comparison to that of midstream sites.

Key words: Community structure, floodplain, pollution, species composition, co-inertia

Introduction
Zooplankton constitute an important link in food chain as grazers and serve as food for aquatic organisms, particularly fishes. Monitoring of zooplankton as biological indicators may act as fore warning for health of riverine ecosystem. A number of factors including hydrographic stability, filtering effect of aquatic vegetation, pollution and overall biotic interactions determine the structure and dynamics of zooplankton communities.

Despite the recent increased interest in large river ecosystems, our knowledge of the zooplankton of these habitats remains fragmentary. Relatively little attention has been paid to river zooplankton compared with lake zooplankton, although data on zooplankton composition and seasonal dynamics exist for some rivers in Europe and America (e.g. Kofoid, 1903; Reinhard, 1931 Klimowicz, 1981; Pourriot et al., 1997; Kreczkowska-Woloszyn, 1985; Saunders & Lewis, 1988; Ferrai et al., 1989; Vasquez and Rey, 1989; Pace et al., 1991; Thorp et al., 1994; Vandijk & Van Zanten, 1995).This lack of research may have resulted from the impression that rivers were not suitable environments for zooplankton as the stream flows have negative effects on zooplankton by transporting them into unfavourable environments physically damaging them and diluting their food availability (Rzsoka, 1978; Pace et at., 1992, Basu and Pick, 1996).

The abundance of zooplankton in rivers is controlled by variations in transport and variations in growth. The physical interaction of flow regime and source areas regulates transport by determining the rate at which plankton are added to the main channel of the river. A rise in river level, for example, may bring the river into contact with floodplain water bodies and flush plankton into the river as documented by Saunders and Lewis, 1987, 1988 & 1989.

River ecologists should consider biological as well as physical loss factors when assessing zooplankton populations in large rivers (Jack and Thorp, 2002) as biotic interactions in rivers may be more important in structuring zooplankton communities than was previously thought (Gosselain et at., 1998a,b; Welker and Walz ,1998; Viroux, 1997, 1999; Jack and Thorp ,2000; Descy et al., 2003).

The main changes of water quality with an increase of organic pollution and eutrophication shown by a greater concentration of $NH4\ +$, $NO2^-$ and total P and a lower dissolved oxygen concentration (Descy et al., 1988), fluctuation in turbidity caused by erosion, agricultural runoff and silt being washed in with heavy rainwater (Michael, 1968), consequent lack of transparency (Mc Combi, 1953) and blanketing effect of suspended materials (Welch, 1952) have been studied to show their interference with the photosynthesis of phytoplankton and the zooplankton productivity which feed on them, both in the lotic and lentic habitats.

Because of the heterotrophic nature and constituting a major link in the food chain and in view of their key role in recycling the organic materials in aquatic habitats (Kulshrestha et al., 1989), zooplankton have been considered for use as indicators in biological monitoring of pollution both for saprobic and trophic conditions(Khan and Rao, 1981). Various studies have shown the excessive susceptibility of zooplankton to heavy metal pollution as compared to fish (Anderson, 1980; Sharma et al. 2000) and accordingly suggested use of zooplankton as preferred indicators. Much of the earlier work on the subject has been critically reviewed by Sladeck (1973).

The present paper highlights basic structure and dynamics of zooplankton communities of River Yamuna and its floodplain in Delhi stretch. The emphasis is on highlighting the interrelationships of water quality changes with zooplanktonic communities, which could provide critical input to development of ecological indicators for sustainable management of riverine ecosystems.

Study Area

River Yamuna located between 28o 24′ 17′′and 28 o 53′ 00′′ N and between 76o 50′ 24′′ and 77o 20′ 37′′E extends from Palla in the north to Okhla in the south .The length of river in Delhi stretch is 50km with almost 50% in the north of Wazirabad barrage and balance in the south. The riverbed gradually decreases between 204 to 195 above MSL from Palla to Okhla downstream indicating a mild slope within the stretch. Three barrages located at Wazirabad, ITO and Okhla essentially influence hydrological regimes of the river stretch in Delhi.

Delhi has urbanized at a faster rate with concomitant increase of population from 2.6 million in 1961 to 13.8 million in 2001. Rapid urbanization and industrialization has led to generation of 3700 mld of wastes which directly or indirectly flow into the river through 22 drains. Najafgarh, Barapulla and Shahdara are the major drains contributing more than 70% of the total pollution load. The floodplain although largely contained within bunded embankments constitutes a significant floodplain environment. The area covered by floodplain is 94.84 km^2 and that of the river channel is 19.31 km^2. Broadly floodplain area comprises of forests, agriculture, settlements and lakes / ponds. The floodplain is doted with numerous lakes, ponds, pools and puddles that\ get inundated by lateral spread of water during monsoon and by direct precipitation. A survey conducted indicated 45 lakes / ponds distributed all along eastern and western sides of floodplain area of river stretch from Palla to Okhla downstream. Most of these water bodies have lost their connection with the river channel but the connectivity is ensured during monsoon due to lateral moment of the water from the river channel

Hydrologically, four zones: i) Jhangola to upstream Wazirabad barrage; ii) downstream Wazirabad barrage to upstream ITO; iii) ITO downstream to upstream Okhla and iv) Okhla downstream to Jaitpur were identified in the river stretch considering location of barrages. The sewage and industrial wastes draining the catchment are discharged through 22 drains into the river channel. Based on hydrological factors and sewage outfalls 14 sites were selected representing river floodplains and lakes / ponds (Fig. 1). R1 and R2 stations located in the upper zone are relatively less polluted. R3, R4 and R5 are subjected to heavy load of pollution from Delhi city through major drains from the western side. R6 receiving water from Hindon cut remains inundated throughout the year. R7 located downstream of Okhla barrage receives industrial effluents from Shahdara drain.

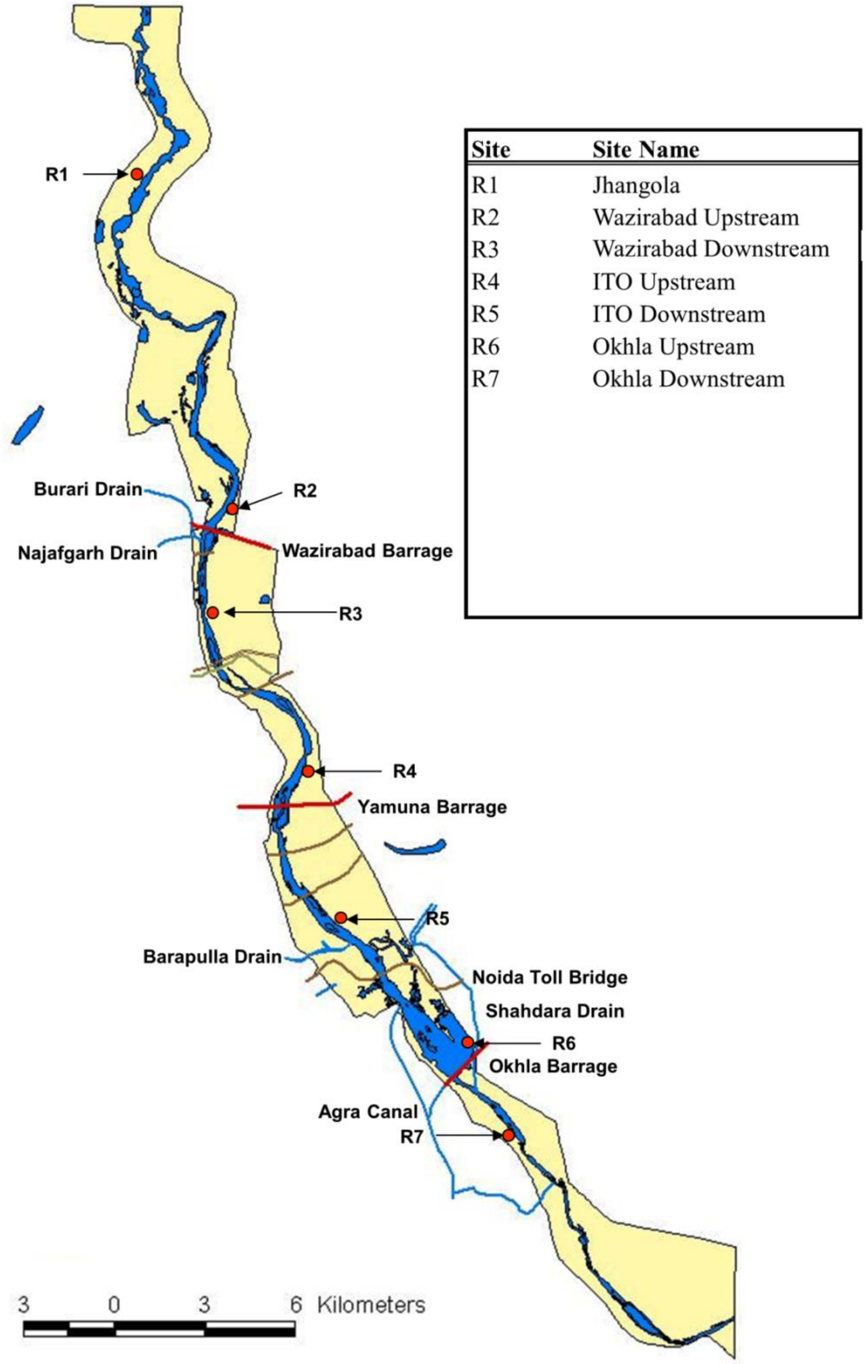

Fig 1. Location of sampling sites

Methodology

Sampling for water analysis was carried out seasonally during pre-monsoon (February-May), monsoon (June-September) and post-monsoon (October-January) at 7 sites during 2002 – 2003 (Fig.1). Water analysis was carried out following standard method as reported in APHA (1998) and Trivedy et al., (1998).

Estimation of zooplankton was carried out by concentrating 40 litres of water through plankton net of bolting silk cloth with mesh size 25. The samples were collected in 4% sucrose formalin in a vial of 20-ml capacity. Enumeration of zooplankton was done using Sedgwick Rafter Counter. The density of organisms was expressed as ind./L. Standard identification keys and manuals were used for identification (Michael and Sharma, 1987; Sharma, 1998; and Sehgal, 1983). Species diversity was calculated following Shannon and Weaver (1949) and Kothe's deficit index (1962).

Kothe's Species Deficit Index

This index is based on the principle that in a flowing ecosystem the number of species decreases after they are exposed to some pollutant discharge. In this method the number of species are counted at polluted and non-polluted points and index is calculated by using following formula:

$$\text{Kothe's species deficit index} = \frac{A_1 - A_x}{A_1} \times 100$$

Where A1 number of species at the unpolluted site

A_x number of species at the polluted site, downstream

It gives the data in a percentage linear scale and is very useful in indicating the consequences of point sources of wastewater discharge. The higher the value of deficit more is the level of pollution at that site.

Principal Components Analysis (PCA) was employed to investigate the factors causing variations in the water quality data, species composition and density of zooplankton in river floodplain of Yamuna in Delhi stretch. The concordance between the biotic components and physico-chemical structures has been assessed using co-inertia analysis. The co-structures were plotted on the factorial plane and the statistical significance of the co-structure was established using random permutation test (Dole´dec et al., 1994; Dray et al., 2003). The models have been estimated using the software ADE-4 (Thioulouse *et al.*, 1997).

Results

Water quality:

Physical and chemical features of water of study sites is given in Table 1**.**

Table 1. Physical and chemical features of water in River Yamuna floodplains during 2002-2003

Parameters	River Floodplain						
	R1	R2	R3	R4	R5	R6	R7
Air Temperature (0C)	30	29.8	32	31.4	31.4	31.2	31.4
Water Temperature (0C)	26.8	26	26.4	27.4	27.8	27	27.5
PH	7.07	7.11	7.14	7.13	6.98	7.2	7.08
DO (mg/L)	2.74	2.26	0.6	0.64	1.56	1.64	0.32
BOD (mg/L)	1.6	1.6	20.2	16.4	20.6	13.4	17.2
Total Hardness (mg/L)	122.4	114.2	175.4	169.4	161.8	125	238.8
Ca Hardness (mg/L)	31.9	29.9	40.2	35.3	49.7	37.5	57.7
Mg Hardness (mg/L)	12.0	10.0	28.3	19.9	18.8	7.8	23.3
Chloride (mg/L)	58.1	44.7	126.6	112.2	100.9	83.6	159.5
Sodium (mg/L)	40.6	28.6	68.2	78.2	75	54.6	53.2
Potassium (mg/L)	4.6	5.2	14.2	12.4	13.6	10.2	21
Ammoniacal Nitrogen □□g/L)	207.6	263.6	336.4	347.4	345.6	803.8	1807.8
Nitrite Nitrogen □□g/L)	51.2	33.8	684.2	48.6	558.2	197.2	1575.4
Nitrate Nitrogen □□g/L)	472.4	10	22.4	162.6	1.6	21.4	21.6
Phosphate Phosphorus □□g/L)	78	237.4	338.8	712.8	749.6	822.8	863

Ni □□g/L)	45	35	100	110	150	150	170
Cu □□g/L)	120	130	170	200	230	220	310
Zn □□g/L)	120	190	200	230	250	130	160
Pb □□g/L)	50	80	120	110	105	50	100

Zooplanktonic community:

Species Composition and Dynamics

Overall 62 species comprising 24 species of cladocera, 32 species of rotifera and 6 species of copepoda were identified from the study sites during 2002-2003 (Table 2). The annual species richness varied between 5 and 19 species for riverine sites and 7 to 27 for ponds/lakes. Longitudinally the river stretch exhibited variation in that R1 had 14 species, which increased to 19 at R2. There was a drastic reduction in the middle stretch covering sites R3 to R5. However, at R6 there was again increase and maximum 16 species were found at this site. At R7 site, a drastic decline in species number was observed.

Table 2. List of zooplankton species found in River Yamuna in Delhi stretch during 2002-2003

Cladocera

Pseudosida bidentata Herrick
Diaphanosoma excisum Sars
Bosminopsis deitersi Richard
Bosmina longirostris Muller
Simocephalus vetulus Muller
Simocephalus exspinosus Koch
Ceriodaphnia quadrangula Muller
Ceriodaphnia laticaudata Muller
Moina micrura Kurz
Moina macrocopa Straus
Moina brachiata Jurine
Moinodaphnia macleayi King
Pleuroxus denticulatus Birge
Alona quadrangularis Muller
Alonella excisa Fischer
Chydorus sphaericus Muller
Chydorus barroisi Richard
Biapertura karua King
Leydigia sp.
Daphnia lumholtzi Sars
Macrothrix goeldii Richard
Macrothrix spinosa King
Macrothrix laticornis Jurine
Scapholeberis kingi Sars

Rotifera

Brachionus angularis Gosse
Brachionus bidentata Anderson
Brachionus caudatus Barrois and Daday
Brachionus calyciflorus Pallas
Brachionus diversicornis Daday
Brachionus forficula Wiezerzejski
Brachionus falcatus Zacharias
Brachionus patulus Muller
Brachionus plicatilis Muller
Brachionus quadridentatus Daday
Brachionus rubens Ehrenberg
Brachionus mirabilis Daday
Keratella tropica Apstein
Filinia terminalis Plate
Filinia pejleri Hutchinson
Filinia opoliensis Zacharias
Filinia longiseta Ehrenberg
Platyias quadricornis Ehrenberg
Testudinella parva Ternetz
Cephalodella auriculata Muller

Trichocerca cylindrica Imhof
Lecane unguitata Fadeev
Lecane stokesii Pell
Lecane aculeata Jakubski
Monostyla sp.
Asplanchna priodonta Gosse
Polyarthra vulgaris Carlin
Conochilus sp.
Ascomorpha saltans Bartsch
Notholca sp.
Pompholyx sulcata Hudson
Hexarthra mira Hudson

Copepoda
Paracyclops sp.
Microcyclops sp.
Cyclops sp.
Mesocyclops sp.
Arctodiaptomus sp.
Heliodiaptomus sp.

Seasonally species number was higher in pre-monsoon and post-monsoon. In case of monsoon there was drastic decline in species richness except at R6 were unusually high species richness was observed. The species richness of cladocera was higher in post-monsoon (1-9 species) compared to pre-monsoon (1-5 species). During monsoon species were washed off at all sites except at Okhla where 8 species have been recorded. In case of rotifera, species richness was more in post-monsoon compared to pre-monsoon. Copepoda did not show any significant seasonal change. The highest species richness was, however, found in the upper stretch. During monsoon 5 species of copepods were exclusively confined to R6 (Table 3).

Table 3. Seasonal variation in species richness of different groups of Zooplankton at various study sites

Station	River floodplain						
	R1	R2	R3	R4	R5	R6	R7
Cladocera							
Premonsoon	5	5	3	2	2	1	2
Monsoon	-	-	-	-	-	8	-
Postmonsoon	1	9	1	2	-	5	2
Rotifera							
Premonsoon	5	5	2	4	3	1	5
Monsoon	-	-	-	-	-	3	-
Postmonsoon	-	2	-	1	-	3	-
Copepoda							
Premonsoon	2	3	1	1	-	1	-
Monsoon	-	-	-	-	-	5	-
Postmonsoon	3	1	1	-	-	1	-
Annual number of zooplankton species	14	19	6	8	5	16	9

Species Density and Diversity

The total density varied spatio-temporally during the study period. In general, the population varied between 42 and 362 ind./L at different sites. All the river sites except Okhla upstream (62 ind./L) were devoid of zooplankton population during monsoon.

Major peaks of zooplankton density were recorded in post-monsoon at R2 and R6. Almost a peak of similar magnitude was found at R5 during pre-monsoon. Moderate peaks were observed at R4 and R7 sites during pre-monsoon. At R1 and R3 sites minor peaks were found during pre-monsoon and post-monsoon respectively (Fig.2). The peak at R2 was mainly constituted by Simocephalus vetulus (43%), Microcyclops (24%), and Nauplii (34%). The peak at R6 was mainly due to Daphnia lumholtzi (69%). The contribution of 8 other species varied between 2 to 8%. Notholca (55%) and Asplachna priodonta (32%) were the main constituents of R5 peak. The moderate peak at R4 was mainly due to Asplachna priodonta (35%), Ascomorpha saltans (27%) and Brachionus angularis (14%) while as another moderate peak at R7 was mainly constituted by Notholca (18%), Testudinella (16%), Brachionus bidentata and Monia micrura (14% each). R1 and R3 did not show pronounced peaks. However, they exhibited marked difference in regard to density population contributions. The site R1 with 13 species had almost equal density contribution by the constituent species. Microcyclops sp. and Ceriodaphnia sp. had equal contribution of 50% population density at R3.

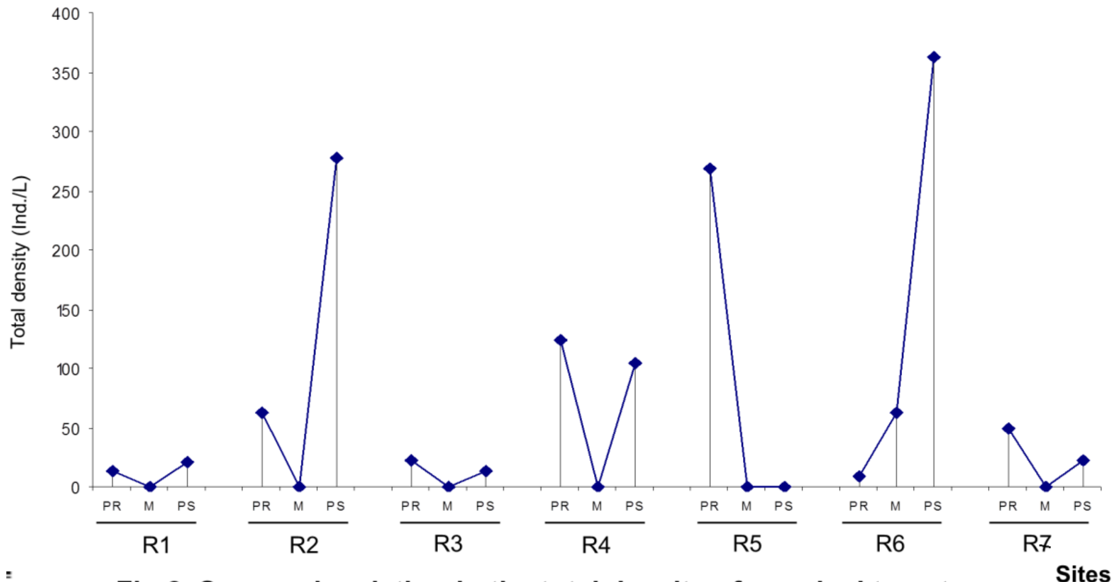

Fig 2. Seasonal variation in the total density of zooplankton at various river floodplain sites

Percentage wise population contribution of three groups, viz. cladocera, copepoda and rotifera is presented in (Fig. 3). It was observed that rotifers contributed significantly to zooplankton population at sites R4 to R7 during pre-monsoon with maximum recorded at R5. Cladocerans at R2, R6 and R7 dominated during post-monsoon representing 60 to 100% of the total zooplankton density. Copepods had the highest contribution at R4 followed by R3, R1 and R6 in decreasing order.

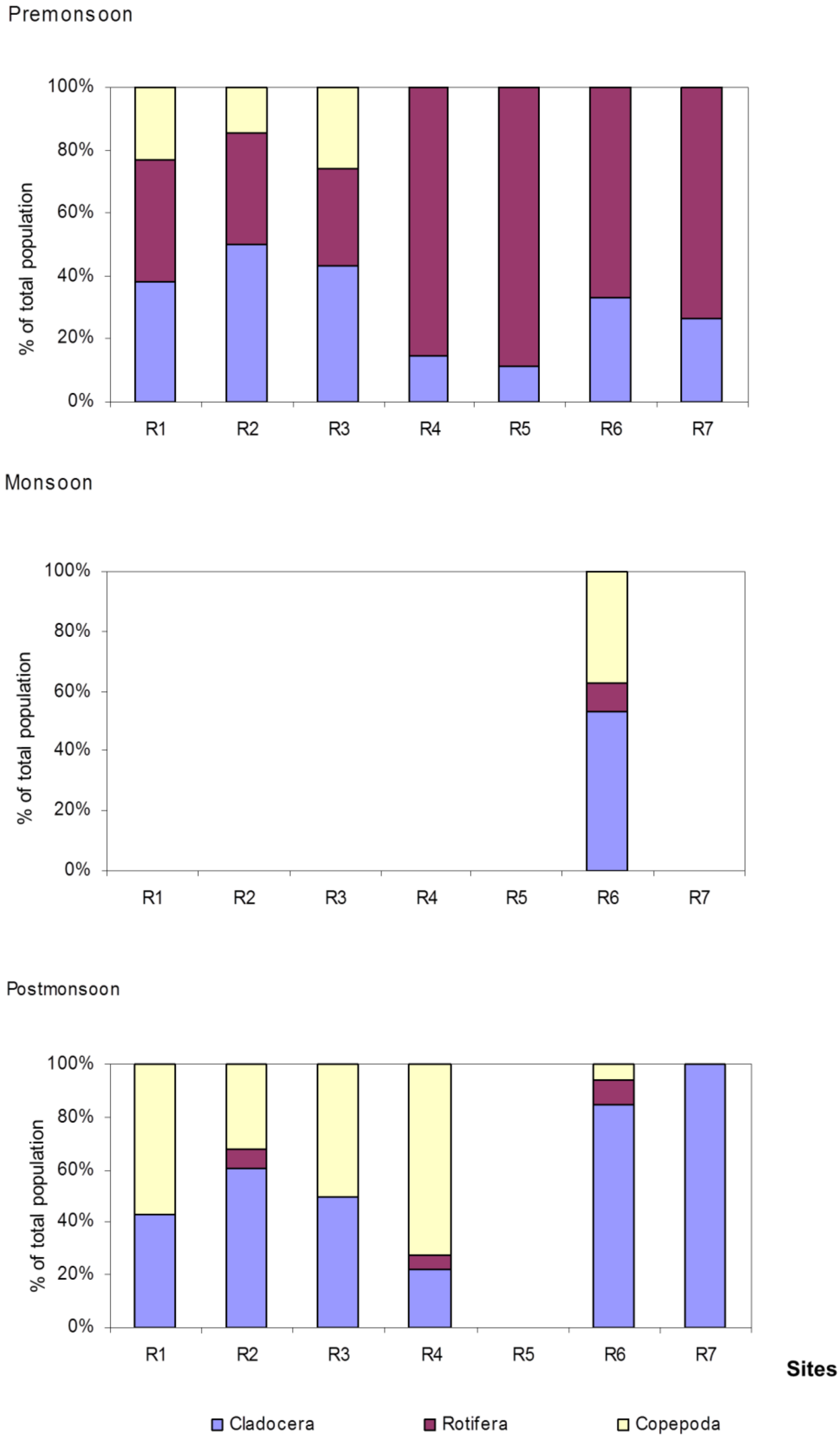

Fig. 3. Seasonal variation in percent composition of zooplanktonic groups at various river floodplain sites during 2002 - 2003

Species Diversity

The Kothe's species deficit index calculated for zooplankton species of riverine sites showed higher values from R3 to R5 and R7 having the maximum level of pollution at these sites. This revealed that maximum species elimination takes place in mid stretch only. In comparison, R6 showed lesser values. The Shannon diversity index values fluctuated between sites as well as between seasons. In general, maximum diversity (>3) in stretch was found at R1, R2 and R6. In rest of the station diversity values were below 3 indicating reduced zooplankton diversity at these sites (Table 4).

Table 4: Kothe's deficit index and Shannon diversity Index

Sites	R1	R2	R3	R4	R5	R6	R7
KD Index (%)	-	Reference site	68.42	57.89	73.68	15.79	52.63
SW Index(H)	0-3.7	0-3.5	0-2.4	0-2.9	0-1.5	0.9-4.8	0-2.8

Discussion

On the basis of earlier studies carried out in India, the species composition of zooplankton comprising higher species richness of rotifers, followed by cladocerans and copepods in decreasing order is not unusual (Jana, 1973 and Nassar, 1977). Rotifers were numerically dominant in premonsoon over other groups of zooplankton in all the sites subjected to heavy load of pollution. Higher temperature and nutrient concentration seem to be favouring growth of rotifers. Similar observations have been made by several investigators (Karande and Inamder, 1961; George, 1966; Michael, 1968; Moitra and Mukherjee, 1972; Nassar, 1977 & 1978). Jyoti and Sehgal, (1979) observed a rotifers as a group appear temperature facultative and only marked temperature changes on other side of optima of different species would influence their population density.

Fernando (1980) reviewed the literature on zooplankton fauna of the tropical regions, has concluded that the tropics have fewer zooplankton species as compared to the temperate zone. Morton and Bayly (1977) report 60 species of cladocerans and copepods from temporary pools in Victoria, Australia.

Floodplain lakes / ponds existing along the periphery of river channels in the floodplain are important sources of zooplankton. Variation in river level govern contact of flowing waters with these source areas (Paggi and Paggi, 1974). Spates may cause the elimination of plankton from river channel, although smaller but repeated fluctuations in river level may be more significant in this respect (Saunders and Lewis, 1988). Floodplain lakes / ponds may support plankton growth because the habitats have little or no flow when river levels are low. Seasonal rises in river level greatly increase flow in these habitats and thereby push resident plankton into the main channel (Osmera, 1973; Vranovsky, 1974; Saunders and Lewis, 1988). This zooplankton appear to originate along the river margin and the floodplain lakes are probably significant as an energy input for food webs in the river channel and as in occurrence to floodplain habitats at the time of inundation. At low water in the Orinoco River, Venezuela, where there was no contact with the floodplain, the transport of Copepods (mainly naupli) and *Bosminia* increased downstream by more than could be ascribed to additions from the tributaries or the reproduction in transit.

Similar observations have been made in the present study as the sudden influx of copepods at different sites during postmonsoon can be attributed from wash off from the floodplain lakes. Moreover, during monsoon when plankton population is almost completely washed off from the main river channels, fish find abundant food material in the floodplain lakes / ponds for their breeding and spawning (Ray, 2005).

The site ordinations based on water quality parameters and species richness and density indicate close relationship between zooplankton communities and water quality. Larger assemblages of zooplankton found in the upper zone and at Okhla correspond to relatively better water quality conditions existing at these stations. Lower number of co-existing species observed at R3, R4, R5 and R7 are due to stress conditions created by heavy pollution load. The rigorous chemical milieu eliminates most of the species existing in the upper cleaner zone. Co-inertia between water quality and zooplankton density exhibited strong co-structure at sites R7, R4 and R5 indicating water quality deterioration as the causative factor for lower species number.

Conclusion

zooplankton populations within the river floodplain system serve as an important conduits in the food chain thereby supporting a healthy stock of fish fauna and other inter dependant aquatic organisms (Ray, 2005). Pollution is main stressor suppressing overall diversity and density of zooplankton thereby impacting energy transfers to other trophic levels. Floods play a critical role in mitigating harsh conditions created by high nutrient concentrations. Inundation of floodplains sets the process for regeneration of river conditions through connectivity between river channel and floodplains lakes. The variability across the river system linking various patches undertaken for the present study has highlighted the role of floodplain lakes in determining the structure and dynamics of zooplankton communities. These aspects need to be undertaken for monitoring and overall management of river ecosystem health.

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