AQUATIC ECOSYSTEM
HEALTH & MANAGEMENT

Community structure of macrobenthic invertebrates in the River Ganga in Bihar, India

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*Benthic macroinvertebrates are reliable indicators of the environmental health of rivers as their distributions vary in response to variations in time and space and available habitats. We investigated the longitudinal and seasonal distribution of macrobenthic assemblages in different habitats (such as vegetated and unvegetated/sand, silt, rock and clay) in the River Ganga. Samples were collected in September 2010, and January, April and June 2011 at four study sites in the heterotrophic Meta-Potamon part extending from Patna through Bhagalpur covering a 249-km stretch of the river. Sampling stations were located along a gradient of macrophytic coverage in marginal water and sediment texture. A total of 69 taxa belonging to 47 families and 23 orders were identified. The data of benthic communities from all samples were subjected to non-metric multi-dimensional scaling (NMDS). NMDS of all data segregated samples on the basis of seasons. The most indicative taxon of monsoon was Culicidae followed by the Corixidae (*Sigara distorta*) and Micronectidae; whereas, the most indicative taxon in January was* Plumatella bombayensis *followed by Libellulidae. Highest abundance and species richness were recorded at Bhagalpur. Species richness and abundance were significantly higher in marginal habitats with macrophytes compared to similar habitats without vegetation. Furthermore, differences in species composition were recorded at different substrate types. The persistence of a well-structured macrobenthic community, including families of marine origin in the middle to lower reaches, indicates that the Ganga ecosystem is resilient enough to recover to its pristine ecological value.*

Keywords: macrobenthos, biodiversity, index value

[Supplementary materials are available for this article. Go to the publisher's online edition of *Aquatic Ecosystem Health and Management* to view the free supplementary files.]

Introduction

Benthic macroinvertebrates are useful and reliable bio-indicators of changing aquatic conditions. Such indicators are more accurate than indicators based on chemical or microbiological variables (Ikomi et al., 2005). According to Odiete (1999), the most popular biological method in assessment of freshwater bodies receiving domestic and industrial wastewaters is the use of benthic macroinvertebrates.

Macrobenthic invertebrates are defined as organisms that live on or inside the deposit at the bottom of a water body (Idowu and Ugwumba, 2005). It

Aquatic Ecosystem Health & Management, 16(4):385–394, 2013. Copyright © 2013 AEHMS. ISSN: 1463-4988 print / 1539-4077 online
DOI: 10.1080/14634988.2013.846200

includes a heterogeneous assemblage of different organisms, representing different functional feeding groups and feeding modes. They have a relatively longer generation time than plankton, periphyton and other micro-organisms.

Most benthic organisms feed on debris settled on the bottom and, in turn, serve as food for bottom-feeder fish and invertebrates. These animals are responsible for circulation and recirculation of nutrients, because they constitute the link between the unavailable nutrients in detritus and useful protein materials in nektonic forms and fish (Bell and Woodin, 1984). They play an important role in transfer of energy from detritus or meio-faunal community to upper trophic levels in the water column directly affecting biogeochemical processes in the sediment and sediment stability (Bell and Woodin, 1984).

In riverine ecosystems macrobenthic invertebrates show a patchy distribution varying largely in time and space (Bilgrami, 1991a,b; Roy, 2007). Their heterogeneous distribution patterns is attributed to many factors such as bottom substrate/sediment type, anthropogenic perturbation to benthos, presence of macrophytes in marginal waters, climatic variations, etc.

Knowledge about the number of species residing in rivers is more incomplete for invertebrates than for vertebrates (Balian et al., 2008), particularly in tropical regions as compared to temperate regions. Earlier studies on macrobenthos from Ganga River focused mainly on documenting the species (Datta Munsi et al., 1988, Subba Rao, 1989, Sinha and Sharma, 2001, Nesemann et al., 2003, 2004, 2005, 2011). Only a very few studies reported occurrence and diversity of macro-benthic invertebrates in the Ganga River (Krishna Murthy et al., 1991; Roy, 2007), which is more dynamic and variable in physical, chemical and biological characteristics compared to other lotic systems due to its irregular flow and diverse habitat structure.

In the present study, we investigated the spatial and seasonal distribution of macrobenthic invertebrates from different habitat types (such as vegetated and unvegetated/sand, silt, rock and clay) to understand if macro-benthic assemblages in the Bihar stretch of the river (Patna to Bhagalpur) are structured by the season, and/or habitat type.

Description of study site

The River Ganga originates from the ice-cap of Gaumukh at the top of Gangotri glacier (10,020 feet elevation above sea level) of Himalaya in the Uttar Kashi district of Uttarakhand province in India. It flows in the form of a mountain stream to Indo-Gangetic plain at Haridwar and from here after travelling about ≈2,525 km confluence into Bay of Bengal. The largest river of the Indian subcontinent drains the entire Western- to the Central Himalayan region of northern India, Nepal and China (Tibet). This river is a vast reservoir of aquatic biota including different variety of fishes and wildlife. The Ganga River is the habitat for a considerable number of endemic and endangered species, including the Gangetic River dolphin, *Platanista gangetica gangetica* (Roxburgh, 1801).

Materials and Methods

Our four study sites in the River Ganga were located in a 249-km stretch extending from Patna (25° 37′41″N and 85° 09′.037′ E) through Bhagalpur (25° 16′ 0″ N, 87° 01′ 0″ E) (Figure 1) at an average elevation of 173 feet from the sea level. In the entire stretch, the river is free flowing with a gradient of 5–7 cm/km and a current velocity of 1.2 m/second in the main channel; the bottom of the riverbed consists mainly of fine sand, silt and clay. Our study sites were located in the mainly heterotrophic Meta-Potamon portion of this stretch: Patna (25° 37′41″N and 85° 09′.037′ E), Mokamah (25° 24′ 0″ N, 85° 55′ 0″ E), Munger (25° 23′ 0″ N, 86° 28′ 0″ E) and Bhagalpur (25° 16′ 0″ N, 87° 01′ 0″ E) (Figure 1). Patna and Mokamah are located in regions with industrial activities and are sites subjected to the influence of discharges of organic and inorganic wastes. For instance, the discharge of effluents from thermal power plants, the oil refinery of Barauni, the Bata shoe factory, and McDowell Distillery of Mokamah have collectively posed a great threat on the ecology of the River Ganga along the sampling stretch. The last sampling station downstream (Bhagalpur) was located in the middle of the Vikramshila Gangetic Dolphin (*Platinista gangetica*) sanctuary. It is the only protected area to save the endangered Gangetic Dolphin in Asia. The important perennial tributaries joining the River Ganga along the stretch are Gandak and Budhi-Gandak (Figure 1).

Sample collection and processing

Samples were collected on 9–14 September 2010, 14–19 January 2011, 3–18 April 2011 and 7–12 June 2011. These dates represent all four

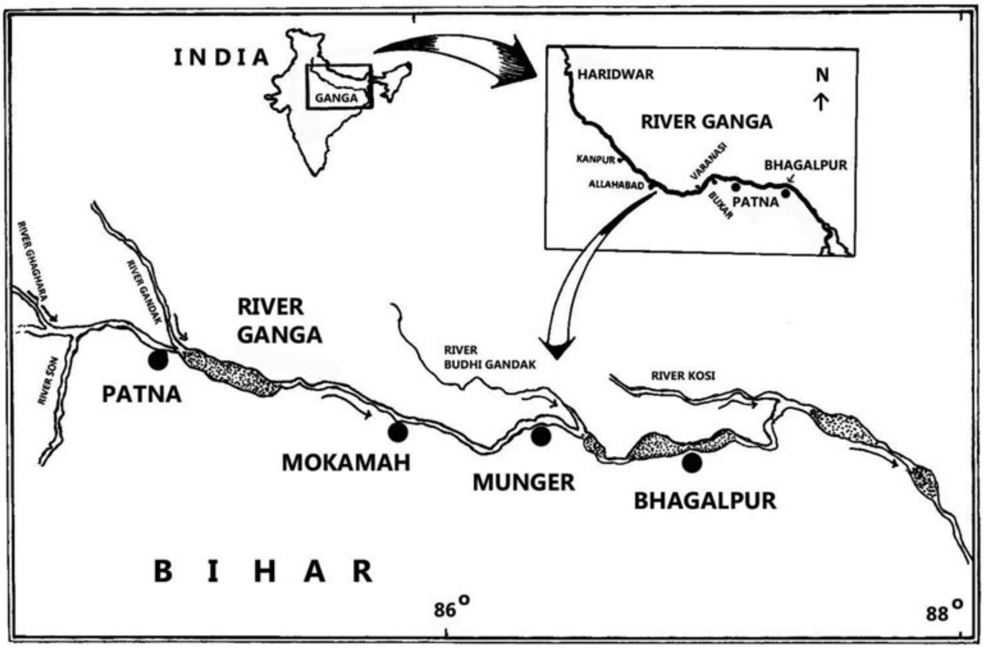

Figure 1. Map of Ganga River showing stations sampled in the present study.

seasons: monsoon, winter, spring, and summer, respectively. Samples were collected at 10 to 16 points at each of the 4 sites. Three replicate bottom grab samples were collected at each point using a 25 cm (d) PVC pipe specially fabricated to grab bottom substrate. The contents of the grab were gently washed through a 0·5 mm sieve. In addition, qualitative samples were rigorously collected using a hand net with a mesh size of 500 μm. The handnet was used for hard substrate to get a thorough species inventory covering larger area.

To elucidate the role of habitat types in structuring the macro-benthic invertebrate community structure, the two relatively unpolluted sites (i.e. Munger and Bhagalpur) were selected for further analyses. At both sites, samples were collected from the surface layer (0 to 2 cm): sand-silt-clay ratios were determined by wet sieving using a 0·063 mm mesh sieve to capture sand-sized particles, and pipetting the washings for silt- and clay-size particles. Fraction weights were determined by drying at 100°C to a constant weight. A variety of habitats (vegetated marginal water and un-vegetated marginal or open water) in each sampling sites were considered; the sampling points are thus located along a gradient of macrophyte coverage and sediment texture. At all sampling "points" at these two "sites" substrate types were also recorded and that these "points" were located in both vegetated and unvegetated areas.

Materials retained on the sieve were fixed differentially. Annelids were preserved in 70% ethanol while leeches were relaxed in 15% ethanol prior to preservation in 70% ethanol. Molluscs and decapods were washed from the sediment samples at the spot if necessary preserved in 4% buffered formaldehyde. The organisms were identified to the lowest possible taxa (Family, Genus and Species) with the help of standard keys for Indian subcontinent and South-Asia for sessile Invertebrates: Annandale (1911), Wood et al., (2006); Annelida: Harding and Moore (1927), Gates (1972), Chandra (1983), Mandal (2004) and Naidu (2005); Crustacea: Valarmathi (2009); Insecta: Prasad and Varshney (1995), Mitra (2003) and Thirumalai (2007); Mollusca: Preston (1915), Subba Rao (1989) and Nesemann et al. (2007).

Statistical analyses

To evaluate patterns in community structure, "species occurrence" × "sampling duration" matrices were analyzed with multivariate analyses. Nonmetric multidimensional scaling (NMDS) ordination was applied to test the similarities in the macrobenthic diversity among 4 seasons. For parametric analyses the abundance data were log(x+1) transformed to reduce heteroscadisticity The software package Paleontological Statistics (PAST) software (Hammer et al., 2001) was used for analyses. Euclidean distance measurement was used to measure distances among samples. We used the Shannon-Wiener diversity index to evaluate the species diversity, and Pielou's evenness to measure the evenness at each sampling station.

To identify differences among seasons and stations (four sites) one way ANOVA with a post-hoc Tukey's honestly significant difference test was applied for abundance, number of taxa, indices of richness, evenness and diversity. All analyses were done using log transformed data.

Indicator species analyses (ISA):

The indicator species for each season were identified through the Indicator Value Index (IndVal) (Dufrêne and Legendre, 1997). This index is obtained by multiplying the product of two independently computed values by 100:

$$IndVal(j, s) = 100SP(j, s)FI(j, s) \qquad (1)$$

where ($SP\ j,s$) is the specificity and ($FI\ j,s$) is the fidelity of a species (s) toward a group of samples (j), and are given by:

$$SP(j, s) = \frac{NI(j, s)}{\Sigma NI(s)}; \quad FI(j, s) = \frac{NS(j, s)}{\Sigma NS(s)} \qquad (2)$$

where $NI(j, s)$ is the mean abundance of species s across the samples pertaining to j, $\Sigma NI(s)$ is the sum of the mean abundance of species s within various groups in the partition, $NS(j, s)$ is the number of samples in j where species s is present, and $\Sigma NS(s)$ is the total number of samples in that group. Indicator Values range from 0 (no indication) to 100 (perfect indication).

Results

Integrating all samples, we identified 69 taxa belonging to 47 families and 23 orders within the phylums Cnidaria, Nematomorha, Nemeretea, Bryozoa, Anneliida, Arthropoda and Mollusca. The taxa richness of different sampling stations is compiled for each phylum/class in Table 1; top ten identified species, genera and families are listed in Table S2 (available in the online supplementary information [SI]) and habitat specific distribution is given in Table 2.

The maximum number of benthic taxa (40) was found at Bhagalpur, whereas the lowest number of taxa (26) was found at Patna. Numbers of taxa found at Mokamah and Munger were 33 and 32, respectively (Table 1). The highest species richness was recorded for Annelida and Arthropoda at Patna sites, whereas Arthropoda was the most dominant phylum at Mokamah. Munger and Bhagalpur sites were dominated by Mollusca (Table 1). The highest diversity and densities of aquatic insects as compared to other sampling sites was recorded in Mokamah. Round Worms (Nematoda) and Ribbon Worms (Nemertea) were not captured. The Munger

Table 1. Longitudinal occurrence of identified taxa in the River Ganga from Patna to Bhagalpur.

	Sampling stations			
Phylum/Class	Patna	Mokamah	Munger	Bhagalpur
Bryozoa	1	—	1	—
Cnidaria	1	1	—	1
Nemathelminthes	1	—	1	1
Nemertea	1	—	—	1
Gastropoda	2	3	5	8
Bivalvia	4	5	7	8
Polychaeta	2	2	2	1
Oligochaeta	2	3	4	3
Hirudinea	4	1	2	2
Malacostraca	5	4	3	5
Insecta	3	14	7	10
Total number of identified taxa	**26**	**33**	**32**	**40**

Table 2. Macrobenthic invertebrate species occurred in significantly higher frequency and abundance in either a marginal vegetated habitat or an unvegetated/open water sediment habitat.

Taxa	Vegetated marginal region	Open water/Unvegetated sediment
Oligochaeta	*Nais* spp. *Chaetogaster limnaei bengalensis* Annandale, 1905	—
Polychaeta	—	*Nephthys oligobranchia* Southern, 1921
Malacostraca	*Macrobrachium* spp. *Caridina* spp.	—
Bivalvia	—	*Corbicula striatella* Deshayes, 1851, *Corbicula bensoni* Deshayes, 1854, *Corbicula assamensis* Prashad, 1828, *Lamellidens corrianus* Lea, 1834, *Lamellidens consobrinus* Lea, 1859, *Radiatula caerulea* Lea, 1831, *Radiatula occata* Lea, 1860, *Radiatula olivaria* Lea, 1831, *Parreysia favidens* Benson, 1862, *Parreysia corrugata laevirostris* Benson, 1862
Gastropoda	*Digoniostoma pulchella* Benson, 1836, *Lymnaea acuminata* Lamarck, 1822, *Indoplanorbis exustus* Deshayes, 1834, *Gyraulus convexiusculus* Hutton, 1849, *Haitia mexicana* Phillipi, 1889	*Thiara* (*Tarebia*) *lineata* Gray, 1828, *Thiara* (*Thiara*) *scabra* O. F. Müller, 1774, *Melanoides tuberculatus* O. F. Müller, 1774, *Brotia costula costula* Rafinesque, 1833, *Bellamya* (*Filopaludina*) *bengalensis* Lamarck, 1822, *Mekongia crassa* Benson, 1836
Insecta	**Mayfly nymphs:** *Baetis* spec. **Damselfly nymphs:** Family Protoneuridae, Family Coenagrionidae **Aquatic bugs:** *Ranatra filiformis* Fabricius, 1790, *Paraplea frontalis* Fieber, 1844, *Micronecta scutellaris scutellaris* Stâl, 1858, *Sigara* (*Tropocorixa*) *distorta* Distant, 1910, *Anispos* spp.	**Sediment burrowing drangonfly nymphs:** *Macrogomphus* cf. *montanus* Selys, 1869, *Paragomphus lineatus* Selys, 1850 **Predatory beetles:** Family Gyrinidae Gen. spp. **Sediment burrowing dipterans:** Family Psychodidae Gen. spp.

sites recorded a total of 32 benthic taxa dominated by the Molluscs followed by Arthropoda (10), Annelida (8) and one Freshwater Bryozoans (Phylactolaemata). A total of 40 benthic taxa were identified at Bhagalpur sites: the Mollusca occurred with the highest diversity including 16 species followed by the Arthropods and Annelids (6 species). Round Worms (Nematoda), Ribbon Worms (Nemertea) and Hydrozoans (Cnidaria) were also recorded at Bhagalpur (Table 1).

Community structure

Overall abundance, number of taxa recorded, indices of Shannon Wiener diversity, richness, and Pielou's evenness are depicted in Figure 2. The index of richness varied from 3.62 in September at Patna to 7.95 in April at Munger, the evenness index varied from 0.79 in September at Patna to 0.92 in April at Munger and the Shanon Weiner diversity index varied from 2.37 in September at Patna to

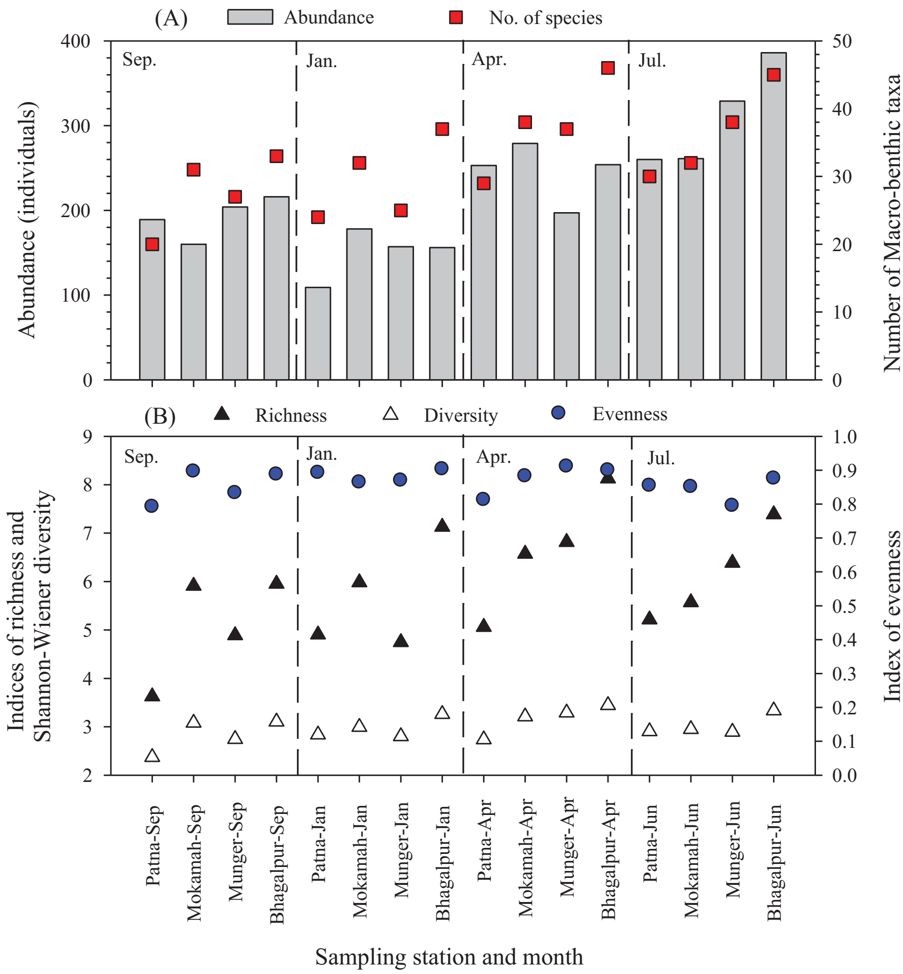

Figure 2. Abundance, number of taxa (a), indices of richness, Pielou's evenness and Shannon-Wiener diversity (b) recorded in September 2011, and January, April and June 2012 at 4 stations in the River Ganga. (Color figure available online.)

3.86 at Munger in April (Figure 2). The NMDS segregates samples on the basis of seasons (Figure 3). The index-values (%) for top 10 taxa occurred in each group are provided in Table S2. None of the reported taxa showed index values higher than 10%. Therefore no species turned out to be true indicator (Dufrêne and Legendre, 1997). Relatively the most indicative taxa of monsoon turned out to be Culicidae followed by the Corixidae (*Sigara distorta*) and Micronectidae (Table S2).

The most indicative taxon in January was *Plumatella bombayensis* followed by Libellulidae. The seasonal patterns of abundance (a), number of taxa (b), indices of richness (c), evenness (d) and diversity (e) are shown in Figure 4. The January samples showed significantly lower values than that in April ($p = 0.023$) and June ($p = 0.001$). Furthermore values recorded in September were significantly lower ($p = 0.006$) than June (Figure 4). Longitudinal zonation in the Ganga River section shows an increasing abundance (a), number of taxa (b), indices of richness (c), evenness (d) and diversity (e) towards Bhagalpur. However only the Patna samples differed significantly in species number ($p = 0.012$), richness index ($p = 0.005$) and diversity index ($p = 0.007$) from those at Bhagalpur (Figure S1, available in the SI).

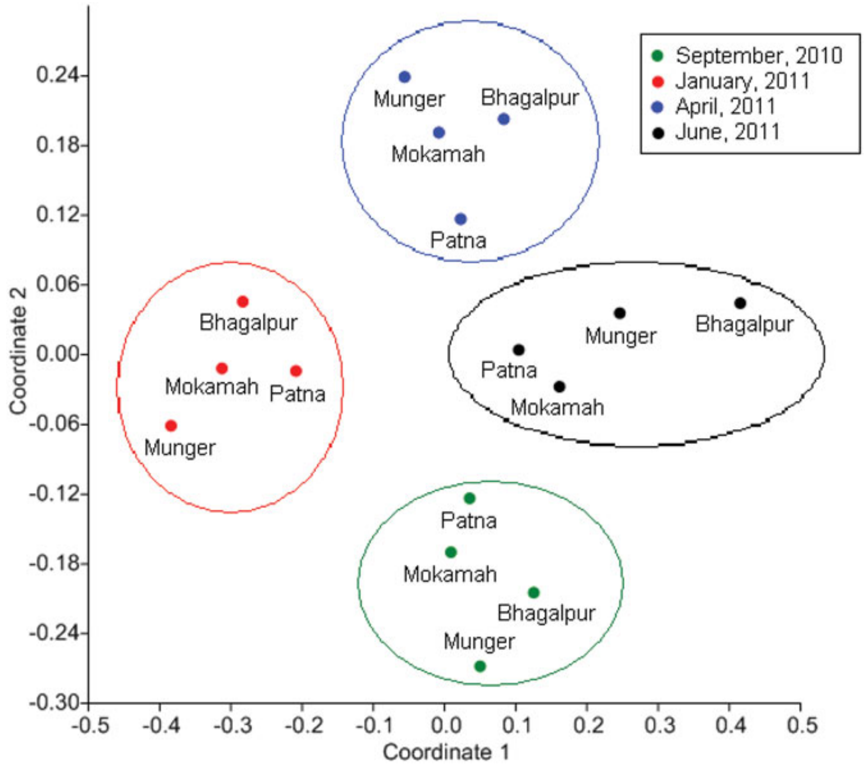

Figure 3. Results of NMDS of all samples collected during September 2011, and January, April and June 2012 at 4 stations in the River Ganga. (Color figure available online.)

Microhabitat types as driving force of community structure

Marginal vegetated habitats recorded significantly higher species richness and abundance than the open water unvegetated habitats (Figure 5). List of species occurred with significantly higher frequency and abundance in either a marginal vegetated or unvegetated/open water sediment habitat is provided in Table 2. Occurrence and abundance of species in relation to substrate/ sediment types at Munger and Bhagalpur section are listed in Table S1.

Discussion and Conclusions

Our results indicated that the structure of the macrobenthic community in a meso to metapotamon portion of the River Ganga is mainly driven by seasons and microhabitat types. Relatively lower abundances at the Patna and Mokamah sites compared to Bhagalpur may be attributed to the discharge of industrial effluents and bank fixation. The decline of rheophilic species (such as Psammobiidae, Nereididae and Hymenosomatidae) near Patna has been previously attributed to the effluents and bank fixation, whereas increasing abundance of lithoplilic species (leeches and snails) has been driven by bank fixation with boulders and other hard substrate (Nesemann et al., 2011).

The composition of the top 10 indicative taxa consisted mainly of the insect families Culicidae, Libellulidae, Chironomidae and reflected the influence of residual flow and organic loads that support the lentic fauna (Nesemann et al., 2011). The alien invasive neozoan gastropod *Haitia mexicana* turned out to be the third highly indicative species in January samples. This nearctic, Mexican Physidae has invaded many riverine ecosystems in India since the last two decades (Surya Rao et al., 1997). Mass occurrence of this species has been recorded at highly polluted sites at Patna (Sinha et al., 2003); Mokamah and Munger (present study). This invasive species is believed to have originated from central Mexico in North America, and is pollution tolerant.

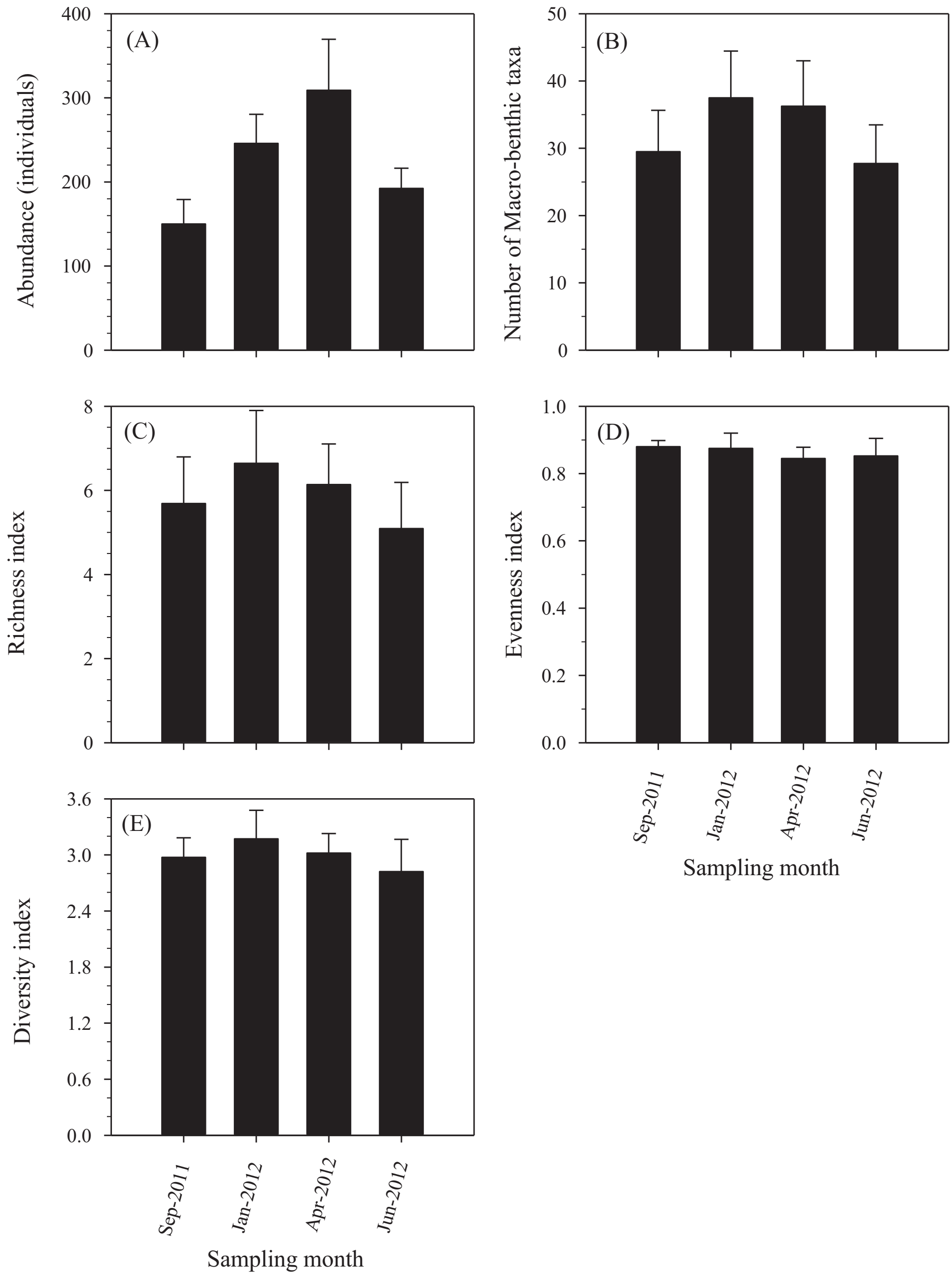

Figure 4. Abundance (a), number of taxa (b), indices of richness (c), evenness (d) and diversity (e) of macrobenthic invertebrates recorded in September, January, April and June at four stations in the River Ganga.

Similar to large European rivers, e.g. Rhine and Danube (Kinzelbach, 1983, 1985; Obrdlik et al., 1995; Bernerth et al., 2005), the benthic fauna of the River Ganga is dominated by molluscs, especially by suspension feeding Bivalvia and a few omnivorous sediment scrapers and filter feeder Prosobranchia snails, mainly belonging to Viviparidae, Thiaridae and Pleuroceridae. The prominence of nemerteans further indicates the similar community structure of Ganga River to other large rivers (Sunderberg and Gibson, 2008). Beside these invertebrate groups there are locally abundant marine originating endemic taxa (Annandale, 1922, Datta Munshi et al., 1989, Nesemann et al., 2011) which

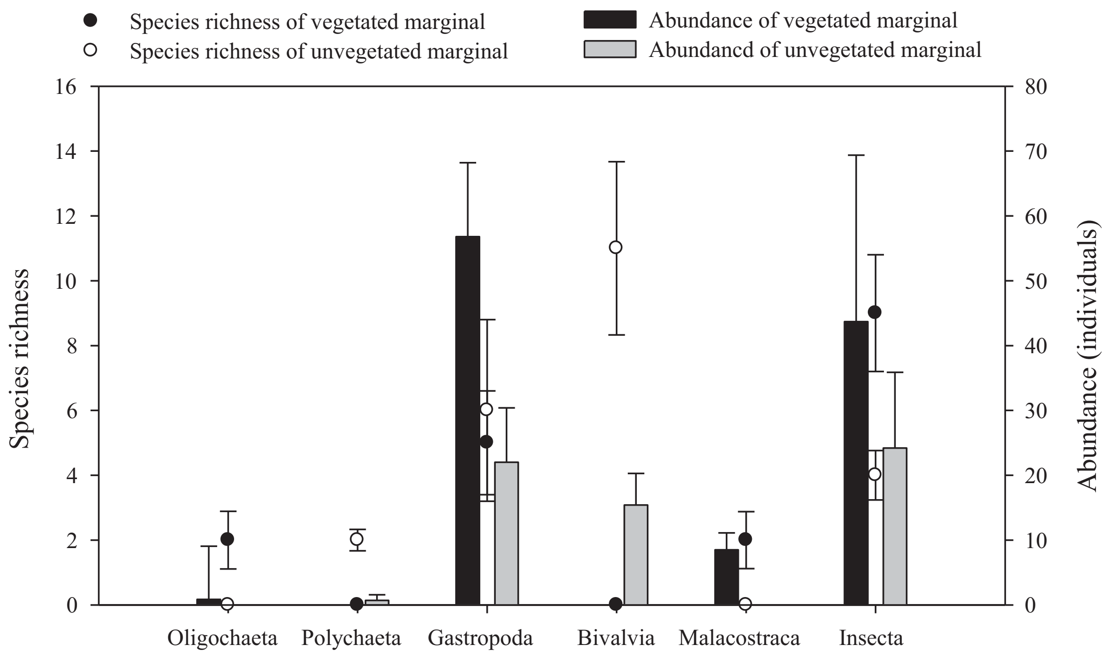

Figure 5. Species richness and abundance of macrobenthic invertebrates in marginal vegetation and open water, unvegetated habitats.

are strictly confined to the Meta-potamon of the rivers. These are comprised of Bristle Worms (Polychaeta: Nephthydae and Nereididae) and spider crabs (Brachyura: Hymenosomatidae). Another important feature of the larger macrofauna is the strong representation of sediment burrowing nymphs of dragonflies (Odonata: Gomphidae and Libellulidae) together with the largest mayflies (Ephemeroptera: Palingeniidae). The macrophyte vegetated marginal habitats support greater species richness and abundance than the neighbouring unvegetated habitats. Furthermore, the soft sediment (muddy/clayey substrate) communities are dominated by opportunistic species (Oligochaeta and chironomid-larvae), following a heavy disturbance event (post monsoon).

The indicator species analyses in the present study suggested that the lowland Ganga River basin is not dominated by any particular species; rather it harbours a wide diversity of benthic invertebrates. Since the Ganga River ecosystem was not inhabited by very dense assemblages of macrofauna, density-dependent variables probably played a minor role in structuring the communities, which were probably affected more by other factors, such as habitat types, sediment structure, and seasons. We also need to assess the rate of invasion of *Haitia mexicana* and its impact on native biodiversity of Ganga ecosystem.

Acknowledgements

We are thankful to Dr. A. P. Sharma, director CIFRI, India for inviting Ram Kumar and Hasko Nesemann to the author's workshop. We thank Dr. Dilip Kumar and Dr. M. Munawar for their suggestions on a previous version of the manuscript. P. Swami and other staff of Environmental Science Laboratory, at Central University of Bihar are thanked for their assistance at various stages of this study. Comments made by two anonymous reviewers substantially improved the quality of the manuscript.

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