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Diversity and Community Assemblage of Littoral Zone Benthic Macroinvertebrates in Jagadishpur Reservoir

[1]Deep N. Shah, [1]Ram D. Tachamo Shah and [2]Bandana K Pradhan
[1]*Hindu Kush Himalayan Benthological Society, Kathmandu*
[2]*Department of Community Medicine and Family Health, Institute of Medicine, Tribhuvan University*
e-mail: deepnarayanshah@hkhbenso.org

Abstract

Littoral benthic macroinvertebrates diversity and community assemblage of Jagadishpur Reservoir were studied during post-monsoon (2008) and pre-monsoon (2009) seasons. Altogether twelve sites in the littoral zone of the reservoir were sampled for benthic macroinvertebrates by using a kick-and-sweep method with a standard handnet. At each site, benthic macroinvertebrate samples were taken from different possible substrate types. The environmental variables of each site were collected based on Lentic Ecosystem Field Protocol during sampling. Biological metrics were used to describe the diversity and composition of benthic macroinvertebrates. The relationship between benthic macroinvertebrates assemblage and substrate types were examined by using principal component analysis. Cluster analyses were performed to describe the similarity among samples. In total, 50 taxa, belonging to 15 orders were recorded for littoral zone of the reservoir. The recorded higher number of taxa (family level) belonged to order Heteroptera (water bugs) and Diptera (flies), and class Mollusca. Mollusca for post-monsoon and Diptera (particularly Chironomidae) for pre-monsoon shared the highest proportion in the total density. Shannon diversity index (H') for post-monsoon was 1.82±0.46 and for pre-monsoon was 1.38±0.53 and was significantly different between seasons ($p=0.01$). Principal component analysis revealed that increase in taxa numbers were positively correlated to soft substrates while negatively correlated to non-soft substrates in littoral zone of the reservoir. Cluster analyses discriminated the sites into two main groups for both seasons. The study concludes that benthic macroinvertebrates diversity is highly influenced by substrate types, water level fluctuation, and human accessibility to the reservoir. Therefore, in order to stabilize benthic macroinvertebrates diversity and their abundance, it is essential to maintain surface water level, stabilize bank substrate and minimize human pressure.

Key words: benthic macroinvertebrates, aquatic biodiversity, littoral zone, reservoir, substrates

Introduction

The ecological attributes of wetlands (rivers, lakes, reservoir, marshy lands, paddy fields etc) are highly diverse and provide especially important ecosystem services (Costanza *et al.* 1991). These valued ecological attributes, such as water storage capacity, biogeochemical cycling, biotic productivity, and biodiversity, are integral to the structure and function of wetland ecosystems and their ecological integrity (Stevenson & Hauer 2002).

Benthic macroinvertebrates (BMI) play an essential role in key processes (food chain dynamics, productivity, nutrient cycling and decomposition) within wetland ecosystems (Batzer *et al.* 1993, Hann 1991, Reice & Wohlenberg 1993, Schriver *et al.* 1995). For example, many fish and waterfowl species depend on BMI communities for food (Wiley *et al.* 1984, Euliss & Grodhaus 1987; Swanson 1988, Euliss *et al.* 1991). They also indicate any environmental changes like eutrophication and several other modes of lake degradation which are reflected by related changes in their structure (abundance and species composition) (Solimini *et al.* 2006, Sharma & Rawat 2009). Hydrological and morphological alterations cause the most severe impact on littoral BMI structures since their low mobility restricts their ability to follow the receding water than fish, and exhibit a much higher dependence on littoral habitat types (Solimini *et al.* 2006). The water level fluctuations reduce diversity and alter the composition of littoral habitats (Baxter 1977; Hellsten *et al.* 1996; Hill and Keddy 1992; Solimini *et al.* 2006) which may affect littoral species composition. In such system, macrophytes play important role by providing attachment sites and materials to build protective retreats to invertebrates (Soszka 1975, Lodge 1985, Dudley 1988). Biological metrics such as species richness, diversity, and composition measures are often used to describe ecological changes of an ecosystem (e.g., Niemi & McDonald 2004, Shah *et al.* 2011) as they integrate the effects of multiple stressors, including those whose mechanisms or even existence might be poorly known.

Jagadispur reservoir is one of the most important wetlands of Nepal designated as Ramsar site in 2003 and is also highlighted in the Directory of Asian Wetlands chiefly because of its support for threatened and endangered species of birds and mammals. A total of 118 bird species are recorded from the reservoir in which seven species are globally Threatened and three species are Near Threatened (Baral 2008). The globally Threatened smooth-coated Otter (*Lutrogale perspicillata*) also occurs in the reservoir area (DNPWC & IUCN 2003 cited in Baral 2008). Nearly 2000 people live in the immediate vicinity of the lake within 500m radius. The majority of people living in the area are from Tharu, Yadav and Muslim communities. There are also migrated hill tribes eg. Brahmin, Chhetris, Gurungs, Magars, etc. Majority of villagers that live in the adjacent area are farmers and are poor.

The reservoir was built in the early 1970s over Jakhira Lake and agricultural land for irrigation purpose. Currently, it supplies water for 6,200 ha of surrounding cultivated lands for irrigation (Fact sheet of Nepal 2005). It also provides tremendous economic benefits to local people, for example, fisheries; maintenance of water table and nutrient retention in surrounding wetlands; timber production; energy resources (fuelwood and fodder collection), domestic use (e.g. laundry), harvesting of wetland products (e.g. Gastropods-apple snails, macrophytes-water-chestnut), recreation (e.g. picnic spots, bathing) and tourism opportunities.

The reservoir water is extensively used by local farmers during crop seasons. Although, the reservoir gets replenished from the Banganga river, the water level fluctuates remarkably from dry to wet seasons. The water level becomes very low during pre-monsoon and only covers its bottom which is mainly composed of soft substrates like mud, organic debris. In contract, the water level is relatively higher during post-monsoon and reaches up to its dike which is composed of non-soft substrates like boulders, cobbles and stones. Additionally, it is subjected to various human use e.g. fishing, grazing, fuel wood and fodder collection, domestic use (e.g. laundry), harvesting of wetland products, recreation (e.g. picnic, bathing, boating) and supply of water for irrigation.

There have been some studies focused on assessment of water quality (Gautam and Bhatarai 2010) and birds' status (Baral 2008). However, the diversity and structure of littoral benthic macroinvertebrates are still poorly known from the reservoir though it has high significance in understanding the overall status of the ecosystem. Thus, the present research focuses on diversity and community assemblage of benthic macroinvertebrates and their relation to stressors of the reservoir for post-monsoon (2008) and pre-monsoon (2009) seasons.

Methodology

Study area

Jagadishpur Reservoir (also known as Sagar Taal), located at 27º35'00''N and 83º05'00''E (altitude 197m) in Taulihawa county, Kapilbastu district, is the largest (157 ha) manmade reservoir in Nepal (Fig. 1) with a total shoreline perimeter of approximately 5 km (Bhuju *et al.* 2007). The average depth of the reservoir is 3 m. The eastern part of the reservoir has shallow water body whereas the western part is deeper. Marsh meadows and extensive mudflat fringed by marsh lies in the northern part. The reservoir is surrounded by cultivated land and few smaller lakes. It is fed by Banganga River which exhibits a large catchment in the Churia hills.

The reservoir banks are paved with boulders, cobbles and stones. *Dalbergia sisoo* (sisoo) and *Acacia catechu* (khair) are dominated trees along the dyke. Since 2007, commercial fish farming has started in the reservoir by contractors.

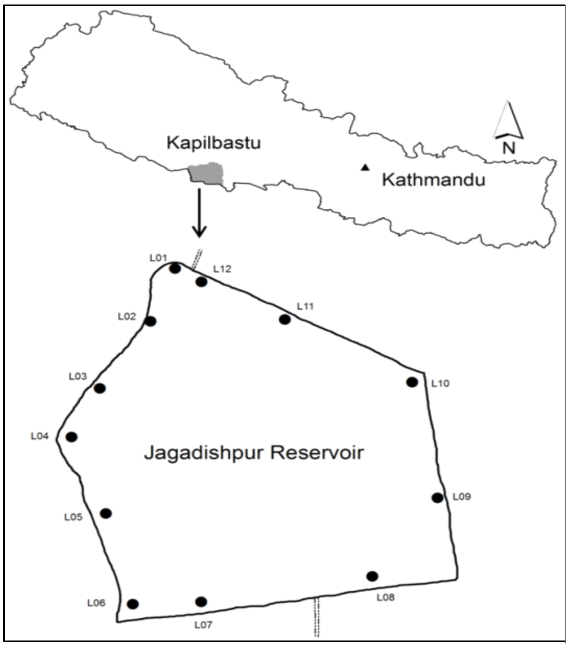

Fig. 1. Jagadishpur reservoir with the location of sampling sites (indicated by filled circles) and site codes

Study design

The Lentic Ecosystem Field Protocol (LEFP) was developed (Annex I) based on the preliminary survey and literature review (David *et al*. 1998; Moog & Sharma 2005). During survey, the sketch of the reservoir including various features such as littoral zone substrate types, bank condition and structure, riparian vegetation, wetland use, inflow and outflow conditions etc, and stressors like fish farming, waste disposal, washing, bathing, open defecation, resource extraction etc were noted down to locate sampling sites evenly along the littoral zone considering all habitat types. In total, twelve sites in littoral zone were selected for BMI samples and environmental variables (Fig. 1).

At each site, substrate composition assessment was performed by manually investigating the substrate having at least 5% habitat coverage in the sampling transect and estimating the proportion of the following substrate categories (macrophytes, algae, organic debris, clay, silt, sand, gravel and boulder).

BMI sampling, sorting and identification

We conducted sampling during post-monsoon (November 2008) and pre-monsoon (April 2009) seasons. The selection of sampling dates was dependent on the maximum and minimum water levels and the vegetation development. At each site, BMI were sampled for 5 minutes at 10 m stretch of littoral zone (extending perpendicular from shore to a maximum depth of 1m) by using a kick-and-sweep method with a standard handnet (mesh size of 500 µm). While sampling, we scoured the bottom to ensure that sedentary animals and associated debris were collected. In addition, we turned over the stones, cobbles and plant parts within the sampling area in order to dislodge and collect animals that were hidden underneath or attached to the bottom.

Samples from different sites of the reservoir were separately preserved in 4% formaldehyde in field. All the BMI were sorted in the laboratory of Hindu Kush Himalayan Benthological Society (HKH BENSO). Animals were identified to the family or genus level based on available keys (Dudgeon 1999, Nesemann *et al.* 2007, Nesemann *et al.* 2011). Identified BMI were preserved in 70% ethanol.

Water sampling

We collected water sample from each site at a 10 cm depth before carrying out BMI sampling. Samples were stored in 500 ml polyethylene jars. The sample containing jars were stored on ice and were kept cool until arriving at the CDES/TU laboratory for the analysis. The samples were analysed within two weeks after collection.

Dissolved oxygen (DO), temperature, pH, conductivity, free CO_2, nitrate-nitrogen, ammonium-nitrogen, ortho-phosphate phosphorus, Ca^{++} hardness, Mg^{++} hardness, total hardness, total alkalinity and chloride were measured (based on methods APHA 1995, and Trivedy & Goel 1984) for each site.

Data analysis

Biological metrics: Alpha diversity (Taxa richness, Shannon diversity index), ETO (Ephemeroptera, Trichoptera and Odonata) taxa, Diptera taxa and composition measures (% of Diptera taxa, % of ETO taxa, % of Diptera individuals, % of Non-insecta individuals, % of Mollusca individuals and % of Oligochaetes and Leeches) were calculated for assessing variability in diversity and community assemblages of BMI in post-monsoon and pre-monsoon seasons.

Multivariate analyses: Detrended Correspondence Analysis (DCA), Principal Component Analysis (PCA), and Cluster Analysis (CA) were carried out for both seasons separately in PC-ORD 5.16 version (McCune and Mefford 2006). Taxa occurrence in less than 12% of total sites were excluded from the analysis to avoid down weighting BMI distribution pattern. Density of the taxa were transformed into $\log_{10}(x+1)$ in prior to the analysis. The logarithmic transformation was used to reduce the effect of absolute density. DCA was initially conducted to calculate the maximum amount of variation in the BMI assemblage data. Based on the length of the gradient, an appropriate ordination technique (PCA) was selected for analyzing relationship between biological data and substrate types. Cluster analysis was performed to describe the similarity among the biological samples, where Sorensen Bray-Curtis was used as distance measures and flexible beta for group linkage method.

Statistical tests were carried out in statistical program SPSS (version 10 for windows; SPSS Inc, Chicago, IL). Non-parametric Spearman correlation test was performed between taxa richness and soft substrates (organic debris, mud/clay and macrophytes) and non-soft substrates (cobbles, boulders) for both seasons separately. In addition, non-parametric Wilcoxon Signed Ranks Test was conducted for statistical significance difference in biological metrics and environmental variables between post-monsoon and pre-monsoon seasons.

Results and Discussion

BMI diversity and assemblages

In total, fifty families of BMI belonging to fifteen orders were recorded from littoral zone of the reservoir. Forty six families belonging to fourteen orders in post-monsoon and thirty eight families belonging to fifteen orders in pre-monsoon were documented. Higher number of families was recorded from Heteroptera (water bugs), Diptera (flies) and Mollusca for the both seasons (Fig. 2). Mean density of BMI was 260.4 ind./m^2 for post-monsoon and 453.05 ind./m^2 for pre-monsoon seasons. Chironomidae density alone occupied 24.6% and 53.1% in post-monsoon and pre-monsoon seasons respectively. Similarly, Mollusca contributed 34.6% in post-monsoon and 24.6% in pre-monsoon while water Bugs contributed only 6.6 % in post-monsoon and 1.2% in pre-monsoon to the total BMI density.

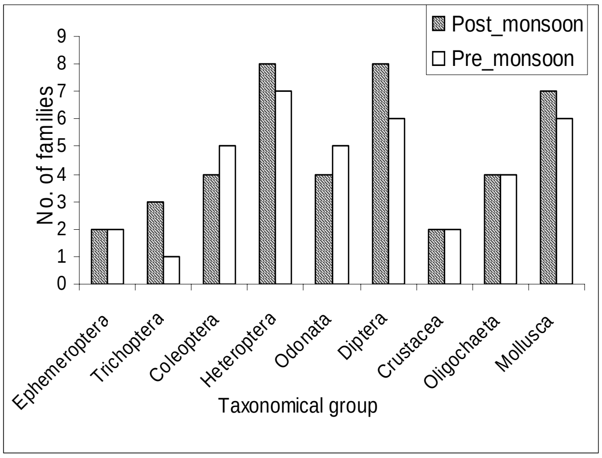

Fig. 2. Comparison of number of families present per taxonomical group in post-monsoon (November 2008) and pre-monsoon (April 2009) seasons.

Biological metrics

Shannon diversity index (H') was 1.82±0.46 in post-monsoon and 1.38±0.53 in pre-monsoon and was significantly different between seasons (Wilcoxon Signed Ranks Test (Z) = -2.196, p=0.03) (Fig. 3) while taxa richness (total no. of taxa) (Z= -0.747, p=0.46), no. of ETO taxa (Z= -0.258, p=0.79), no. of Diptera taxa (Z = -1.75, p=0.08), no. of Mollusca taxa (Z =-1.25, p=0.2) were not significantly different between post-monsoon and pre-monsoon seasons (n=12 for all cases).

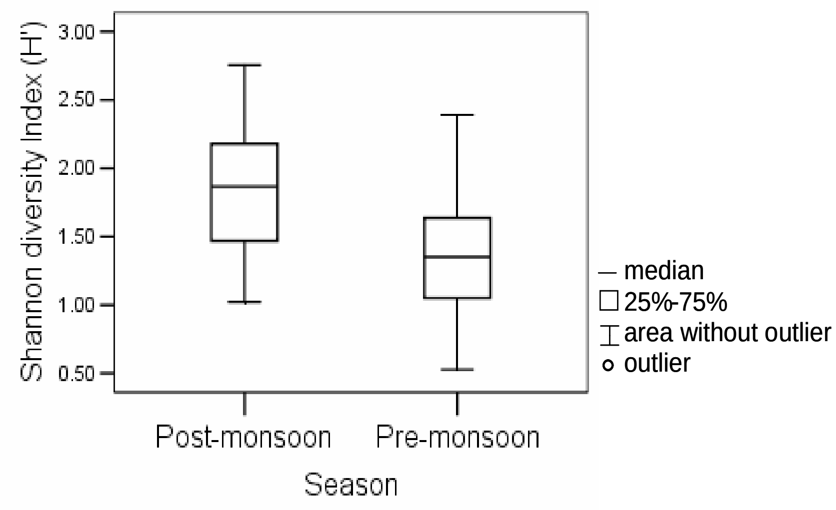

Fig. 3. Box and whisker-plots of Shannon diversity index for post-monsoon (November 2008) and pre-monsoon (April 2009) seasons in Jagadishpur Reservoir.

Composition measures like density (Z= -3.059, p=0.002), % of Diptera taxa (Z= -2.35, p=0.02), % of Diptera ind. (Z= -3.059, p=0.002), % of non-insecta ind. (Z= -2.59, p=0.01) were significantly different between post-monsoon and pre-monsoon (Fig. 4) seasons. However, % of ETO taxa (Z= -0.355, p=0.72), % of Mollusca taxa (Z= -1.33, p=0.2), % of Oligochaeta and Leeches ind. (Z=-0.978, p=0.32) and % of Mollusca ind. (Z=0.182, p=0.2) were not significantly different between seasons (n=12 sites for all cases).

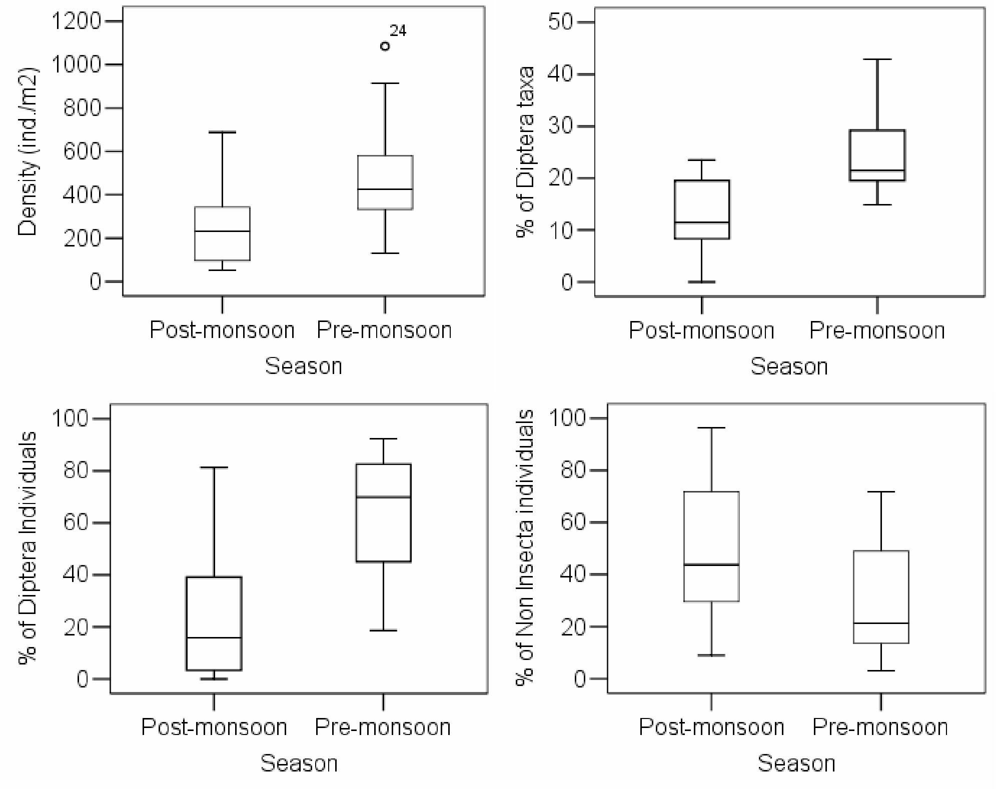

Fig. 4. Box and whisker-plots of composition measures (n=12) for post-monsoon (November 2008) and pre-monsoon (April 2009) seasons in Jagadishpur Reservoir.

Physical and chemical attributes

Temperature, pH, dissolved oxygen, free CO_2, total alkalinity, Ca^{++} hardness, Mg^{++} hardness and Orthophosphate phosphorus significantly varied between seasons (Wilcoxon Signed Ranks Test) (Table 1).

Table 1. Physical and chemical variables measured in 12 littoral sites of Jagadishpur Reservoir during the period post-monsoon (November 2008) and pre-monsoon (April 2009). The symbol -* indicates that the variables are significantly different between seasons (Wilcoxon Signed Ranks Test, $p<0.05$). nitrate-nitrogen was measured for only one time in post-monsoon (November 2008), thus it is not included in the analysis.

Parameters	**Post-monsoon (Mean± SD)**	**Pre-monsoon (Mean± SD)**
*Temperature (°C)	24.±1.24	31.83±2.38
*pH	7.72±0.16	8.13±0.34
Conductivity (µS/cm) (p= 0.4)	388.42±39.59	373.25±42.87
*DO (mg/l)	7.95±0.76	6.0±1.2
*Free CO_2 (mg/l)	26.55±4.17	14.92±5.72
*Total alkalinity (mg/l)	293.04±147.04	178.58±24.22
*Ca^{++} Hardness (mg/l)	45.29±6.85	28.29±7.90
*Mg^{++} Hardness (mg/l)	19.65±2.23	32.11±4.29
Total Hardness (mg/l) (p=0.08)	193.67±16.42	206.03±25.72
Chloride (mg/l) (p=0.86)	23.24±2.93	23.51±2.22
Nitrate-N (mg/l)	0.305±0.224	-----
Ammonium-N (mg/l) (p=0.47)	0.090±0.017	0.089±0.016
*Orthophosphate-P (mg/l)	0.305±0.0224	0.563±0.273

Community assemblages and environmental variables

PCA and CA for post-monsoon season

The first and second PCA axes explained 51.62% of the variance in littoral BMI data set (Fig 5a). Three axes explained 65.7% of cumulative variance in species composition. Axis 1 is positively correlated with non-soft substrate and negatively correlated with soft substrates. Higher taxa richness was recorded at soft substrates (spearman r= 0.65, $p<0.05$) while lower at non-soft substrates (Spearman r= -0.61, $p<0.05$) in the reservoir.

The cluster analysis performed on the samples discriminated two main groups, with two sub groups within each group (Figure 5b). The main groups correspond to sample sites with majority of soft and non-soft substrates.

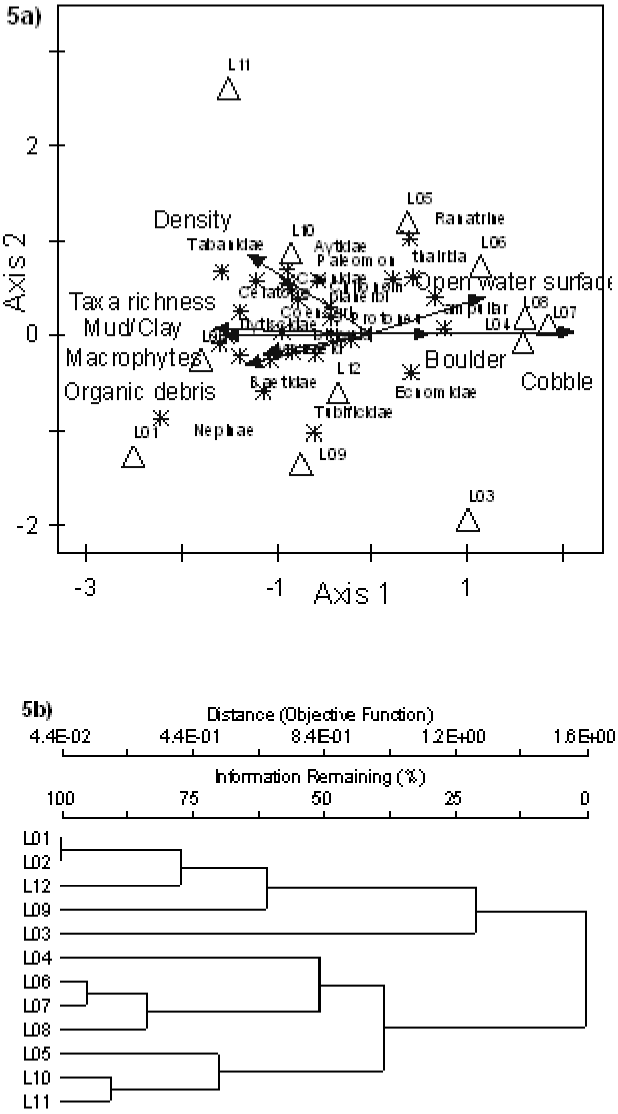

Fig. 5. a) Principal Component Analysis (PCA) biplot showing relationship between BMI data and substrate types. * represents benthic macroinvertebrate taxon, triangle (") indicates sample site (n=12) and vectors represent biological metrics and substrate types. b) Cluster Analysis of sites based on BMI assemblage for post-monsoon (November 2008). Distance measure: Bray–Curtis similarity; linkage method: flexible beta (= -0.25).

PCA and CA for pre-monsoon season

The first and second PCA axes explained 54.5% of the variance in littoral BMI data set (Fig 6a). Three axes explained 71.8% of cumulative variance in species composition. Axis 1 is positively correlated with non-soft substrate and negatively correlated with soft substrates. Higher taxa richness was recorded at soft substrates (spearman r= 0.66, p<0.05) and lower at non-soft substrates (Spearman r= -0.67, p<0.05) in the reservoir.

The cluster analysis performed on the samples discriminated two main groups, with two sub groups within each group (Figure 6b). The main groups correspond to sample sites with majority of soft and non-soft substrates.

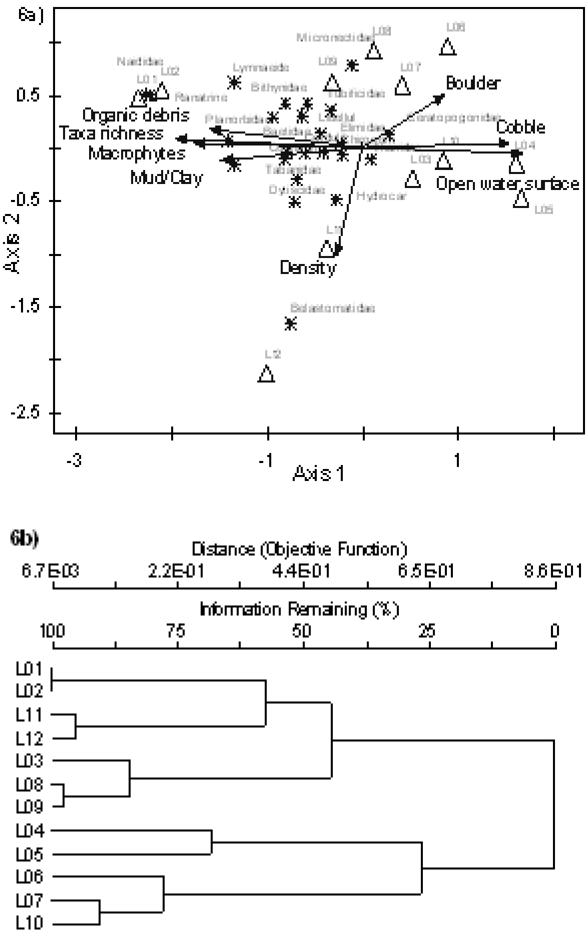

Fig. 6. a) Principal Component Analysis (PCA) biplot showing relationship between BMI data and substrate types. * represents benthic macroinvertebrate taxon, triangle (“) indicates sample site (n=12) and vectors represent biological metrics and substrate types. b.) Cluster Analysis of sites based on BMI assemblages in pre-monsoon (April 2009). Distance measure: Bray–Curtis similarity; linkage method: flexible beta (= -0.25).

BMI diversity, assemblages and biological metrics

We recorded slightly higher number of taxa for post-monsoon than pre-monsoon season. This could be due to decreased water level resulting to decreased wetted reservoir surface area and habitat types. In addition, it could also be due to BMI life cycle length, flight time etc. In both seasons, the littoral zone was dominated by Diptera (flies) and Mollusca (particularly gastropods) which in particular are dominant taxonomic groups in low land stagnant water bodies.

The overall mean BMI density was about half in post–monsoon than pre-monsoon season and showed significant difference between the seasons. However, mean BMI densities recorded for both seasons in the reservoir are comparable to other reservoirs like Jinshahe and Daoguanhe, China (Lv *et al.* 2010) where densities about 300 individuals/m^2 were documented. Mollusca and Diptera contributed high proportion in total densities of BMI for both seasons. However, relatively lower densities of Mollusca in pre-monsoon season might be due to the harvest of snail (*Pila globosa*, *Bellamya bengalensis* etc.) by local people for food resource. Among Diptera, higher density of Chironomids was documented for both the seasons which are typical for many freshwater systems (Heatherly and Whiles 2005). Relatively higher density of Chironomidae was recorded in pre-monsoon season, this might be attributed to the presence of soft and fine substrates (Heatherly and Whiles 2005; Weatherhead and James 2001). Also, the fish harvest (January/February 2009) might have reduced predation on BMI (e.g., Solimini *et al.* 2006) during pre-monsoon season.

The mean value of diversity index in the reservoir (1.82, post-monsoon and 1.38, pre-monsoon) is an indication of the disturbance in the environmental conditions (Wilhm & Dorris 1968). The index value is relatively lower for post-monsoon compared to other manmade wetlands like Asan wetland (Sharma & Rawat 2009). The commercial fish farming with the introduction of exotic species and alteration in substrate composition due to surface water level fluctuation might have strongly influenced the diversity index which is in accordance with other studies (Baxter 1977, Hellsten *et al.* 1996; Hill & Keddy 1992). In addition, other anthropogenic utilization (Wetzel 1990) might also be influencing the reservoir’s BMI diversity.

PCA and CA analysis

The result of PCA showed higher number of BMI taxa at sites dominated with soft substrate habitats than those dominated by cobbles and boulders for both seasons, supporting the studies conducted by Watkins *et al.* (1983) and Mcewen and Butler (2010).

The similarity in community assemblages of BMI are primarily driven by substrate distribution in littoral zone. For instance, similar substrate habitats in L01 and L02 (inlet side) sites showed almost similar taxa assemblage (family level) for both seasons in the reservoir. The change in substrate types modified BMI assemblages (see Solimini *et al.* 2006) because substrate is an important factor directly controlling littoral BMI distribution and abundance (e.g. Weatherhead & James 2001).

We conclude that the diversity and community assemblage of littoral BMI is highly dependent on substrate distribution in the reservoir, i.e., higher numbers of taxa are associated with soft-substrates than non-soft substrates. Therefore, maintaining littoral zone habitat in natural condition will enhance stable BMI assemblage. Our study also foresee that intensive fish farming and surface water level fluctuation could have adversely affected littoral BMI diversity and community assemblage, however, more research are required for better understanding of the mechanism. Sustainable water harvest and low human activities will prevent the loss of littoral habitat and thus maintain benthic macroinvertebrate diversity and assemblage. In turn, this will help to maintain nature conservation interest.

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