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MACROINVERTEBRATE COMMUNITY ASSOCIATED WITH MACROPHYTES IN THE SANTRAGACHI JHEEL LAKE, WEST BENGAL, INDIA

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Abstract

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This study is aimed at finding the seasonal abundance and population fluctuation of the macro-invertebrate community related to macrophytes in the Santragachi jheel lake, West Bengal, India. Here, a total of 29 species of aquatic macrophytes were recorded and then categorized into 6 groups, (1) obligatory submerged or partially submerged plants (OSPS), (2) those with aerial shoot and inflorescence stalk, (3) free floating (FF), (4) rooted floating leaved plants, rooted floating stem plants, (5) emergent (Emer) and (6) marginal (Marg). Macroinvertebrate fauna associated with macrophytes revealed a total of 69 macroinvertebrate species represented in this lake. Crustaceans, Insects and Gastropods are the most dominant groups in the jheel in terms of abundance. The mean density of total macroinvertebrate fauna associated with macrophytes was 1084.27/m^2 in the Santragachi jheel lake. Oligochaeta, Ephemeroptera, Odonata, Coleoptera, Diptera had higher abundance here. Among the 11 major groups, Oligochaeta, Arachnida, Odonata, Hemiptera showed peak abundance during the monsoon period. Post-monsoon peak was observed by Hirudinea, Crustacea, Ephemeroptera, Coleoptera, Diptera, Gastropoda and Bivalvia in the jheel. The total macroinvertebrate faunal abundance has been positively influenced by macrophytal biomass especially of the OSPS type of macrophytes. Oligochaeta prefers the emergent and marginal type of macrophytes. The arachnids are positively correlated with the FF, Emer and Marg types of macrophytes. Hemiptera has a positive relationship with Emer and Marg type of macrophytes. Gastropoda exhibit a strong positive correlation with OSPS type of macrophytes. This investigation revealed that macro-invertebrates in the Santragachi jheel lake are closely related to the macrophytes there.

Key words: Santragachi jheel lake, eutrophication, macroinvertebrate, Oligochaeta Coleoptera, Hirudinea, Crustacea

Introduction

Aquatic vegetation forms an important element of the aquatic environment in freshwater ecosystem. Diverse types of aquatic animal life especially of macro-invertebrate fauna inhabit the vegetation of wetlands and provide significant support to the complex food chain. They not only manufacture their food, but also provide suitable surface area for shelter, a site for oviposition, development, resting and nesting ground in addition to ambient weather and hiding places for macro-invertebrates, pisces and other aquatic life. During daytime, the macrophytic vegetation contributes to enrich the dissolved oxygen content of water and harbours a wide variety of macro-invertebrate (Krecker, 1939). These macro-invertebrate faunal communities form the food for fish, prawns and birds. The associated fauna of weeds is dispersed in the wetland when they are uprooted and float (Rai, 1974). Empirical studies indicate that the total abundance of both epiphytic and benthic macro-invertebrates is correlated with the biomass of macrophytes and weed bed characteristics (Cyr, Downing, 1988).

Few limnological studies have been done on macrobenthos in different types of wetlands. Although several works have been made by the scientists abroad, very little information is known about the macro-invertebrate faunal community associated with macrophytes inhabiting the Indian fresh water wetlands. Needham (1929) reported that macro-invertebrates living on macrophytes were many times more abundant than those living in bottom sediments. Gerking (1957), and Minto (1977) described the method of sampling of littoral macrofauna associated with aquatic vegetation. Hutchinson (1967) coined the term epiphytic macroinvertebrates. Petr (1968) studied the population changes in aquatic invertebrates living on two water plants – *Pistia stratiotes* and *Ceratophyllum demersum* in a tropical man-made lake. McLachlan (1969, 1975) studied the role of aquatic macrophytes on the variety and abundance of benthic fauna in a newly created lake in the tropics named lake Kariba. Pieczynski (1973) reported experimentally on the abundance and biomass of the fauna associated with macrophytes in a fish stocking pond. Soszka (1975), Vioghts (1976) and Smock and Stoneburner (1980) reported temporal variations in the abundance of epiphytic macroinvertebrates. Gilinsky (1984) reported the role of macrophytes towards the macroinvertebrate from the predators. Biochino, A.A. and Biochino, G.I. (1980), Vincent et al. (1982) and Downing (1986) worked on the epiphytic invertebrates in relationship to the biomass of macrophytes. Friday (1987) reported on the diversity of macro-invertebrate and macrophyte communities in ponds.

In India, freshwater wetlands have undergone critical changes in recent years, largely due to rising pressure on land and lack of awareness about their benefits and functions. A limited number of works have attempted to study the macrophyte associated macro-invertebrate fauna in India (Laal, 1989; Singh, Roy, 1991a, b). Prakash et al. (1994) worked on the ecology of weed fish in relationship to macrophytes in a tropical wetland of the Kawar lake (Bagusarai), Bihar. Pandey et al. (1994) worked on correlation of gastropod population with macrophytes. Prasad and Singh (2003) studied the zoobenthos community in a tropical water-body in Bihar. Ghosh and Chattopadhyay (1990) worked on a macro-benthos population of a Calcutta wetland. Bhattacharya and Gupta (1991) studied the insect populations related to macrophytes. Pal and Nandi (1997) constructed a simple device for the quantitative sampling of macrofauna from littoral macrophytes. Pal (2000) studied macrofauna associated with macrophytes in two urban lakes in Calcutta (West Bengal). Ghosh and Chattopadhyay (1994) worked on biological resources in Santragachi jheel lake. Since it did not cover the macrophyte associated with macro-invertebrate fauna in the lake's water, to supplement the present knowledge here, an inventory and population and ecological studies of the macrophytes associated with macrinvertebrates were instituted for fortnightly surveys during 2000–2002. This study is expected to provide interesting insights into interactions between macrophytes and associated macro-invertebrate fauna. Detailed investigations on the community structure and relative abundance of macro-invertebrates associated with macrophytes were carried out in this wetland of Santragachi jheel lake.

Material and methods

Study area

Santragachi jheel lake (22°58′ N and 88°27′ E) is one of the most important urban wetlands in the Howrah district of West Bengal, India. The total area of the Santragachi jheel lake is 10.87 ha, with a roughly rectangular shape. Its length is about 915 m and the width is 305 m, perimeter is 2418 m and the mean depth varies from 4–7 ft. This jheel is surrounded by human habitation including railway quarters, shops, railway yard, a number of industrial units and a domestic and commercial cattle shed. This lake receives domestic sewage water, waste materials, materials from unauthorized cow and buffalo sheds, faeces from unwanted users of some parts of the lake who also use it as a dumping ground for their garbage and waste materials, plus sewage waters from shops beside it.

Sampling sites

To study the macroinvertebrate faunal community associated with macrophytes, regular samplings of water were made fortnightly during February, 2000 to January, 2002 from the following three selected lake sites :

Station 1 (S1): located on its western side near the commercial cattle shed.

Station 2 (S2): located at the middle southern side, and devoid of sewage outlets.

Station 3 (S3): located on the eastern side, where most major sewage points are found.

Collection of macrophytes and associated macro-invertebrates

Collection of data on the biotic component of this jheel was performed fortnightly along the littoral zone usually delimited by the rooted aquatic vegetation. Qualitative sampling of macrophytes and macroinvertebrate fauna were made by means of hand picking, drag netting and sampler measuring 20x20x40 cm^3 (Pal, Nandi, 1997; Patra et al., 2010) These were at different depths of the selected stations of the lake. For effective evaluation of the data, 9 samples were taken from each station, totalling 27 samples. For the isolation of macro-invertebrate fauna from weeds, macrophytes enclosed in the sampler were quickly washed thoroughly in water and filtered subsequently through a sieve of 0.5 mm mesh (Havgaard, 1973; Parsons, Mathews, 1995). Macro-invertebrates retained in the sieve were then sorted in a large enamel tray in fresh condition in the laboratory. The sorted organisms were preserved in 70% alcohol. Macrophytes were manually collected, processed, ,and with herbaria, were prepared for identification (Patra et al., 2010).

Identification of macrophytes and associated macroinvertebrates

The identification of preserved macrophytes was carried out by consulting the available literature (Biswas, Calder, 1936; APHA, 1989; Ghosh, 1994; Anonymous, 1998). The macro-invertebrates associated with the macrophytes were identified with the help of the Experts of Zoological Survey of India, as well as using the available literature (Tonapi, 1980; Srivastava, 1993; Jayaram, 1981; Subba Rao, 1989; De, Sengupta, 1993; Patra et al., 2010).

Biomass estimation of macrophytes

The macrophytic samples were dried at 60 ^{o}C for 48 hours (Rai, Sharma, 1991) and then weighed after cooling (Patra et al., 2010).

Population density and percentage frequency determination

The number of individuals per unit area represents the population density. The number of macro-invertebrates associated with macrophytes was expressed as number of individuals per square metre using the formula of Welch (1948; Patra et al., 2010)

$$n = \frac{o}{a \times s} \times 10{,}000,$$

where
n = number of organisms per square metre
o = number of organisms counted
a = area of the sampler
s = number of replicates taken.

Percentage frequency is the percentage of quadrats in which a given species is found, and this is determined as follows:

$$\text{percentage frequency} = \frac{\text{number of quadrats in which the species occurred}}{\text{total number of quadrats}} \times 100.$$

Community analysis

The following five biological indices were used; The Shannon–Wiener index of diversity (Shannon, Wiener, 1949), species richness (Margalef, 1958), index of dominance (Simpson, 1949) and evenness index (Pielou, 1966).

Statistical analysis

ANOVA (2-way)

After transforming the value of each data to log (x +1), a two-way analysis of variance (ANOVA) was calculated to establish the significance of the differences in density of macro-invertebrate groups in the different types of macrophytes, stations and seasons.

Pearson's correlation coefficient

Pearson's correlation coefficients were evaluated for the determination of relationships between macrophytal biomass (dry weight) and macro-invertebrate faunal abundance. The correlations were tested at 5% and 1% levels of significance.

Stepwise multiple regression

For the analysis of relationship between the controlling factors and macro invertebrates, the stepwise multiple regression method was applied. This analysis was performed with the relevant software programme under SPSS, version 6.0.

Results

Macrophytes

The aquatic macrophyte species recorded during this study period are listed in Table 1. Based on the habits of the macrophytes, these are broadly divided into the following six categories; obligatory submerged or partially submerged plants with aerial shoot and inflorescence

T a b l e 1. Presence of macrophytes in Santragachi jheel lake.

Obligatory or partially submerged plants (OSPS) **Family: Hydrocharitaceae** *Hydrilla verticillate* (L.) Royle **Family: Scrophulariaceae** *Limnophila indica* L. *Ottelia alismoides* L. **Rooted floating leaved plants (RFLP)** **Family: Nymphaeaceae** *Nymphaea stellata* Burman *Nymphaea alba* L. **Family: Pontederiaceae** *Monochoria hastate* L. **Rooted floating stem plants (RFSP)** **Family: Amaranthaceae** *Alternanthera sessilis* L. **Family: Asteracea** *Enhydra fluctuans* Loureiro **Family: Convolvulaceae** *Ipomoea aquatica* Forsskaal **Marginal (Marg)** **Family: Polygonaceae** *Polygonum barbatum* L. *Polygonum hydropiper* L. **Family: Onagraceae** *Ludwigia adscendens* L. **Family: Compositae** *Mikania scandens* Deny	**Free Floating (FF)** **Family: Azollaceae** *Azolla pinnate* Brown **Family: Pontederiaceae** *Eichhornia crassipes* Marcius **Family: Lemnaceae** *Lemna acquinoctialis* Welwitsch *Spirodella polyriza* L. **Family: Araceae** *Pistia stratioites* L. **Family: Salviniaceae** *Salvinia molesta* Mitchell **Emergent (Emer)** **Family: Acanthaceae** *Hygrophila schulli* Hamilton **Family: Araceae** *Colocasia esculenta* (L.) Schott **Family: Cyperaceae** *Cyperus pangorei* Roottbak *Juncelles inumdatus* L. *Fimbristylis bisumbellata* L. **Family: Convolvulaceae** *Ipomoea fistulosa* Martinusex Choisy **Family: Amaranthaceae** *Alternanthera philoxeroides* L. **Family: Alismataceae** *Sagittaria montevidensis* Chamissoet Sc. **Family: Typhaceae** *Typha domingensis* Persoons **Family: Poaceae** *Eragrostris* sp. L.

T a b l e 2. Presence of macroinvertebrates fauna (Annelida, Mollusca and Arthopoda) associated with macrophytes in the Santragachi jheel lake.

ANNELIDA	MOLLUSCA	ARTHROPODA		
OLIGOCHAETA	**GASTROPODA**	**CRUSTACEA**	Order: Odonata	**Family: Pleidae**
Family: Tubificidae	**Family: Viviparidae**	Order: Decapoda	**Family: Libellulidae**	*Plea* sp.
Branchiura sowerbyi	*Bellamya bengalensis*	**Family: Palaemonidae**	*Brachythemis* sp.	**Family: Notonectidae**
HIRUDINEA	**Family: Thiaridae**	*Macrobrachium dayanum*	**Family: Coenagrionidae**	*Anisops breddini*
Family: Glossophonidae	*Brotia costula*	*Macrobrachium lamarrei*	*Agrioenemis pygmaea*	Order: Coleoptera
Hemiclepsis marginata asiatica	*Thiara granifera*	**Family: Potamonidae**	*Ceriagrion coromandelianum*	**Family: Chrysomelidae**
Family: Hirudidae	**Family: Bithyniidae**	*Sartoriana spinigera*	*Ischnura senegalensis*	*Dicladispa armigera*
Hirudinaria manillensis	*Digoniostoma cemeopoma*	**ARACHNIDA**	*Ischnura aurora*	*Cassida* sp.
	Gabbia orcula	Order: Araneae	*Pseudagrion* sp.	**Family: Dytiscidae**
	Family: Pilidae	**Family:Lycosidae**	Order: Hemiptera	*Hydrocoptus subvittulus*
	Pila globosa	*Evippa shivajii*	**Family: Gerridae**	*Hydaticus fabricii*
	Family: Lymnaeidae	*Paradosa annandalei*	*Gerris adeloidis*	*Hydrovatus* sp.
	Lymnaea luteola	*Paradosa birmanica*	*Gerris spinolae*	*Canthydrus laetabilis*
	Lymnaea accuminata	*Paradosa pusiota*	*Limnogonus* sp. (2 species)	*Canthydrus luctuosus*
	Family: Planorbidae	**Family: Araneidae**	*Micronecta* sp.	*Clypeodytes* sp.
	Gyraulus convexiusculus	*Larinia* sp.	**Family: Hydrometridae**	*Laccophilus* sp. (2 species)
	Gyraulus labiatus	**Family: Salticidae**	*Hydrometra* sp. (2 species)	**Family: Hydrophilidae**
	BIVALVIA	*Myrmarachni* sp.	**Family: Nepidae**	*Amphiops pedestris*
	Family: Unionidae	**Family: Theridae**	*Ranatra elongata*	*Berosus indicus*
	Lamellidens corrianus	*Theridion* sp.	*Ranatra filiformis*	*Helochares anchoralis*
	Lamellidens marginalis	**INSECTA**	*Ranatra sordidula*	*Sternolophus rufipes*
	Family: Pisidiidae	Order: Ephemeroptera	*Laccotrephes grisesus*	Order: Diptera
	Pisidium clarkeanum	**Family: Baetidae**	**Family: Belostomidae**	**Family: Chironomidae**
		Cloeon sp.	*Diplonychus annulatum*	*Chironomus* sp. (2 species)
			Diplonychus sp.	**Family: Culicidae**
				Anopheles sp.
				Culex sp.
				Family: Stratiomyidae
				Odontomyia dorsoangulata

stalk (OSPS), free floating (FF), rooted floating leaved plants (RFLP), rooted floating stem plants (RFSP), emergent (Emer) and marginal (Marg). These macrophytes are represented by 29 species (Patra et al., 2010).

Macro-invertebrate fauna

The qualitative study reveals the presence of 3 major phyla represented by 69 species under 32 families (Table 2). Phylum Annelida includes Oligochaeta, represented by 2 species belonging to the Tubificidae family and Hirudinea, represented by 2 species. 1 species belongs to the Glossophonidae family and 1 species to the Hirudidae. Phylum Arthropoda includes Crustacea, and is represented by 3 species. 2 species belong to the family Palaemonidae, and 1 species in the family Potamonidae. Arachnida is represented by 7 species in 4 families and Insecta by 41 species under 15 families. Phylum Mollusca includes Gastropoda, and this is represented by 11 species in 6 families. Bivalvia is represented by 3 species under 2 families (Patra et al., 2010).

Macrophyte-macro-invertebrate association

For the determination of the diversity of macro-invertebrate faunal community associated with macrophytes, six types of macrophytes were selected. The macro-invertebrate faunal elements collected from each of these six types are listed in Table 3. It is evident that the highest number (41) of macro-invertebrate species was associated with the OSPS type of macrophytes and the lowest (10) with emergent type of plants. This exhibits the general tendency that there is higher taxonomical variability of associated organisms with greater macrophyte leaf fragmentation. It is also evident that amongst the various types, OSPS macrophyte is the most preferred one for the assemblage of diverse macro-invertebrates. The relatively high number of 7 coleopteran species was noted within the free floating macrophytes. Bushy root and leaf surfaces of the macrophytes often provide shelter and the spongy petiole affords a feeding ground and egg laying site. Arachnida is usually an epineustonic form, and hence it is recorded from free floating and marginal macrophytes. The OSPS type of macrophytes support the maximum number of Gastropod species (11) as they provide ample surface area for shelter and also the sites for feeding, oviposition, development and hiding places. The mergent plants with their comparatively hard stem failed to support any Coleopteran species.

Variation of population of major macro-invertebrate faunal groups

The macro-invertebrate faunal community associated with macrophytes of Santragachi jheel lake comprized the following eleven major macro-invertebrate groups; Oligochaeta, Hirudinea, Crustacea, Arachnida, Ephemeroptera, Odonata, Hemiptera, Coleoptera, Diptera, T a b l e 3. Dominant macroinvertebrate fauna associated with various categories of macrophytes.

Macroinvertebrate groups	**Major macroinvertebrate species associated with macrophytes**					
	OSPS *	FF	RFLP	RFSP	Emer	Marg
Oligochaeta	Brs, Lh **	Brs, Lh	Brs	Lh	-----	-----
Hirudinea	Hma, Pe, Hm	Hma	Hma	Hma	-----	-----
Crustacea	Ca, Md, Ml	Ca, Md, Ml, Ss	Md, Mi	Ml, Ss, Vl	Md, Mi	Md, Mi
Arachnida	-----	Pa, Pb, Pp, Ts	Pa, Us	-----	-----	Lys, Pa
Ephemeroptera	Cs	Cs	Cs	Cs	Cs	Cs
Odonata	Bs, Cc, Ia, Is, Pds	Bs, Is, Pds, Os	Cc, Ia, Ps, Os	Cc, Ia, Pds	Ap, Pds	-----
Hemiptera	Ab, Da, Ds, Rs, Hys, Ms, Gs	Ab, Da, Ds, Ps, Rs, Ms, Gs	Ab, Da, Ds, Rs ,Ps, Hys, Gs	Ab, Da, Rs, Gs	Da, Rs	Ab, Ds, Rs, Rf
Coleoptera	Cla, Ha, Hs, Ls	Bi, Cla, Cls, Ha, Hs, Ls, Res	Cla, Ha, Hs, Ls	Bi, Cla, Ha, Hs, Ls	-----	Bi, Cla, Ha, Hs, Ls
Diptera	As, Cus, Od	As, Cus, Od	As, Cus, Od	As, Cus, Od	-----	-----
Gastropoda	Bb, Brc, Gl, Go, Ie, Tg, Tl, Dc, La, Ll, Pg	Bb, Brc, Gl, Go, Ie, Tg	Bb ,Brc, Go, Tg	Bb, Brc, Gl, Ie, Dc, Tg	Bb, Gl, Go	Bb, Go, Ie, Tg, Tt, Brc
Bivalvia	Lm, Pc	-----	Lm, Pc	-----	-----	-----

Notes: Emer – emergent; FF – free floating; Marg – marginal; OSPS – obligatory or partially submerged plants; RFLP– rooted floating leaved plants; RFSP – rooted floating stem plants.

Ab –*Anisops breddini,* Ap – *Agrioenemis pygmaea,* Ara – Arachnida, As – *Anopheles* sp., Bb – *Bellamya bengalensis,* Bi – *Berosus indicus,* Biv – Bivalvia, Brc – *Brotia costula,* Brs – *Branchiura sowerbyi,* Bs – *Brachythemis* sp., Ca – *Caridina* sp., Cc – *Ceriagrion coromandelianum,* Cla – *Canthydrus laetabilis,* Cls – *Clypeodytes* sp., Col – Coleoptera, Cru – Crustacea, Cs – *Cloeon* sp., Cus – *Culex* sp., Da – *Diplonychus annulatum,* Dc – *Digoniostoma cemeopoma,* Dip – Diptera, Ds – *Diplonychus* sp., Eph – Ephemeroptera, Gas – Gastropoda, Gl – *Gyraulus labiatus,* Go – *Gabbia orcula,* Gs – *Gerris spinolae,* Ha – *Helochares anchoralis,* Hem – Hemiptera, Hir – Hirudinea, Hm – *Hirudinaria manillensis,* Hma – *Hemiclepsis marginata asiatica,* Hs – *Hydrocoptus subvittulus,* Hys – *Hydrometra* sp., Ia – *Ischnura aurora,* Ie – *Indoplanorbis exustus,* Is – *Ischnura senegalensis,* La – *Lymnaea accuminata,* Lh – *Limnodrilus hoffmeisteri,* Ll – *Lymnae luteola,* Lm – *Lamellidens marginalis,* Ls – *Laccophilus* sp., Lys – *Lycosa* sp., Md – *Macrobrachium dayanum,* Ml – *Macrobrachium lamarre,* Ms – *Micronecta* sp., Od – *Odontomyia dorsoangulata,* Odo – Odonata, Oli – Oligochaeta, Os – *Orthetrum* sp., Pa – *Paradosa alii,* Pb – *Paradosa birmanica*, Pc – *Pisidium clarkeanum,* Pds – *Pseudagrion* sp., Pe – *Placobdella emydae,* Pg – *Pila globosa,* Pp – *Paradosa pusiota*, Ps – *Plea* sp., Rf – *Ranatra filiformis,* Rs – *Ranatra sordidula,* Res – *Regimbertia* sp., Ss – *Sartoriana spinigera,* Tg – *Thiara granifera,* Tl – *Thiara lineata,* Ts – *Theridion* sp., Tt – *Thiara tuberculate,* Us – *Unionicola* sp., Vl – *Varuna litterata*

Gastropoda and Bivalvia (Table 3). Seasonal mean abundance and relative composition of different groups are shown in Tables 4 and 5.

The density of Oligochaetes varied from 8.53/m^2 (February, 2000) to 153.33/m^2 (August, 2001) in Santragachi jheel lake. The population here showed marked increase during the monsoon, but

T a b l e 4. Seasonal mean abundance (no/m^2) and relative composition (%) of different macroinvertebrate groups in Santragachi jheel lake.

Macroinvertebrate groups	**Season**					
	Premonsoon		**Monsoon**		**Postmonsoon**	
	no/m^2	%	no/m^2	%	no/m^2	%
Oligochaeta	53.38	5.75	122.06	15.02	52.69	3.88
Hirudinea	6.59	0.71	6.49	0.79	22.67	1.67
Crustacea	37.29	4.02	41.99	5.18	81.42	5.99
Arachnida	6.46	0.69	18.17	2.24	6.47	0.47
Ephemeroptera	10.88	1.17	11.74	1.44	19.33	1.42
Odonata	24.39	2.63	25.94	3.19	15.44	1.14
Hemiptera	38.75	4.17	61.10	7.52	33.82	2.49
Coleoptera	53.05	5.71	34.76	4.28	69.13	5.09
Diptera	36.09	3.89	21.30	2.62	96.17	7.08
Gastropoda	659.92	71.06	466.00	57.35	958.40	70.51
Bivalvia	1.89	0.20	2.99	0.37	3.56	0.26

T a b l e 5. Biannual mean density (no/m^2) of different macroinvertebrate groups in Santragachi jheel lake.

	Mean density (no/m^2)	
	2000–2001	**2001–2002**
Oligochaeta	51.04	89.53
Hirudinea	10.35	16.18
Crustacea	49.33	64.56
Arachnida	8.17	10.61
Ephemeroptera	14.17	15.03
Odonata	24.93	26.67
Hemiptera	44.39	40.17
Coleoptera	54.46	55.89
Diptera	59.89	54.96
Gastropoda	767.97	701.98
Bivalvia	4.76	3.49
Total	1089.46	1079.07

this declined considerably during pre-monsoon (Table 4).The maximum density was recorded in August, 2001. In this lake, the Oligochaeta group was represented by a single dominant species, *Limnodrilus hoffmeisteri*. Apart from the postmonsoon peak, the density and percentage composition of Hirudinea was negligible while population density was highest (60/m^2) during January, 2002. Crustacea showed marked seasonal fluctuation. Here, the maximum density and percentage abundance was observed during postmonsoon (81.42/m^2, 5.99%) season. The peak density (134.33/m^2) was observed during January, 2001. The Arachnida population did not show any definite seasonal pattern. They were represented by only 7 species, and no dominant species was found during the study period. However, a peak was found during monsoon in the jheel (18.17/m^2, 2.24%). The Ephemeropterans were represented by high frequency (19.33/m^2, 1.42%) during the postmonsoon period (Table 4). Odonates were regularly represented by good numbers in the lake, during this study period, and these were well supported by aquatic macrophytes. Although the peak density here was observed during January, 2002, the average density and percentage composition were higher during monsoon (25.94/m^2, 3.19%). The population density and percentage of Hemiptera were significantly high in monsoon period. The population density and distribution percentage of Coleoptera were significantly high in the Santragachi jheel lake. Peak density was observed in October – November in the jheel. The mean density and percentage frequency of Diptera were high in Santragachi jheel lake. They showed a prominent seasonal trend of greater abundance and percentage during the postmonsoon period (96.17/m^2, 7.08%). However, the peak abundance was recorded at 207.67/m^2 during January, 2001. Gastropoda was the largest group of macro-invertebrate fauna associated with macrophytes in the lake. It showed remarkable seasonal fluctuation in terms of abundance and percentage (Table 4). *Bellamya bengalensis* was found to be the most significant species associated with the macrophytes in this water body. The Bivalvia group did not show any regular patterns of monthly variation in Santragachi jheel lake, mainly because different Bivalve species had different temporal abundance. In addition, *Lamellidens corrianus clarkeanum* and *Lamellidens marginalis* were also recorded in this jheel.

Community analysis

The community analysis in Santragachi jheel lake is represented in Table 6.

Shannon– Wiener index of diversity

The Shannon–Wiener index was found to be highest (0.947–1.642) with mean value 1.312 at S2 station and lowest (0.614–1.015) with mean value 0.914 at S3 station in Santragachi jheel (Table 6).

Table 6. Macroinvertebrate community indices of Santragachi jheel lake.

Indices	Range of values (mean)			
	Santragachi jheel lake			
	Stations			Range
	S1	S2	S3	
H'	0.832–1.342	0.947–1.642	0.614–1.015	0.614–1.642
d	1.814–3.159	2.832–3.894	1.717–3.014	1.717–3.894
c	0.237–0.612	0.158–0.421	0.304–0.701	0.158–0.701
e	1.140–2.580	1.380–2.950	1.080–2.070	1.080–2.950

H' = Shannon-Wiener index of diversity
d = Margalef's species richness
c = Index of dominance
e = Evenness index

Margalef's species richness

The Margalef's species richness (d) values ranged from 1.717–3.894, with a mean value of 2.709 in Santragachi jheel lake (Table 6).

Index of dominance

The maximum value of c (0.304–0.701), with a mean of 0.641 was observed at S3 station and the minimum value (0.158–0.421) with a mean of 0.256 was recorded at S2 station in Santragachi jheel lake (Table 6) .

Evenness index

The evenness index (e) values ranged from 1.08 to 2.95, with a mean value of 1.71 in Santragachi jheel lake (Table 6) .

Statistical analysis
ANOVA (2-way)

Analysis of variance (ANOVA) was applied for the investigation of macro-invertebrate faunal differences in relation to macrophytes, seasons and stations in the lake. The results are presented in Table 7.

T a b l e 7. Distribution of various macroinvertebrate faunal groups in relation to macrophytes, stations, seasons (ANOVA- 2 Way).

Macroinvertebrate groups	F ratio with significance					
	Macrophyte associated Macroinvertebrate fauna			Santragachi jheel lake		
	macrophytes Df = 5	seasons Df = 2	macrophytes x seasons Df = 10	stations Df = 2	seasons Df = 2	stations x seasons Df = 4
Total macroinvertebrate	23.148**	19.284**	4.584*	10.482**	8.279**	5.651**
Oligochaeta	10.384**	14.584**	3.842*	15.412**	9.184**	4.814*
Hirudinea	-----	11.518**	4.814*	-----	-----	-----
Crustacea	40.184**	23.184**	7.284**	12.412**	17.528**	5.412*
Ephemeroptera	4.084*	-----	-----	-----	-----	-----
Odonata	5.814**	10.584**	-----	-----	4.459*	-----
Hemiptera	16.184**	5.189**	3.514*	9.514**	5.273**	4.117*
Coleoptera	27.184**	17.284**	3.172*	-----	7.123**	3.814*
Diptera	25.164**	21.412**	5.109**	23.842**	19.172**	5.242**
Gastropoda	51.284**	23.814**	4.282*	6.612**	7.148**	5.108**
Bivalvia	4.814*	-----	3.178*	-----	-----	-----

Notes:* – significant at 5% level, ** – significant at 1% level.

The significant differences were observed as no/100 gm macrophyte dry weight. The seasonal variation in macro-invertebrates also projected significant differences with respect to 10 groups. Total macro-invertebrate in terms of abundance showed significant difference between different stations ($P < 0.01$) and,seasonality (premonsoon, monsoon and postmonsoon) (Df = 2, F = 8.279**).

Pearson's correlation coefficient

Pearson's correlation coefficients were calculated to determine the relationship amongst the various biotic factors existing between the macrophyte and macro-invertebrate fauna. Only results at 5% and 1% level of significance were considered, and denoted by single asterisk ($_*$) and double asterisk ($_{**}$) respectively. Negative r values were prefixed by the negative sign (-) and positive values were shown without prefix.

Correlation between macrophytal biomass (gm.dry wt./m^2) and macro-invertebrate faunal abundance (no/m^2)

The correlation coefficient values between macrophytal biomass and macroinvertebrate faunal abundance are summarized in Table 8.

Total macroinvertebrate faunal abundance exhibited a positive correlation with 3 macrophytal parameters (maximum r value with OSPS, r = 0.7213*) and a negative correlation with both the Emer and Marg type of macrophytes in Santragachi jheel lake. Oligochaeta recorded positive correlation with FF, Emer and Marg (maximum r value = 0.7494** with Emer) and negative correlation with T-MACP and RFSP. The Hirudinea population positively correlated with biomass of 4 macrophytal categories in the lake, while Marginal macrophytes exhibited negative correlation with Hirudinea. Crustaceans showed positive correlation with T-MACP and RELP and negative correlation with FF (r = -0.6089**). Arachnida expressed positive correlation with FF, Emer, Marg in the jheel having highest r value with Emer (r = 0.7211**). Ephemeropterans exhibited a positive correlation with T-MACP, OSPS and a negative correlation with FF (r = -0.7122**). Odonata expressed positive correlation only with OSPS (r = 0.5346*). Hemiptera exhibited positive correlation with T-MACP, FF, Emer and Marg in the lake and r value with Marg (r = 0.7734**). Coleopterans showed positive correlation with FF and Marg and negative correlation with OSPS in Santragachi jheel lake. Diptera showed correlation with 4 lake parameters Meanwhile, FF showed maximum positive r value of 0.7746** and Gastropoda exhibited positive correlation with 4 parameters in the lake and Bivalvia showed a positive relationship with T-MACP.

Stepwise multiple regression

The stepwise multiple regression technique is adapted to study the macrophytes' effects on the abundance of total macro-invertebrates, as well as different groups. The R^2 values for

T a b l e 8. Correlation coefficient (r value) between macrophytal biomass (gm.dry wt./m^2) and macroinvertebrate abundance (no/m^2) in Santragachi jheel lake.

	Macrophyte category	r value between macrophytal biomass and macroinvertebrate abundance											
		T-MACI	Oli	Hir	Cru	Ara	Eph	Odo	Hem	Col	Dip	Gas	Biv
Santragachi jheel lake	T-MACP	0.5057*	-0.5314**	0.4122*	0.4512*	-----	0.4712*	-----	0.4338*	-----	0.4831*	0.7018**	0.4502*
	OSPS	0.7213**	-----	0.6955**	-----	-----	0.4974*	0.5346*	-----	-0.6138**	-----	0.6514**	-----
	FF	-----	0.4540*	-----	-0.6089**	0.5181**	-0.7122**	-----	0.5357**	0.5012**	0.7746**	0.7537**	-----
	RFLP	0.4832*	-----	0.5811**	0.5104*	-----	-----	-----	-----	-----	-----	0.6978**	-----
	RFSP	-----	-0.6766**	0.5651**	-----	-----	-----	-----	-----	-----	-----	-----	-----
	Emer	-0.4782*	0.7494**	-----	-----	0.7211**	-----	-----	0.6744**	-----	-0.4668*	-----	-----
	Marg	-0.6012**	0.5537**	-0.4489*	-----	0.6114**	-----	-----	0.7734**	0.5123*	-0.5174**	-----	-----

Notes: *significant at 5% level; **significant at 1% level.

the total macro-invertebrate and groups measure the percentage of variation for the corresponding independent variables (Table 9).

T a b l e 9. Stepwise multiple regression analysis between macrophytal biomass (gm.dry wt./m^2) and macroinvertebrate abundance (no/m^2)in Santragachi jheel lake.

	Macroinvertebrates	Macrophyte category	Multiple regression values between macrophytal biomass and macroinvertebrate abundance				
			ßj	SE ßj	$ß_0$	SE $ß_0$	R^2
Santragachi jheel lake	Total macroinvertebrate	OSPS***	0.1513*	0.0078	3.2184*	37.1802	0.4213*
	Oligochaeta	MARG	1.3223**	0.3253	26.7211**	4.5132	0.4603**
	Hirudinea	FF	-0.0809*	0.0171	24.9726**	0.9310	0.7499**
		OSPS	0.0987*	0.0226			
	Crustacea	OSPS	-0.2991**	0.0470	105.2296**	28.0474	0.8492**
		RFLP	-1.1361**	0.2503			
		RFSP	0.7029*	0.2345			
		Emer	0.3898*	0.0743	-36.9224**	0.7617	0.7449**
	Arachnida	RFSP	0.1715**	0.0399			
		Emer	0.1011**	0.0217			
	Ephemeroptera	OSPS	0.0171*	0.0003	2.0631*	1.1751	0.5763**
	Odonata	Emer	-0.0371**	0.0080	38.9147**	8.9203	0.6840**
	Hemiptera	RFLP	0.4577**	0.0663	-18.4091*	8.9203	0.6840**
	Coleoptera	Marg	0.4078**	0.1458	138.8714**	30.1438	0.3624*
	Diptera	FF	2.5614*	1.2012	-20.6221**	31.5709	0.1712*
	Gastropoda	RFSP	-11.1192**	1.5427	2859.6489**	76.5716	0.7025**
	Bivalvia	Emer	-0.0431*	0.0012	0.2763**	0.0712	0.2106*

Notes: $ß_j$ – partial regression coefficient, $ß_0$ – constant, SE – standard error, R – coefficient determination, * – $p < 0.05$, ** – $p < 0.01$, ***Emer – emergent, FF – free floating, Marg – marginal, OSPS – obligatory or partially submerged plants, RFLP – rooted floating leaved plants, RFSP – rooted floating stem plants, T-MACP – total Macrophyte.

Multiple regression analysis between macrophytal biomass (gm. dry wt./m^2) and macroinvertebrate faunal abundance (no/m^2)

Results presented in Table 9 indicate the influence of macrophytes on macro-invertebrate abundance. OSPS is the common macrophytal category which influences with positive $ß_j$ value on total macro-invertebrate faunal abundance in the jheel. Marginal macrophytes explained 46% variation of Oligochaeta abundance in Santragachi jheel lake. In the R^2 value shown for Hirudinea by FF, OSPS was 0.7499**. OSPS, RFLP, RFSP, Emer type of macrophytes explained 85% variation in the Crustacea population. The OSPS category macrophytes were an important factor affecting the Ephemeroptera population explaining 58% variation in

Santragachi jheel lake. RFLP macrophyte was the common factor which controlled 68% variation of the Hemiptera population. R^2 value shown for Coleoptera by marginal plants was 0.3624*. Free floating macrophytes explained only 17% variation in the Diptera abundance within Santragachi jheel lake. RFSP types of macrophytes were the common plants explaining 70% and 27% of Gastropoda population fluctuations in Santragachi. In addition, Bivalvia were influenced by the Emergent macrophytes (R^2 = 0.2106*).

Discussion

According to the results of the present investigations, the macro-invertebrate population was related with macrophytes (biomass) of the lake in the Santragachi, district Howrah, West Bengal. The density of Oligochaeta population was high in Santragachi jheel lake. It has been reported that Oligochaeta prefers suitable sediment, and a weed environment. The Oligochaeta group was represented by the single dominant species of *Limnodrilus hoffmeisteri*. Soft clay soil with decaying leaves and other organic matter in a sub-littoral zone is suitable for *Limnodrilus* sp. (Pal, 2000). The occurrence of *Limnodrilus* sp. may be attributed to increased eutrophication of a waterbody or to the increased sedimentation of organic matter (Marshall, Westake, 1978). So the higher density of *Limnodrilus* sp. in Santragachi jheel lake indicates this lake's eutrophic nature. In this investigation, it was established that *L. hoffmeisteri* existed amongst weeds at littoral depth.

According to Jonasson (1969), tubicids are well adapted to low oxygen content as their blood is rich in haemoglobin. Mason (1981), Cowell and Vodopich (1981) found a uniformity in the abundance of Oligochaetes throughout all months of the year. Sarkar (1989) found Oligochaeta abundance in summer as well as in the winter. Malhotra et al. (1990) observed the peak density during May, 1988. A monsoon peak was also observed by Gupta (1976) and Singh (1989). Mandal and Moitra (1975a), Barbhuyan and Khan (1992) reported the postmonsoon peak of Oligochaeta population, and this held true for Santragachi jheel lake during this investigation. The Hirudinea postmonsoon peak can be explained by monsoon breeding activities and higher abundance of OSPS plants in this jheel. Crustaceans were represented by two dominant species; *Macrobrachium dayanum* and *M. lamarrei*, and both these species were found throughout the study period. Gupta (1976) noted a trimodal peak in August, September, December in the abundance of *M. lammarrei*. This investigation reports the monsoon and winter peak of this species.

The presence of ephemeropteran larvae among aquatic macrophytes in the lake was similar to the observation of Singh (1989), while low abundance of Ephemeropteran larva during monsoon finds support from previous workers including Singh (1989), Singh and Roy (1991a, b). However, during the present investigation only a single peak was observed in winter season in Santragachi jheel lake. This might be due to different habitat and ecological conditions in the jheel. Odonata larvae are known to use the aquatic plants as their egg laying site (Singh, 1989). Fischer (1961) pointed out that these larvae occur more often in water bodies with aquatic weeds. In this study, Odonates were observed to be regularly represented by good numbers in this lake, and these were well supported by aquatic macrophytes. Kumar and Roy (1994) noted two peaks, one in December and the other in June which supports the present findings. In general, it appears that there is no such specific seasonal abundance in the population distribution pattern of Odonates. It may be possible that the Odonates species breed throughout the year. Srivastava (1986) reported the peak density of Odonates in the month of February, 1984. Kumar and Roy (1994) reported trimodal peaks of dragonfly nymphs in their abundance, during June, September and December, 1992. In the present investigation, only a single peak density of dragon fly larvae was observed in June, 2001. Singh and Roy (1991a) observed the peak density of Hemiptera during the post-monsoon period. Singh (1989) reported the monsoon peak of Hemiptera population which corroborates the present investigation. Rai and Sharma (1991) categorized Hemiptera as free moving forms which are comparatively less associated with macrophytes. Present findings here also support this idea.

The peak density of Coleoptera in April was reported by Singh and Roy (1991a) and Pal (2000). It was also observed that during summer, death and decay of emergent plants took place, which resulted in high rates of detritus production providing favourable conditions for Coleopteran growth and abundance. On the other hand, Singh (1989) and Rai and Sharma (1991 reported peaks in September and October). In the present study two peaks were observed in the lake, one in April and the other in October. The population of Coleoptera was highly influenced by floating and marginal macrophytes. Low population density of Coleopterans may be due to predator pressure as well as competition for space and food availability. Diptera showed peak density during winter in this lake, and this coincided with reports from a number of earlier workers (Barbhuyan, Khan, 1992; Bais et al., 1992; Pal, 2000).

A Molluscan dominance in freshwater bodies was reported by several workers (Sarkar, 1989, 1992; Malhotra et al., 1990) which agrees with the present study, and this is attributed to the soft organically rich bottom (Datta, Malhotra, 1986) and the absence of pollution (Olive, Dambach, 1973). Oommachan and Belsare (1985), Rao et al. (1987) observed a high molluscan population in shallow niches and the lowest in deeper zones. Presence of macrophytes and substratum characterization explain most of the differences in the distribution of gastropods in the littoral zone of lakes (Okland, 1990). Mouthon (1992) argued that littoral-dwelling gastropods have particular affinity for lakes with high organic matter. Although Singh and Roy (1991a) reported the peak density of Gastropods during the premonsoon period, a number of workers including Sarkar (1992), Pandey et al. (1994) and Pal (2000) reported it to be during the postmonsoon peak, which accords with this investigation. Khan (1984) noted that Viviparids breed continuously throughout the year because of moderate food supply in tropical waters. Muley (1977) suggested that *Thiara* sp. are continuous breeders, and adults were found throughout the year, as also observed in this present investigation. Sarkar (1992) reported a postmonsoon peak of *Bellamya bengalensis*, whereas Gupta and Pant (1986) reported the peak in June. This postmonsoon peak was also supported by the present findings in Santragachi jheel lake. The Bivalvia group did not show any regular patterns of monthly variation, mainly due to the fact that different bivalves had different temporal abundance. Mandal and Moitra (1975a) and Vasisht and Bhandal (1979) reported the presence of two species – *Pisidium clarkeanum* and *Lamellidens marginalis* in ponds, lakes and reservoirs, and this supports the present investigation. In the littoral zone where oxygen is not a limiting factor, Bivalves seem to be more sensitive than gastropods (Mouthon, 1992) especially with respect to sediment containing high levels of calcium salts (Aho, 1966). These mainly utilize detritus and algae and they can exploit areas with maximum food supply (Kaushal, Tyagi, 1989).

The nature of the substrate plus detritus availability control the composition and distribution of benthic forms in aquatic fauna (Cummins et al., 1972). Decaying organic matter in this lake is more or less abundantly available. The green vegetation along the embankments and decomposition of aquatic macrophytes is the primary source of leaf litter in this lake and its bottom is muddy,from clay and silt. It contains high organic enrichment which favours positive establishment of macrophytes and associated animal communities such as gastropods, crustaceans and insects. Gupta (1976) stressed aquatic vegetation plays an important role in aquatic ecosystems harbouring macro-invertebrates. Schramm et al. (1987) report that epiphytic macro-invertebrate can be many times more abundant than macro-invertebrates living in lake-floor sediments, which is in accordance with the view of Gerking (1957). The submerged and emergent macrophytes provide excellent diverse niches for molluscs and for both larvae and adults of several insects, (Gupta, 1976; Maitland, 1978).

The high population density of macro-invertebrate fauna was most likely related to macrophytic density. Thienamann (1925) considered that a water-body bed producing more than 1000 ind/m^2 should be considered as highly productive. Meanwhile, Gupta and Pant (1983) argued that Nainital lake (Uttar Pradesh) was hyper-eutrophic and the mean annual density of the different macro-invertebrate species was calculated at 1655 ind/m^2. Bose and Lakra (1994) reported two mesotrophic ponds in Ranchi where their benthic density varied from 730 to 2943 ind/m^2. Herein, mean annual macro-invertebrate faunal density of Santragachi jheel lake exceeds the above values, and in light of these reports, it can be concluded that this lake is highly productive in nature.

Although there is no consensus concerning the causes of seasonal variations in the benthic population, the fluctuations in the distribution and abundance of different forms of aquatic organisms from year to year and within the same year have contributed to the distribution of their habitat (Holme, 1961). This corroborates Oliver's 1960 observations. However, numerous authors have attributed seasonal variations of the benthic population to various factors. These include food quality and quantity (Cowell, Vodopich, 1981), biotic competition and predation interactions (Kajak, Dusoge, 1968), changes in particle size (Sanders, 1958; Hanson, 1990) and macrophytic diversity (Schramm et al., 1987).

The population density of macro-invertebrate fauna in this lake was found to be higher during winter, while its observed lower density was most likely due to the habitat destruction and rise in water level during the monsoon period. Severe falls in population due to heavy rainfall have also been reported by Singh and Roy (1991a) and Pal (2000). Juvenile recovery in population density, however, was rapid,, since the density increased considerably in the following month. This is most likely due to the fact that Gastropods, and especially

Bellamya bengalensis and *Thiara granifera,* breed all year, and immature stages of these species were discovered throughout this study period. Staub et al. (1970) suggested the utility of the species diversity index in the assessment of water quality. The index of diversity (H') is a good indicator of habitat water quality, and it forms a basis for bio-monitoring (Pal, 2000). The mean observed value of the Shannon–Wiener diversity index herein was found to be highest at the S2 site in Santragachi jheel lake, and this indicates that the S2 site is less polluted than S1 and S3. On the basis of the mean value of Margalef's species richness, it is evident that Santragachi jheel lake can be considered a polluted water body, while the low values of evenness index registered there show less equitability in the apportionment of individuals among the species.

The seasonal fluctuations of macro-invertebrates recorded in this investigation are closely related to the macrophytes. The presence of numerous Oligochates reveals the eutrophic nature of Santragachi jheel lake. Here, Hirudinea and Odonata representatives are well adapted in the vegetated zones for habitat and breeding requirements, while Arachnids use the surface of free floating vegetation. Odonates and Coleopterans are well associated with macrophytes in this lake, but representatives of phylum Mollusca prefer pollution free wetlands infested with submerged macrophytes, and this preference is well reflected in Molluscan population density. The community analysis indices, such as the Shannon–Wiener index of diversity, Margalef's species richness and the evenness index utilized herein indicate Santragachi jheel lake's highly polluted state.

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