Poll Res. 41 (1) : 353-361 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i01.052

MULTIVARIATE ANALYSIS SHOWING IMPACT OF DIFFERENT ENVIRONMENTAL FACTORS ON SPECIES RICHNESS AND SPECIES DENSITY OF FRESHWATER MOLLUSC COMMUNITIES INHABITING WATERS OF NORTH-WEST HIMALAYAS

SUNEHA UTTAM[1*], SEEMA LANGER[2], CHAKSHU GUPTA[1], MENAKSHI DHAR[1]

Department of Zoology, University of Jammu, J&K 180 006, India

(Received 18 October, 2021; Accepted 27 December, 2021)

ABSTRACT

Freshwater molluscs face extreme threat due to anthropogenic stress which is reflected in their changing population structure over time. The extent of this phenomenon needs to be monitored and proper management of freshwater ecosystem should be done. In the present communication, an approach was undertaken to study the effect of ten different physical and chemical factors affecting mollusc density and mollusc richness in both lentic and lotic water bodies of North-West Himalayas. A total of 10 species of gastropods and 3 species of bivalves were recorded. Bivalves remained absent from both lentic bodies while gastropods dominated in both lotic waters in terms of taxa richness. On subjecting physical and chemical parameters to a multivariate analysis, 7 out of 10 factors were found significant after univariate Analysis of Variance ($p<0.05$). Principal component analysis showed that all the study stations varied in terms of physical and chemical conditions in different seasons. Canonical correspondence analysis revealed that dissolved oxygen, depth, alkalinity, Calcium ions and Chloride ions were the variables that significantly associated with the distribution of molluscs. The regression analysis revealed that the concentration of chloride ions was the common factor that was negatively related to both taxa richness and taxa density.

KEY WORDS : Freshwater molluscs, Multivariate Analysis, Principal Component Analysis, Canonical Correspondence Analysis, North-West Himalayas

INTRODUCTION

Molluscs being the second largest group of animals after insects, are highly adaptive and have colonised all possible habitats from terrestrial to freshwater, brackish water and marine. Freshwater malacofauna delivers invaluable functions to aquatic ecosystems, but are under high levels of threat (Bohm *et al.*, 2020). Freshwater molluscs form an important link in aquatic food chain and act as biomonitoring agent to detect pollution (Patang *et al.*, 2018). Freshwater bivalves filter water as they feed on organic matter that remains suspended in water column and produce large quantities of pseudofaeces, thereby transfer resources from water column to sediments (Sousa *et al.*, 2013, Higgins *et al.*, 2013). Gastropods harbour many macroparasites inside their body (Thieltgis *et al.*, 2006). Freshwater snails are obligatory first intermediate host of digenetic trematodes e.g; lung fluke, *Paragonimus* sp, schistostomes (Mishkin and Jokinen, 1986), and are also a source of cercarial dermatitis in humans (Doanh *et al.*, 2018). The presence of susceptible snail host is a prerequisite for the occurrence of snail borne infections. Dynamics of snail population and its prevalence in multiple areas should be studied from time to time in order to evolve long term strategic control measures against snail-borne parasitic diseases.

Freshwater ecosystems face extreme stress due to anthropogenic activities (Darwall *et al.,* 2018). Habitat loss being the most cited threat worldwide, accounts for extinction of every one in three freshwater species (Collen *et al.,* 2014). Freshwater molluscs particularly juveniles are the most susceptible to several chemicals in the aquatic ecosystems (Wang *et al.*, 2017). Major threat to freshwater molluscs is the increasing pollution of water bodies due to agricultural run off and sedimentation (Gallardo *et al.,* 2018, Zieritz *et al.,* 2018). Despite rendering ample services to mankind, freshwater malacofauna are under high level of threat. Driving forces for the threat may vary regionally and need to be studied at national, sub-national or regional levels. It is pertinent that comprehensive action plans are drawn up to preserve freshwater ecosystems and its biodiversity.

The present communication is an attempt to enlist some freshwater mollusc species from Jammu waters covering four different aquatic habitats found in the region- two tributaries of Chenab River (Northern Himalayan River), artificial standing water body and a wetland. Prevalence of the species collected and effect of various hydrophysical and hydrochemical parameters on prevalence of these species have been discussed in detail in this paper. A comparison with earlier reports have also been made so that a conclusion is drawn about the changing trend in their population structure over a period of time and conservation strategies can be made to save these shelled creatures from being endangered or extinction.

MATERIALS AND METHODS

1. Study sites: Four study sites in Jammu district (32.73° N, 74.8570° E) of UT of Jammu and Kashmir, North India (lower shivaliks of the Himalayas) were selected based on source of water in these water bodies (Table 1). Of the four, two comprised lentic resources and two lotic resources (streams). Ghou-Manhasan stream, a distributory of River Chenab, traverses through the Ghou-Manhasan village and Sehi stream, a tributary of river Tawi (a part of Chenab river system) traverses through R.S. Pura, a tehsil of Jammu district. Both the streams support small villages and agricultural fields throughout their entire length which affect the limnology of the stream (especially during monsoons). Moreover, the stream receives sewage, domestic waste water from catchment area and also faces anthropogenic stress due to dumping of garbage, washing of clothes, utensils, cattle bathing and fishing. Two lentic water bodies are - a natural Gharana wetland and an artificial pond located in Botanical garden of University of Jammu, Jammu. Gharana wetland conservation reserve is located merely 500m from Indo-Pak border. It is also recognized as an important bird area as it is home to thousands of migratory birds arriving in winters. The wetland is bounded on left side by village and on the right side by agricultural fields. It faces a lot of anthropogenic pressure because of wastewater, dumping of garbage and cattle bathing. On the other hand, botanical garden pond is a freshwater artificial pond free from anthropogenic stress.

2. Field Collection and laboratory analysis Freshwater molluscs were collected over a period of one year (August, 2020- July, 2021). Specimens were handpicked after dredging and sieving the sediments under water and beating the submerged vegetations over a sieve (Planorbidae). Specimens were counted live on field. Some specimens were released back into water after counting and some were taken to laboratory for preservation and identification purpose. Specimens were first narcotized in water sprinkled over by Magnesium sulfate, then fixed and preserved in 70% ethyl alcohol. Identification was done according to Rao (1989), Ramakrishna and Dey (2007), and Thorp (2016).

Water samples were also taken from each water

Table 1. Descriptive data of four selections sites.

Station	Geo-coordinates	Water source	Bottom
Ghou-Manhasan Stream (GMS)	32.69754°N, 74.68219°E	River Chenab, precipitation, waste water and run off	Sandy, gravel
Sehi Stream (SS)	32.304008°N, 74.43269°E	River Tawi, precipitation, waste water and run off	Sandy gravel
Botanical garden pond (BGP)	32.720301°N, 74.8670823°E	Tube well and precipitation	Muddy
Gharana wetland (GW)	32.3228°N, 74.4127°E	Precipitation, waste water and run off	Bottom with macrophytes

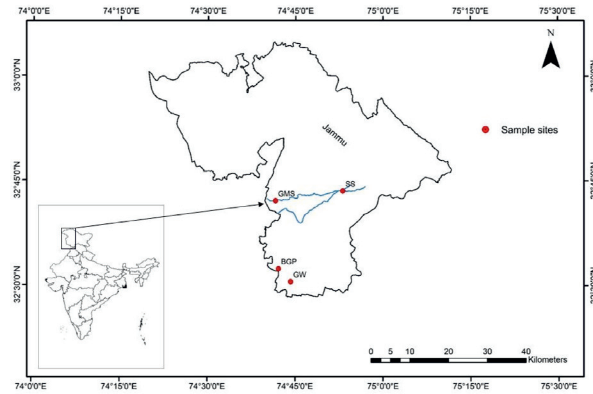

Fig. 1. Map showing locations of sampling sites.

body during collection for estimation of ten environmental variables- air temperature (AT), water temperature (WT), depth, pH, dissolved oxygen (DO), free carbon dioxide (FCO_2), alkalinity, calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}) and chlorides ions (Cl^-). AT and WT were measured via mercury bulb thermometer, pH was analyzed using digital pH meter by Hanna instruments. Remaining variables were analysed as per Adoni (1985).

3. Data analyses

The dominance of molluscs in a study area was calculated using formula $\frac{Ka}{K} \times 100$ (*Ka*: number of individuals of a mollusc species, *K*: total number of individual of all mollusc species). The physical and chemical variables among selected water bodies were subjected to ANOVA (Analysis of Variance) to examine the significance of difference. A non-metric multidimensional scaling (NMDS) was performed on log transformed data of molluscs abundance using Bray-Curtis distance for testing the clustering of different substrates types (sediments with and without macrophytes). A Principal Component Analysis (PCA) was performed to analyze the relationship between environment variables and sampling sites. The relationship between environmental variables and molluscs communities was analysed using canonical correspondence analysis (CCA). Cluster analysis using the unweighted pair-group method with arithmetic mean (UPGMA) on the basis of Bray-Curtis distance measure was used to check the similarity among water bodies in terms of molluscan fauna. Rare taxa were excluded from the analysis. The above analyses were performed using Paleontological Statistics software (PAST version 4.03).

Multiple Regression analyses were used to assess the relationship between environmental variables with taxa richness and mollusc density using Minitab (version 19). Environmental variable with highest p value was removed in each step of regression until only variables related ($p<0.05$) to density and taxa richness remained.

RESULTS

Data depicting the physicochemical variations in various study stations is presented in table 2. Highest alkalinity (596.7 mg/l) is reported in lotic water bodies (maximum: from 490.32 mg/l in GMS to 596.7 mg/l in SS) in comparison to lentic water bodies (maximum: 343.12 mg/l in BGP to 480.3 mg/l in GW). DO was found to be relatively low in stagnant water bodies (lowest value: from 3.4 mg/l in GW to 4.0 mg/l in BGP). Average pH was lowest in GW (pH = 6.3) and highest in SS (pH = 7.81). In BGP, highest contribution of calcium (56.35 mg/l) and magnesium ions (18.70 mg/l) was observed while chloride ions (104.10 mg/l) dominated in GW.

The Analysis of Variance (ANOVA) for each physical and chemical variable of selected water bodies revealed that 7 out of 10 variables showed significant differences ($p<0.05$). These variables

Table 2. The physical and chemical variables of water (ranges) in investigated water bodies.

Parameters	Ghou-Manhasan stream	Sehi Stream	Botanical Garden Pond	Gharana Wetland
Air temperature (°C)	15.6-30.0	17.7-33.6	12.4-34	13-29.4
Water temperature (°C)	13.2-28.7	18-30.4	10.6-28	12-28.6
pH	7.07-7.9	7.7-8.1	6.49-7.8	4.6-8.05
Depth (m)	30-52	39-55	15-15.4	22.6-24.5
Dissolved Oxygen (mgl^{-1})	5.4-9.82	6.4-8.92	4-5.44	3.4-7.03
Free carbon dioxide (mgl^{-1})	0-10	0	0-16	4.2-8.36
Alkalinity (mgl^{-1})	230.7- 490.32	460-596.7	158.32-343.12	151.28-480.3
Chloride ions (mgl^{-1})	8.94-16.40	6.72-10.48	8.51-18.01	71.58-104.10
Calcium ions (mgl^{-1})	5.21-7.01	4.33-6.59	21.10-56.35	6.44-11.34
Magnesium ions (mgl^{-1})	3.40-6.91	2.96-3.208	6.78-18.70	5.39-9.53

include water temperature, depth, dissolved oxygen, alkalinity, calcium ions, magnesium ions and chloride ions. Results of ANOVA applied to different physicochemical variables are presented in table 3. The variables which showed significant difference were further used for analysis.

Table 3. Results of univariate ANOVA applied to 10 physico-chemical variables of water from different sites.

Parameters'	F value	p value
Air temperature	0.438	0.729
Water temperature	7.225	0.004*
pH	2.664	0.09
Depth	19.9	5.96E-05*
Dissolved oxygen	4.592	0.023*
Free carbon dioxide	0.6908	0.525
Alkalinity	6.098	0.009*
Calcium	6.73	0.006*
Magnesium	7.195	0.005*
Chlorine	80.25	3.29E-08*

(* indicates that p value (<0.05) is significant)

1. Mollusc communities and effect of environmental factors

A total of 1278 specimens of freshwater molluscs were collected from different study stations. A detailed account of abundance (%) of species collected at different study sites is presented in table 4. After close examination of the preserved species, 13 freshwater species of molluscs belonging to 9 families were identified from different study stations. Of which, 10 species were gastropods belonging to 6 families and 3 were bivalves belonging to 3 families. Gastropods formed dominant assemblages over bivalves at all study stations except at GMS. Taxa richness, indicated by high value of Shanon-Wiener index (H') was observed in lotic water bodies i.e., GMS (H' = 1.342) and SS (H' = 1.784). Contrary to this, a low value of Shanon Wiener index in lentic water bodies like BGP (H' = 0.536) and GW (H' = 0.7006) indicated these sites to be less diverse in terms of malacofauna diversity. The species present in GW were not common with other water bodies. Complete dominance of gastropods and absence of bivalves was observed at lentic water bodies. The overall order of dominance of freshwater water molluscs followed the trend: *Melanoides tuberculata* (45.61%) > *Pisidium mitcehlli* (23.08%) > *Physa acuta* (9.94%) > *Bellamya bengalensis* (4.77%) > *Lamellidens corrianus* (4.54%) > *Gyraulus ladacensis* (4.30%) > *Biomphlaria sp.* (3.05%) > *Lymnaea luteola* (1.56%) > *Indoplanorbis exustus* (1.41%) > *Lymnaea auricularia* (0.93%) > *Corbicula cashmiriensis* (0.57%)> *Bithynia tentaculata* (0.31%) > *Corbicula cashmiriensis* (0.23%) > *Helisoma sp.* (0.23%). One invasive alien species was recorded among them, i.e. *Physa acuta.* Two endemic species of the region *Bithynia tentaculata* and *Corbicula cashmiriensis* were also found, but in very less numbers.

The NMDS plot based on log transformed data of mollsucs abundance did not indicate grouping or

Table 4. Values of dominance (D%), species count and Shanon-Wiener index for mollusc communities in selected water bodies

Families	Name of species	GMS (D%)	SS (D%)	GW (D%)	BGP (D%)	Jammu district (D%)
Thiaridae	*Melanoides tuberculata* (Muller, 1774)	27.43	31.00	0	71.70	45.61
Viviparidae	*Bellamya bengalensis* (Lamarck, 1822)	*5.73*	12.67	0	0	4.77
Bithyniidae	*Bithynia tentaculata* (Linnaeus, 1758)	*0*	0	8.51	0	0.31
Physididae	*Physa acuta* (Draparnaud, 1805)	*2.24*	5.00	0	19.43	9.94
Lymnaeidae	*Lymnaea luteola* (Lamarck, 1822)	*4.23*	0	2.13	0	1.56
	Lymnaea auricularia (Linnaeus, 1758)	*0*	4.00	0	0	0.93
Planorbidae	*Gyraulus ladacensis* (Nevill, 1878)	*0.50*	2.00	0	8.87	4.30
	Indoplanorbis exustus (Deshayes, 1834)	*1.75*	3.67	0	0	1.41
	Helisoma sp. (Swainson, 1840)	*0*	0	6.38	0	0.23
	Biomphlaria sp.(Preston, 1910)	*0*	0	82.97	0	3.05
Unionidae	*Lamellidens corrianus* (Lea, 1834)	*5.23*	12.34	0	0	4.54
Sphaeridae	*Pisidium mitchelli* (Prashad, 1925)	*52.61*	28.00	0	0	23.08
Cyrenidae	*Corbicula cashmiriensis* Deshayes, 1855)	*0.25*	0.67	0	0	0.23
	Total individuals	401	300	530	47	1278
	No. of species	9	10	4	3	13
	Shanon-Wiener index H'	1.342	1.784	0.771	0.622	1.669

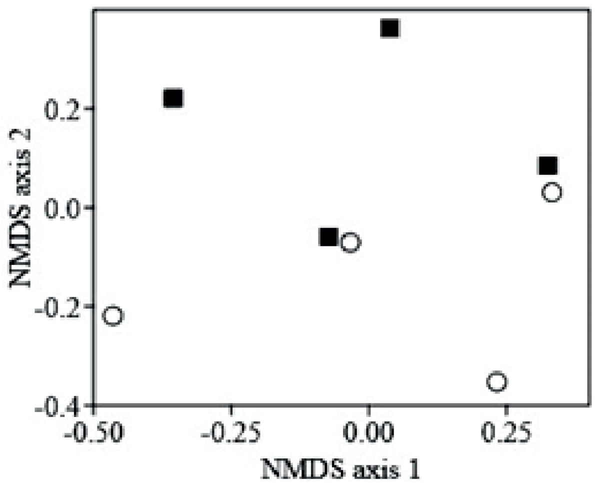

Fig. 2. NMDS plot (based on log transformed abundance data) showing relationship of sampling sites with different substrate types (sediments with macrophytes-O; Sediments without macrophytes-■)

clustering of sampling sites with different substrate types (Figure 2). It can be inferred that molluscs abundance at different sites was not affected much by the presence or absence of macrophytes.

The PCA analysis showed that the first two principal components accounted for 69% of total variability among four study sites. First three principal components which accounted for 85.21% of the total variability (48.22% of PC1, 20.78% of PC2 and 16.211% of PC3) with Eigen value >1 and statistical significance were extracted. Principal components with Eigen value <1 were excluded from analysis. The significant loading scores based on correlation matrix, for first three principal components is listed in table 5. The variables constituting different principal components were extracted based on loading scores (correlation coefficient >0.60) of these variables. The variables related to PC1 were depth, dissolved oxygen, alkalinity, calcium ions and magnesium ions. The most significant loading score in case of PC2 was of water temperature. The scatter plot of PC1 and PC2 indicated the clear separation of GMS and SS (lotic water bodies) from BGP and GW (lentic water bodies). A slight overlap between BGP and GW was observed. All four study sites were found to have different environmental conditions as very less or no overlapping between symbols from different sites was there in PCA plot (Figure 3).

Table 5. Results of Principal Component Analysis (PCA) performed on 10 most differentiated physico-chemical variables of water bodies and significant correlation loading scores (>0.60) for the first the three principal components (PC)

Variables	PC 1	PC 2	PC 3
Eigen values	3.375	1.454	1.134
% variance	48.22	20.78%	16.211%
WT	0.042	0.877	0.415
Depth	0.904	0.292	0.126
DO	0.704	-0.218	-0.540
Alkalinity	0.831	0.045	0.135
Cl^-	-0.376	-0.533	0.707
$Ca2^+$	-0.767	-0.514	-0.291
Mg^{2+}	-0.798	-0.008	-0.224

The CCA showed that dissolved oxygen, depth, alkalinity, chlorine and calcium best explained the variance in distribution of malacofauna in selected water bodies. The first two axis explained 99.61% of variance in relationship between environment variables and taxa. *Bithynia tentaculata, Helisoma sp.* and *Biomphlaria sp* were found to be sensitive species and were associated with high concentration of

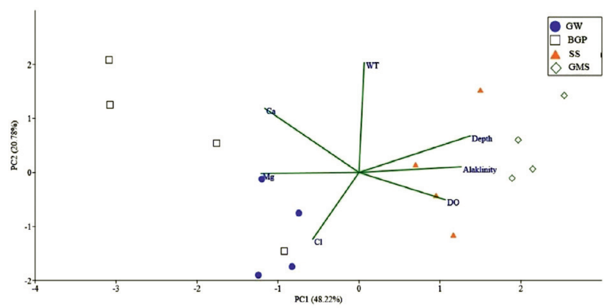

Fig. 3. Scatter plot of Principal Component Analysis (PCA) using six statistically significant physico-chemical variables of water

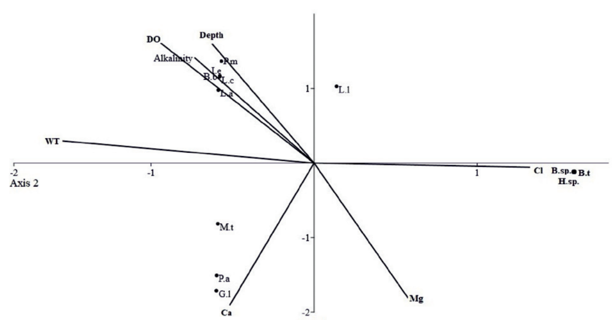

Fig. 4. Result of canonical correspondence analysis (CCA): ordination diagram of best explanatory variables and molluscs abundance data (*M.t*: *Melanoides tuberculata*, *B.b*: *Bellamya bengalensis*, *B.t*: *Bithynia tentaculata*, *P.a*: *Physa acuta*, *L.a*: *Lymnaea auricularia*, *L.l*: *Lymnaea luteola*, *H.sp*: *Helisoma species*, *B.sp*: *Biomphlaria species*, *I.e*: *Indoplanorbis exustus*, *G.l*: *Gyraulus ladacensis*, *P.m*: *Pisidum mitchelli*, *L.c*: *Lamellidens corrianus*)

chloride ions, whereas other species were found in water bodies with comparatively low levels of chlorides. *Melanoides tuberculata, Physa acuta* and *Gyraulus ladacensis* were predominantly related to high concentration of calcium ions and low concentration of magnesium ions in water. *Lymnaea auricularia* was associated to greater extent with DO than with alkalinity and depth. *Bellamya bengalensis*, *Indoplanorbis exustus* and *Lamellidens corrianus* were associated more with alkalinity than depth and dissolved oxygen. *Pisidum mitchelli* was found to be affected more by depth and alkalinity and less by dissolved oxygen.

The multiple regression analysis revealed that the taxa richness was positively related to depth (adj. R^2 = 55.35%, p = 0.001), dissolved oxygen (adj. R^2 = 38.86%, p= 0.006), alkalinity (adj. R^2 = 35.91%, p= 0.008) and pH ((adj. R^2 = 23.03%, p=0.03) whereas it was negatively related to chlorides (adj. R^2 = 44.13%, p=0.003) and magnesium (adj. R^2 = 38.63%, p= 0.006). The taxa density was positively related to calcium ions (adj. R^2 = 28.19%, p=0.02) and negatively related to chloride ions (adj. R^2 = 54.52%, p= 0.001). No significant results were obtained when regression analysis was performed on taxa richness as a function of taxa density. The graphs illustrating linear regression equations for 'taxa richness' and 'taxa density' as function of different physical and chemical variables is presented in Figure 5.

A cluster analysis based on structure of mollusc communities separated the lotic water bodies (GMS and SS) and BGP in a distinct group and less similarity was found in GW which showed a different community structure. Further, GMS and SS showed similar species composition (8 common species) and were grouped together (Figure 6).

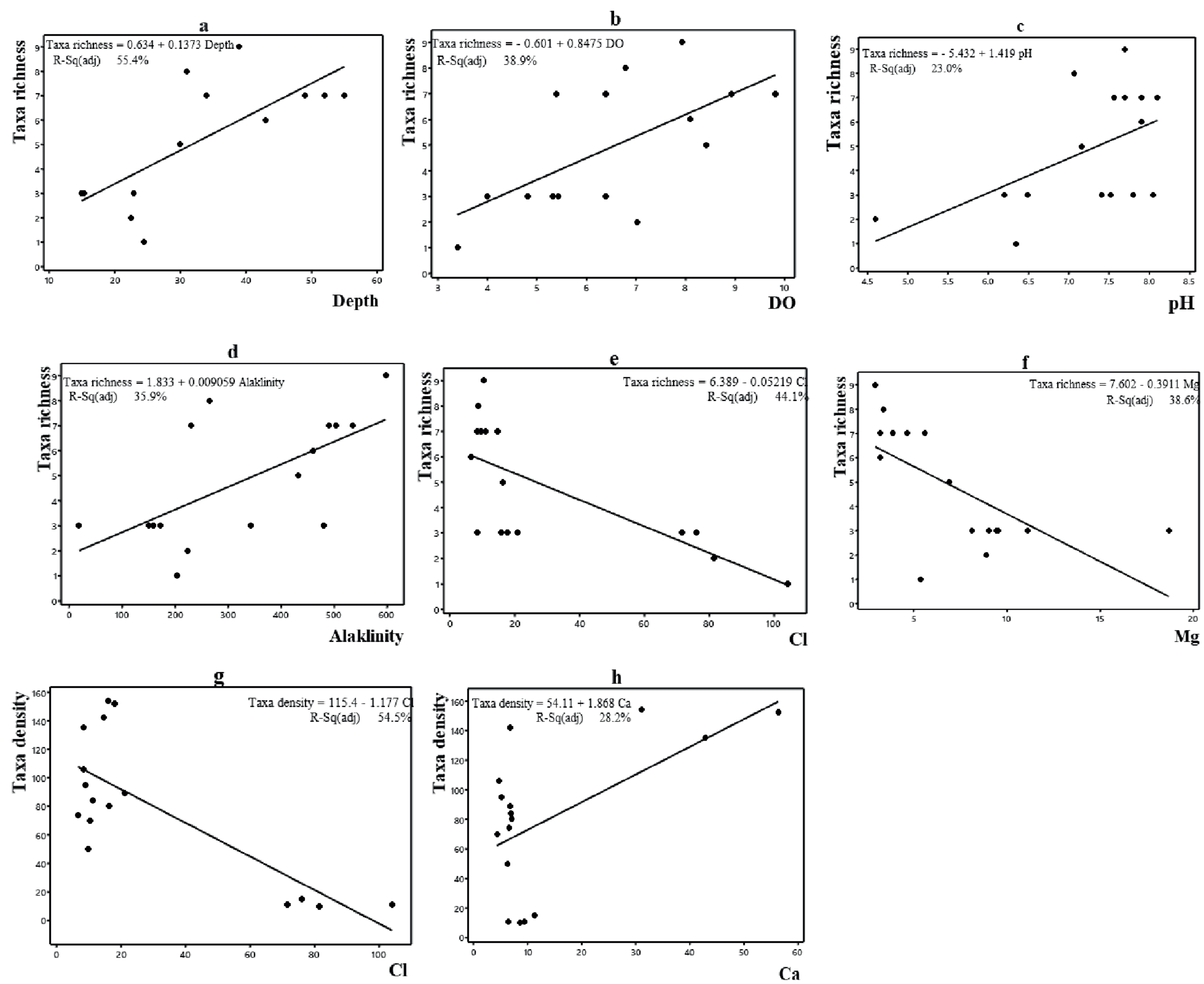

Fig. 5. Linear regression equations for the (a) Depth, (b) DO, (c) pH, (d) alkalinity, (e) Cl^- and (f) Mg^{2+} as a function of taxa richness; (g) Cl^- and (h) Ca^{2+} as a function of taxa density; R-Sq (adj)- coefficient of determination.

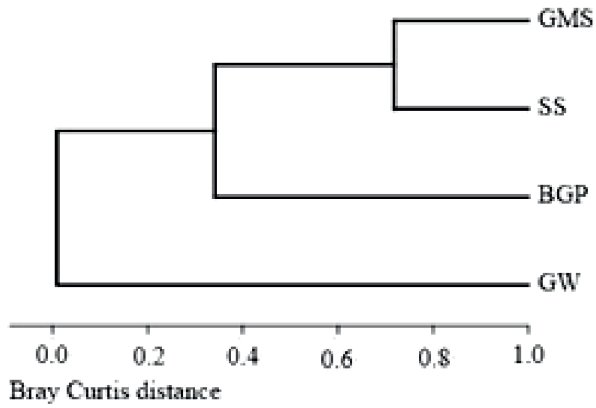

Fig. 6. Diagram of the faunal similarities among selected study sites using UPGMA (Unweighted pair-group methods with the arithmetic mean (UPGMA) based on Bray Curtis distance measure

DISCUSSION

The observations from present communication revealed that the common variable affecting both taxa richness and taxa density was the concentration of chloride ions. Both taxa richness and taxa density showed a decline when compared to chloride ions in a linear regression. The findings of the present study showed complete dominance of gastropods over bivalves in studied lentic water bodies (BGP and GW). Taxa richness was also less in both sites and represented by ony 3-4 taxa during the study period. Since fishes are required for development and dispersal of glochidia (Pip, 1986) so, absence of fishes in these water bodies could be the reason for disappearance of bivalves and hence less taxa richness. Less dominance of *Lamellidens corrianus* in GMS (5.23%) compared to SS (12.34%) might be due to a comparatively high value of chlorides in GMS. Unionid mussels, particularly glochidia are sensitive to elevated concentration of chlorides (Gills 2011; Patnode *et al.,* 2015).

Linear regression between taxa density and calcium showed significant results. The reason for positive relationship between taxa density and calcium ions could be related to the findings of Rundle *et al.* (2003), who observed that high concentration of calcium ions in habitat results in stronger shells thus it helps in defensive mechanism against predation. The highest abundance of gastropods (41.47% of total individuals from all sites) was reported from BGP which was found to have highest calcium concentrations (21.10-56.35 mg/l) in all seasons among all sites. Calcium is an essential requirement for shell calcification in molluscs. Previous study by Lodge et al 1987 also showed that low calcium concentration (<4.5 mg/l) is the limiting factor for successful establishment of gastropods in pond. Further, our field patterns supported the laboratory studies by Thomas *et al.* (1974) and Madsen (1987) who also witnessed reduced growth and reproduction of gastropods reared at low calcium concentration (<5 mg/l).

Taxa richness was related to magnesium ions with a negative binomial according to linear refression results. The reason for this could be that high levels of magnesium ions over calcium ions result in high Mg^{2+}/Ca^{2+} ratio which interfere with the fecundity of snails. Harrison *et al.* (1966) observed that Mg^{2+}/Ca^{2+} ratio of 19:7 caused the stoppage of egg laying in a planorbid snail *Biomphlaria pfeifferi.*

The taxa richness was positively related to pH, alkalinity, depth, dissolved oxygen. According to Okland (1983) calcium ions are hardly available to freshwater snails at low pH as calcium dissolution increases with low pH. Freshwater molluscs are the most intolerant group to acidification and are sensitive to decreasing alkalinity and low pH of habitat (Hunter, 1988; Bendell and Mc Nicol, 1993). Alkalinity and habitat area positively influences gastropod richness in an ecosystem (Hoverman *et al.,* 2011). This might be the reason that despite optimum values of calcium ions in GW (average pH = 6.3), molluscs richness and density both were low. In BGP, pH fluctuated from acidic (6.49) to alkaline (7.8), so inspite of high calcium concentrations (21.10-56.35 mg/l), taxa richness was low. In GMS and SS high alkalinity and pH near to (7-8) favoured more number of species to flourish. CCA results indicated that *Pisidium mitchelli* was related positively to depth. Similar observstions were made by Bespalaya (2014) in a congeneric species *P. lilljeborgi* which was found to inhabit deeper site with a sandy-gravel substrate.

Taxa richness showed an increase with DO in water bodies. Many researchers (Sowa *et al.*, 2019) did not find any relation of mollusc taxa richness and dissolved oxygen. Few researchers such as Satheeshkumar and Khan (2012), Dzul and Castaneda (2016) however reported a positive correlation of DO with dominance of molluscs. The reason for this could be that lower layers of water are hypoxic. At low DO, mostly the prosobranchs communities fail to establish as these gill breathing snails are completely dependent on dissolved

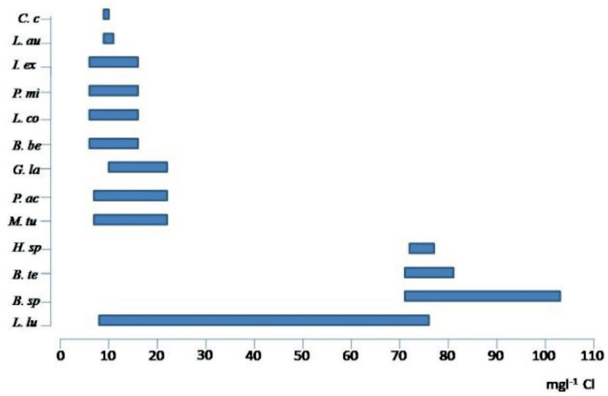

Fig. 7. Distribution of molluscs taxa along a chloride ion gradient (*M.tu*: *Melanoides tuberculata*, *B.be*: *Bellamya bengalensis*, *B.te*: *Bithynia tentaculata*, *P.ac*: *Physa acuta*, *L.au*: *Lymnaea auricularia*, *L.lu*: *Lymnaea luteola*, *H.sp*: *Helisoma species*, *B.sp*: *Biomphlaria species*, *I.ex*: *Indoplanorbis exustus*, *G.la*: *Gyraulus ladacensis*, *P.mi*: *Pisidium mitchelli*, *C.ca*: *Corbicula cashmiriensis*, *L.co*: *Lamellidens corrianus*)

oxygen in water for respiration whereas pulmonates can climb stones or aquatic vegetation to inhale atmospheric air.

Result of our studies indicated chloride levels to be the common factor which negatively relates to taxa density of molluscs. A graph illustrating distribution of studied molluscs along a chloride gradient (Figure 7). GW molluscs particularly *Biomphlaria* and *Helisoma* could be looked upon as potential indicator of high level of chlorides in a water body. Most affected among all studied molluscs are bivalves which disappeared completely from sites experiencing high chloride concentrations (BGP and GW).

Out of total 13 species, three species- *Corbicula cashmiriensis, Biomphlaria sp.* and *Pisidium mitchelli* have found to be data deficient whereas remaining ten species show a 'Least Concern' status according to IUCN red list. The categorization is based on the basis of global data. No information particulary from Oriental region is available. Though the current status of *Bithynia tentaculata* is 'Least Concern' according to IUCN, but extremely low abundance values of this species (0.31% of total mollusc density from all sites) which is endemic to the region is a matter of concern as it might lead to extinction of these species from the native area. *Corbicula cashmiriensis* was reported as rare taxa, contributing only 0.23% of total mollusc community from all sites. The observations are in accordance with Sharma *et al.,* (2013) who also found *C. cashmiriensis* to be rare taxa while sampling in GMS stream. Therefore, a check has to be done on pollution levels of such water bodies, use of chloride containing fertilizers and arrangement for proper disposal of human sewage and animal waste should be made.

ACKNOWLEDGEMENTS

The authors would like to thank Head, Department of Zoology, University of Jammu and Department of Science and Technology (DST), Government of India (GoI) for providing necessary facilities and equipments purchased out of RUSA (Rashtriya Uchchatar Shiksha Abhiyan), FIST (Fund for improvement of S&T) and PURSE (Promotion of University Research and Excellence) programs. Further, the corresponding author is highly thankful to Council of Scientific and Industrial Research (CSIR) for providing research fellowship in the form of CSIR-SRF.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

REFERENCES

Adoni, A.D. 1985. *Workbook on Limnology*. Pratibha Publishers, C-10, Gour Nagar Sagar, India.

Bendell, B.E. and McNicol D.K. 1993. Gastropods from small northeastern Ontario lakes: their value as indicator of acidification. *The Canadian Field-Naturalist*. 107(3): 267-272.

Bespalaya, Y. 2015. Molluscan fauna of an Arctic lake is dominated by a cosmopolitan *Pisidium* species. *Journal of Molluscan Studies* 81:294-298. http://doi.org/10.1093/mollus/eyu081

Bo¨hm, M., Richman, N.I.D., Seddon, M., Ledger, S.H.E. 2020. The conservation status of the world's freshwater molluscs. *Hydrobiologia.* 848:3231-3254. https://doi.org/10.1007/s10750-020-04385-w

Collen, B., Whitton, F., Dyer, E.E. et al. 2014. Global patterns of freshwater species diversity, threat and endemism. *Global Ecology and Biogeography*. 23: 40-51.

Darwall, W., Bremerich, V. and DeWever, A. 2018. The Alliance for Freshwater Life: a global call to unite efforts for freshwater biodiversity science and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 28: 1015-1022.

Doanh, P.N., Tu, L.A., Hien, H.V., Duc, N.V., Horii, Y., Blair, D. and Nawa, Y. 2018. First intermediate hosts of *Paragonimus* spp. in Vietnam and identification of intramolluscan stages of different *Paragonimus* species. *Parasites and Vecctors*. 11(1):328.

Dzul, J.G.K. and Castañeda, V.D. 2016. The Relationship between Mollusks and Oxygen Concentrations in Todos Santos Bay, Baja California, Mexico. *Journal of Marine Sciences*.

Gallardo, B., Bogan A.E. and Harun, S. 2018. Current and future effects of global change on a hotspot's freshwater diversity. *Science of the Total Environment*. 635: 750-760.

Gills, P. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: Implications for salinization of surface waters. *Environmental Pollution*. 159(6): 1702-1708.

Harrison, A.D., Nduku, W. and Hooper, A.S.C. 1966. The effects of a high magnesium-to-calcium ratio on the egglaying rate of an aquatic planorbid snail, *Biomphalaria pfeifferi*. *Annals of Tropical Medicine and Parasitology*. 60(2): 212-214.

Higgins, C.B., Tobias, C., Piehler, M.F., Smyth, A.R., Dame, R.F., Stephenson, K. and Brown, B.L. 2013. Effect of aquacultured oyster biodeposition on sediment N_2 production in Chesapeake Bay. *Marine Ecology Progress Series*. 473: 7-27.

Hoverman, J.T., Davis, C.J., Werner, E. E., Shelly, D.K., Relyea R.A. and Yurewicz, K.L. 2011. Environmental gradients and the structure of freshwater snail communities. *Ecography*. 34: 1049-1058.

Hunter, R.D. 1988. Effects of acid water on shells, embryos, and juvenile survival on *Planorbella trivolvis* (Gastropoda: Pulmonata): a laboratory study. *Journal of Freshwater Ecology*. 4(3): 315-327.

Lodge, D.M., Brown K.M. and Klosiewski, S.P. 1987. Distribution of freshwater snails: spatial scale and the relative importance of physicochemical and biotic factors. *American Malacological Bulletin*. 5: 73-84.

Madsen, H. 1987. Effect of calcium concentration on growth and egg laying of *Helisoma duryi*, *Biomphalaria alexandrina*, *B. camerunensis* and *Bulinus truncatus* (Gastropoda: Planorbidae). *Journal of Applied Ecology*. 24(3): 823-836.

Mishkin, E.M. and Jokinen, E.H. 1986. Effects of environmental calcium on fecundity and cercarial production of *Biomphalaria glabrata* (Say) infected with *Schistosoma mansoni* Sambon. *Journal of Parasitology*. 72(6): 885-890.

Okland, J. 1983. Factors regulating the distribution of freshwater snails (Gastropoda) in Norway. *Malacologia*. 24(1): 277-288.

Patang, F., Soegianto, A. and Hariyanto, S.2018. Benthic maroinvertebrates diversity as bioindicator of water quality of some rivers in East Kalimantan, Indonesia. *International Journal of Ecology*. 1-11.

Patnode, K.A., Hittle, E., Anderson, R.M., Zimmerman, L. and Fulton, J.W. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. *Journal of Wildlife Management*. 6(1): 55-70.

Pip, E. 1986. A study of pond colonization by freshwater molluscs. *Journal of Molluscan Studies*. 52: 214-224.

Ramakrishna and Dey, A. 2007. *Handbook on Indian Freshwater Molluscs*. Director, Zoological Survey of India.

Rao, N.V.S. 1989. *Freshwater Molluscs of India*. Director, Zoological Survey of India

Rundle, S.D., Spicer, J.I., Coleman, R.A., Vosper and Soane, J. 2003. Environmental calcium modifies induced defences in snails. *Proc. R. Soc. Lond. B* (Suppl.). 271: 67-70.

Satheeshkumar, P. and Khan, A.B. 2012. Influence of environmental parameters on the distribution and diversity of molluscan composition in Pondicherry mangroves, southeast coast of India. *Ocean Science Journal*. 47(1): 61-71.

Sharma, K.K., Bangotra, K. and Saini, M. 2013. Diversity and distribution of mollusca in relation to the physico-chemical profile of Gho-Manhasan stream, Jammu (J&K). *International Journal of Biodiversity Conservation*. 5(4): 240-249.

Sowa, A., Krodkiewska, M., Halabowsli, D. and Lewin, I. 2019. Response of the molluscs communities to environmental factors along an anthropogenic salinity gradient. *The Science of Nature*. 106: 60(1-17).

Thieltges, D.W., Krakau, M., Andresen, H., Fottner, S. and Reise, K. 2006. Macroparasite community in molluscs of a tidal basin in the Wadden Sea. *Helgoland Marine Research*. 60: 307-316.

Thomas, J.D., Benjamin, M., Lough, A. and Aram, R.H. 1974. The effects of calcium in the external environment on the growth and natality rates of *Biomphalaria glabrata* (Say). *Journal of Animal Ecology*. 43(3): 839-860.

Thorp, J.H. 2016. Phylum Mollusca, p. 189-221. In Thorp, J.H. and Rogers, D.C. (eds) Keys to Nearctic Fauna, *Thorp and Covich's Freshwater Invertebrates*, 4th edn. Academic Press.

Wang, N., Ivey, C.D., Ingersoll, C.G., Brumbaugh, W.G., et al. 2017. Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. *Environmental Toxicology and Chemistry*. 36: 786-796.

Zieritz, A., Bogan, A.E., Froufe, E., et al. 2018. Diversity, biogeography and conservation of freshwater mussels (Bivalvia: Unionida) in East and Southeast Asia. *Hydrobiologia*. 810: 29-44.