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Diatom Communities in Himalayan River (Lower Stretch of Alaknanda, Srinagar): Periodic Variations in Relative Abundance

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Abstract: The mountain rivers are under anthropogenic stress, especially from habitations along the banks, exemplified by Srinagar Garhwal (Uttarakhand) situated on the banks of lower stretch of Alaknanda. The relative abundance patterns characterise a community and hence the ecosystem. In view of this, a study was designed to assess short and long-term response of benthic diatoms at 5-year and 30-year intervals. For this study we made species count by examining the diatom mounts of 1st, 2nd and 3rd period (1991-92, 1995-96 and 2021-22). The 1st and 2nd periods were characterised by consistently high relative abundance of *A. pyrenaicum* and *A. minutissimum.* In contrast, 3rd period is characterised by high relative abundance of *A. pyrenaicum* in January only and that of *A. minutissimum* and *C. excisa* from February to April. The relative abundance varies significantly (p=0.0043) in long-term interval. Flora varies conspicuously in these periods as some of the taxa exhibited restricted distribution; 5 of 54, 6 of 53 and 33 of 92 species in respective periods. Species diversity increases from 1st to 3rd periods and varies significantly for long-term interval. The variations in long-term interval reflect lack of stability in the ecosystem, possibly due to the flow modification (flooding and desiccation) caused by the power house. The temporal patterns of relative abundance and hence community structure over a period of time would be a suitable bench-mark for ecosystem integrity, and hence restoration.

Keywords: Mountain rivers, Alaknanda, Diatom communities, Relative abundance, Temporal

The rivers in Himalaya are under stress, the magnitude of which is proportionate to the human habitations along its course, well reflected by changing land use from forests, grasslands, marshes, agriculture to built-up area. The mountain rivers that appear to be serene are severely stressed due to tourist and pilgrim activities besides general development in urbanized pockets along its course. The benthic community structure has been studied at different scales, such as spatial and temporal (Nautiyal and Nautiyal 2002, Potopova and Charles 2003, Nautiyal et al 2004, Nautiyal 2009 and Mirzahasanlou et al 2020), but scarcely examined for a short and long-term intervals of 2-5 years (Stevenson and Hasim 1989) and >5years to decade (Strayer et al 2014, Stonik 2021 and Gonzalez-paz et al 2021). Connell and Sousa (1983) suggested that examination of long-term data can be useful for assessing community stability.

Different organisms respond variously in short and long-term intervals; year-to-year variation in aquatic macroinvertebrate fauna from 1980-87 in the Big Sulphur Creek stream, California affected by Mediterranean climate (McElravy et al 1989); long term changes in benthic diatom composition and density under conditions of high (1977 to 1980) and low (1987 to 1993) organic waste input during 1977 to 1993 in the intertidal brackish mudflat in the Ems-Dollard estuary, Netherland/Germany (Peletier 1996); changes in diatom community structure due hydro-morphological changes on a decadal basis from 1991 to 2009 and 2019 in the Danube river, Hungary (Ács et al 2020); long term (1974 to 2008) shift in fish assemblages, body size and functional feeding group in the Wabas river U.S due to increasing anthropogenic activities (Broadway et al 2015).

This study records a short and long-term periodic response of the diatom communities to anthropogenic stressors for 5-year (1991-92 and 1995-96) and 30-year interval (1991-92 and 2021-22) in the river Alaknanda at Srinagar, the largest human habitation along its course from source to confluence with the Bhagirathi at Devprayag. Owing to its holy nature, it is of high religious value (one of the ecosystem services) and is the major source of water for domestic use. Presently, the hydroelectric project and other anthropogenic stressors have severely affected the river ecosystem (Bartwal and Nautiyal 2023).

MATERIAL AND METHODS

Study area: The ~200 km long Alaknanda is one of the two major source tributaries of the river Ganga. The upper ~100 km has a steep gradient, compared to its lower half. The river forms five confluences (prayag) known for their religious value, of which Vishnuprayag lies in the upper half while

Nandprayag, Karanprayag, Rudraprayag and Devprayag in the lower half. Owing to the religious Kedarnath and Badrinath shrines ~70 and 50 km upstream of Rudraprayag and Vishnuprayag, respectively, there is an immense pilgrim and tourist inflow. The size of human habitations have gradually increased around these 'prayags' and pilgrim destinations. Srinagar is the largest habitation in the lowermost part of the Alaknanda. This study has been carried out at Srinagar, an important station along the pilgrim route that has gradually grown in dimension, horizontally and vertically due to development (Government and private infrastructure). Subsistence agriculture in the Srinagar-Chauras valley facilitated by a wide terrace before the year 1980 was gradually replaced by an increase in the built-up area. The Srinagar hydroelectric project became functional in 2014 that modified hydrology of the river.

Numerous studies have been conducted on the Alaknanda by virtue of its proximity to our University. It was sampled for the diatom community structure in past years (1991-92, 1995-96) at Srinagar around Alkeshwar temple on left bank of the river. This location cannot be sampled now due to construction of Alkeshwar Mahadev Ghat under National Mission for Cleaning Ganga (NMCG) and Rishikesh-Karanprayag railway project. Hence sampling was carried out opposite to powerhouse which is ca~200 meter upstream of the past location. Availability of Naphrax diatom mounts for stated periods provided the opportunity to examine changes in the diatom community over a period of time.

Since the diatom mounts are prepared according to Brun's method (Sarode and Kamat 1984) in Pleurax/Naphrax (mountant of high refractive index) they could be stored in the lab. These diatom mounts were prepared for studies related to Ph. D. or research project work from time-to-time. The possibility of using these diatom samples for deciphering the changing riverscape over a period of time was explored in this study. The present samples collected during 2021-22 were subjected to acid treatment and the permanent diatom mounts were prepared in Naphrax. Identification was carried out using OLYMPUS CX41 Trinocular research microscope. Examination of the past mounts was also required to incorporate changes in the taxonomy and current nomenclature, particularly around “minutissimum” and “pyrenaicum” complex of *Achnanthidium* derived from *Achnanthes* s.l. (a species-rich genera, Nautiyal et al 2004) that usually occur in high abundance (Nautiyal and Nautiyal 2002). The species count data was generated from diatom mounts for recording relative abundance in these periods.

Data analysis: The samples of 1991-92, 1995-96 and 2021-22 respectively represent the 1st, 2nd and 3rd period in the following text. One-way ANOSIM and SIMPER dissimilarity matrix (Bray Curtis measure) were performed for determining significant differences and average dissimilarity in the taxa attaining >10% relative abundance of diatom communities between these periods. Kruskal-Wallis test was used to determine significant differences in the species diversity between periods. All statistical analyses and Shannon species diversity were computed using PAST software ver 4.11 (Hammer et al 2001).

RESULTS AND DISCUSSION

Structure of Diatom Communities: Periodic Variations in Relative Abundance

Short-term interval: The 1st period is characterized by higher relative abundance of *Achnanthidium pyrenaicum* (Hustedt) Kobayasi (27.5 to 52.6%) followed by *Achnanthidium minutissimum* (Kutzing) Czarnecki (14.4 to 27.7%) across all months except April when *Nitzschia palea* (Kutzing) W. Smith attains high abundance (37.6%) and that of *A. pyrenaicum* declines (Fig. 1). Similar patterns occurred for 2nd period also (33.1 to 61% *A. pyrenaicum;* 16-33.5% *A. minutissimum*) during most of the months, but in alternating inconsistent fashion from November to March as *A. minutissimum* and *Diatoma moniliformis* Kutzing attain higher abundance in December and February, respectively Additionally, consistent abundance was shown by *Achnanthidium crassum* (Hustedt) Potapova and Ponader, extending from January to April during the 2nd period. *Synedra inaequalis* var. *jumlensis* Jüttner & Cox and *S. inaequalis* Kobayasi attains >10% relative abundance during December only in both the periods (Fig. 1). SIMPER shows only 35.7% average dissimilarity. *A. pyreniacum* (9.9%)*, A. minutimssimum* (6.4%)*,* and *N. palea* (5.1%) are most contributing taxa to the average dissimilarity between the periods (Table 1). One-way ANOSIM does not reflect significant difference (p = 0.5581) in the relative abundance during 1st and 2nd period (short-term interval). ANOSIM statistic exhibits (R= -0.02037) low dissimilarity between the periods relative to within periods.

The 3rd period is in contrast characterised by high relative abundance of *A. pyrenaicum* (33.4%) and *Gomphonema olivaceum* (Hornemann) Brébisson (17.6%) in January only. *A. minutissimum* (20.04 to 33.3%) and *Cymbella excisa* Kützing (13.6 to 24.6%) consistently occur in high abundance from February to April (33.3%). *G. olivaceum* in November (23.05%) and *C. excisa* in December (21.01%) characterise the long-term interval (Fig.1). The presence of *Achnanthidium latecephalum* Kobayasi as a taxon with >10% too was notable. The average dissimilarity between 1st and 3rd periods is 60.2%. *A. pyreniacum* (21.9%), *C. excisa*

(8.2%) and *A. minutissimum* (7.7%) are the most contributing taxa (Table 1). There is a significant (p=0.0043) difference in taxa attaining >10% relative abundance for long-term interval and ANOSIM statistic (R=0.5222) shows a high dissimilarity between the periods compared to within periods. Consequently, the patterns appear to be visibly different during long-term for all species with >10% abundance (Fig. 1). Box plot of ANOSIM analysis shows larger variation in 3rd period compared to 1st and 2nd (Fig. 2).

Species richness and diversity: Besides relative abundance the community features like species richness and diversity were useful in understanding the response of the community. Of 114 species recorded from the periods under observation; 54 taxa in the 1st, 53 taxa in 2nd and 92 taxa occurred in the 3rd period. Restricted distribution was observed in these periods; 5 and 7 taxa to 1st and 2nd period respectively, while 33 taxa to 3rd period only (Table 2). Some of these taxa have preferences for higher trophic (19 taxa, meso-eutrophic to eutrophic) and saprobic (7 taxa, α-mesosaprobe to α-meso - >polysaprobe taxa) category (van Dam et al 1994) in 3rd period compared to 4 taxa in 1st and 5 taxa (only eutrophic) in 2nd period. Like-wise species diversity (H) and Evenness (E) were observed to be relatively low (2.388, 0.7885) during 1st period compared to 2.536, 0.8367 in the 2nd period and 3.28, 0.9233 in the 3rd period (Fig. 3). Kruskal-Wallis test indicates no significant difference in species diversity in short-term interval (p= 0.02497), in contrast to significant difference during long-term interval.

The mountain river ecosystems are highly varied but stressed by urban development. They provide a variety of habitats and hence support exemplary biodiversity considering the meager share of freshwater on the Earth. This study aimed to record short and long-term responses vis-a-vis temporal variability in diatom taxa exhibiting > 10 % of the relative abundance in the Alaknanda at Srinagar. The relative abundance of *A. pyrenaicum* and *A. minutissimum* was persistently high, as observed in other glacier-fed rivers (Nautiyal and Nautiyal 2002, Nautiyal and Mishra 2013, Nautiyal et al 2015). In south-eastern Alps the taxa belonging to *Achnanthidium* including those related to *A. pyrenaicum* were also abundant in clean, fast flowing streams with stony substratum (Cantonati and Spitale 2009). Consistently high

Table 1. Dissimilarity and % contributing taxa between the periods of short and long-term intervals

Short-term interval	1st and 2nd period		
Average dissimilarity	35.79 %		
Taxon	Average dissimilarity	Contribution (%)	Cumulative (%)
A. pyrenaicum	9.966	27.85	27.85
A. minutissimum	6.466	18.07	45.92
N. palea	5.153	14.4	60.32
A. crassum	4.329	12.1	72.42
D. moniliformis	3.19	8.915	81.33
*S. i.*var.*jumlensis*	2.481	6.932	88.26
T. inaequalis	1.752	4.897	93.16
C. excisa	1.541	4.306	97.47
G. olivaceum	0.5452	1.524	98.99
Long-term interval	1st and 3rd period		
Average dissimilarity	60.2%		
A. pyrenaicum	21.9	36.38	36.38
C. excisa	8.283	13.76	50.14
A. minutissimum	7.731	12.84	62.98
G. olivaceum	6.093	10.12	73.11
N. palea	5.619	9.334	82.44
A. latecephalum	3.975	6.603	89.04
A. crassum	2.562	4.256	93.3
S. inaequalis var.*jumlensis*	1.828	3.037	96.34
D. moniliformis	1.496	2.485	98.82

Table 2. Characteristics taxa present in each period

Taxa	P1	P2	P3
Achnanthes brevipes Agardh	+		
Fragilaria capitellata (Grunow in Van Heurck) J.B. Petersen	+		
Nitzschia communis Rabenhorst	+		
Nitzschia minuta Bleisch`	+		
Cymbella turgidula var.*bengalensis* Krammer	+		
Fragilaria brevistriata Grunow in Van Heurck		+	
Navicula erifuga Lange-Bertalot in Krammer & Lange-Bertalot		+	
Navicula schroeteri Meister		+	
Surirella sp.		+	
Cymbella cistula (Hemprich in Hemprich et Ehrenberg) Kirchner		+	
Cymbella exigua Krammer		+	
Sellaphora bacillum (Ehrenberg) D.G.Mann		+	
Psammothidium pseudoswazi (Carter) Bukhtiyarova et Round			+
Halamphora montana (Krasske) Levkov			+
Amphora veneta Kützing var. *veneta*			+
Cyclotella pseudostelligera Hustedt			+
Cymbella novazeelandiana Krammer			+
Cymbella tropica Krammer			+
Craticula ambigua (Ehrenberg) Mann			+
Craticula dissociata (Reichardt) Reichardt			+
Cyclotella atomus Hustedt			+
Cyclotella sp.			+
Cymbella excisa var. *subcapitata* Krammer			+
Cymbella parva (W.Sm.) Kirchner in Cohn			+
Cymbella pervarians Krammer			+
Encyonema silesiacum (Bleisch in Rabh.) D.G. Mann			+
Encyonopsis cf *microcephala* (Grunow) Krammer var. *microcephala*			+
Eunotia sp.			+
Fragilaria capucina var. *perminuta* (Grunow) Lange-Bertalot			+
Gomphoneis olivaceoides (Hustedt) Carter & Bailey-Watts ex. Tuji			+
Nitzschia acicularis Kützing) W.M.Smith			+
Navicula caterva Hohn & Hellerman			+
Nitzschia draveillensis Coste & Ricard			+
Nitzschia frustulum (Kützing) Grunow var. frustulum			+
Navicula symmetrica Patrick			+
Navicula amoena Manguin ex Kociolek & Reviers			+
Navicula exilis Kützing			+
Nitzschia inconspicua Grunow			+
Nitzschia intermedia Hantzsch ex Cleve & Grunow			+
Diatoma tenue Agardh var. *tenue*			+
Pinnularia sp.			+
Synedra acus Kützing			+
Surirella linearis W.M.Smith in Schmidt et al.			+
Synedra dorsiventralis O.Müller			+
Sellaphora stroemii (Hustedt) Kobayasi in Mayama Idei Osada & Nagumo			+

(Acronyms: P1- 1st period, P2- 2nd period, P3- 3rd period)

Table 2 (Continued). Taxa common to any two periods

Taxa	P1	P2	P3
Achnanthidium minutissimum complex	+	+	
Cymbopleura korana Krammer	+	+	
Navicula radiosafallax Lange-Bertalot	+	+	
Nitzschia sinuata var. *delognei* (Grunow in Van Heurck) Lange-Bertalot	+	+	
Cymbella laevis Naegeli ex Kützing	+	+	
Synedra ulna var. *oxyrhynchus* (Kützing) O'Meara		+	+
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	+	+	
Diatoma mesodon (Ehrenberg) Kützing	+	+	
Melosira varians Agardh		+	+
Cyclotella meneghiniana Kützing		+	+
Nitzschia dissipata (Kützing) Grunow		+	+
Diatoma vulgaris Bory		+	+
Platessa conspicua (A.Mayer) Lange-Bertalot		+	+
Gomphonema lagenula Kützing		+	+
Gomphonema olivaceum (Hornemann) Brébisson		+	+
Gomphonema pumilum var*. rigidum* Reichardt & Lange-Bertalot	+		+
Gomphonema parvulum (Kützing) Kützing	+		+
Cocconeis pediculus Ehrenberg	+		+
Fragilaria capucina Desmazieres	+		+
Cymbella excisa var.*angusta* Krammer	+		+
Nitzschia amphibia f. amphibia Grunow var. amphibia	+		+
Achnanthidium microcephalum Kützing	+		+
Achnanthidium cf. *subatomus* (Hustedt) Lange-Bertalot	+		+
Planothidium lanceolatum (Brébisson) Round et Bukhtiyarova	+		+
Navicula caterva Hohn & Hellerman	+		+
Nitzschia linearis (Agardh)	+		+

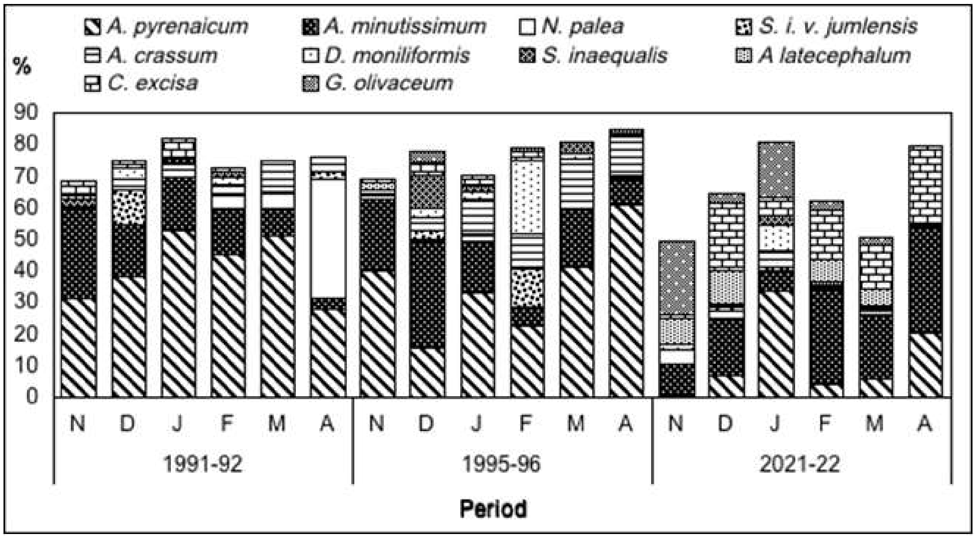

Fig. 1. Temporal patterns of diatom species figuring >10% relative abundance in the community during 1st,2nd and 3rd periods. The relative abundance of *A. pyrenaicum* and *A. minutissimum* is continuously high for 5-months in the 1st period, while it increases or decreases intermittently in the 2nd period. *A. minutissimum* and *C. excisa* attain higher relative abundance in the 3rd period

abundance of a species in tune with seasonal hydrology is a feature of undisturbed ecosystem as observed in the 1st period. This is attributable to the natural unhindered flow of the river responsible for the supply of nutrients as the river is in semi-natural state and not severely impacted by human activities. This accounts for consistent abundance of *A. pyrenaicum* in this period. Long-term interval clearly reveal the symptoms of disturbances and severe anthropogenic stressors. The relative abundance pattern in the 3rd period differ significantly from the 1st period characterised by increase in relative abundance of *A. minutissimum*, *C. excisa* and *G. olivaceum* attributed to water abstraction and modified hydrology for the peaking requirements (hold and release during generation) of Srinagar hydro-project. The impact of such flow modification has been studied for the macroinvertebrate community in the serially impounded Bhagirathi R. (Kumar and Nautiyal 2019 a, b).

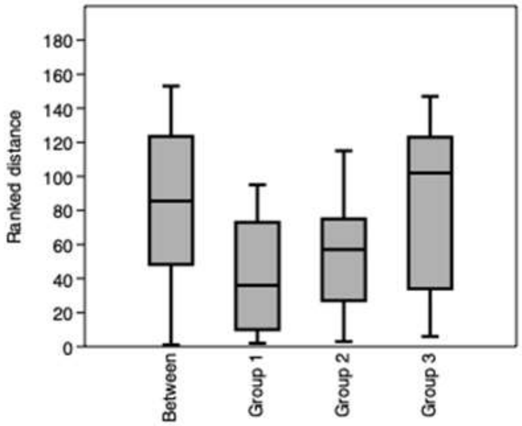

Fig. 2. Box Plot of ANOSIM analysis shows dispersion of data among and between group 1 (1991-92), group 2 (1995-96) and group 3 (2021-22). The horizontal line in the middle indicates median (Q2). The edges of the plot represent lower quartile (Q1) and upper quartile Q3. The vertical lines (whiskers) from the edges of box represent the minimum and maximum value

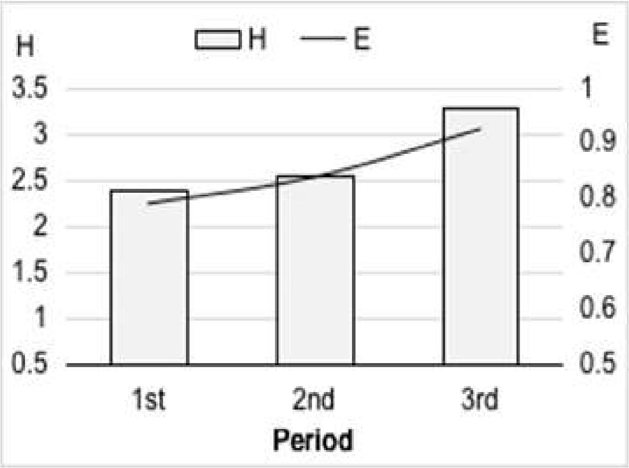

Fig. 3. Shannon species diversity (H) and Evenness (E) between 1st, 2nd and 3rd periods

In short-term interval the community reflects only increase or decrease in relative abundance as compared to shift during long-term interval due to replacement of taxa attaining high abundance (Fig. 1). Stevenson and Hasim (1989) studied diatoms in two streams during two summers (1983, 1984) and observed little change between the years (average similarity between the years was 72%) when compared to the same stream and habitat. Gonzalez-paz et al (2021) found no significant difference in the composition of diatom assemblages between the periods (2003-2008 and 2016-2020) attributed to no remarkable change in land use, although agriculture seems to have declined over the last decades in this well-preserved protected area (Picos de Europa National Park, Spain). Stonik (2021) examined long term (1992 to 2015) variation in the composition of bloom forming genus *Pseudonitzschia* and with no significant difference between them. Significant increase in sspecies diversity during long-term interval was attributed to moderate levels of disturbance due to hydroelectric project at Srinagar. The mega developmental activities in recent times are responsible for increased species diversity (Bartwal and Nautiyal 2023) and cannot be used to explain impacts of habitation, organic and/or nutrient load in particular. Gonzalez-paz et al (2021) found a decrease in diversity and evenness over the two periods in which forest area had increased while agriculture had declined. Though inferences from the species diversity explain impacts of hydropower only, the increase in the number of taxa showing restricted distribution and preferences of various taxa with low relative abundance in the 3rd period provide an insight into the ecological health of the Alaknanda. The prevalence of mesotrophic and ß-mesosaprobic taxa, implies lack of pristine conditions. Thus mild nutrient load and hence mild impact prevails in the river for the short-term interval. The presence of taxa those known for mesotrophic to eutrophic and ß-mesosaprobic to α-meso ->polysaprobe (OMNIDIA ver 6.0.8 Lecointe et al 1993) in the long-term interval indicates the presence of nutrient and organic load, mainly from the habitation at Srinagar.

CONCLUSIONS

The examined community features show a significant shift for long-term interval only. These shifts could be investigated at decadal interval and could be used as a criterion for monitoring human-impacted rivers.

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