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Impacts of Hydropower on Seasonal Rhythms of Diatoms in Indian Himalayan Region

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***Abstract*:** The hydrology of river Alaknanda in the Indian Himalayan region having glacier at source varies due to magnitude of melt in different seasons. Power generation requirements cause abrupt perturbations in the discharge of serially impounded Alaknanda River. Diatom assemblages were recorded at eight stations within and outside hydroelectric project (HEP) area to study the seasonality in diatom assemblages during 2017-2018. The assemblages reflected the bare minimum of seasonality at each station viz. *Achnanthidium pyrenaicum-Achnanthidium minutissimum* during May and June of summer season at S3; *A. pyrenaicum - Cymbella laevis* during January and February of winter season at S4; late summer at S5 (*A. pyrenaicum-C. placentula* var. *euglypta*), S6 (*A. minutissimum-A. pyrenaicum*) and S8 (*A. pyrenaicum-A. minutissimum*). The assemblages showcased no seasonal consistency during the study period. These were inferred as perturbations caused by discharges held and released for power generation, suggesting the unstable nature of communities in the Alaknanda River ecosystem impacted by serial impoundments.

Keywords: Alaknanda, hydropower, Diatom assemblages, Seasonality, Indian Himalayan region

The Alaknanda is one of the two source rivers of the holy Ganga flowing in the State of Uttarakhand in Indian Himalayan region (IHR), and constitute the headwater ecosystem. The hydrology of the Alaknanda varies seasonally due to snow accumulation during winters, melting of glaciers in summer and surface run-off during monsoon which translates into lean flow during winter (November - February), low flow during summer (March - June) and high flow during monsoon (July to September ~ October). Other than monsoon floods the natural discharge crucial to the ecosystem is held back for hydropower generation which alters the hydrology or hydrodynamic parameters in rivers downstream of the power house (PH). It involves the release of peak flows downstream of the HEP, inducing abrupt fluctuations of discharge and physical parameters (e.g. water velocity, transparency) associated with it. Fluvial changes affect the river ecosystems. The construction of dams with a reservoir alters the domain of flowing water. They impose greater pressure on the aquatic systems in relation to longitudinal trends in species and, functional composition (Braatne et al 2010). Many studies have been conducted on the seasonality of diatoms in the past, though not with respect to HEP (Everest and Aslan 2016, Shaawiat and Hassan, 2017, Goldenberg Vilar et al 2018, Snell et al 2019 and Paches et al 2019).

Few studies have examined seasonality in producer communities impacted by hydroelectric projects viz. impact of a large hydroelectric dam in the river Colorado, USA (Peterson 1986); impact of barrages in the regulated section between Rishikesh and Haridwar of the river Ganga (Badoni et al 1999); impacts of small run-of-river dams in the Xiangxi river, China (Wu et al 2010); seasonal dynamics of phytoplankton due to water level fluctuations in a reservoir of south-eastern China (Li et al 2018); seasonality of benthic diatom assemblages in the Kiskore reservoir of the Great Hungarian plain (Kokai et al 2019) and effects of altered flow regimes in three Spanish river basins (Goldenberg-Vilar et al 2022). The findings by Singh and Parikh (2020) shed light on the ecological significance of endemic diatoms identified in urban ecosystems. Considering this, a study was conducted to investigate the seasonality of diatom assemblages in the river Alaknanda modified for hydropower generation.

MATERIAL AND METHODS

Study area: The study area extends from upstream Vishnuprayag hydroelectric project (VHEP; 30°40'37"N, 79°30'37"E) in upper stretch to downstream Srinagar hydroelectric project (SHEP) powerhouse (30°13'19"N, 78°40'54"E) in lower stretch. Eight sampling stations (S1 to S8) depending on the accessibility and which were directly influenced by these hydroelectric projects were selected for sampling (Fig. 1, Table 1). The riverscape in the study area comprised of steep to moderate slopes having dense *Cedrus* to open *Pinus* Forest with spread-out small human habitations from headwaters to mouth.

Rationale for selection of stations: The river in the study area was categorized into i) Area of Influence (AoI) of HEP extending from ca. 1 km upstream (u/s) of impounded section to power house (PH- the point where diverted discharge returns to the river) and ii) free flowing river sections (FFRS) extending from downstream (d/s) of PH to ca. 1 km u/s tail of impounded section. Hence, there were two HEP-AoI and two free flowing river sections, one between V-HEP-AoI and other downstream (d/s) of S-HEP-AoI. Three sampling locations were selected within each AoI i) u/s impounded section, ii) dewatered section 10-15 km d/s of dam and iii) 10-15 km d/s of PH. In case of V-HEP the river is not accessible for long distance after the power house. Hence, the river could not be sampled for nearly 53 km after V-HEP power house. In S-HEP the river is accessible for sampling at one place before power house and two places after power house.

Methodology: The stations, S1 and S2 were sampled for the period of seven month only depending on the accessibility while the stations downstream to the V-HEP and S-HEP powerhouse (S3-S8) were sampled regularly at monthly intervals during September, 2017-August, 2018. Samples obtained from S7 were devoid of diatoms for which reason the results are not discussed for this station. The epilithic diatom samples were obtained by scraping a 3x3 cm^2 area of substrate from the river bed at a depth of 15 to 30 cm with the help of razor and brush at each station. Three samples were collected from three different flows (one from each) viz. turbulent flow, fast flow and slow flow. The samples were fixed in 4% formalin in field itself. In laboratory, the samples were first washed with distilled water and subjected to acid-peroxide treatment to remove organic coatings and to obtain clean frustules. The sample was taken in 100 ml beakers. Each sample was digested for 24 hours with an equal amount of concentrated hydrochloric acid (HCl). Following this treatment, the samples were washed multiple times with double distilled water to remove any remaining acid traces. The samples were then treated for 24 hours with hydrogen peroxide (H_2O_2) to digest the remaining debris before being washed with distilled water to remove any traces of it. The suspension was stirred before being placed on the coverslip drop by drop until it reached the edges and allowed to dry. The Naphrax (Brunel Microscopes Limited; Refractive index of 1.74) was then placed on a microscope slide and warmed on a hotplate at 40°C. The Naphrax mounts were examined under bright field using a BX-40 Trinocular Olympus Microscope (x10 and x15 wide field eyepiece) fitted with a PLANAPO x100 oil immersion objective under the bright field using different suitable filters to identify species.

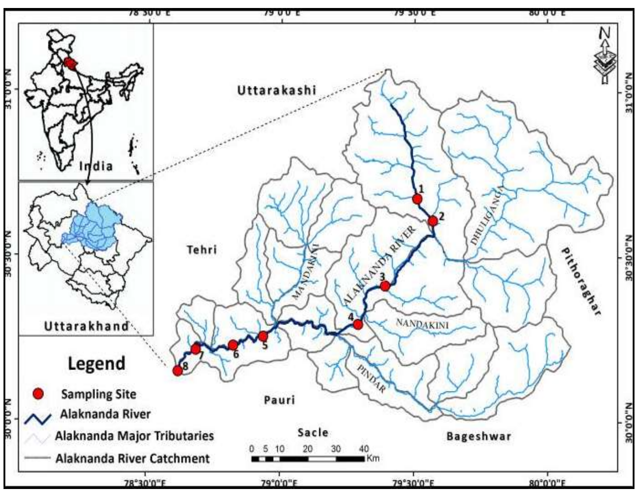

Fig. 1. Location of the sampling stations (red spots) on the river Alaknanda. The Vishnuprayag hydroelectric project (VHEP) near Lambagarh is located between S1 and S2 while Srinagar hydroelectric project (SHEP) between S5 and S6 near Srinagar

Species were identified according to standard literature (Hustedt 1985, Krammer and Lange-Bertalot 1986, Krammer 2002-2003). Diatom counts were performed on each flow till 100 to 150 valves were counted. Counts for all three flows were integrated to represent the maximum habitat. Relative abundance (as %) was computed to determine the dominant

Table 1. Geographical location of the sampling stations on the river Alaknanda and fall among stations

Station	Name	Lat (˚N)	Long (˚E)	Alt	Fall (m)	DBS (Km)
S1	1.2km u/s VHEP	30°40'37”	79°30'37”	2500		0
S2	Govind Ghat d/s VHEP	30°36'45”	79°33'55”	1800	700	9
S3	Birahi	30°24'37”	79°23'22”	1068	732	35
S4	Langasu	30°17'36”	79°17'18”	800	268	24
S5	Narkota	30°15'17”	78°55'46”	600	200	43
S6	Srinagar D/s SHEP	30°14'23”	78°49'57”	560	40	20
S7	Srinagar D/s SHEP-PH	30°13'42”	78°49'11”	535	25	5
S8	Bagwan	30°13'19”	78°40'54”	500	35	14

Acronyms: Lat- Latitude, Long- Longitude, Alt- Altitude (m asl), D/s - downstream, DBS- Distance between stations, VHEP- Vishnuprayag hydroelectric project, SHEP- Srinagar hydroelectric project, PH- powerhouse for each assemblage. Taxa with the highest relative abundance were considered dominant, and those with the second highest relative abundance were considered subdominant in the assemblage. The dominant and the sub-dominant characterized the assemblage.

RESULTS AND DISCUSSION

The diatom assemblages varied with seasons at S1 and S2. The assemblages exhibited more similarity within a season at S2 viz. *A. pyrenaicum* (Hustedt) Kobayasi-*A. minutissimum* Kutzing during summer and *A. pyrenaicum* - *Reimeria sinuata* during monsoon but differs in winter (*A. minutissimum* - *A. pyrenaicum* during November and *C. placentula* var. *euglypta* (Ehrenberg) Grunow-*A. minutissimum* during February) and less similarity within a season at S1. At S3, assemblages differed during winter and monsoon and occurred intermittently during summer. At S4, assemblages resembled during late winter (*A. pyrenaicum* - *Cymbella laevis* Naegeli in Kutzing during January and February) while differed during the rest period. During summer and winter, assemblages differed. In terms of dominants, *A. pyrenaicum* showed maximum occurrence round the year at S3 and S4. At S5, the assemblages show less variability among the seasons. At S6 and S8, assemblages varied at monthly intervals except few months of summer. *A. pyrenaicum* showed predominance at S5 and S8 like S3 and S4 whereas *A. minutissimum* exhibited predominance at S6 (Table 2). *A. pyrenaicum* - *A. minutissimum* (28%) followed by *A. minutissimum* - *A. pyrenaicum* (16%) showed the highest frequency among the diatom assemblages in the river (Table 3). Temporally, the number of assemblages were 4 at S1 and 5 each at S2, S3, S4, S5, S6 and S8. Spatially, the numbers of assemblage were relatively low with an exception in one or two months.

Developing hydropower projects in the Himalayas has various added advantages, including being a more sustainable kind of energy generation, being locally produced, and the river traits being appropriate for this type of operation. The increasing developmental activities and climate changes influences the ecological patterns of rivers in the Indian Himalayan region (Rawat et al 2020). The construction of hydroelectric projects is considered to be the most substantial anthropogenic impact on lotic ecosystems. Dams and barrages modify the natural hydrological regime of the river and consequently disrupt the continuum of a lotic ecosystem. These dams consequently effect the seasonality as well as day-to-day changes that are markedly different from natural flow patterns. As a result, ongoing human development jeopardises river habitats and ecosystems (Vorosmarty et al 2010). The hydropower developments on river Alaknanda, therefore, impacts the flow patterns due to the peaking requirements and hence, the ecosystem services.

During the present study, the diatom assemblages differed at monthly intervals at the majority of the stations, indicating lack of seasonality at these sites. In a year, 4-5 (approx.) assemblages were formed at each site, exhibiting the inconsistency of seasonal trends. In the previous studies, the highest frequency of *Achnanthidium minutissimum*-*Achnanthidium nodosa* from winter to summer (October to May) was recorded on the Alaknanda River at Srinagar (Nautiyal 2005). This shows high seasonality in the assemblages of unregulated rivers. In contrast, the assemblages displayed relatively more temporal than spatial

Table 2. Epilithic diatom assemblages during different seasons in the river Alaknanda during 2017-18

Season	Month	S1	S2	S3	S4	S5	S6	S8
Winter	November	Rs-Am	Am-Ap	Am-Ap	Ap-Am	Ap - Am	Am - Ami	Si - Am
	December	SF*	SF*	Ap-Am	Cl-Ap	Ap - Am	Am - Ap	Ap - Am
	January	SF*	SF*	Ap-Cl	Ap-Cl	Ap - Cpe	Am - Ami	Cep - Ap
	February	Ap-Am	Cpe-Am	Ap-Cpe	Ap-Cl	Ap - Si	Cep - Am	Ap - Cep
Summer	March	Am-Ap	Ap-Dm	Ap-Cpe	Ap-Cl	Ap - Cl	Cep - Ap	Ap - Cep
	April	NS	NS	NS	NS	NS	Am - Cep	NS
	May	Ap-Cep	Ap-Am	Ap-Am	Am-Ap	Ap - Cpe	Am - Ap	Ap - Am
	June	Ap-Am	Ap-Am	Ap-Am	Ap-Am	Ap - Cpe	Am - Ap	Ap - Am
Monsoon	July	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	August	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	September	Nil	Ap-Rs	Ap-Rs	Ap-Am	Nil	Nil	Nil
	October	Ap-Am	Ap-Rs	Am-Ap	Ap-Nd	Cp - Am	Am - Ap	Np - Am

Acronyms: SF*- Snow fed, NS- Not sampled, Am- *Achnanthidium minutissimum, Ap- A. pyrenaicum, Ami- A. microcephala, Cpe- Cocconeis placentula var euglypta, Cp- C. placentula, Cl- Cymbella laevis, Cep- Cymbella excisa var procera, Rs- Reimeria sinuata, Si- Synedra inaequalis, Dm- Diatoma moniliformis, Nd- Nitzchia dissipata, Np- N. palea*

Table 3. Colour chart indicating the diatom assemblages having high frequency during different seasons

Season	Months	S1	S2	S3	S4	S5	S6	S7	S8	Assemblage (Frequency in %)
Winter	November		Am - Ap	Am - Ap	Ap - Am	Ap - Am				Ap - Cpe (9)
	December			Ap - Am	Ap - Am	Ap - Am	Am - Ap		Ap - Am	Ap - Cl (9)
	January			Ap - Cl	Ap - Cl	Ap - Cpe				Ap - Cep (5)
	February	Ap - Am		Ap - Cpe	Ap - Cl				Ap - Cep	Ap - Am (28)
Summer	March	Am - Ap		Ap - Cpe	Ap - Cl	Ap - Cl			Ap - Cep	Am - Ap (16)
	April									
	May	Ap - Cep	Ap - Am	Ap - Am	Am - Ap	Ap - Cpe	Am - Ap		Ap - Am	
	June	Ap - Am	Ap - Am	Ap - Am		Ap - Cpe	Am - Ap		Ap - Am	
Monsoon	July									
	August									
	September				Ap - Am					
	October	Ap - Am		Am - Ap			Am - Ap			

heterogeneity during the present study. Kokai et al (2019) also found pronounced temporal heterogeneity in phytobenthos composition than spatial heterogeneity. It is evident from the present study that the altered hydrology perturbs seasonality of the assemblages.

The composition, structure and seasonal trends of phytoplankton alters due to the changes in water level and the general environmental drivers driving the change are flushing, dilution and intervention with the seasonal water stratification processes (Li et al 2018). Goldenberg Vilar et al (2022) observed sensitivity of diatom communities to the effect of flow alteration even during one single season. Krajenbrink et al (2019) highlighted the effects of flow regulation on diatom communities and found that autumn diatom samples showed higher sensitivity to the effects of river regulation, with more indicator taxa found than in spring samples. The diatom assemblages demonstrate unstable river ecosystem. The maximum occurrence of *A. pyrenaicum* or *A. minutissimum* as a dominant indicates that the hydroelectric project has altered the benthic diatom assemblages, as more tolerant taxa or indifferent taxa have replaced the sensitive dominants. Goldenberg Vilar et al (2022) also reported higher abundance of *A. minutissimum* in altered sites. Furthermore, because diatoms are at the base of the ecosystem's trophic structure, they are more sensitive to changes in water chemistry, particularly nutrients, the availability of which is inhibited by the reduced quantum and hindrance to river flow. The assemblage lack predictable pattern attributed to modified hydrological regime for peaking purpose resulting in extremely varying flow regimes (on a daily basis) throughout the year. Unlike a natural ecosystem where the peak occurs invariably in same month all along the river, the occurrence of peak in different months of a season indicates impact of hydropower on assemblages.

CONCLUSIONS

The assemblages at S1 and S2 varied during different seasons. Few samples at S1 and S2 preclude any conclusions about the seasonality of the assemblages. At S3, S4, S5, S6 and S8, the assemblages differed from month to month showing lack of seasonality at these stations. Assemblages tend to predominate in a natural hydrological regime which changes seasonally. If regime is manipulated, the assemblages become vulnerable to modifications or replacement resulting in a lack of seasonality as various physical and chemical gradients are lost. These were interpreted as perturbations caused by discharges held and released for the purpose of generating electricity, implying the unstable nature of these communities in the river ecosystem impacted by serial impoundments.

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