

Structure of Diatom Community in a Hydropower Impacted Himalayan River

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ABSTRACT

Hydropower development significantly alters the natural flow regime, affecting the riverine biodiversity of mountain rivers. This study assesses the impacts of hydropower on the diatom community structure in the dewatered stretch downstream of the dam at Srikot and the regulated stretch below the powerhouse in the Alaknanda River. Sampling was conducted monthly to examine the temporal variation in the diatom community and its environmental drivers. The diatom community structure revealed a marked difference between the two sites. At Srikot, the persistent dominance of the tolerant taxon *Achnanthes lanceolatum*, along with recurring nutrient-tolerant taxa, indicates community homogenization under reduced discharge and nutrient accumulation. In contrast, a shift among dominants *A. minutissimum*, *A. lanceolatum*, *Cymbella excisa*, *Gomphonema olivaceum*, and *A. pyrenaicum* at Srinagar reflects habitat instability due to hydropeaking requirements. Canonical correspondence analysis identifies water temperature and electrical conductivity as major drivers of the community in the dewatered section at Srikot. In contrast, water current velocity and transparency are the major drivers in the regulated section at Srinagar. The study revealed that flow regulation for hydropower alters the diatom community structure associated with low discharge and hydropeaking requirements. These findings highlight the sensitivity of diatoms as indicators of hydrological disturbances and emphasise the need for further region-specific biomonitoring strategies and flow management in Himalayan regulated rivers, particularly those with glaciers at their sources.

Key words: Hydropower, Glacier-fed river, Alaknanda, Hydropeaking, Biomonitoring

INTRODUCTION

Among the common energy sources, hydroelectric projects (HEPs) are considered most cheap and clean. Hydropower not only generates electricity but also supports irrigation and water management resources (Branche 2017). Hence, regions with mountainous terrain are a boon, as they provide natural settings for developing hydropower on rivers. Apart from its plains, a vast stretch of India is endowed with mountainous terrain in both the Himalayan and peninsular regions. The Himalayan rivers are hence an obvious choice for developing hydropower.

However, hydropower development has fragmented a substantial part of the world's major rivers (Chong et al. 2021). The construction of HEPs diminishes the longitudinal and lateral connectivity of rivers, resulting in fragmented and heterogeneous habitats over short distances (He et al. 2024). This fragmentation has direct implications for hydrological characteristics, river system connectivity, and the ecological requirements of the communities. It also indirectly affects regional biodiversity due to habitat loss and degradation (Dudgeon et al. 2006). All these characteristics tend to vary from one HEP to another, depending on the dam's dimensions, the deepwater column in the upstream section, and the dewatered river section d/s of the dam, while the stretches below the powerhouse experience frequent flooding and desiccation due to hydropeaking requirements.

Sub-daily flow fluctuations are known to have a detrimental effect on aquatic organisms, leading to habitat degradation, species displacement, and ecosystem destruction (Bipa et al. 2024).

The Alaknanda River, a major glacier-fed headwater tributary of the Ganges, is impacted by the R-o-R (run-of-the-river) hydroelectric project at Srinagar, located before its confluence with the sister tributary, the Bhagirathi, at Devprayag, a river of high religious value for Indians. Against this backdrop, we aim to address the following research questions: (i) How do the composition and diversity of benthic diatom communities vary across months when comparing a dewatered section at Srikot to a hydropeaking section below the powerhouse at Srinagar under HEP influence? (ii) What are the environmental drivers shaping the benthic diatom communities at both impacted sites? (iii) Assessing the ecological status of these stretches using diatom indices.

Here, we are specifically concerned about the producer communities in the section below the dam and the powerhouse. Studies on aquatic biodiversity affected by HEPs have primarily focused on fishes and macroinvertebrates, with comparatively less attention to diatoms (Wang et al. 2022). Moreover, very few have focused on the impact of hydropeaking on aquatic biodiversity, particularly diatoms (Bipa et al. 2024). However, in Himalayan rivers, recent studies have been conducted in the areas of

influence of HEPs, such as the reservoir tail and the river section below the powerhouse (Sharma and Nautiyal 2022, Bartwal and Nautiyal 2023a, Kumar and Nautiyal 2024).

The present work addresses an important knowledge gap, as benthic diatom communities are well-suited to respond to slight changes in their immediate surroundings (Schultz et al. 2024). The diatom communities are known to respond to disturbances in response to alterations in flow caused by dams (Goldenberg Vilar et al. 2022, Jakovljević et al. 2024). Their well-known indicator value makes them useful for assessing the impacts of multiple stressors (Potapova and Charles 2003, Mbao et al. 2022), while their short generation time and rapid reproduction enable them to reflect environmental changes within relatively short time scales (Szczerba et al. 2023). Therefore, variation in community structure, dominance shifts, and diatom index performances provide an important insight into two disturbed habitats created by hydropower regulations.

Sampling locations

The study area extends from 30°13'40" to 30°13'43" N latitude and 78°47'18" to 78°49'07" E longitude

at an elevation of 529-539 m above sea level. The Alaknanda River flows through a wide valley in a bow-shaped meander for a distance of 9-10 km from Srikot to Shriyantra Tapu (Kirtinagar). Along this stretch, the left bank along Srikot and Srinagar is characterized by a low but wide terrace. In contrast, the right bank has a higher terrace with cliff-like topography from Srikot to the Chauras bridge along the river channel (Fig. 1). Land use in the Srinagar-Srikot area is occupied by dense habitation representing built-up area and pine forest on the left bank. In contrast, the right bank comprises sparse human habitation and sub-tropical mixed forest.

The river stretch along Srikot is dewatered due to the diversion discharge through a headrace tunnel and subsequently a tailrace channel (5.4 km in length). Consequently, this section of the river experienced very low flow during summer and winter, turning riffles into shallow pools. A long weir has been constructed to hold back the water and divert it for riverbed mining, creating several channel bars. The sediment-rich riverbed consists of cobble, rocks, boulders, gravel, pebbles, sand, silt, and clay.

The regulated flow from the powerhouse of the Srinagar hydroelectric project strongly influences

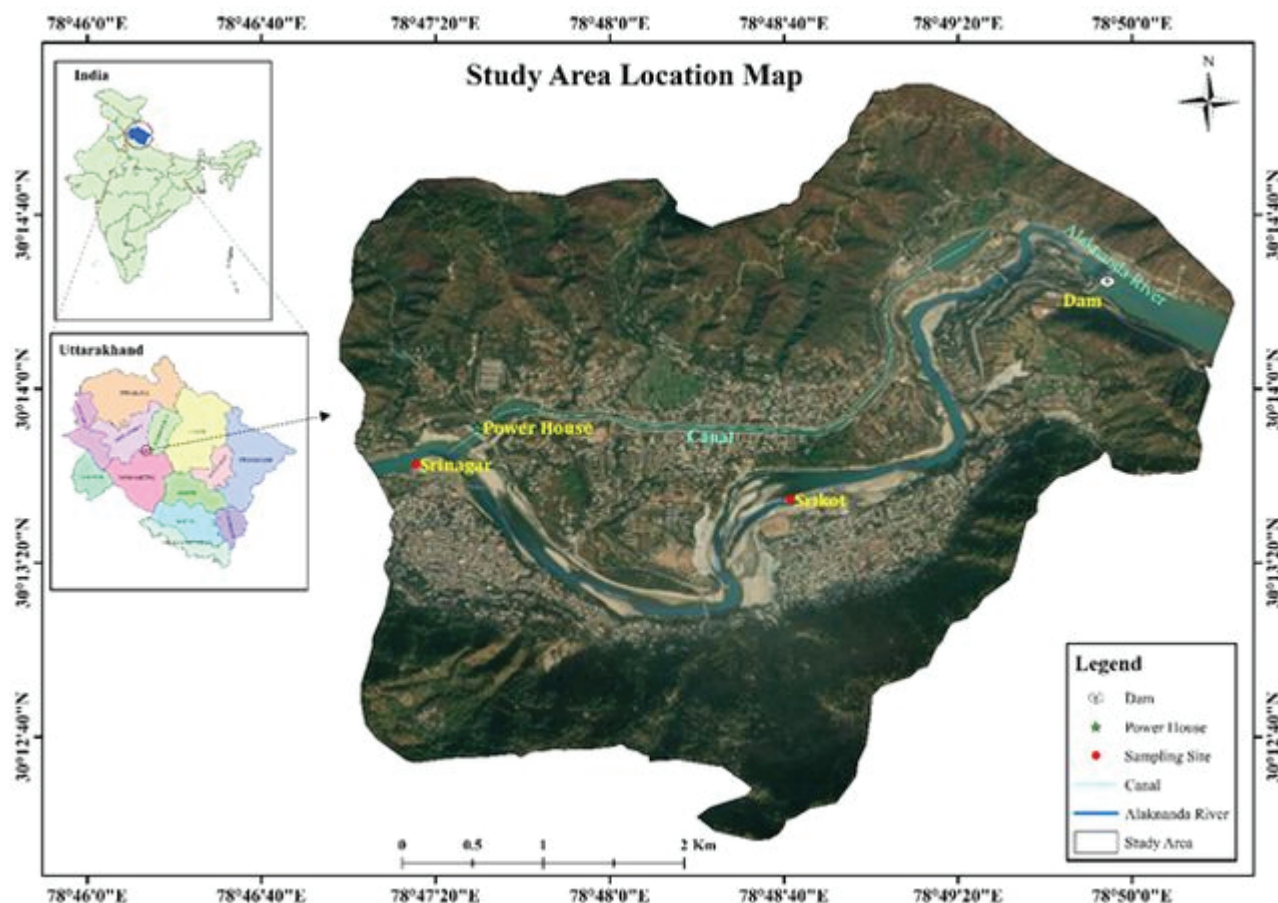


Figure 1. Study area showing sampling locations in 2021-22, labeled Srikot (u/s) and Srinagar (d/s) on the map; Srikot lies in a dewatered stretch, and Srinagar is at the power house of the Srinagar hydroelectric project

the river section at Srinagar. Flow at this station fluctuates on a sub-daily basis due to intermittent powerhouse release. The timing and duration of discharge depend on the season and power generation requirements. The riverbed at Srinagar primarily consists of cobbles, small boulders, pebbles, and silt. The habitat is characterised by shallow riffles, pools, and wide, shallow pools in the study area.

METHODOLOGY

Physicochemical parameters

Air temperature ($^{\circ}\text{C}$), water temperature ($^{\circ}\text{C}$), pH, and electrical conductivity were measured by a digital meter (PCT tester 35, multimeter). The Secchi Disc was used to measure transparency. The disc was gently immersed in the river, and the depth at which it became invisible was recorded. Another measurement was recorded while lifting the disc at the point it becomes visible. Transparency was calculated as the average of the two values. During the lean period when flow was minimal, the transparency was recorded as depth. The float method was used to measure the water current velocity (m s^{-1}).

Diatom sampling

Sampling of diatoms was carried out by scraping a 3 x 3 cm area of cobble from July 2021 to June 2022. The obtained samples were treated with hydrochloric acid for 24 hrs. The samples were then repeatedly washed with distilled water to remove traces of acid using a centrifuge at 1000 RPM for 5 minutes. The processed material was mounted in Naphrax to prepare the permanent mount for each sample. Each mount was examined under an Olympus CX41 trinocular microscope at x1500 magnification. Species counts were performed according to standard literature for diatoms (Krammer and Lange-Bertalot 1986-2000, Krammer 2002, 2003, Lange-Bertalot 2001, Metzeltin and Lange-Bertalot 2002, Lange-Bertalot et al. 2003, Metzeltin et al. 2005). Internet sources, such as Diatoms of North America (<https://diatoms.org/>), were used as additional aids. Approximately 250-300 valves were enumerated from each sample following the standard methodology for further analysis (Kelly et al. 2008).

Community structure

Species Diversity and Richness (SDR) software was used to compute species richness, Shannon H, and Simpson-E indices from species counts. The relative abundance of each species in the sample was computed as the ratio of the number of valves of one species to the total number of diatom valves. The relative abundance thus obtained was tabulated for diatom taxa with more than 10% to record the assemblage. The taxa below 10% relative abundance are provided in the Supplementary Table 2. The

taxa with the highest abundance were categorized as dominant, while the others were recorded as subdominant.

Diatom indices

Diatom indices were computed to assess the ecological status of these structures. The various diatom indices, including the Biological Diatom Index (IBD) (Coste et al. 2009), Specific Pollution-Sensitivity Index (IPS) (Anonymous 1982), Trophic Diatom Index (TDI) (Kelly and Whitton 1995), Diatom Index of Saprobity and Eutrophication (IDS/E) (Leclercq and Lecointe 2008), Trophic Index (ROTT TI) (Rott et al. 1999), Saprobic Index (ROTT SI) (Rott et al. 1997), Generic Diatom Index (IDG) (Rumeau and Coste 1988), Schiefele and Schreiner Index (SHE) (Steinber and Schiefele 1988), Eutrophication Pollution Diatom Index (EPID) (Dell'Uomo 1996), and Commission for Economic Community Metric (CEC) (Descy and Coste 1991), were selected for this study. These indices were computed from species count data using OMNIDIA software version 6.0.9. They were selected based on a 70- 90% inclusion rate for the species. The interpretation of the indices is provided in Supplementary Table 1. However, the interpretation values of a few indices, such as IBD (1 -worse to 7 -best), CEC (0- heavily polluted to 10 -pure water), and IDG (1-worse to 5-best), are presented as ranges in the respective publications. Accordingly, these ranges were adopted to interpret index scores in the present study.

Data analysis

Statistical differences in diversity parameters between stations were assessed using the nonparametric Kruskal-Wallis test in R. Canonical Correspondence Analysis (CCA) was applied to examine the influence of environmental variables on diatom communities in the river stretch at Srikot and Srinagar. The analysis was performed using CANOCO software (ter Braak and Šmilauer 2002). Forward selection, followed by unrestricted Monte Carlo permutations, was used to identify the minimum set of environmental variables that explained the maximum variation. The taxa with <5% relative abundance were excluded from CCA to avoid statistical noise.

RESULTS

Physiochemical parameters

Air temperature ranged from 8.1 to 31.9 $^{\circ}\text{C}$ during December and September, respectively, at Srikot, while water temperature ranged from 11.1 to 23.4 $^{\circ}\text{C}$ with peaks in June and a minimum in December. The water current velocity ranged from 35.8 cm s^{-1} (March) to 132 cm s^{-1} , peaking during monsoon months. There was no flow during November and

December. Transparency in general ranged from 10 (July-August) to 14 (June). Electrical conductivity ranged from 134 $\mu\text{S cm}^{-1}$ (September) to 291 $\mu\text{S cm}^{-1}$ (April) and was $<200 \mu\text{S cm}^{-1}$ in most of the months. The range of pH extended from 6.73 to 8.43 in September and May, respectively (Fig. 2). At Srinagar, air temperature ranged from 10.5 to 31.9°C, following the seasonal trend similar to Srikot. Water temperature ranged from 13.5°C (December) to 24.5°C (May). Water current velocity varied between 21 cm s^{-1} (January) and 71.6 cm s^{-1} in March and April, with no flow during November and December. Transparency ranged from 6.5 cm (October) to 17 cm (March), remaining generally low throughout the year. pH ranged from 6.75 (September) to 9.3 (March), indicating mostly neutral to alkaline conditions throughout the study period. The electrical conductivity varied from 137 (September) to 231 (November), with lower values during monsoon and relatively higher during winter (Fig. 2).

Diatom communities at Srikot (dewatered section) and Srinagar (regulated section)

At Srikot, species richness ranged from 7 (July) to 43 taxa (December). Shannon diversity ranged from 1.482 (August) to 2.592 (December), while evenness ranged from 0.596 (August) to 0.937 (July) (Fig. 3). Higher richness and diversity were recorded during winter from November to February. In contrast, lower richness values occurred during monsoon months (July-October).

In case of relative abundance, *Achnanthyidium latecephalum* remained consistently dominant throughout the study year, except in May. *A. minutissimum* contributed $>10\%$ relative abundance in seven months, while *A. pyrenaicum* was restricted to three temporally distant months (August, December, and April). *Cymbella excisa* also occurred in notable abundance in August and December, while *Diatoma moniliformis* and *Nitzschia palea* were recorded only in January. *Achnanthyidium* cf. *delmontii* occurred only during May (Table 1).

At Srinagar, species richness ranged from 4 (June) to 48 taxa (December and March). Shannon diversity ranged from 1.136 (September) to 3.116 (March). Evenness ranged from 0.607 (July) to 0.976 (August). Elevated richness and diversity were observed during winter and early summer (November–March), while lower values were recorded during monsoon and late summer months (Fig. 3).

The highest abundance was recorded for *A. minutissimum*, which dominated the assemblages for six months and occurred as a subdominant during August, October, and December. *A. latecephalum* occurred in notable abundance over five months. *A. pyrenaicum* attained abundance from April to June and again in January. *C. excisa* occurred continuously from February to June and in December as a dominant taxon. *Gomphonema olivaceum* was dominant in November and subdominant in January. A suite of different taxa appeared at this station: *G. pumilum* var. *rigidum* (November) and *C. excisa*

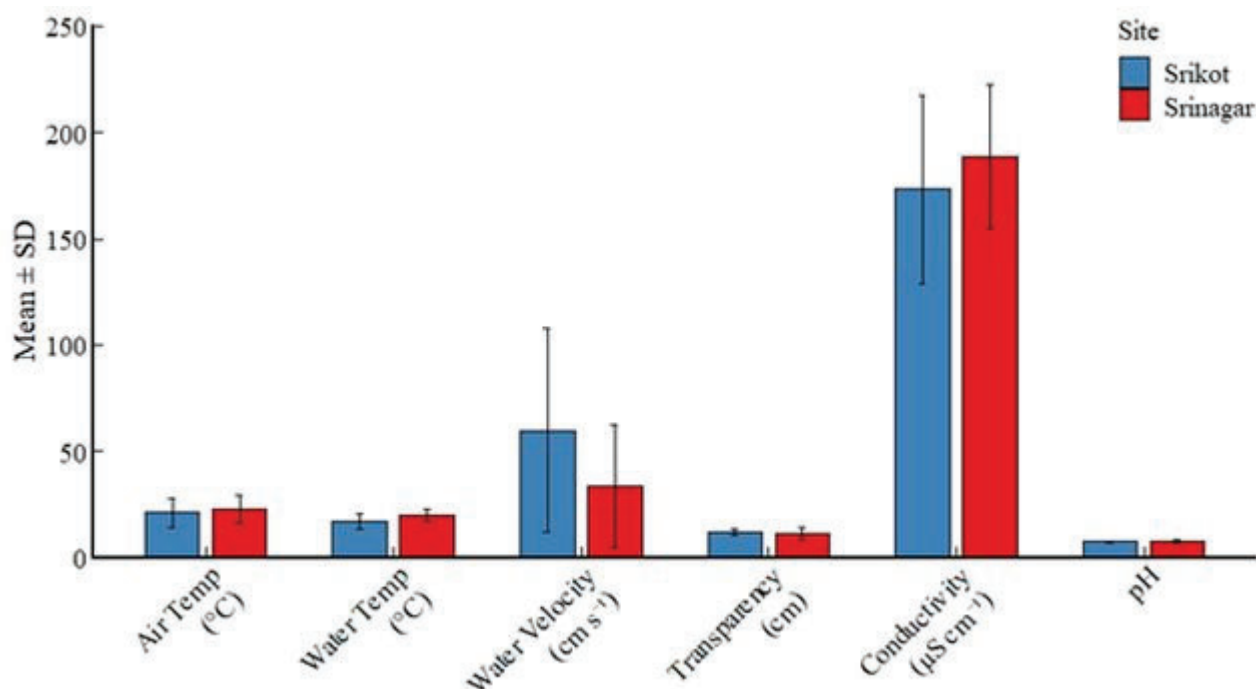


Figure 2. Mean ($\pm$ SD) of physicochemical parameters in Srikot and Srinagar sampling sites during the study period

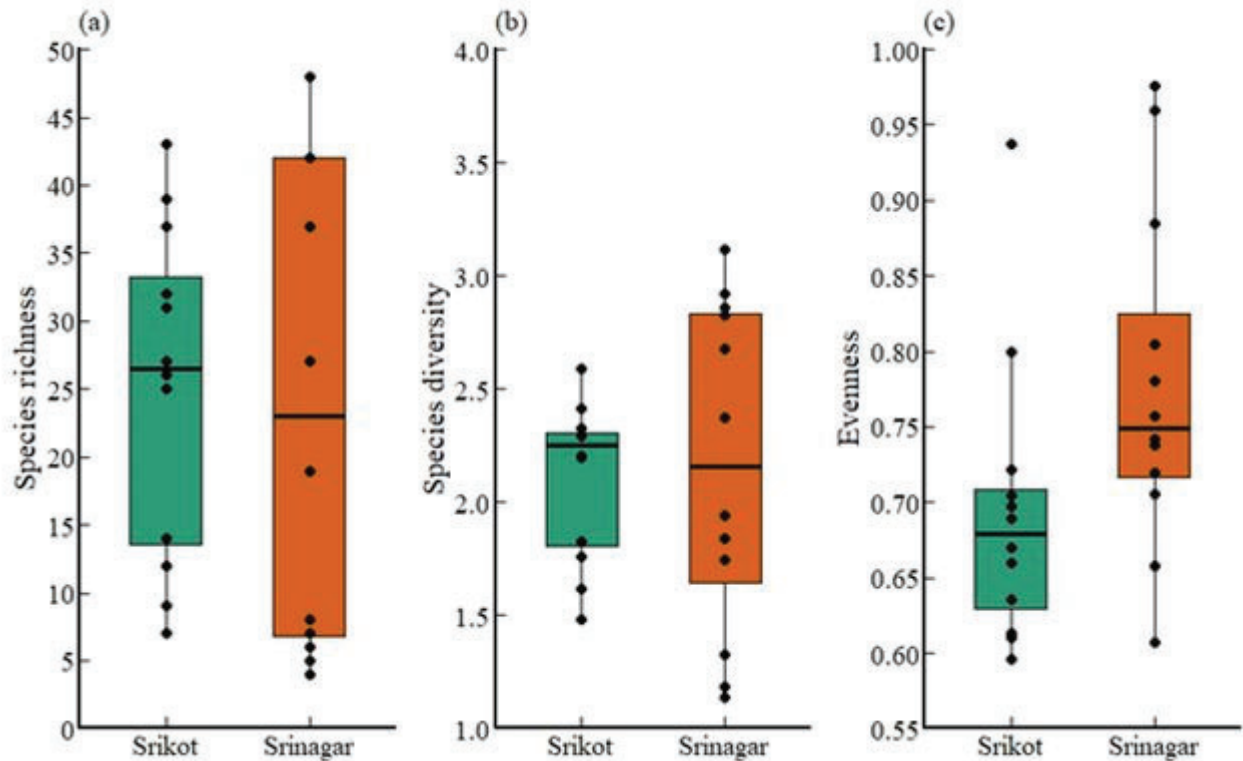


Figure 3. Box plot representing the variation in a) species richness, b) species diversity, and c) evenness between Srikot and Srinagar. No significant difference ($p > 0.05$) was observed between the two sites for richness and diversity

Table 1. Monthly variations in diatom assemblages in the Alaknanda river at Srikot and Srinagar. Species acronyms used in the table are listed in Supplementary Table 2 in accordance with the species code of the OMNIDIA software

Month	Srikot		Srinagar	
	Assemblages	%	Assemblages	%
Jul-21	ADLA	63	ADMI	68
Aug	ADLA-ADMI-ADCR-ADPY-CAEX	24-24-18-12-12	ADLA-ADMI-CAEX-ENMI-ENSU-CSLP	29-14-14-14-14
Sept	ADLA-ADMI	60-11	ADMI-ADLA	50-29
Oct	ADLA-ADMI	47-11	ADLA-ADMI-ADPY	29-24-18
Nov	ADLA	50	GOLI-GPRI	23-10
Dec	ADLA-ADMI-ADPY-CEAX	19-14-13-10	CAEX-ADMI-ADLA	21-18-10
Jan- 22	ADLA- DMON-NPAL	38-14-12	ADPY-GOLI	33-18
Feb	ADLA	43	ADMI-CAEX	30-16
Mar	ADLA-ADMI	40-14	ADMI-CAEX	20-14
Apr	ADLA-ADPY-ADMI	29-20-16	ADMI-CAEX-ADPY	33-24-21
May	ADCR-ADLA-ADMI-ADEL	24-14-14	ADMI-ADPY	30-11
June	ADLA	41-15-11	ADLA-ADPY-CAEX-CEPR	33-33-17-17

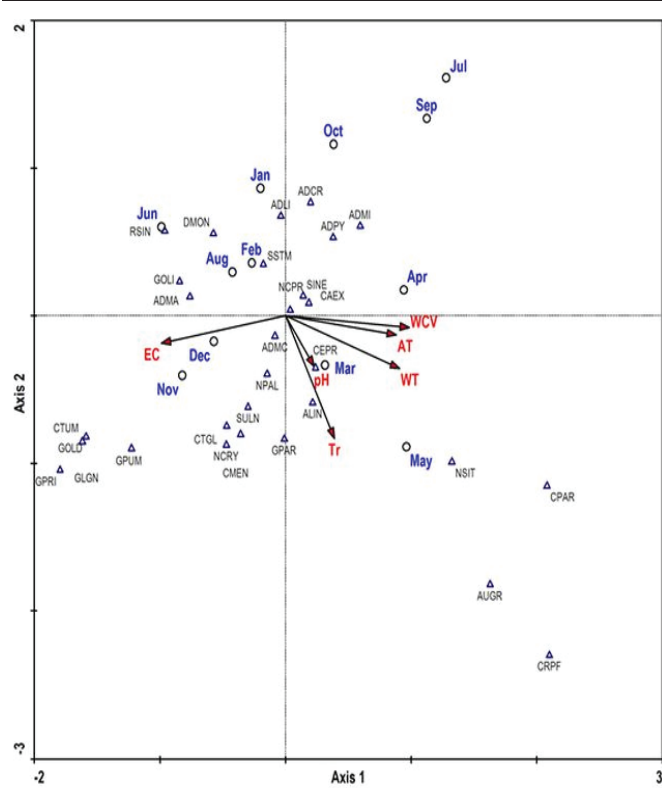


Figure 5. Canonical correspondence analysis showing the influence of environmental variables on the diatom community. The dominants lack a strong association with the selected variables at Srinagar

conditions, while the ROTT SI values of 1.73 and 1.80 showed moderate organic pollution. TDI index values of 47.32 and 49.33 showed significant eutrophication. SHE index values of 5.56 at Srikot and 5.69 at Srinagar indicated increasing organic pollution and reduced oxygen conditions. However, the IPS values of 3.54 and 4.09 classified Sirkot as moderately polluted or significantly eutrophic, while Srinagar was classified as slightly polluted. In contrast, the IDG values of 4.08 and 4.22 indicated low pollution, while the EPI-D values of 0.95 and 0.96 reflect good ecological water quality (Table 2).

DISCUSSION

The operations of hydropower infrastructure have visibly altered the diatom community structure of the Alaknanda River. At Srikot in the dewatered stretch, species richness was relatively higher in winter months (November-February), while diversity remained moderately high until June. In contrast, Srinagar, located below the powerhouse, exhibited intermittent increases in richness from November to May, with the lowest values recorded in March and June. A fluctuating temporal pattern of these parameters was observed at Srinagar, suggesting perturbed seasonality (Chen et al. 2015). Richness and diversity, including evenness, were slightly

Table 2. Water quality status using diatom indices at Srikot and Srinagar. Colors - skyblue: no pollution; green: slight pollution; yellow: slightly elevated pollution; reddish orange: moderate pollution

Indices	Srikot	Srinagar
IBD	5.29	5.62
IPS	3.54	4.09
IDG	4.22	4.08
IDS/E	3.94	3.93
EPID	0.95	0.96
ROTT TI	2.23	2.23
ROTT SI	1.73	1.8
CEE	7.34	7.61
TDI	47.32	49.33
SHE	5.56	5.69

higher below the powerhouse at Srinagar. This is consistent with the findings of Sharma and Nautiyal (2022). Dams tend to increase minimum flows and diminish peak flows, leading to a homogenised flow regime, a reduction in channel complexity, and, consequently, river biodiversity (Poff et al. 2007).

The diatom assemblages at each site serve as biological indicators of localized stressors associated with hydropower operations. At Srikot, *A. latecephalum* (14-63% relative abundance) persisted as dominant throughout the year. This species is considered tolerant to organic pollution (S = 2.6) in the IPS index list. The continued dominance of this tolerant species in the flow-deficient section is noteworthy, suggesting that reduced flow, along with organic load, causes homogenization of the diatom community. Similar synergetic effects of sewage inputs and hydrological alteration led to homogenization in diatom assemblages in Mediterranean streams (Tornés et al. 2018). Although its ecological preferences are not well documented, its presence, along with *G. parvulum*, *G. pumilum*, and *C. placenula*, is associated with base-rich sites with modified channels (Jüttner and Cox 2001).

A. minutissimum (11-23%) occurred frequently as a subdominant taxon. The other taxa, *A. pyrenaicum*, *D. moniliformis*, *N. palea*, *C. excisa*, and *A. cf. delmontii*, exhibited intermittent increases in abundance. Many of these prefer high-trophic conditions (van Dam et al. 1994), reflecting increased nutrient accumulation in the flow-deficient section under reduced discharges due to low dilution capacity (Wen et al. 2017), which likely contributes to the observed community structure. The occurrence

of *A. latecephalum* and *A. cf. delmontii* is notable, as these taxa have not previously been reported from the Alaknanda or Bhagirathi sub-basins of the Ganga basin. Possibly, if present, they were accounted for as a part of the *A. pyrenaicum* species complex (Pérès et al. 2012, Trábert et al. 2020). *A. cf. delmontii* has been observed to invade and prefer calcareous, eutrophic waters with moderate to high electrolyte content (Falasco et al. 2016, Buczkó et al. 2022).

In contrast, the regulated section at Srinagar exhibits a greater temporal variability in assemblage structure, exemplified by shifts in dominance among *A. minutissimum*, *A. latecephalum*, *C. excisa*, *G. olivaceum*, and *A. pyrenaicum*. Although *A. minutissimum* was dominant during six months (17–68%), it remained consistent in about four months. The repeated dominance of this species can be attributed to habitat instability due to hydropeaking requirements. This species is an attached diatom and is often among the first to pioneer a recently scoured site due to its high resistance to scouring (Peterson and Stevenson 1992, Stevenson and Bahls 1999). The colonization of high-resistance-to-disturbance taxa, or low-profile taxa, most likely occurred under the hydropeaking treatment (Smolar-Žvanut and Klemenčič 2013). The other species, *C. excisa* and *G. olivaceum*, are known to prefer eutrophic conditions (van Dam et al. 1994).

The presence of *A. minutissimum* at both stations across most months reflects its wide ecological tolerance (Potapova and Hamilton 2007). However, the differences in community structure between the two locations were also rather intriguing, as both stations are barely 5 km apart, highlighting the discharge-driven impact on the community. Historical data from Bartwal and Nautiyal (2023b, 2025) revealed that in 1991–92, both stations supported similar community dominance (sensitive species) before the construction of the dam, which even persisted in the same location during 1995–96 but differed in 2021–22, dominated by tolerant species, indicating the impact of flow regulation and nutrient accumulation.

Ordination analysis revealed different environmental drivers shaping the diatom community at two stations. At Srikot, water temperature and electrical conductivity emerged as the major drivers of the community, with water temperature being a significant driver, as also reported by Toman et al. (2014). This station, below the dam, with low-flowing conditions forming a flow-deficient section, likely modifies the water chemistry, thereby influencing species composition.

A. pyrenaicum, *A. minutissimum*, and *A. latecephalum* showed strong positive associations with conductivity, water temperature, and water current velocity, respectively. The nutrient-tolerant taxa (e.g., *N. paleacea*, *N. phylleptosoma*) showed weak associations with in-stream factors and

appeared in winter, when flow almost ceases, thereby enhancing nutrient and organic loads.

At Srinagar, water current velocity and transparency were identified as the significant environmental drivers of the community. *A. lineare* was strongly associated with transparency, while *C. excisa* and *N. capitatoradiata* were associated with water current velocity. Noticeably, a suite of taxa (e.g., *G. parvulum* var. *rigidum*, *G. pumilum*, *N. palea*, and *C. meneghiniana*) with preferences for higher trophic states and saprobity form a distinct group during winter and show a weak negative influence of electrical conductivity. By virtue of the powerhouse, this section is characterised by alternating flooding and desiccation, rendering it suitable for colonisation by diatoms with indifferent preferences (*A. minutissimum*, *A. linearis*) or opportunistic species that respond quickly to disturbance (Norkko et al. 2006).

Earlier studies have reported conductivity as an important driver of diatom richness and composition in different habitats (Potapova and Charles 2003, Bere and Tundisi 2011, Lee et al. 2021). Similarly, in Finland streams, total nitrogen, total phosphorus, and water conductivity were reported as key factors for the diatom community. At the same time, physical factors such as water current velocity and depth also affected the diatom community structure across multiple sampling years (Virtanen and Soininen 2012, 2016).

The diatom indices revealed different levels of organic pollution and nutrient enrichment, although the magnitude varied among the indices. The IBD index at both stations indicated moderate pollution, respectively, further supported by the elevated CEC index value. Similarly, IDS/E reflected moderate degradation of water quality, suggesting a moderate level of saprobity and eutrophication associated with anthropogenic activity in the river catchment. The trophic and saprobic indices consistently indicated nutrient enrichment and organic pollution. The ROTT TI classified the station as meso-eutrophic, while TDI indicated significant eutrophication, suggesting that organic pollution is likely to contribute significantly to the eutrophication of the sites. Similar observations were obtained from the SHE indices, confirming nutrient enrichment at both stations. These conditions are likely associated with increasing nutrient loads from domestic sewage and municipal runoff from the Srinagar-Srikot town, further exacerbated by hydropower regulation (Bartwal and Nautiyal 2023a). The IPS index shows contrasting results at both stations. The slight changes in this index may reflect the intermittent flushing effect associated with peaking discharges from the powerhouse. At the same time, at Srikot, the increasing level of organic pollution or significant eutrophication was attributable to a dewatered section below the dam. Several studies

have demonstrated the utility of diatom indices for assessing water quality and ecological status in regulated rivers (Solak et al. 2020, Lee et al. 2021). However, EPI-D and IDG indicated better water quality or low pollution, despite the 50-60% species inclusion rate. These indices were developed for different environmental gradients. For example, IDG is based on the genus level and therefore may be less sensitive to subtle species-level changes. This suggested that it is important to exercise caution when relying solely on certain diatom indices, as they may not provide a comprehensive assessment of water quality (Tan et al. 2017, Bartwal and Nautiyal 2023a).

CONCLUSIONS

The study demonstrates that hydropower regulation shapes the diatom communities in the Alaknanda River. Richness and diversity show perturbed seasonality, particularly at Srinagar. Reduced discharges in the flow-deficient section led to community homogenization dominated by tolerant taxa. At the same time, hydropowering requirements create unstable habitat conditions, resulting in temporal variation in diatom community structure. The distinct community patterns, despite the proximity of the sites, highlight the influence of localised stressors resulting from flow regulation. Environmental variables and diatom indices further confirmed the disturbances at both sites; however, variation among indices indicates the need for cautious application in the Himalayan regulated river. Flow regulation, along with nutrient accumulation, can modify the habitat quality in the Alaknanda River. However, meteorological factors may also play a major role in shaping the diatom community in this regulated, glacier-fed river. Therefore, future research should incorporate the meteorological factors of such rivers to understand the combined effect of hydrological and climate factors on community dynamics. Further, this study emphasizes the need for flow management and a region-specific biomonitoring program for such rivers.

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Supplementary Table 1. Ecological criteria and interpretations of diatom indices based on the original publications. Acronyms: mt: most tolerant towards pollution; ht: highly tolerant towards pollution; t: tolerant towards pollution; s: sensitive towards pollution; hs: highly sensitive towards pollution; eu: eutraphent species; o: oligotraphent species

Diatom Index of Saprobity and Eutrophication (IDSE)		
Index value	Index value	
5.0-4.3	Non-existent	blue
4.2-3.6	Low	green
3.5-3.0	Moderate	yellow
2.9-2.3	High	orange
2.2-2.1	Very high	reddish orange
EPI-D values	Quality	colour
0.0 < EPI-D ≤ 1.0	excellent quality environment	heavenly
1.0 < EPI-D ≤ 1.5	good quality environment	blue
1.5 < EPI-D ≤ 1.8	sufficient quality environment	dark green
1.8 < EPI-D ≤ 2.0	slightly altered environment	light green
2.0 < EPI-D ≤ 2.2	moderately polluted environment	yellow
2.2 < EPI-D ≤ 2.5	heavily polluted environment	orange
2.5 < EPI-D ≤ 3.0	heavily polluted environment	red
3.0 < EPI-D ≤ 4.0	fully degraded environment	brown
Schiefele and Schreiners index (SHE)		
Classification class	Criteria	
Trophy I	0≥50%, hs ≥10%, eu<10%, t+ht+mt+s<10%	unpolluted, nutrient poor, but oxygen-rich
Trophy II	o≥10%, hs ≥ 10%, eu <50%, t+ht+mt+s<10%	Slightly polluted, moderately nutrient enriched and well oxygenated
Trophy III	0<10%, hs ≥10%, eu ≥50%, t+ht+mt+s<10%	Moderately Polluted, nutrient enriched but still well oxygenated (eutrophic)
Trophy IV	0<10%, hs<10%, eu≥50%	Highly nutrient -rich with low oxygen availability (Eutrophic)
Saprobic Index (ROTT SI)		
	Abwassermeider	
< 1.3	Pollution sensitive	Güteklasse I und besser (no or very liittle pollution)
	Abwassertolerante	
1.4 – 1.7	Pollution-tolerant weak	Güteklasse I-II (slight pollution)
1.8 – 2.1	moderate to strong	Güteklasse II (moderate Pollution)
	Abwasserverwerter	
2.2 – 2.5	Saprophile	Güteklasse II-III (moderately to heavily polluted)
2.6 – 3.0	Saprobionten	Güteklasse III (heavily polluted)
3.1 – 3.4		Güteklasse III-IV (heavily to very heavily polluted)
> 3.5		Güteklasse IV (very heavily polluted)

Trophic diatom index (TDI)	
Index value	Interpretation
< 20% of total valves belonging to tolerant taxa	Free of significant eutrophication
> 21% & <40% of total valves belonging to tolerant taxa	Some evidenced of organic pollution
> 41% & <60% of total valves belonging to tolerant taxa	Organic pollution likely to contribute significantly eutrophication of sites
> 61% of total valves belonging to tolerant taxa	Sites are heavily contaminated with organic pollution
Specific pollution-sensitivity index (IPS)	
>4.5	Better biological quality, no pollution
4.5-4	Almost normal water quality (slight change in diatom sensitive forms,
4-3	Moderate pollution or significant eutrophication
3-2	Dominant resistant species regression or disappearance of sensitive forms (reduced diversity), heavy pollution
2-1	Marked dominance of a few resistant species (many species have disappeared) very high pollution
Rott Trophic Index	
≤1.0	Ultraoligotrophic
1.1-1.3	Oligotrophic
1.4-1.5	Oligo-mesotrophic
1.6-1.8	Mesotrophic
1.9-2.2	Meso-eutrophic
2.3-2.6	Eutrophic
2.7-3.1	Eu-polytrophic
3.2-3.4	Polytrophic
>3.4	Poly-hypereutrophic

Supplementary Table 2. Monthly variation in the relative abundance of diatom community in Srikot Srinagar sampling sites. Species acronyms used in the table and figures are as listed in accordance with the species code of the OMNIDIA software. Srk - Srikot, Srn - Srinagar

		Jul-21		Aug		Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Jun-22	
		Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm
ADCR	<i>Achnanthisdium crassum</i> (Hustedt) Potapova & Ponader	17.6	0	0	0	3.17	0	0	0	0	0	0	0	1.42	5.64	0.66	0.73	1.29	0	6.49	0	23.8	1.19	1.0949	0
ADLA	<i>A. latecephalum</i> Kobayasi	23.53	0	63	28.6	60.3	36.4	47.4	29.4	49.8	7.99	21.2	10.5	37.9	0	43.2	7.3	40	5.6	29	0.71	14.5	0.4	40.876	33.3
ADMC	<i>A. microcephalum</i> Kützing	0	0	3.7	0	0	0	0	0	1.06	0.3	2.83	1.35	1.42	0	4.32	4.74	1.94	3.2	0.43	1.42	0	1.0949	0	
ADMI	<i>A. minutissimum</i> (Kützing) Czarniecki	23.53	67.5	9.26	14.3	11.1	50	10.5	23.5	5.65	9.47	14.8	17.6	4.96	6.02	7.31	29.9	13.5	20.4	16	33.3	13.6	30.2	10.584	0
ADPC	<i>A. pseudoconspicuum</i> (Foged) Jittner et Cox	0	0	0	0	0	0	0	0	0	0	0	0.68	0	1.5	0	2.19	0	0	0	0	0	0	0	0
ADPY	<i>A. pyrenaicum</i> (Hustedt) Kobayasi	11.76	7.5	0	0	4.76	0	5.26	17.6	0.35	0.59	13.8	7.09	6.03	33.5	1.99	4.01	8.39	5.6	20.3	20.6	2.13	11.1	1.8248	33.3
ADRI	<i>A. rivulare</i> Potapova & Ponader	0	0	0	0	0	0	0	0	0	0	0	0	0	1.88	0	0.36	0	0.4	0	0	0	0	0	0
ADMO	<i>A. cf. delmontii</i> Peres, Le Cohu et Barthes	0	0	0	0	1.59	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0	10.6	0	0	0	0
ACLI/ALIN	<i>A. lineare</i> W.Smith	0	0	0	0	0	0	0	0	0	0	0	0.68	0	0	1.09	0	1.2	0.43	0	0	0.79	0	0	0
ADMA	<i>A. macrocephalum</i> (Hustedt) Round & Bukhtiyarova	0	0	0	0	0	0	0	0	4.95	2.66	2.83	8.11	1.42	2.63	3.65	4.74	0	2.4	0	0	0.43	0	0	0
ADSU	<i>A. cf. subatomus</i> (Hustedt) Lange-Bertalot	0	0	1.85	0	3.17	0	5.26	0	0	0	0	0	0	0	1.46	0	0.4	0	0	6.81	1.98	0	0	0
ADCG	<i>A. convergens</i> (Kobayasi) Kobayasi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.13	0	0	0	0
AEEL	<i>A. exiguum</i> var. <i>elliptica</i> (Hustedt) M.A. Harper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0
ADJK	<i>A. jackii</i> Rabenhorst	0	0	0	0	0	0	0	0	0	0	0	0.34	0	0.38	0	0.36	0	0.8	0	0	0	0	0	0
AUGR	<i>Aulacoseira cf. granulata</i> (Ehrenberg) Simonsen (emend Genkal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	3.17	0	0	0
CAMB	<i>Craticula ambigua</i> (Ehrenberg) Mann	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0.43	0	0	0	0
CRDI	<i>C. cf. dissociata</i> (Reichardt) Reichardt	0	0	0	0	0	0	0	0	0	0	0	0	0.35	0	0.33	0	0	0	0.87	0	0	0	0	0
CDIS	<i>Cocconeis disculus</i> (Schumann) Cleve in Cleve et Jentzsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0	0	0.8	0	0	0.79	0	0	0
CPED	<i>C. pediculus</i> Ehrenberg	0	0	0	0	1.59	0	0	0	0	0	0	0	0	0	0	0	0	0	0.87	2.84	0.85	0.79	0	0
CPLA	<i>C. placentula</i> Ehrenberg	0	0	0	0	0	0	0	5.88	0	0.3	0.35	0	0	0	0.33	0	0	0	3.03	0	3.4	0	1.8248	0
CPLE	<i>C. placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	0	0	0	0	0	0	0	5.88	0	0	0	0	0	0	0.33	0	0	0	0	0	14	0	0	0
CPLI	<i>C. p. var. lineata</i> (Ehrenberg) Van Heurck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.87	0	0	0	0	0
CYCL	<i>Cyclotella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0.36	0	0	0	0	0	0	0	0
CATO	<i>C. atomus</i> Hustedt	0	0	0	0	0	0	0	0	0	0	0	0.34	0	0	0	0	0.65	0.4	0	0	0	0	0	0
CMEN	<i>C. meneghiniana</i> Kützing	0	0	0	0	0	0	0	0	0	0	1.06	1.01	0	0	0	0.36	0	4.8	0	0	0	0.4	0	0
CPST	<i>C. pseudostelligera</i> Hustedt	0	0	0	0	0	0	0	0	0	1.18	0	0.68	0	0	0	0	2.4	0	0	0	0	0	0	0
CAEX	<i>Cymbella excisa</i> Kützing	11.76	0	0	14.3	4.76	4.55	5.26	0	0	0.89	10.6	20.9	0.71	5.64	5.65	15.7	5.81	13.6	0	24.1	0.43	7.54	15.328	16.7
CEAN	<i>C. excisa</i> var. <i>angusta</i> Krammer	0	0	0	0	0	0	0	0	0	0.3	0.71	0	0	0	0	0.36	0	1.6	0	0	0	0	1.0949	0
CEPR	<i>C. e. var. procera</i> Krammer	5.882	0	0	0	0	0	0	5.88	2.12	0.59	8.13	3.72	0	0	5.65	1.09	0.65	2.8	0	2.84	0.43	3.97	0	16.7
CESC	<i>C. e. var. subcapitata</i> Krammer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	0	2.84	0	0	0	0
CPAR	<i>C. parva</i> (W. Sm.) Kirehner in Cohn	0	0	0	0	0	0	0	0	0	0	0.35	0	0	0	0	0	0	0	0	2.13	0	2.38	0	0
CPVA	<i>C. pervarians</i> Krammer	0	0	0	0	0	0	4.55	0	0	0	0	1.01	0	0	1	0	0	0.4	1.73	0.71	0	0	1.0949	0
CTGL	<i>C. turgidula</i> Grunow in A. Schmidt et al.	0	0	0	0	0	0	0	5.26	0	3.89	7.4	1.06	0.68	0.35	0	2.19	0.65	0.8	0.43	0	0.43	1.59	2.5547	0
CTRO	<i>C. tropica</i> Krammer	0	0	0	0	1.59	0	0	0	0	0.71	1.06	0	0	0	0.33	0.36	0	1.2	0	0	0	0	0.7299	0
CSLP	<i>C. subleptoceros</i> Krammer	0	0	0	0	0	0	0	0	0	0.35	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0
CNCI	<i>C. neocistula</i> Krammer	0	0	0	0	0	0	0	0	0	1.06	0	0	0	0	0	0	0.65	0	0	0	0	0	0	0

	Jul-21	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun-22
	Srk	Srn	Srk	Srn	Srk	Srn	Srk	Srn	Srk	Srn	Srk	Srn
CRPF	0	0	0	0	0	0	0	0	0	0	0	0
CTUM	0	0	0	0	0	2.66	1.41	0.68	0	0	0	1.4599
CNZL	0	0	0	0	0	0.35	1.18	0	0.33	0	0	0
CNOV	0	0	0	0	0	8.13	1.41	0	0.33	0	0.87	0
DMES	0	0	0	0	5.88	0	0	0	0.66	0	0	0
DMON	0	0	0	0	0	0.35	1.78	0.68	14.2	8.27	0	0
DTEN	0	0	0	0	0	0	0	0.35	1.13	2.99	0	0
DVUL	0	0	0	0	0	0	0	0.35	0	0.66	1.42	0
DVER	0	0	0	0	0	0	0	0	0	0	0	0
DENT	0	0	0	0	0	0	0	0	0	0.43	0	0
ENMI	0	1.85	14.3	0	0	0.35	0.89	0.68	1.42	0.33	0.71	0
ESLE	0	0	0	0	0	0	0	0.34	0	0.66	0	0
ENSU	0	0	14.3	4.55	0	0	0	0	0	0	0	9.1241
ENCM	5.882	0	0	1.59	0	0	0	0.34	0	0.66	0	0.79
EUNO	0	0	0	0	0	0	0	0	1.09	0	0	0
FBCP	0	0	0	0	0	0	0	0	0	0.87	0	0
FCAP	0	0	0	0	0	0	0	0	0	0.4	0	0
FCPE	0	0	0	0	0	0.3	0	0	0	0	0	0
GCLA	0	0	0	0	0	0.35	0.59	0.35	0	0	0	0
GLGN	0	0	0	0	0	0.35	1.78	0	0	0	0	0
GMIN	0	0	0	10.5	0	0.35	0.89	0	0.35	1.13	0.87	1.4599
GOLD	0	0	0	0	0	0	2.66	0.35	1.01	0	0	0
GOLI	0	1.85	0	0	0	2.47	23.4	2.47	3.04	17.7	1.94	0.365
GPAR	0	3.7	0	0	0	0.35	2.66	0	0.35	1	0.43	0
GCLE	0	0	0	0	0	0	0	0	0	0	0	0.365
GPEX	0	0	0	0	0	0	0	0	0	0	0	0.365
GCON	0	0	0	0	0	0	0	0	0	0	0.79	0
GPRI	0	0	0	0	0	9.76	0.71	0	0.71	0	0	0
GPUM	0	0	0	0	0	2.66	0.35	0.34	0.35	0	0.87	0.365
GSCL	0	0	0	0	0	0.59	0.35	0	0	0	0	0
GANG	0	0	0	0	0	0	0	0.35	0	0	0	0
GSCA	0	0	0	0	0	0	0	0	0	0	0	0
HLMO	0	0	0	0	0	0.35	0.3	0.71	0.34	0	0.43	0
HVEN	0	0	0	0	0	0.35	0.3	0	0.33	0.73	0	0
HARC	0	0	0	0	0	0.35	0	0	0.36	0	0	0
KLAT	0	0	0	0	0	0	0	0	0	0	0	0
MVAR	0	0	0	0	0	0	0	0	0.65	0	0	0
NCPN	0	0	0	0	0	0.35	0	0.35	1	0.65	0	0
NCRY	0	0	0	0	0	0.35	0	1.88	1.82	0.33	0.43	0.7299
	0	0	0	0	0	3.04	0	0	0	0	0.43	0

		Jul-21	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun-22
		Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm	Srk	Sm
NRHY	<i>N. rhynchocephala</i> Kützing	0	0	0	0	0	0	0	0	0	0	0	0
NANT	<i>N. antonii</i> Lange-Bertalot	0	0	0	0	0	0	0	0	0	0	0	0
NTRV	<i>N. trivialis</i> Lange-Bertalot	0	0	0	0	0	0	0	0	0	0	0.43	0
NCTV	<i>N. caterva</i> Hohn & Helleman	0	0	0	0	0	0	0	0	0	0	0	0.365
NRCH	<i>N. reichardiana</i> Lange-Bertalot	0	3.7	0	0	0	0	0	0	0	0	0	1.0949
NMNA	<i>N. minuta</i> (Cleve) Cleve-Euler	0	1.85	0	0	0	0	0	0	0	0	0	0.365
NHRD	<i>N. harderi</i> Hustedt	0	0	0	0	0	0	0	0	0	0	0	0.365
NPNV	<i>N. perminuta</i> Grunow in Van Heurck	0	0	0	0	0	0	0	0	0	0	0	0
NITZ	<i>Nitzschia</i> sp.A.H. Hassall	2.5	0	0	0	0	0	0	0	0	0	0	0
NIST	<i>N. sinuata</i> var. <i>tabellaria</i> (Grunow) Grunow in Van Heurck	0	0	0	0	0	0	0	0	0.36	0	0.43	0.365
NLIN	<i>N. linearis</i> (Agardh) W.M.Smith	0	0	0	0	0.35	0	0.34	0	1.46	0	0	0
NDIS	<i>N. dissipata</i> (Kützing) Grunow	0	0	0	0	0.35	0	0.34	0	0.33	0	0	0
NDEME	<i>N. dissipata</i> var. <i>media</i> (Hantzsch) Grunow in Van Heurck	0	0	0	0	0	0	0	0	0	0	0	0.365
NILA	<i>N. lacuum</i> Lange-Bertalot	0	0	0	0	0	0	0	0	0	0	0	0
NPAL	<i>N. palea</i> (Kützing) W.Smith	0	2.5	0	0	0	0.35	0.36	0.38	0.73	0	0	1.8248
NPAE	<i>N. paleacea</i> (Grunow) Grunow in Van Heurck	0	7.5	0	0	0	0.59	0.34	0.35	0	0	0	1.19
NFON	<i>N. fonticola</i> Grunow in Cleve et Möller	0	0	0	0	0	0.59	0.34	0	1.46	0	0	0
NAMP	<i>N. amphibia</i> Grunow	0	0	0	0	0	0.3	0	0	0.36	0	0	0.365
NREC	<i>N. recta</i> Hantzsch ex Rabenhorst	0	0	0	0	0	0.35	0.34	0	0	0	0	0
NIFR	<i>N. frustulum</i> (Kützing) Grunow	0	0	0	0	0	0	0	0.33	0	0	0	0
NINT	<i>N. intermedia</i> Hantzsch ex Cleve et Grunow	0	0	0	0	0	0	0.34	0	0	0	0	0.365
NDRA	<i>N. draveillensis</i> Coste & Ricard	0	0	0	0	0	0	0.34	0	0	0	0	0
NACI	<i>N. acicularis</i> (Kützing) W.M.Smith	0	0	0	0	0	0	0.34	0	0	0	0	0
NSBL	<i>N. sublinearis</i> Hustedt	0	0	0	0	0	0	0	0.66	0	0	0	0
NINC	<i>N. inconspicua</i> Grunow	0	0	0	0	0	0	0.34	0	0	0	0	0
PTCO	<i>Platessa conspicua</i> (A.Mayer) Lange-Bertalot	0	0	0	0	0	0	0.34	0.38	0	0	0	1.0949
PLCM	<i>Planothidium lanceolatum</i> (Brébisson) Round et Bukhtiyarova	0	0	0	0	0	0	0	0.38	0	0	0	0
PINU	<i>Pinnularia</i> sp.	0	0	0	0	0	0	0.34	0	0	0	0	0
RCUR	<i>Rhoicosphenia curvata</i> (Kützing) Grunow	0	0	0	0	0	0	0	1.13	0	0	0	0
RSIN	<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	0	0	0	0	0	1.78	0.35	0.71	0.66	0.43	0	0
SINE	<i>Synedra inaequalis</i> Kobayasi	0	0	0	0	0	0	0.35	0.68	0.73	0	0	1.98
SUU	<i>S. inaequalis</i> var. <i>jumensis</i> Jüttner & Cox	0	0	0	0	0	1.06	1.35	2.84	1.13	0	0	0.4
SULN	<i>S. ulna</i> (Nitzsch.) Ehr.	0	1.85	0	0	0	1.78	1.01	0.35	0	0	0	2.78
SUOX	<i>S. ulna</i> var. <i>oxyrhynchus</i> (Kützing) O'Meara	0	0	0	0	0	0.3	0	0	0	0	0	0.365
SDOR	<i>S. dorsiventralis</i> O.Müller	0	0	0	0	0	0.35	0	0	0	0	0	0
SACU	<i>S. acus</i> Kützing	0	0	0	0	0	0	0	0	0	0	0	0
SRUM	<i>S. rumpens</i> Kützing	0	7.5	0	0	0	0.3	0.34	0	0	1.6	0.71	0.79
SPIN	<i>Staurirella pinnata</i> (Ehrenberg) Williams et Round	0	0	0	0	0	0	0.35	0	0	1.6	0.71	0
SPUP	<i>Sellaphora pupula</i> (Kützing) Merschikowsky	0	0	0	0	0	0	0	0	0	0	0	0
SSTM	<i>S. cf. stroomii</i> (Hustedt) Kobayasi in Mayama Idoi Osada & Nagumo	0	0	0	0	0	5.88	0	0	0	0	0	0.4
										3.28	0.43	0	0