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Epilithic Diatom Assemblages in a Mountain Stream of the Lesser Himalaya (India): Longitudinal Patterns

PRAKASH NAUTIYAL* AND ASHEESH SHIVAM MISHRA

Aquatic Biodiversity Unit, Department of Zoology & Biotechnology, H.N.B. Garhwal University, Srinagar 246174, India
* Corresponding author; Email: *lotic.biodiversity@gmail.com*

ABSTRACT

Epilithic diatoms were examined longitudinally with respect to trophic status and factor governing their distribution from a spring-fed lesser Himalayan stream; the Khanda Gad. The samples were collected at 4 stations from headwater to mouth; K1 to K4. The annual means of environmental variables - water temperature, channel width, depth, current velocity, discharge and dissolved oxygen increased from K1 to K4 downstream. The taxa were grouped into exceptionally high (>50%), moderate (20-50%) and low (10-20%) abundance. The species, *Achnanthidium minutissimum*, *Cymbella affinis*, *Cocconeis placentula* var. *euglypta* and *Gomphonema olivaceum*, were abundant longitudinally. The longitudinal variation in the taxa abundance downstream were; decreasing abundance (*Achnanthidium minutissimum*, *Planothidium frequentissimum*, *Platessa conspicua*), increasing abundance (*Cymbella affinis*, *Cocconeis placentula* var. *euglypta, G. olivaceum*) and other abundant taxa that appeared and disappeared. The trophic state was eutraphentic at K1 and K4, while mesoeutraphentic at K2 and K3. The share of eutraphentic and mesoeutraphentic taxa varied little at K1 but was considerably different at K4 compared to K2 and K3 where both forms accounted for 24-25% each.

Key Words: Lesser Himalaya, Epilithic Diatoms, Assemblages, Distribution Patterns, Trophic State

INTRODUCTION

The interest in Himalayan freshwater ecosystems is increasing because these ecosystems have experienced a lesser degree of human interference and can serve as potential reference sites for other mountain freshwater regions (Ormerod et al. 1994, Rothfritz et al. 1997, Nautiyal 2001, Nautiyal et al. 1996 a, Cantonati et al. 2001, Jüttner and Cox 2001). At the same time development and urbanization is affecting the Himalayan streams (Jüttner et al. 1996, Jüttner et al. 2003, Nautiyal et al. 1996 b, Nautiyal et al. 1997 a-b). Previous studies have shown the importance of diatoms in these mountain streams (Nautiyal 1984, Singh et al. 1994, Nautiyal et al. 1997 a, Nautiyal et al. 2000; Nautiyal et al. 2004a, b). Diatom assemblages are intimately linked to spatial (physical) aspects of the environment and can be used as a tool to identify and distinguish the habitat quality, microhabitats and different ecological zones (Margalef 1960, Round 1981, Kawecka and Szczesny 1984).

The diatom flora have been studied only in the major rivers of the Ganga (Alaknanda, Mandakini and Ganga) in the Himalaya (Nautiyal et al. 1996a, b, 1997a, b, 2004a, b, 2005, Nautiyal and Nautiyal 1999, 2002, Badoni et al. 1997). The diatom flora and diversity of low order spring-fed streams, which form an extensive network in the mountains, remain unknown except River Mandakini basin (Nautiyal et al. 2004a) and Henwal (Verma and Nautiyal 2009) in the lower Ganga basin. Low order streams emerge at different elevations all along the width of Himalaya while major glacier-fed rivers mostly emerge in Greater Himalaya and mainly drain Lesser Himalaya and Sivalik. Low order streams have been rarely examined with respect to the altitudinal and longitudinal zonation of benthic algae. The diatom assemblage at smaller and larger spatial scale can be used to assess the influence of human interference and land use on a typical Lesser Himalayan stream, since diatom communities are excellent indicators of environmental change (Ghosh and Gaur 1991, Cox 1991, Whitton and Kelly 1995, Nautiyal et al. 1996 b, Badoni et al. 1997).

Several studies have determined variations in assemblages on different spatial scales: along the length of the streams, between streams in different sub-basins, between many streams within one basin and between streams of large major river basins. Spatial variation along longitudinal gradients has been studied extensively in temperate zones including mountain streams (Whitton 1984, Ward 1986, 1994, Nautiyal and Nautiyal 1999).

The objective of the present study is to examine variation in relative abundance and structure of diatom assemblages on longitudinal and temporal scale in the Khanda Gad - a tributary of River Alaknanda, and to assess the trophic state of the stream as it represents a typical mountain stream that serves many villages in its catchment.

STUDY AREA

The Khanda Gad ('gad' means stream in local dialect) is a Lesser Himalayan spring-fed left bank tributary of the glacier-fed Alaknanda (Figure 1). The entire Khanda basin, composed mainly of schistophyllite and statythyllite (metasedimentaries) of the Kumaun super group (Kumar and Aggrawal 1975), lies between 30° 6' 42" to 30° 13' 23" N latitudes and 78° 41' 48" to 79° 5' 4" E longitudes covering an area of 96.7 km^2. The stream originates at an elevation of 2143 m and flows from south-east to north-west to join River Alaknanda at Billokedar (520 m altitude). Khanda Gad changes from first to second order stream within a short distance of 21 km. The stream was sampled at 4 stations (Figure 1). Sampling locations and other physical and chemical information are summarized in Table 1. The substratum consisted of large boulders (>256 mm), cobbles (64-256 mm) and pebbles (16-32 mm) in the upper stretch, to cobbles and pebbles in the middle section and moderately sized round-edged boulders and cobbles in the lower section.

At higher altitude, the slopes are covered by forest (>1400 m), while in the lower stretch, agriculture and two human settlements are the major land use in the Khanda Gad basin. At Pauri (a large township at >1800 m), organic, medical, and solid wastes along with drainage and oil washings from an automobile garage are carried by monsoon storm waters into the Khanda Gad. The mouth zone at Billokedar is a semi-urban locale, extensively used for domestic, recreational and religious activities. Villages surrounded by terraced agricultural land occur on the slopes of the basin. Water is abstracted from the middle and lower sections of the stream (<1000 m altitude) for agriculture and horticulture on the terraces on surrounding gentle slopes. Fertilizers and pesticides are used intensively in the fields around Khanda Chatti (K3, Figure 1) where the stream is also used for washing, bathing,etc. and by wildlife (larger mammals - barking deer, black bears, jungle cats and leopards).

The severe winters above 1800 m have little rainfall and the summers are hot (16-34 °C, Table 1) in the lower basin. The region has a short wet (monsoon) season from July to September and a long dry season from October to June with local rains. Bushes occur along the banks of the Khanda Gad but do not shade the stream.

MATERIALS AND METHODS

The sampling was carried out at regular monthly intervals from January to December 1998. Epilithic diatom samples were collected from cobbles. Samples were taken from left, middle and right parts of the stream Fat depths of 15-50 cm. Four to five small cobbles (64-128 mm size) were collected from different flow conditions such as above and below turbulent waters with fast flow and slow flow. Replicates were obtained within 2 m and kept separate. The selected cobbles lacked any visible growth of periphyton. A 3x3 cm area was marked using a sharp-edged razor. The periphyton were then scraped from the marked area using a razor and a brush to dislodge diatoms from crevices and minute cavities on the surface.. Samples were preserved in 4% formaldehyde solution. Samples for light microscopy were processed following Reimer (1962). The treated samples were washed repeatedly to remove traces of acid. Permanent mounts were prepared using Pleurax (RI 1.5) and examined under a BX-40 trinocular Olympus microscope (x10 and x15 wide field eyepiece) fitted with a PLANAPO x100 oil immersion objective. Diatoms were identified according to Hustedt (1931-59), Sarode and Kamat (1984), Krammer and Bertalot (1986) and Gandhi (1998). The slides are held at the Aquatic Biodiversity Unit of Garhwal University.

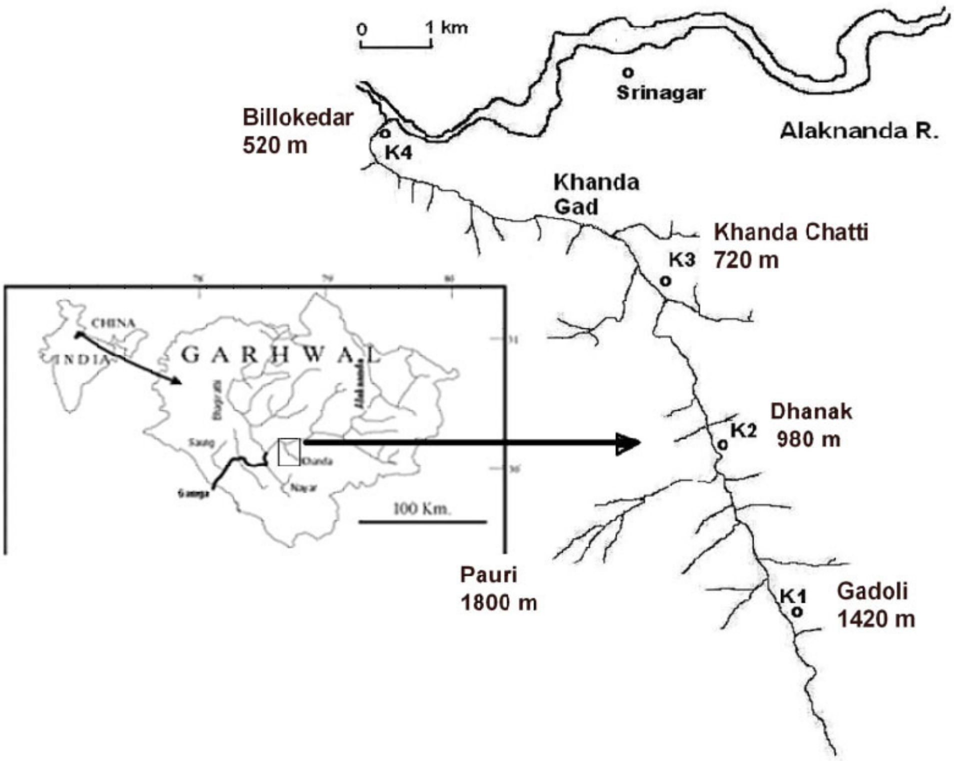

Figure 1. The spring-fed stream Khanda Gad from origin (> 2143 m altitude) to confluence with the glacierfed Alaknanda at Billokedar (520 m altitude) and the sampling locations (K1 to K4) along the 13.25 km stretch of the stream.

Table 1. Location and site characteristics of four sampling stations along Khanda Gad. Values for stream characters are annual averages along with ± SE.

Parameters	Near Gadoli (K1)	Near Dhanak (K2)	Near Khanda Chatti (K3)	Near Billokedar (K4)
Latitude (N)	30° 07' 01″	30° 09' 18″	30° 11' 30″	30° 12' 0″
Longitude (E)	78° 48' 08″	78° 47' 42″	78° 46' 53″	78° 44' 33″
Altitude (m)	1420	980	720	520
Land use	Forest	Agriculture	Agriculture, Horticulture	Domestic, recreational & religious activities
Depth (cm)	11.06± 3.31	19.1± 3.3	21.6± 4.71	21.04± 4.2
Stream width (m)	1.46± 1.62	2.6± 0.2	3.08± 3.43	3.49± 3.67
Current velocity (cm s^{-1})	37± 7	40± 7	47± 8	50± 8
Discharge (L s^{-1})	120± 50	300± 110	500± 180	560± 200
Water Temperature (°C)	16.38± 1.49	18.1± 1.43	19.8± 1.58	17.92± 1.49
Dissolved oxygen (mg L^{-1})	7.47± 0.20	8.29± 0.32	8.85± 0.39	8.86± 37

The relative abundances (as %) were determined on the basis of 400 valves from each sample for the three samples and their replicate from each station. During the monsoon fewer valves were found and the counts were therefore limited to 250 valves only. Variations in the abundance of taxon with >10% relative abundance at any one station and in any month over the period of observation were recorded to understand the spatial (longitudinal, altitudinal) patterns. Mean abundance of each taxon was compared for all four stations to observe the longitudinal variation in their abundance. The data on abundance was also used to record the taxa which often occurred together. In order to characterize the assemblages at each site, the taxa with >10% relative abundance in any one of the sample along transect were designated as abundant.

Digital probes for air (AT) and water temperature (WT), a EMCON velocity meter for water current velocity (CV) and standard methods (APHA 1996) for depth (D), discharge (Di) and dissolved oxygen (DO) were used to analyze all the water samples at the sites. The minimum-maximum values and mean (along with SE) over the sampling period were determined.

Data Analyses

Cluster analysis (Ward's method) was performed on log (x+1) transformed relative abundances of taxa from left, middle and right section of the river having >10% abundance with the help of STATISTICA ver. 6.0 to determine similarity among the stations. The sites groups were characterised using abundances of diatom taxa, based on the premise that a significant difference in altitude and/or source distance between the groups will affirm that there is a longitudinal pattern. The data matrix for November was also used to identify groups of species with similar abundance levels and to describe the composition of assemblages in the stream.

RESULTS

Physical and Chemical Characteristics

The mean air temperature, water temperature, width, depth, current velocity, discharge and dissolved oxygen increase gradually from K1 to K4 (Table 1). The air and water temperature exhibited an increase of 2 ºC from K1 to K2. A decline of 1 ºC was registered in air temperature and 2 ºC in water temperature at K4. The major increase in average depth (8 cm) was observed between stations K1 and K2, compared with K2 and K3 (2 cm), being similar at K3 and K4. The CV and DO showed a gradual increase. The discharge increased by 0.2 m^3 s^{-1} between each station from K1 to K3. The AT, WT, width, depth, CV and discharge were low during winter (December-January) at all stations. The DO was low in monsoon, usually August or sometimes July and high in winters, varying from December to February at different stations. At station K1 it was low in May (Figure 2).

Spatial and Longitudinal Variations in Abundance

The number of taxa exhibiting >10% abundance were more or less similar at K1 (16 taxa), K2 (18 taxa), K3 (17 taxa) and K4 (15 taxa; Table 2). *Coconeis placentula* var. *euglypta* indicated high monthly frequency at K1 and K4, while *Cymbella affinis-Achnanthes minutissima* and *Cymbella affinis* indicated high monthly frequency at K2 and K3, respectively (Table 2). *Achnanthidium minutissimum* (except K3 between 11-17), *Cymbella affinis*, *Gomphonema olivaceum* and *Cocconeis placentula* var. *euglypta* were found abundant at all four stations (Table 2). However, at >20% abundance, the other important taxa were *Platessa conspicua* at K1 *Navicula radiosa*, *Diatoma vulgaris*, *Gomphonema parvulum* at K2, *Pauliella taeniata*, *Achnanthidium divergens*, *Achnanthidium biasolettianum* and *Nitzschia palea* at K3 and *Gomphonema olivaceum* var. *calcarea* at K4 (Table 2). *Ulnaria ulna* was abundant at K2. At K2, *U. ulna* continues to be abundant and *Gomphonema intricatum* become important but are not abundant in K3, with the exceptions of *U. ulna* (disappears) and *G. parvulum*, which continues to be important in K3. They loose importance in K4 and a new set of important species *Nitzschia fonticola* appears in K4 samples.

Some taxa indicated longitudinal distribution in the Khanda Gad (Figure 3). The mean abundance of *Achnanthidium minutissimum*, *Planothidium lanceolatum var. rostrata* and *Planothidium conspicua* show gradual decrease while *Ulnaria ulna* and *Gyrosigma scalproides* shows punctuated decrease. Similarly *Nitzschia foticola, Gomphonema olivaceum, Cocconeis placentula* var. *euglypta* and *Achnanthidium divergens* show consistent increase while *Gomphonema parvulum* is slightly different owing to increase at K2 and K3 compared with K1 and K4.

Spatial and Longitudinal Variation in Assemblage Patterns

The diatom assemblages differed spatially as well as longitudinally in the Khanda Gad, primarily by virtue of dominants. Thus *Achnanthidium minutissimum* and *Cymbella affinis* formed dominant assemblage at K1 and K2, as compared to only *C. affinis* at K3 and *Cocconeis*

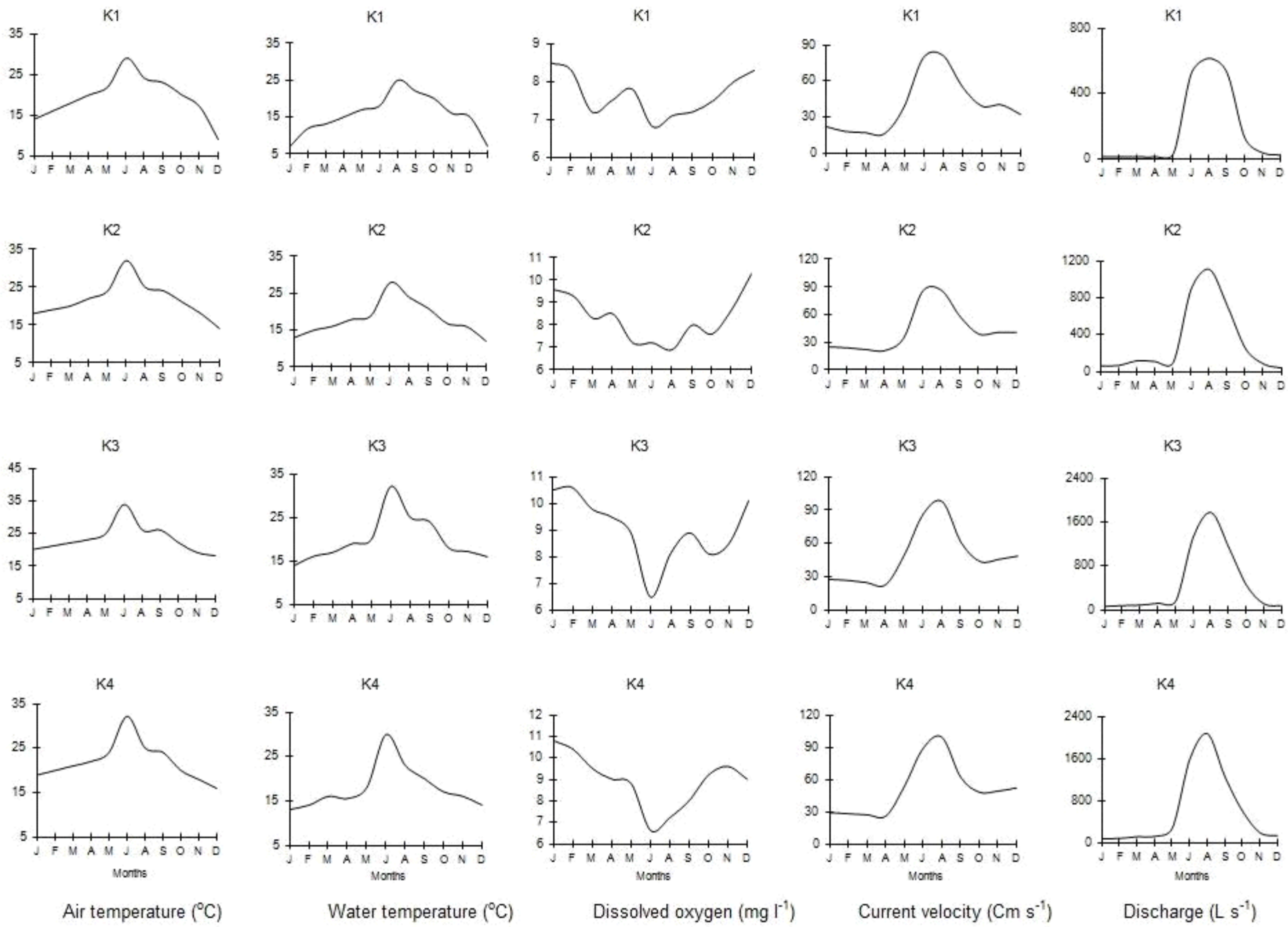

Figure 2. Monthly variations in the physical and chemical characteristics of the stream Khanda Gad. The air and water temperature (°C) exhibit identical profiles of annual variation as the stream is shallow and influenced by ambient regimes. The profile of these parameters was identical from K2 to K3 and differed slightly at K1 by virtue of peak prominence. The dissolved oxygen (mg L^{-1}) profile at K1 exhibited a tendency of homogeneity and hence differed from downstream stations where more variation was evident. The current velocity (m s^{-1}) profile was identical at all the stations while the discharge (cusecs) pattern except for minor variation at K1 and K2 was same.

placentula var. *euglypta* at K4. *G. olivaceum* was common to all assemblages from K1 to K4 and was always a part of *Cymbella affinis* dominated assemblage from K1 to K3 and *Cocconeis placentula var. euglypta* assemblage at K4.

Similarly, *Gomphonema parvulum* was associated with *Achnanthidium minutissimum* from K1 to K2 except with *C. affinis* at K3. However, *Achnanthidium minutissimum* was present in the assemblage which indicates its association with taxa along with *G. parvulum*. The assemblages *Achnanthidium minutissimum* - *Platessa conspicua*--*Gomphonema parvulum* and *Cymbella affinis*-*Ulnaria ulna* - *Gomphonema olivaceum* at K1, *Achnanthidium minutissimum*-*Gomphonema parvulum* --*Ulnaria ulna*-*Gomphonema intricatum*- *Gomphonema olivaceum* and *Cymbella affinis*-*Diatoma vulgare*-*Encyonema minutum* at K2, *Cymbella affinis* – *Gomphonema parvulum*, *Gomphonema olivaceum*, *Cocconeis placentula* var. *euglypta* – *Achnanthidium minutissimum* at K3 and *Cocconeis placentula* var. *euglypta* – *Cymbella affinis*- *Achnanthidium minutissimum* – *Gomphonema olivaceum* at K4. Cluster analysis indicated a gradual transition in the abundance of dominants in the assemblage from the upper to the lower stretch of the stream. The presence of similar kind of taxa in the assemblages at the stations resulted grouping of the different stations in the cluster (Figure 4). The taxa present at both the stations K1 and K2 were *Achnanthidium minutissima*, *Gomphonema parvulum*, *Cocconeis placentula* var. *euglypta*, *Synedra ulna*, *Cymbella affinis* and *Achnanthidium divergens* at K3 and K4 (Figure 5).

Table 2 Annual occurrences (frequency) of diatom taxa showing >10% relative abundance and those taxa exhibiting relatively exceptionally high (>50%), moderate (30-50%) and low (10-30%) abundance along the longitudinal and altitudinal gradient in the Khanda Gad. The high and moderate abundance is indicated by * and + respectively. The values not indicated by any symbol show low abundance. The taxa with abundance slightly higher than upper limit for moderate abundance have been retained in the low abundance category. Similarly, those slightly lower than lower limit for exceptionally high abundance were considered in that category. Since the table displays the highest category of abundance attained by the taxa, only those attaining highest abundance in any month of a year were considered.

Taxa	Monthly occurrence				Abundance (%)			
	K1	**K2**	**K3**	**K4**	**K1**	**K2**	**K3**	**K4**
Achnanthidium minutissimum (Kützing) Czarnecki	3	4	5	4	50-71*	50-60*	11-17	27.9-34.4
Cymbella affinis Krammer & Lange-Bertalot	4	4	10	5	45-58+	45-50+	55.6-61.5*	43.9-61.3*
Gomphonema olivaceum (Hornemann) Brebission	3	2	2	3	14-32+	10-20	11.9-28.2	87.3*
*Ulnaria ulna (*Nitzsch.) Compère	2	2	-	1	26-31+	20.5-36.3+	-	-
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	6	3	7	10	12-19	13-28	31-45+	22.1-45.8+
Gomphonema parvulum (Kützing) Kützing	2	2	3	2	18-34	19-34	10.6-31.8	-
*Cymbella tumida (*Bréb. in Kütz.*)* Grunow in Van Heurck	2	2	4	-	-	-	-	-
*Platessa conspicua (*A. Mayer*)* Lange-Bertalot	3	-	-	-	50*	-	-	-
Planothidium lanceolatum var. *rostrata* (Lange-Bertalot) Lange-Bertalot	2	2	-	-	10-17	-	-	-
Sellaphora bacillum (Ehrenberg) Mann	1	-	-	-	10-11	-	-	-
Rhoicosphenia curvata (Agardh) Lange-Bertalot	4	-	-	-	15-19	-	-	-
Gyrosigma scalproides (Rabh.*) Cleve*	3	-	-	-	-	-	-	-
Gomphonema sphaerophorum Ehrenberg	1	-	-	-	-	-	-	-
Planothidium fragilaroides (Petersen) Round & Bukhtiyarova	1	-	1	-	-	-	-	-
Rhoicosphenia vanheurcki (Kützing) Grunow	1	-	-	1	-	-	-	-
Diatoma vulgaris Bory	-	2	-	-	-	33.3-34.7	-	-
Gomphonema intricatum Kützing	-	4	-	-	-	11.2-23	-	-
Cocconeis placentula var. klinoraphis Geitler	-	1	-	-	-	-	-	-
Fragilaria capucina Desmaz	-	2	-	-	-	-	-	-
Navicula viridula Kützing	-	2	-	-	-	-	-	-
Navicula cryptocephala Kützing	-	1	-	-	-	-	-	-
Encyonema minutum (Hilse in Rabenhorst) Mann	-	1	2	1	-	11-17	-	-
Navicula radiosa Kützing	-	1	2	1	-	61-67*	-	-
Pauliella taeniata (Grunow) Round & Basson	-	-	1	-	-	-	20.8-28.8+	-
Achnanthes crenulata Grunow	-	-	2	-	-	-	-	-
Sellaphora pupula (Kützing) Mereschkowsky	-	-	1	-	-	-	-	-
Diatoma anceps (Ehrenberg) Kirchner	-	-	1	-	-	-	-	-
Achnanthidium divergens A. Cleve-Euler	-	-	1	2	-	-	22.2-30+	-
Achnanthidium biasolettianum (Grunow) Lange-Bertalot	-	1	2	1	-	-	25-29+	-
Nitzschia palea (Kützing) W. Smith	-	-	2	-	-	-	20-26+	-
Gomphonema olivaceum var. calcarea (Cleve) Van Heurck	-	-	-	1	-	-	-	58.8-62*
Nitzschia fonticola Grunow	-	-	-	3	-	-	-	19-23.2+
Navicula rhyncocephala Kützing	1	-	2	5	-	-	-	16.9-19
Gomphonema pala Reichardt	-	-	-	1	-	-	-	-
Total number of taxa	**16**	**17**	**17**	**15**				

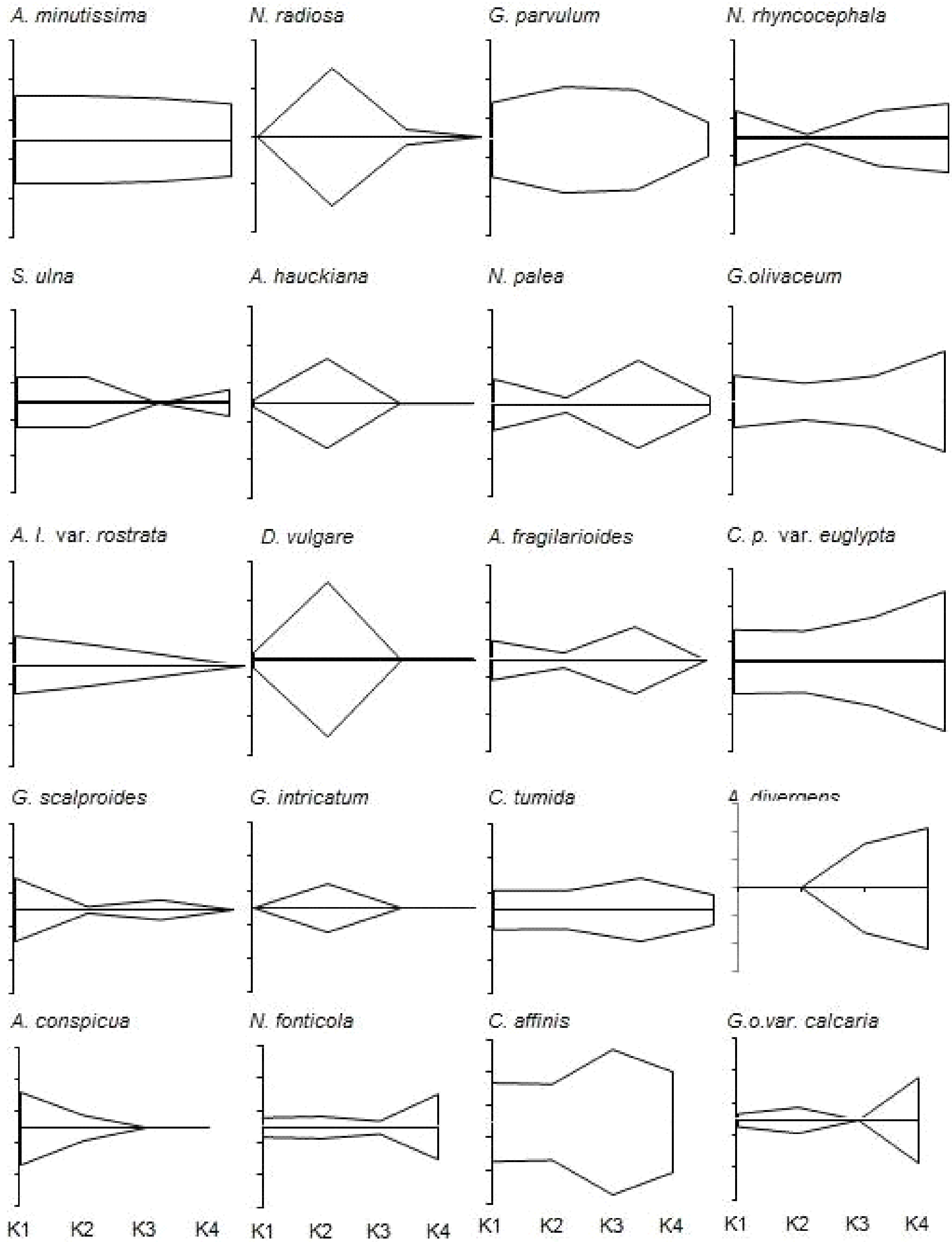

Figure 3. Longitudinal patterns of the abundance of some important taxa from K1 to K4.

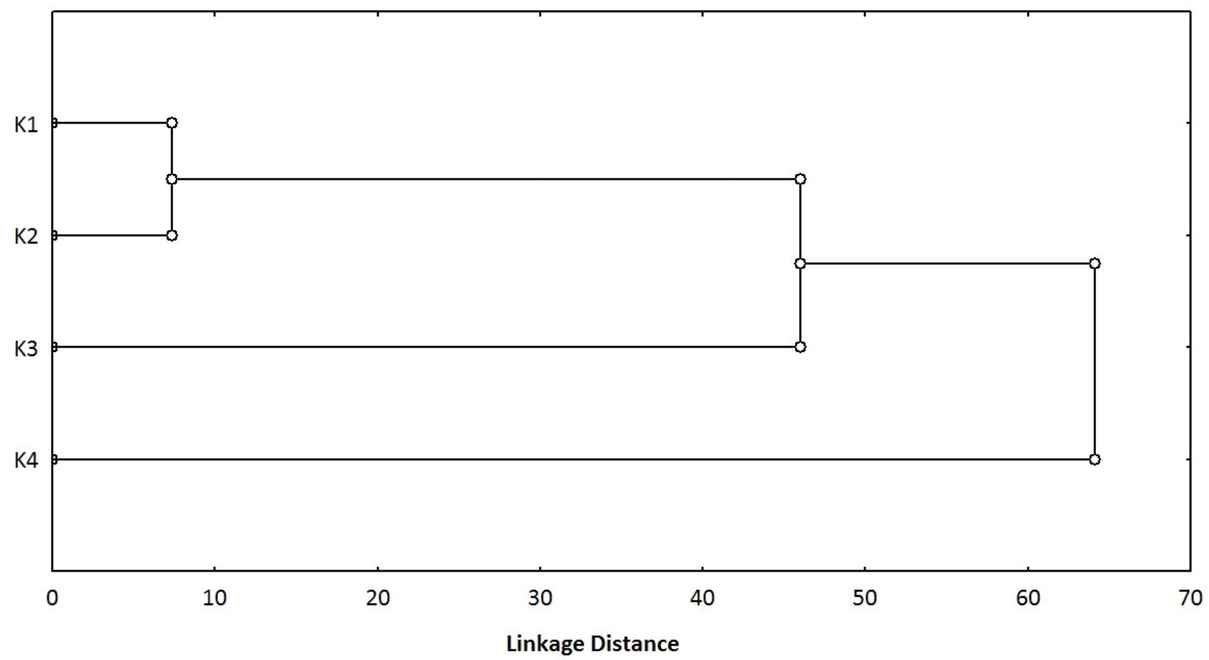

Figure 4. Cluster analysis to classify diatom taxa with identical abundance pattern at stations K1, K2, K3 and K4.

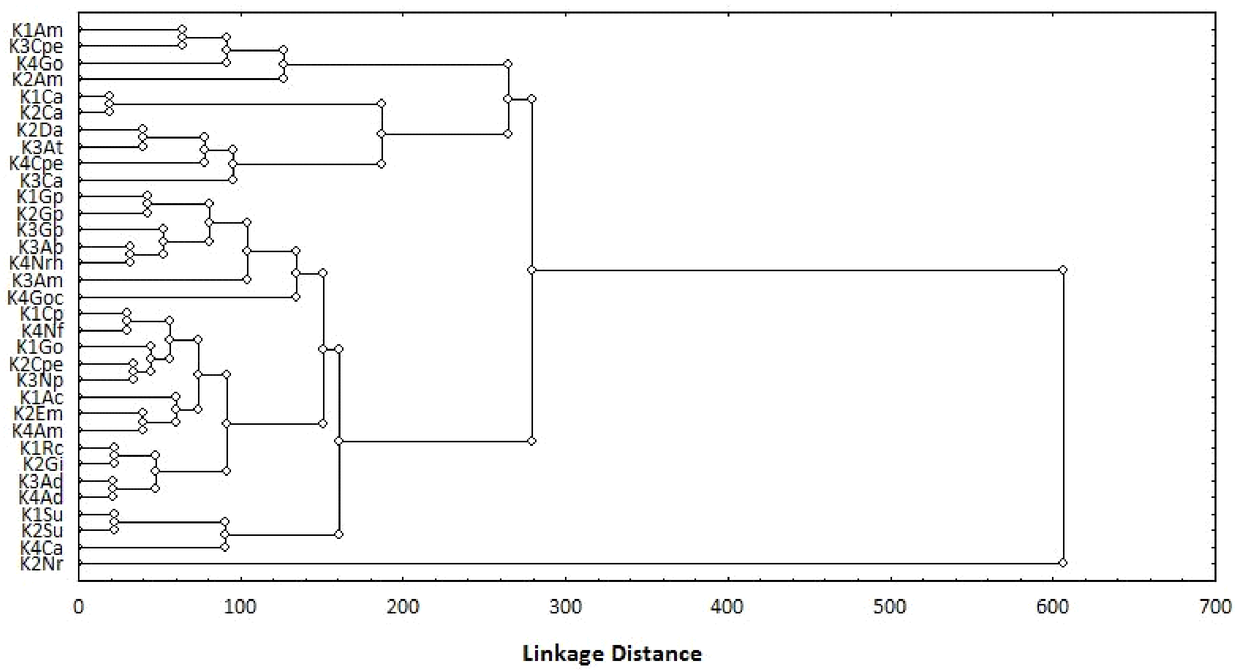

Figure 5 Cluster analysis indicates grouping of similar taxa with different stations.

Acronyms: Am- *Achnanthidium minutissima*; Gp-*Gomphonema parvulum*; Cpe-*Cocconeis placentula* var. *euglypta*; Rc-*Rhoicosphenia curvata*; Ca- *Cymbella affinis*; Go- *Gomphonema olivaceum*; Su-*Synedra ulna*; Ac-*Achnanthidium conspicua*; Dv- *Diatoma vulgare*; Nr-*Navicula radiosa*; Gi-*Gomphonema intricatum*; Em-*Encyonema minutum*; At-*Achnanthidium teaniata*; Np-*Nitzschia palea*; Ad-*Achnanthidium divergens*; Ab-*Achnanthidium biasolettiana*; Goc-*Gomphonema olivaceum var. calcarea*; Go- *Gomphonema olivaceum*; Nf-*Nitzschia fonticola*; Nrh- *Navicula rhyncocephala*

Trophic State

The general features at each station included alkaliphilic (42-46% of taxa), fresh- brackish (59-69% of taxa), N-autotrophic tolerant (39-50% of taxa), O_2 moderate (15-29% of taxa), β-mesosaprobic excluding K2 (39-50% of all taxa) and the proportion of aquatique strict and sub-aériens diatom taxa were almost similar except at K1. The trophic state was eutraphentic at K1 and K4, while mesoeutraphentic at K2 and K3. The share of eutraphentic and mesoeutraphentic taxa varied little at K1 but was considerably different at K4 compared to K2 and K3 where both forms accounted for 24-25% each (Table 3).

Table 3 Ecological preferences of epilithic diatoms (Van Dam et al. 1994) at four sampling stations along the Khanda Gad. Slight differences occurred in the trophic state and moisture requirements at K2 and K3. D = Ecological preference of the dominant taxa in the assemblage. For explanation of indicator values, see Annex 1.

Stations	**Parameters**	**Indicator Values for Ecological Parameters**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**D**
K1	pH			21	42	11			4 - Alkaliphilous
	Salinity	1	69	3					2 - Fresh brackish
	Nitrogen uptake	9	43	4	3				2 - Nitrogen autotrophic taxa
	O_2	17	18	15	10				2 - Fairly high
	Saprobity	4	39	2	12	3			2 - β - mesosaprobic
	Trophic state	4	1	10	14	23	3	17	5 - Eutraphentic
	Moisture	9	19	30	1				3 - Mainly occurring in water
K2	pH			19	43	11			4 - Alkaliphilous
	Salinity	6	59	8					2 - Fresh brackish
	Nitrogen uptake	11	46	3	7				2 - Nitrogen autotrophic taxa
	O_2	14	29	19	6				2 - Fairly high
	Saprobity	8	50	6	5	1			2 - β - mesosaprobic
	Trophic state	4	0	3	25	24	1	11	**4** - Meso-eutraphentic
	Moisture	22	21	22	1				**1** - Rarely occurring outside water
K3	pH			19	46	9			4 - Alkaliphilous
	Salinity	6	60	8					2 - Fresh brackish
	Nitrogen uptake	11	45	3	7				2 - Nitrogen autotrophic taxa
	O_2	13	28	18	5				**2** - Fairly high
	Saprobity	8	48	6	5	1			2 - β - mesosaprobic
	Trophic state	2	0	8	24	24	1	11	**4** - Meso-eutraphentic
	Moisture	22	20	22	1				**1** - Rarely occurring outside water
K4	pH			25	45	7			4 - Alkaliphilous
	Salinity	13	62	2					2 - Fresh brackish
	Nitrogen uptake	22	39	5	2				2 - Nitrogen autotrophic taxa
	O_2	14	27	20	7				2 - Fairly high
	Saprobity	14	39	5	9	2			2 - β - mesosaprobic
	Trophic state	5	0	6	9	28	2	21	5 - Eutraphentic
	Moisture	19	28	20	1				2 - Mainly occurring in water
K1-K4		H'	6	E	1				
	pH			21	44	9			4 - Alkaliphilous
	Salinity	6	63	5	0				2 - Fresh brackish
	Nitrogen uptake	13	43	4	4				2 - Nitrogen autotrophic taxa
	O_2	14	25	18	7				2 - Fairly high
	Saprobity	8	44	5	8	2			2 - β - mesosaprobic
	Trophic state	4	0	7	18	25	2	15	5 - Eutraphentic
	Moisture	18	22	24	1				3 - Mainly occurring in water

DISCUSSION

By virtue of their indicator values diatoms have been used successfully to assess the water quality of streams in various parts of the globe (Palmer 1969, Lange-Bertalot 1979, Eloranta 1994, Van Dam et al. 1994, Leland 1995, Prygiel et al. 1999, Potopova and Charles 2002, Bucka 2004, Bak et al. 2004, John 2004, Lobo et al. 2004, Ni Chathain et al. 2004). However, diatoms have not been used as indicators of the streams or river health in India nor do we have vast information on ecological preferences of different diatom species. The water temperature, dissolved oxygen, current velocity and discharge increased downstream from K1 to K4. Water temperature (7-32 °C), current velocity (16-99 cm s^{-1}) and DO (6.5-10.8 mg L^{-1}) of the spring-fed Khanda Gad were higher than in the glacier-fed Alaknanda (Nautiyal et al. 2004b). The concentration of PO_4 ions varied from 14 ± 0 µg L^{-1} in the upper stretch (between stations K1 and K2) to 20 ± 1µg L^{-1} in the lower region (between stations K3 and K4) while NO_3-N levels were constant (37 ± 7 µg L^{-1}) along the entire stretch (Dutt 2005).

The study on Khanda Gad shows that some diatom taxa viz *Achnanthidium minutissimum, Cymbella affinis, Cymbella placentula* var. *euglypta*, *Cymbella tumida* and *Gomphonema olivaceum* were present at all stations and times, while other taxa though present at most of the times in a year, were more restricted spatially such as *Planothidium fragilarioides*, *Planothidium lanceolatum*, *Rhoicosphenia curvata* at K1; *Gomphonema intricatum* at K2; *Gomphonema parvulum*, *Planothidium frequentissimum* at K1 and K2; while *Achnanthidium biasolettianum, Gomphonema pala*, *Navicula rhyncocephala* and *Encyonema minutum* at K4. Nautiyal (2005) observed *Planothidium fragilarioides* and *Rhoicosphenia curvata* in the gushing ice cold waters of Alaknanda at an elevation of 1000 m. Hence, the presence of certain taxa at some stations only indicates narrow range of their ecological preferences.

A sudden change in the frequency of *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* was notable and seems to punctuate the continuum attributed to the change in the physico-chemistry of the stream caused by changes in the landuse. However, this needs in-depth examination of more Himalaya streams before fitting them into a conceptual framework. Pielou (1984) suggested that the gradient will affect the distribution of species in any one of the three ways: in some situations the organisms may spread along the gradient and their distributions may be governed by the strength of the gradient; when stations are located not along a gradient but throughout a region in which the pattern of environmental variation is less well defined; in some cases the situation is intermediate between the above two. It arises when there is an abiotic gradient of known direction: e. g. downstream.

Spatial Scales of Mean Abundance

Two important features of longitudinal distribution were evident in the Khanda Gad; first, comparatively exceptionally high to moderate abundance of some taxa at spatial scale and second decline in the abundance of *Achnanthidium minutissimum* compared with increase in the abundance of *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* with decrease in altitude and increasing distance from source (K1 to K4). Exceptionally high levels of abundance were observed for *Achnanthidium minutissimum*, *Navicula radiosa*, *Cymbella affinis*, *Cocconeis placentula* var. *euglypta*, *Gomphonema olivaceum* var. *calcarea* and *Gomphonema olivaceum* in the Khanda Gad. Instances of exceptionally high abundance were also found in other mountain streams in Indian Himalaya (Nautiyal et al. 1996a, b, 2004a, Nautiyal and Nautiyal 2002 and at up to 91% (*Achnanthidium minutissimum*) in some streams of the Alps and the Himalaya (Cantonati et al. 2001).

Jüttner et al. (1996) reported high abundances of *Gomphonema parvulum* in the Kathmandu Valley of the Himalayan region but much lower in the Likhu Khola and Arun Valleys which were less affected by anthropogenic impacts. *Gomphonema parvulum* is known for tolerance towards organic pollution (Van Dam et al. 1994). In the Alaknanda at Srinagar *Cocconeis placentula* var. *euglypta* and *Cymbella affinis*, showed abundances between 10-20%, while *Gomphonema parvulum* and *Gomphonema olivaceum* were present at less than 10% abundance (Nautiyal et al. 1996 a, b). In contrast in the foothill regulated section of the Ganga (ca. 25 km in length) Badoni et al. (1997) reported that *Gomphonema parvulum* and *Gomphonema olivaceum* rarely attained >10% abundance, while *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* occasionally attained >10% abundance. This is because of *Achnanthidium minutissimum* which often attained abundance >10% and sometimes as high as 52% in the regulated section. However, the abundance of *Achnanthidium minutissimum* varied in the in upstream (62%) and downstream (57-69%) of the regulated section. Thus high abundances vary in the Nepal and adjoining west Himalaya. In the Alps and Himalayan mountain streams, *Cocconeis placentula* var. *euglypta* was found at 20-27 sites and *Cymbella affinis* at only 5 out of 40 sites (Cantonati et al. 2001). *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* have also been reported as the dominant taxa in other flowing waters (Round 1981, Venkateswarlu 1983, Kawecka and Szczesny 1984, Eloranta 1994).

Longitudinal Variations in the Assemblages

The assemblages differed longitudinally in the Khanda Gad, primarily by virtue of dominant taxa. Thus *Achnanthidium minutissimum* and *Cymbella affinis* dominated assemblage were present at K1and K2 (1420-980 m), compared to only *Cymbella affinis* at K3 (720 m) and *Cocconeis placentula* var. *euglypta* at K4 (520 m). These assemblages have not been recorded from other adjoining Himalayan region; Nepal Himalaya (Juttner et al. 2003). Kawecka and Szczesny (1984) also observed variations in the composition of the assemblage with altitude in the European river Dunajec: *Chamaesiphon polonicus* and *Hydrurus foetidus* in the first zone (1500-1000 m); *Diatoma hiemale* and *Melosira varians* in the second zone (1000-750 m) and *Diatoma vulgare*, *Diatoma vulgare* var. *ehrenbergii*, *Cymbella affinis*, *Cymbella helvetica* and *Nitzschia gracilis* in the third zone (750-600 m). The Dunajec's third zone resembled with stations K2, K3 and K4 of the Khanda stream where *D. vulgare*, *R. curvata*, *Cymbella affinis*, *Navicula radiosa*, *Navicula viridula* and *Encyonema minutum* were abundant. *Diatoma hiemale* in the first zone of the Dunajec was equivalent to *Achnanthidium minutissimum* or *Cocconeis placentula* var. *euglypta* in the Khanda. The water current velocity and discharge of the Khanda Gad was less compared to the Dunajec. *Cocconeis placentula* var. *euglypta* was the only abundant taxon common to the Khanda Gad and European mountain streams studied in the Tatra, Kebnekaise and the Fagaras Mts. (Kawecka 1980), which became abundant at 900-1500 m elevations. In the Khanda Gad this taxon was more abundant at altitudes less than 900 m.

The shift from *Achnanthidium minutissimum* dominated assemblage at K1 to *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* dominated assemblage at K4 can be attributed to the abiotic gradients in the Khanda Gad, primarily to the physical factors influenced by altitude and secondarily to distance from the source and longitudinal gradients of water temperature, depth, width, current velocity and substratum. The magnitude of slope of the river bed was high at K1 and K2 and low at K3 and K4, because elevation decreased rapidly (from 2140 to 1420 m) within a short distance (ca. 7.5 Km) from origin to K1 and from K1 to K2. There were no pools between these stations, just riffles. *Achnanthidium minutissimum* dominated the assemblages at K1 and K2 while *Achnanthidium minutissimum* and *Achnanthidium biasolettianum* were part of the *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* dominated assemblages at K3 and K4 respectively. Keithan and Lowe (1985) found that the streams with fast flow were suitable for luxurious growth of *Achnanthidium minutissimum* and other *Achnanthes* species. Nautiyal (2005) observed succession of dominance and abundance by an array of *Achnanthidium* species in the glacier fed Alaknanda at 800-1000 m altitude. Since, assemblages dominated by this species complex are common in upper stretch of the spring fed Khanda Gad as well as the glacier fed Alaknanda, the flow rather than the thermal regime becomes important for the abundance of *Achnanthidium minutissimum*. Though the current velocity was low at K1 and K2 compared with K3 and K4, the turbulence caused by swift flow over larger boulders compared with cobbles and pebbles at K3 and K4 provides ideal habitat. *Achnanthidium minutissimum* dominated assemblages at K1 and K2 can be attributed mainly to turbulence and secondarily to disturbance to substratum by human activities owing to proximity of road, and movement of debris from the higher slopes. The taxon has high tolerance for stream sections impacted by human activities, especially altered flow and nutrient levels (Nautiyal and Nautiyal 2006). *Cymbella affinis* and *Cocconeis placentula* var. *euglypta* dominate the assemblages at K3 and K4 because of diminished turbulence as the stream flows through smaller riffles and large pools due to flatter slope and smaller substrate. These species are known be abundant at elevations from 500 to 700 m (Nautiyal 1996), flow and substratum being the obvious factors governing their abundance. However, various studies have indicated that flow (Round 1981), the chemical variables (pH and nitrate; Van Dam and Mertens 1995) and grazers (Karouna and Fuller 1992; McCormik et al. 1994) were important for the longitudinal distribution of diatom flora.

Saprobic and Trophic state

Examination of the Van Dam Indicator value shows that the diatom community of the Khanda Gad thus comprised of alkaliphilic (pH), fresh - brackish (salinity), N-autotrophic tolerant (nitrogen uptake metabolism), O_2 moderate (oxygen requirements), eutraphentic (trophic state), β-mesosaprobic (saprobity) and subaériens (moisture) forms. The diatom assemblages in the coastal streams in north Poland and Szczecin Lagoon respectively were also dominated by eutraphentic (eutrophic) and fresh brackish water forms while mesosaprobic (β - mesosaprobic) state prevailed in the latter (Bak et al. 2004, Zgrundo and Bogaczewicz-Adamczak 2004)

However, the trophic state varied at stations; K1 and K4 indicated eutraphentic while K2 and K3 méso-traphentic. The forms (taxa) showed variation with respect to the moisture requirements, primarily at K1 as the subaériens forms (mainly occurring in water bodies, also regularly on wet and moist places) accounted for 30%. At the downstream stations the share of subaériens, aquatique strict (never or very rarely occurring outside water bodies) and aquatique ou subaérien (mainly occurring in water bodies, sometime on wet places) varied little (20-22% at K2 and K3; 19-28% at K4). Thus the middle and lower sections of the stream harboured forms having similar moisture requirements. However, the larger share of subaériens and aquatique ou subaérien diatoms at K1 and K4 and similar share at K2 and K3 resulted in the stream being characterized by the sub-aériens category. The differences in the trophic state at K1 and K4 (eutra-phentic) compared to K2 and K3 (mesoeutraphentic) were due to greater share of eutraphentic forms at the former stations, especially at K4 compared to the latter stations where their share was at par with meso-eutraphentic forms. Thus, K1 did not have large number of eutraphentic forms. In fact 10% of mesotraphentic which occurred in low numbers at down-stream stations decreased the share of mesoeutraphentic forms thus elevating the share of eutraphentic forms. Hence, the longitudinal gradient of increase in the nutrient status is very much in existence. However, eutraphentic state does indicate similarity in the anthropogenic stress at K1 and K4, of which the severity was evidently higher at K4. It is notable that both stations are devoid of agriculture. Thus it may be said that agriculture related activities keep anequilibrium between the meso-eutraphentic and eutraphentic forms whereas direct human interference leads to increase of eutraphentic forms. In the whole stream the eutraphentic forms emerged as representative forms due to greater share at K1 (23%) and K4 (28%) and similar share at K2 (24%) and K3 (23%).

Cantonati et al. (2001) investigated the ecological preferences in the Himalaya and found 30-46% alkali-philous and 38-46% circumneutral taxa, 49% occurring in water bodies and in wet places, 11-19% meso-eutraphentic and 13- 25% eutraphentic. In present study the ecological preferences in the Khanda Gad were 42-46% of alkaliphilous and 19-25% circumneutral taxa. In respect of moisture, 20-30% taxa occur in wet places (subaerians), 19-28% aquatique or subareian, 9-22% aquatique strict, while trophic state consists of 23-28% eutraphentic, 9-25% mesotraphentic taxa. The anthro-pogenically impacted Khanda Gad has lesser share of circumneutral taxa and has equal share of moisture related taxa (3 categories). Jûttner and Cox (2001) based on Canonical Correspondence Analysis listed diatom species indicating anthropogenic influences due to artificial channel modifications in the Kumaon region (Himalaya, North west India). Ormerod et al. (1994) and Jûttner et al. (1996) similarly inferred changes in the diatom communities caused by anthropogenic stress in Nepal Himalaya.

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Annex 1. Seven levels of various parameters to assess Indicator Values of diatoms according to Van Dam et al. (1994)

	1	**2**	**3**	**4**	**5**	**6**	**7**
pH	acidobiontic	Acidophilous	Circumneutral	Alkaliphilous	Alkalibiontic	Indifferent	-
Salinity	Fresh	Fresh-brackish	Brackish fresh	Brackish	-	-	-
Nitrogen uptake	N- autotrophic*	N- autotrophic**	Facultatively N- heterotrophic***	Obligately N- heterotrophic****			
O_2 requirements	Continuously high (~ 100% saturation)	Fairly high (>75% saturation)	Moderate (>50% saturation)	Low (>30% saturation)	Very low (~10% saturation)		
Saprobity	Oligosaprobic	β –mesosaprobic	α-mesosaprobic	α-meso/polysaprobic	Polysaprobic		
Trophic state	Oligotraphentic	Oligo-mesotraphentic	Mesotraphentic	Meso-eutraphentic	Eutraphentic	hypereutraphentic	Oligo- to eutraphentic
Moisture	Never or very rarely, outside water bodies	Mainly occurring in water bodies, some-time in wet places	Mainly occurring in water bodies, also rather regularly on wet and moist places	Mainly occurring in wet and moist or temporarily dry places	Nearly exclusively occurring outside water		

*tolerating very small concentrations of organically bound nitrogen; ** tolerating elevated concentrations of organically bound nitrogen;
*** heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen;
**** needing continuously elevated concentrations of organically bound nitrogen