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Diversity and Seasonal Variations of Plankton Communities After Major Flash Flood in the River Mandakini of Garhwal Himalaya

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ABSTRACT

Plankton diversity acts as an ecological indicator of aquatic ecosystems due to their rapid response to environmental changes. Plankton samples were collected monthly for a period of 24 months. A total of 35 genera of phytoplankton belonging to three classes, Bacillariophyceae (21 genera), Chlorophyceae (9 genera) and Cyanophyceae (5 genera) were found. The abundance of phytoplankton was in the order, Bacillariophyceae (83%) followed by Chlorophyceae (9%) and Cyanophyceae (8%). Maximum phytoplankton density in winter season was attributed to the low water temperature, gentle water velocity, high transparency, availability of sufficient nutrients and most stable substratum. Eight genera of zooplankton belonging to three major groups, Protozoa (2 genera), Rotifera (5 genera) and Copepoda (1 genus) was recorded. Shannon-Wiener diversity index of phytoplankton and zooplankton was computed maximum to be 2.61 and 1.56 respectively in the winter season. PCA indicates *Cymbella, Navicula, Synedra, Cocconeis, Achnanthidium, Amphora, Nitzschia, Tabellaria, Fragilaria, Ulothrix, Spirogyra* and *Phormidium* to be most dominant genera in the Mandakini river. Total alkalinity, water temperature, transparency, velocity, dissolved oxygen, free carbon dioxide, turbidity, phosphate and nitrate were found to be the most important factors affecting plankton diversity in the Mandakini river.

INTRODUCTION

Plankton are free-swimming or floating organisms in aquatic ecosystems divided into two major groups such as phytoplankton and zooplankton. Plankton communities occupy the base of aquatic ecosystems functioning. They show seasonal fluctuation, multi annual trends and shifts in an aquatic ecosystem. An in-depth study of plankton communities is necessary to manage aquatic resources and to predict future ecological changes (Morabito et al. 2018). They are the excellent indicators of healthy aquatic ecosystems.

Phytoplankton are chlorophyll bearing microscopic organisms consisting mainly algae and belong mainly to Bacillariophyceae, Chlorophyceae and Cyanophyceae groups. Phytoplankton, are primary producers and source of food for various animal groups like zooplankton, macroinvertebrates, fishes, etc. Zooplankton are microscopic free-swimming animals represented by taxonomic groups like protozoans, rotifers, cladocerans, crustaceans and copepods. Zooplankton consume phytoplankton and thus connect primary producers and higher trophic levels in the aquatic ecosystems.

Flood events directly affect the freshwater organisms (plankton, periphyton, macrophytes, macroinvertebrates, fish, etc.) inhabiting a river by displacing or killing them. They change the geomorphology of the river thus influencing freshwater ecosystems. The structure of river ecosystems determines the quality and quantity of habitat that is available to freshwater organisms (Death et al. 2015). The discharge and velocity of the water increase during flash flood which dilutes the water and modifies the concentration of nutrients, therefore changing the processes at biological level (Muntean & Alexoaie 2013). River flooding in Himalaya is commonly caused by heavy rainfall in a short period, river blockade failure and sometimes snow melting. The Mandakini river hit by major flash flood during 16-17 June, 2013 resulted into big loss to aquatic flora and fauna and changed the geomorphology of the Mandakini river. Therefore, the present study was conducted to observe the status of plankton density, diversity and recovery of ecosystem after this major flash flood.

MATERIALS AND METHODS

Mandakini river, a perennial glacier-fed tributary of the river Alaknanda, flows in the Rudraprayag district of Uttarakhnd Himalaya. It originates from the Chaurabari Glacier and passes through Kedarnath (3684m a.s.l.), Rambara (2722m a.s.l.), Gaurikund (1838m a.s.l.), Kund (998m a.s.l.), Chandrapuri (827m a.s.l.), Agustyamuni (760m a.s.l.), Tilwara (724m a.s.l.) and ultimately merges with the river Alaknanda at Rudraprayag (620m a.s.l.) after covering its course of 72 km. Three sampling sites; S_1, S_2 and S_3 were selected along the Mandakini River at Kund, Agustyamuni and Rudraprayag (Fig. 1).

Monthly samples were collected from January 2014 to December, 2015 for the analysis of plankton density and diversity of the Mandakini river. The plankton collection was done by filtering 10 litres of river water through plankton net (0.1 mm mesh size) at each sampling site and samples were collected in the sample jars. While collecting water samples, minimum disturbance of water to prevent avoidance reaction by plankton was taken care of. The samples were preserved in 4% formalin in the plastic jars. The plankton taxa were identified under the light microscope and Sedgwick-Rafter cell of 1 mL capacity was used for counting the individuals. One mL of sample was transferred in Sedgwick-Rafter count cell and covered by cover slip, avoiding any kind of air bubble. Sedgwick rafter counting cell was placed under microscope after settling down of plankton for 10-15 minutes. The plankton were counted by moving the cell horizontally and the identification was done to the lowest recognizable level with the help of keys by APHA (2005), Ward & Whipple (1992), Wetzel (1979), Needham & Needham (1980) and Bellinger & Sigee 2010.

STATISTICAL ANALYSIS

The statistical analysis of the data was done using data analysis tool pack available in the MS Excel in PC. Shannon-Wiener Diversity Index, Principal Component Analysis (PCA) and Canonical Component Analysis (CCA) was done with the help of PAST version (2.1) software.

RESULTS & DISCUSSION

Phytoplankton

Phytoplankton community directly provides food for zooplankton, macroinvertebrartes and fishes of aquatic ecosystem. A total of 35 phytoplankton genera belonging to three major classes, Bacillariophyceae (21 genera), Chlorophyceae (9 genera) and Cyanophyceae (5 genera) were recorded from the Mandakini river after major flash flood (Table 1). Flash flood can deplete phytoplankton population, however it recovers soon after some months due to their short life cycle. Flood events result into increased water velocity, decreased food supply, increased sediment load and physical damage to aquatic organisms consequently affecting abundance and composition of aquatic organisms (Sagar 1986).

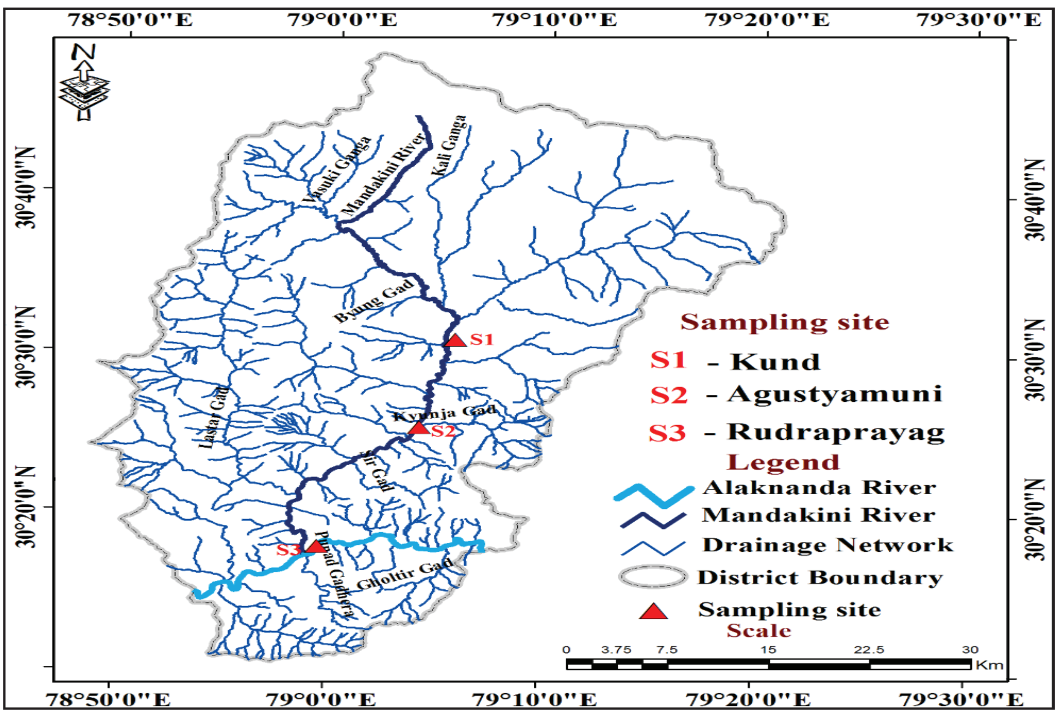

Fig. 1: Location of sampling sites in the drainage map of Mandakini river.

The average density of phytoplankton of the study area was calculated maximum (317.12±7.75 cells L^{-1}) in winter, moderate (271.02±5.54 cells L^{-1}) in summer and minimum (144.03±2.75 cells L^{-1}) in monsoon season (Fig. 2). Similar trend of seasonal fluctuation in plankton density was also observed in Ganga river and its tributaries in Garhwal Himalaya (Negi et al. 2012); river Mahanadi, Odisha (Panigrahi & Patra 2013) and Baldi river (Sharma et al. 2016). High plankton diversity and abundance in winter season was also reported by Kumar (2014) from glacial fed Goriganga river of Kumaun Himalaya, Uttarakhand. Highest plankton density during winter was attributed to the favourable environmental conditions like low water temperature, low water velocity, high transparency, availability of sufficient nutrients and most stable substratum. In monsoon season, the phytoplankton density and diversity were lowest due to high water velocity, high turbidity and most unstable substrate conditions during the period. These factors affect the growth of phytoplankton adversely in the monsoon season which was also reported from river Mahanadi by Panigrahi & Patra (2013).

The density of phytoplankton was in the order of Bacillariophyceae (diatoms) > Chlorophyceae (green algae) > Cyanophyceae (blue-green algae). A total of 21 genera of Class Bacillariophyceae were reported from the study area which included *Nitzschia, Navicula, Cymbella, Amphora, Fragilaria, Diatoma, Pinnularia, Gomphonema, Rhopalodia, Tabellaria, Cocconeis, Synedra, Encyonema, Fragilariforma, Achnanthidium, Surrirella, Gyrosigma, Cyclotella, Caloneis, Rhoicosphenia* and *Denticula.* Bacillariophyceae (83%) was a dominant class of phytoplankton and constituted a major component of producers in the study area and most resistant to water velocity. This class was also found dominant in the river Yeúilirmak, Turkey (Soylu & Gönülol 2003); Imo river, Nigeria (Ogbuagu & Ayoade 2012); Kenti River Republic of Karelia (Chekryzheva 2014) and Baldi stream, Doon valley (Sharma et al. 2016).

Chlorophyceae and Cyanophyceae were found very less in number in the Mandakini river. Their contribution was 9% and 8% respectively in the total phytoplankton population. Nine genera of Chlorophyceae (green algae) including *Ulothtrix, Hydrodictyon, Spirogyra, Chlorococcus, Cosmarium, Closterium, Desmidium, Stigeoclonium* and *Micrasterias* were recorded from the Mandakini river (Table 1). Seasonal density of Chlorophyceae was calculated to be highest (18.50±8.75 cells L^{-1}) at S_2 in summer and lowest (5.63±7.70 cells L^{-1}) at S_3 in the month of monsoon (Fig. 2). Maximum density of green algae (Chlorophyceae) in summer may be due to favourable water temperature and light intensity subsequently increasing photosynthetic activity. A total of 5 genera of Cyanophyceae (*Phormidium, Oscillatoria, Anabaena, Sprilium* and *Merismopedia*) were recorded from the study area. The average density of blue-green algae was computed maximum (25.34±8.92 cells L^{-1}) at S_3 in winter season and minimum (9.92±10.81 cells L^{-1}) at S_1 in monsoon season (Fig. 2). Hassan et al. (2004) also found a clear seasonal variation in phytoplankton communities in the ecosystem of Shatt Al-Hilla, Iraq. Maximum density of Cyanophyceae depends upon the concentration of phosphates and nitrates (Smith 1983). Phosphates and

Table 1: Plankton diversity of Mandakini river of Garhwal Himalaya (Uttarakhand).

S. No.	Types of Planktons	Name of Groups	Name of Genera	% Composition
1	Phytoplankton	Bacillariophyceae	*Nitzschia, Navicula, Cymbella, Amphora, Fragilaria, Diatoma, Pinnularia, Gomphonema, Rhopalodia, Tabilaria, Cocconeis, Synedra, Encyonema, Fragilariforma, Achnanthidium, Surrirella, Gyrosigma, Cyclotella, Caloneis, Rhoicosphenia, Denticulla*	83%
		Chlorophyceae	*Ulothtrix, Hydrodictyon, Spirogyra, Chlorococcus, Cosmarium, Closterium, Desmidium, Stigeoclonium Micrasterias*	9%
		Cyanophyceae	*Phormidium, Oscillatoria, Anabaena, Spirulina, Merismopedia*	8%
2	Zooplankton	Protozoa	*Tetrahymina, Loxodes*	22%
		Rotifera	*Notholca, Asplanchna, Branchionus, Dipleuchlanis propatula, Lepidella*	74%
		Copepoda	*Cyclops*	4%

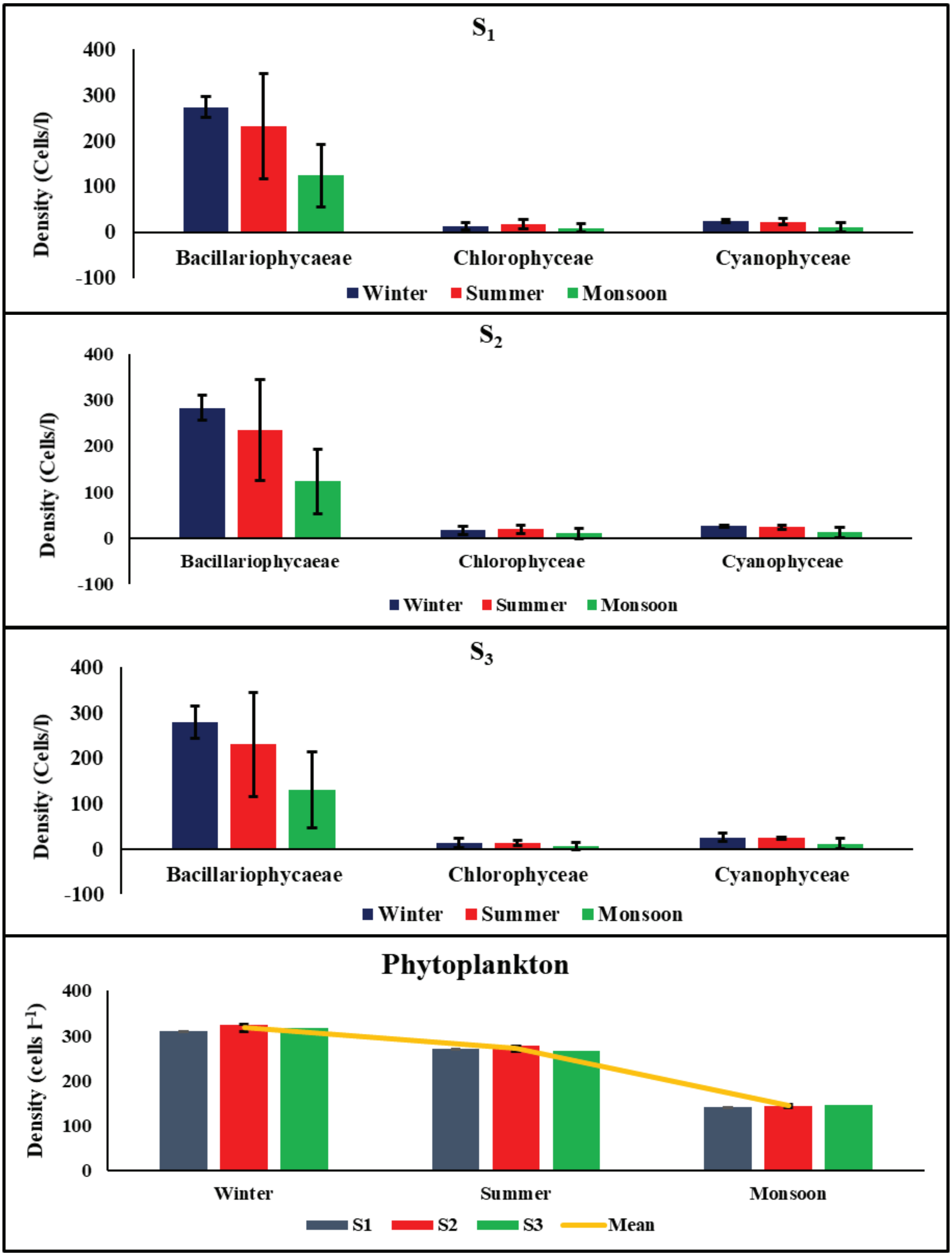

Fig. 2: Seasonal variations in the composition of phytoplankton (cells.L^{-1}) at three sampling sites (S_1, S_2 and S_3) in the Mandakini river of Garhwal Himalaya.

Table 2: Monthly variations in Shannon-Wiener Diversity Index ($\overline{H}$) computed for phytoplankton and zooplankton of the Mandakini river.

Months	Shannon-Weiner Diversity Index					
	Phytoplankton			Zooplankton		
	S_1	S_2	S_3	S_1	S_2	S_3
January	2.57	2.56	2.54	-	-	0.69
February	2.47	2.61	2.49	0.66	0.69	1.56
March	2.35	2.45	2.38	-	-	-
April	2.26	2.44	2.27	-	1.09	-
May	2.49	2.34	2.34	0.64	0.61	0.66
June	2.42	2.39	2.49	-	-	-
July	1.79	1.87	1.78	-	-	-
August	2.14	2.29	2.15	-	-	-
September	2.37	2.19	2.41	-	-	-
October	2.37	2.30	2.26	-	0.66	-
November	2.41	2.47	2.23	1.08	0.50	-
December	2.34	2.34	2.30	-	-	-

nitrates were also found to influence the phytoplankton density and diversity in the present study as shown by CCA.

Shannon-Wiener diversity index of phytoplankton ranged from 1.79 at S_3 in July to 2.61 at S_2 in the month of February in the Mandakini river (Table 2). Water velocity was the most important factor affecting the phytoplankton density and diversity mainly filamentous green and blue-green algae. The water velocity of the lotic body affecting filamentous phytoplankton was also observed in the river Alaknanda by Gusain (1994). Number of phytoplankton decrease due to turbulence and unstable substrata caused by water current was also reported by Chandler (1937) and Wetzel (1975).

Principal Component Analysis (PCA) was done for site-wise representation of various phytoplankton taxa of the Mandakini river. A total of 35 genera of phytoplankton among 3 sampling sites were selected for PCA. PC1 explained 72.004% of the variation in the parameters with eigenvalue of 2946.7. PC1 was mainly represented by phytoplankton genera like *Cocconeis*, *Navicula, Amphora*, *Nitzschia*, *Spirogyra, Ulothrix* and *Tabellaria*. PC2 explained 27.996% of the variation in the parameters with eigenvalue of 1145.7. PC2 mainly represented by genera like *Cymbella*, *Achnanthidium, Phormidium, Synedra* and *Fragilaria* (Fig. 3). Most of the phytoplankton taxa clustered in the centre of the plot indicating their common occurrence at all the three sampling sites. However, some of the taxa like *Amphora* and *Achnanthidium* prevailed at S_1, *Nistzschia*, *Tabellaria*, *Cocconeis*, *Spirogyra* and *Ulothrix* were abundant at S_2 while *Cymbella*, *Navicula*, *Synedra*, *Fragilaria* and *Phormidium* were prevalent at S_3. Statistically, there was no significant difference in the abundance of various taxa among all the sampling sites, hence the sampling site fall apart in the plot.

Canonical Correspondence Analysis (CCA) was applied to examine the effect of physico-chemical parameters on phytoplankton density among sampling sites. A total of 13 physico-chemical parameters and 12 dominant genera of phytoplankton were selected for CCA. Axis 1 explained 75.17% of the variation in the periphyton abundance with eigenvalue of 0.0047183 and Axis 2 explained 24.83% of the variation in the periphyton abundance with eigenvalue of 0.0015583. Total alkalinity, water temperature, water velocity, nitrate, turbidity, dissolved oxygen, free carbon dioxide and phosphate act as the most important parameters affecting plankton density and diversity. However, conductivity, total hardness, transparency and pH were of secondary importance. Nowrouzi & Valavi (2011) also found environmental factors affecting phytoplankton abundance and diversity in Kaftar Lake. Total alkalinity and water temperature were important parameters and favoured the growth of *Synedra* and *Fragilaria* in the present study. Water velocity favoured the taxa like *Amphora, Achnanthidium* and *Navicula*. *Cymbella, Synedra* and *Phormidium* showed positive correlation with air temperature, turbidity and free carbon dioxide. Conductivity, pH, phosphate and nitrate favoured the growth of *Ulothrix, Cocconeis* and *Nitzschia. Spirogyra* and *Tabellaria* were well supported by the pa-

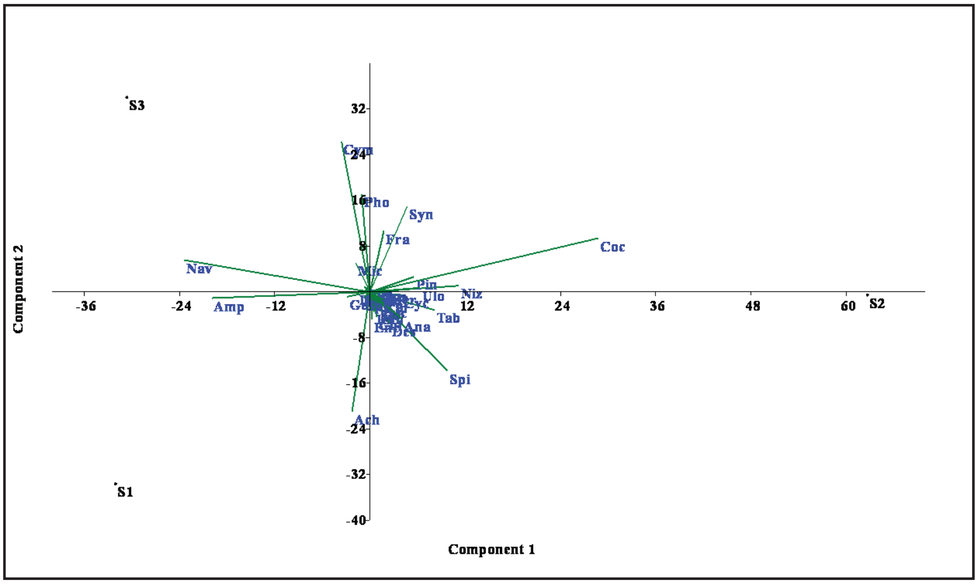

Fig. 3: PCA biplot depicting phytoplankton diversity among sampling sites (S_1, S_2 and S_3) in the Mandakin river of Uttarakhand. **Acronyms:** Niz-*Nitzschia*, Nav-*Navicula,* Cym-*Cymbella,* Amp-*Amphora*, Syn-*Synedra*, Ach-*Achnanthidium*, Tab-*Tabellaria*, Coc-*Cocconeis*, Pin-*Pinnularia*, Den-*Denticula*, Rho-*Rhopalodia,* Fra-*Fragilaria*, Cal-*Caloneis*, Dia-*Diatoma,* Gom-*Gomphonema,* Gyr-*Gyrosigma*, Enc-*Encyonema*, Frg-*Fragilariforma,* Sur-*Surirella*, Rho-*Rhoicosphenia*, Cyc-*Cyclotella,* Clo-*Closterium*, Ulo-*Ulothrix*, Sti-*Stigeoclonium*, Hyd-*Hydrodictyon*, Chl-*Chlorococcus*, Spi-*Spirogyra*, Mic-*Micrasterias*, Des-*Desmidium*, Cos-*Cosmarium*, Pho-*Phormidium*, Osc-*Oscilatoria*, Ana-*Anabaena*, Mer-*Merismapodia*, Spr-*Sprilium.*

rameters transparency and dissolved oxygen (Fig. 4).

Zooplankton

Zooplankton diversity was observed very low after major flash flood and none of the species could be collected in the first year of the study. However, 8 genera belonging to three major groups Protozoa (2 genera), Rotifera (5 genera) and Copepoda (1 genus) were found during the second year of observations. The group Protozoa was represented by two genera, *Tetrahymina* and *Loxodes*. The group Rotifera was represented by *Notholca*, *Asplanchna*, *Brachionus*, *Dipleuchlanis* and *Lepidella.* However, group Copepoda was represented by only one genus *Cyclops*. Rotifera (74%) dominated among zooplankton communities followed by Protozoa (22%) and Copepoda (4%) (Table 1). The composition and diversity of zooplankton provides information about the characteristics and quality of a water body. The nature of flood changes the aquatic biodiversity. Torrential flood destroys lotic habitats and leads to the decrease in biodiversity which was also reported in Vistula River by Napiórkowski & Naspiórkowska (2014).

Rotifera showed the maximum abundance followed by Protozoa and Copepoda in the Mandakini river during the present study. Rotifera to be abundant group of zooplankton in the river ecosystem was also noticed by many researchers in Parnapanema river, Brazil (Sampaio et al. 2002); Prairie river (Thorp & Mantovani 2005); Hinval freshwater stream at Shivpuri (Negi & Negi 2010); Haraz river, Iran (Jafari et al. 2011); Alcantara river, Italy (Rodrigues et al. 2013); Sakarya River Basin, Turkey (Dorak 2013); Cauvery river and Kapila river, Mysore (Sebastian & Yamakanamardi 2014). Rotifers can adapt themselves to adverse environmental conditions as they have a wide range of tolerance to many environmental changes. They are also used as good indicators of water quality. It was also observed by Marneffe et al. (1996), Napiorkowski (2009), Napiorkowski & Napiorkowska (2014).

Shannon-Wiener diversity index calculated for zooplankton ranged from 0.50 to 1.56 being highest in February at S_3 and lowest in November at S_2 (Table 2). The index increases slowly and reached its maximum in winter month indicating the readmission of zooplankton population after the monsoon flood. Changes in zooplankton abundance, diversity and community composition indicate the change or disturbance of environment. High diversity index indicates greater species richness and well-balanced community, while low diversity index indicates stress and impact.

13 physico-chemical parameters and 8 genera of zooplankton were selected for CCA. Axis 1 explained 82.99% of the variation in the zooplankton abundance with eigenvalue of 0.42316 and Axis 2 explained 17.01% of the variation in the zooplankton abundance with eigenvalue of 0.08673 (Fig. 5). Factors like transparency, dissolved oxygen, free carbon dioxide and turbidity were of primary importance

in affecting zoolankton abundance and diversity. However, pH, phosphate, total hardness, conductivity, velocity and nitrate were of secondary importance. Transparency and dissolved oxygen act as the most important parameters affecting the abundance of *Tetrahymina* and *Notholca. Dipleuchlanis propatula*, *Brachionus* and *Loxodes* showed a positive correlation with free carbon dioxide, turbidity, temperature and total alkalinity.

CONCLUSION

Present study concluded that plankton communities recovers soon due to the cleansing mechanism of flash flood and its density and diversity reaches maximum in winter season. The highest diversity of plankton in winter is attributed to most stable substrate conditions and favourable water quality indicating the good recovery of the ecosystem. Among phytoplankton, class Bacillariophyceae showed the maxi-

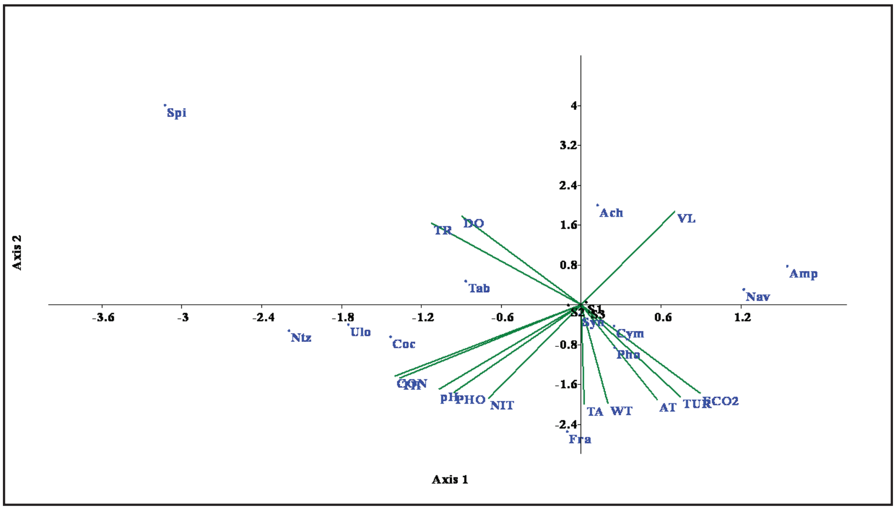

Fig. 4: CCA plot showing the effect of physico-chemical parameters on the dominant phytoplankton genera in the Mandakini river of Uttarakhand. Acronyms: AT- Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO- Dissolved Oxygen, FCO_2-Free Carbon Dioxide, pH-pH, PHO-Phosphates, NIT-Nitrates, CON-Conductivity, TUR-Turbidity, Niz-*Nitzschia*, Nav-*Navicula,* Cym-*Cymbella,* Amp-*Amphora*, Syn-*Synedra*, Ach-*Achnanthidium*, Tab-*Tabellaria*, Coc-*Cocconeis*, Fra-*Fragilaria*, Ulo-*Ulothrix*, Spi-*Spirogyra*, Pho-*Phormidium*.

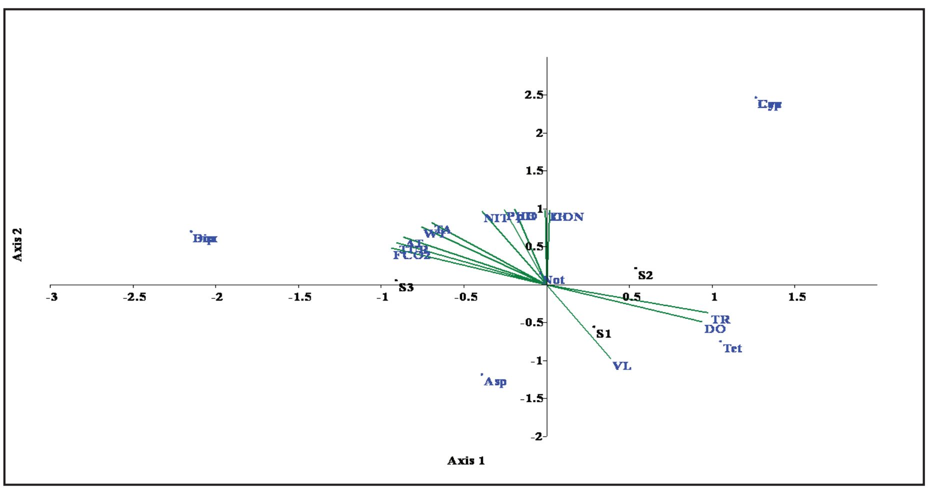

Fig. 5: CCA plot showing the effect of physico-chemical parameters on zooplankton diversity of the Mandakini river of Uttarakhand. Acronyms: AT-Air Temperature, WT-Water Temperature, TR-Transparency, VL-Velocity, TA-Total Alkalinity, TH-Total Hardness, DO-Dissolved Oxygen, FCO_2-Free Carbon Dioxide, pH-pH, PHO-Phosphate, NIT-Nitrate, CON-Conductivity, TUR-Turbidity, Tet-*Tetrahymina*, Lox-*Loxodes*, Not-*Notholca*, Asp-*Asplanchna*, Bra-*Brachionus*, Dip-*Dipleuchlanis*, Lep-*Lepidella*, Cyc-*Cyclops*.

mum abundance (83%) followed by Chlorophyceae (9%) and Cyanophyceae (8%) while Group Rotifera showed the maximum abundance (74%) followed by Protozoa (22%) and Copepoda (4%) among zooplankton in the Mandakini river. Total alkalinity, water temperature, transparency, velocity, dissolved oxygen, free carbon dioxide, turbidity, phosphate and nitrate were important physico-chemical factors regulating plankton diversity in the Mandakini river.

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