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DIATOM DIVERSITY UNDER EXTREME CLIMATE: A STUDY FROM ZANSKAR VALLEY, NW HIMALAYA, INDIA

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ABSTRACT

Understanding the dynamics of life under extreme climate provides valuable information about the diversity and causative factors that play a governing role in biotic adaptations. The biotic components either survive or vanish under extreme climate due to varying physical and chemical parameters. In the extreme climate regimes the biotic components that respond positively can provide important clues to the environmental conditions, physico-chemical alterations, soil-water interactions, erosion and transport dynamics, etc. In this regard, diatoms act as one of the major biotic communities to explore and explain the life under extreme climate. In the present study diatom diversity have been explored in water samples belonging to Penzi-la lake (6 samples) and Zanskar River (18 samples) and their response to underlying physical parameters at an altitude of ~4500m asl. These analyses contribute to the understanding of the hydrological and algological state of environment. The diatom abundance and diversity in the samples of Penzi-la lake show exceptional results as compared to Zanskar river. The study indicates the diatoms survive and proliferate even in the lake waters with low to moderate nutrient availability. The diatoms in river water samples were in low frequencies and hence their possible outcome could not be well established. The lake diatoms and physical parameters were also subjected to statistical test Detrended Correspondence Analysis (DCA) and it supports our hypothesis that diatoms and physico-chemical parameters bear premiere relation and this hold true under the high altitudinal stressed environments.

Key words: Diatoms, extreme climate, Zanskar, NW Himalaya, India.

INTRODUCTION

Diatoms are unicellular microscopic algae having siliceous cell wall (frustule), which make them unique for a wide range of applications. They are able to respond directly to various environmental conditions and are sensitive to several bio-physicochemical characteristics such as pH, salinity, total dissolved solids (TDS), temperature, nutrient concentrations, geology and herbivory of the water body e.g. river, stream or lake/pond (Peterson, 1987; Stanish *et al.,*, 2011). The diatom assemblages and distribution help us to understand habitat conditions, which provide information about nutrients availability like nitrogen (N), phosphorus (P), pristine or faulty water status, sunlight penetration, and also stressors (toxic substances) etc. All these factors govern the variability in diatom diversity (genera/species composition) in a given ecosystem. The distribution of diatoms, either in rivers, streams or lakes, has been used as one of the valuable indicators in environmental studies such as eutrophication, extreme regional localities, lake acidification and climate change (Round *et al.,*, 1990; Stoermer and Smol, 1999; Smol and Stoermer, 2010; Babeesh *et al*., 2016). The relationships between diatoms and water chemistry (cation-anion including trace metals) are well-established and effectively used by workers in context with rivers and lakes (Kelly and Whitton, 1995; Schonfelder *et al.,*, 2002; Kelly *et al*,. 2008; Beltrami *et al.,* 2012). Similarly, their distributions in older sediments (fossil) provide information about the prevailing conditions and have been successfully applied in limnological, palaeoenvironmental and palaeoclimatic studies (Berglund, 1986; Smol *et al.,* 1991; Dixit *et al.,* 1992; Charles and Smol, 1994; Moser, 1996). Although, physical and geochemical properties of the sediment can provide information about past environments (Lami, 2007), biological entities such as diatoms, pollen and chironomids provide credible information about the ecology and environment manifested by climatic deteriorations (Sharma *et al.,* 2012; Leipe *et al.,* 2014). In an exhaustive study, Stevenson (1997) enlisted well organized factors which control diatom distribution under varied climatic and spatial conditions. According to him, specifically in high altitude mountainous regions/terrains, effects of resources and stressors on the diatom assemblages is largely governed by climate, geology, and land use pattern, which in turn help us to assess accurately ecosystem components *viz.*, stream flow conditions, conductivity and ionic composition of the specific water body. Fairly good amount of studies are conducted in the relatively planner regions of India (Prasad *et al.,* 2004; Prasad and Eznzel, 2006; Achyuthan *et al.,* 2007; Singhvi and Kale, 2009; Singhvi *et al.,* 2010), however, very little information is available on freshwater diatom distribution in the ecologically sensitive Zanaskar Valley situated in the northwestern part of Ladakh (also referred as a cold desert), which comes under the Trans-Himalaya region of India (Prasad *et al.,* 1984). The harsh climate, rugged topography and strategic importance are probably the reasons behind limiting the workers to study the diatom distribution of this valley. The present study, thus aims to provide diatom diversity to infer the environmental conditions under the extreme climatic regime.

Study Area

The Ladakh region covering more than half of the Jammu and Kashmir state of NW India (Fig. 1) is referred as “a harsh and mountainous desert of wild beauty, set among the jagged peaks of the western Himalaya” (Norberg-Hodge, 1995). Climatically, it is also termed as “the cold desert of India” receiving moisture largely from the mid latitude westerly’s brought from the Mediterranean region in the form of winter snow (Raj and Sharma, 2013). The region experiences extremely low temperatures (25°C below freezing point), scanty precipitation

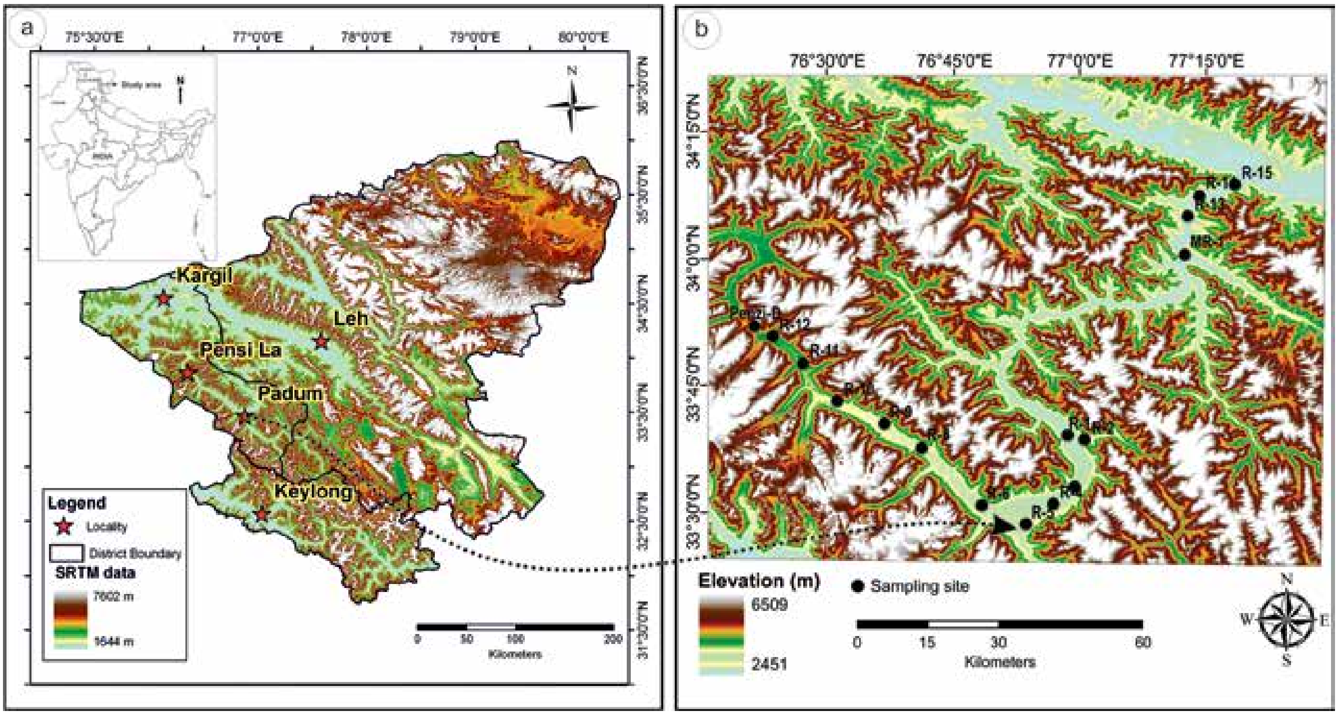

Fig. 1: a. Location map of the study area. The shuttle radar topography mission (SRTM) digital elevation map (DEM) of Ladakh showing the main cities; b. Close up SRTM DEM of the study area showing the sample locations near Penzi-la and along the Zanskar river.

(~80-100 mm/year) (Fort, 1983; Juyal, 2014) with large diurnal temperature variation and abridged growing season (Humbert-Droz and Dawa, 2004). The contributions of moisture from the Indian summer monsoon are very small and limited during the months of July – September (Fort, 1983; Negi, 2002; Lehmkuhl and Owen, 2005). It is vital to note, that the metrological data recorded from the Leh (major city of Ladakh region) station does not provide the true picture of meteorological conditions of the Ladakh region, because the station is situated at an altitude of ~3500 m asl in the valley region, which may not be identical for the relatively higher elevated regions of Ladakh. Due to the aridity and harsh climatic conditions, the vegetation is sparse in Ladakh region, however, plants that survive in this region are well adapted to the extreme conditions. These are relatively dwarf, stunt and xerophytic such as *Caragana*, *Artemisia* and *Juniperus* etc. Besides, at places, the suitability of topography, quality of soil and moisture also have profound control on the vegetation nature and type (Fort, 1983; Phartiyal *et al.,* 2005; Quamar *et al.,* 2016); however, the vegetation in floodplains is rather exceptional where shrubby forests are commonly noticed.

Geology of the area

Geologically, the Zanskar Range Mountains are extended in NW-SE direction and bounded by the Karakoram and Great Himalaya ranges in the north and south respectively. The Zanaskar range is primarily made up of crystalline rocks and also has infolded synclines of metamorphosed volcanic and carbonate beds, where the metamorphosed volcanics are of Permian age and, the carbonates are of Lower Triassic age (Thakur *et al.,* 1990; Thakur, 1992). The Zanskar River, which originates from the Drangdrung glacier near the Penzi-la (pass), is the main river of the Zanskar Valley and major tributary of the Indus River. The geomorphology of the entire Ladakh region is mostly influenced by frost cracked rocks, huge boulders, different types of moraines, scree and talus deposits with occasional occurrence of sand dunes. The varied nature of sediment deposits sometimes get profoundly reworked by various agencies like wind, glacial melt water streams, and mass movement processes, and also by intense rainfall events (cloud bursts).

METHODOLOGY

The present study discusses the results of twenty four (24) water samples collected during July-August, 2015 from Zanskar Valley, Ladakh (~4500 m asl) to delineate the diatom diversity changes in the lentic (lake) and lotic (river) environments in extreme climatic regions (Fig. 1). Among all water samples, 6 samples were collected from the Penzi-la Lake (Fig. 2) and 18 were from the Zanaskar River. The water samples were collected using plankton net in 500 ml bottle tied at the bottom of the net. ~5ml formaldehyde solution was added to preserve the plankton in samples from microbial decay or fungal attack. The plankton bearing water samples were centrifuged (REMI R-8C Laboratory Centrifuge) at 1000 rpm for 20 minutes. The supernatant was removed and the residue was treated with glacial acetic acid and

PLATE I

Diatoms assemblage 1. Bunch of ***Navicula*** diatoms; 2, 16. ***Encyonema hustedtii***; 3. ***Pinnularia*** sp.; 4. ***Hantzschia amphioxys***; 5. ***Amphora*** sp. 6. ***Stauroneis*** sp.; 7. ***Cocconeis placentula***; 8. ***Navicula cryptocephala***; 9. ***Navicula virdis***; 10. ***Achnanthidium minutissium***; 11. ***Pinnularia*** (girdle view); 12. ***Nitzschia levidensis***; 13. ***Pinnularia*** sp.; 14. ***Eunotia*** (girdle view); 15. ***Nitzschia palea***; 17. ***Eunotia***; 18. ***Caloneis ventricosa***

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Plate I

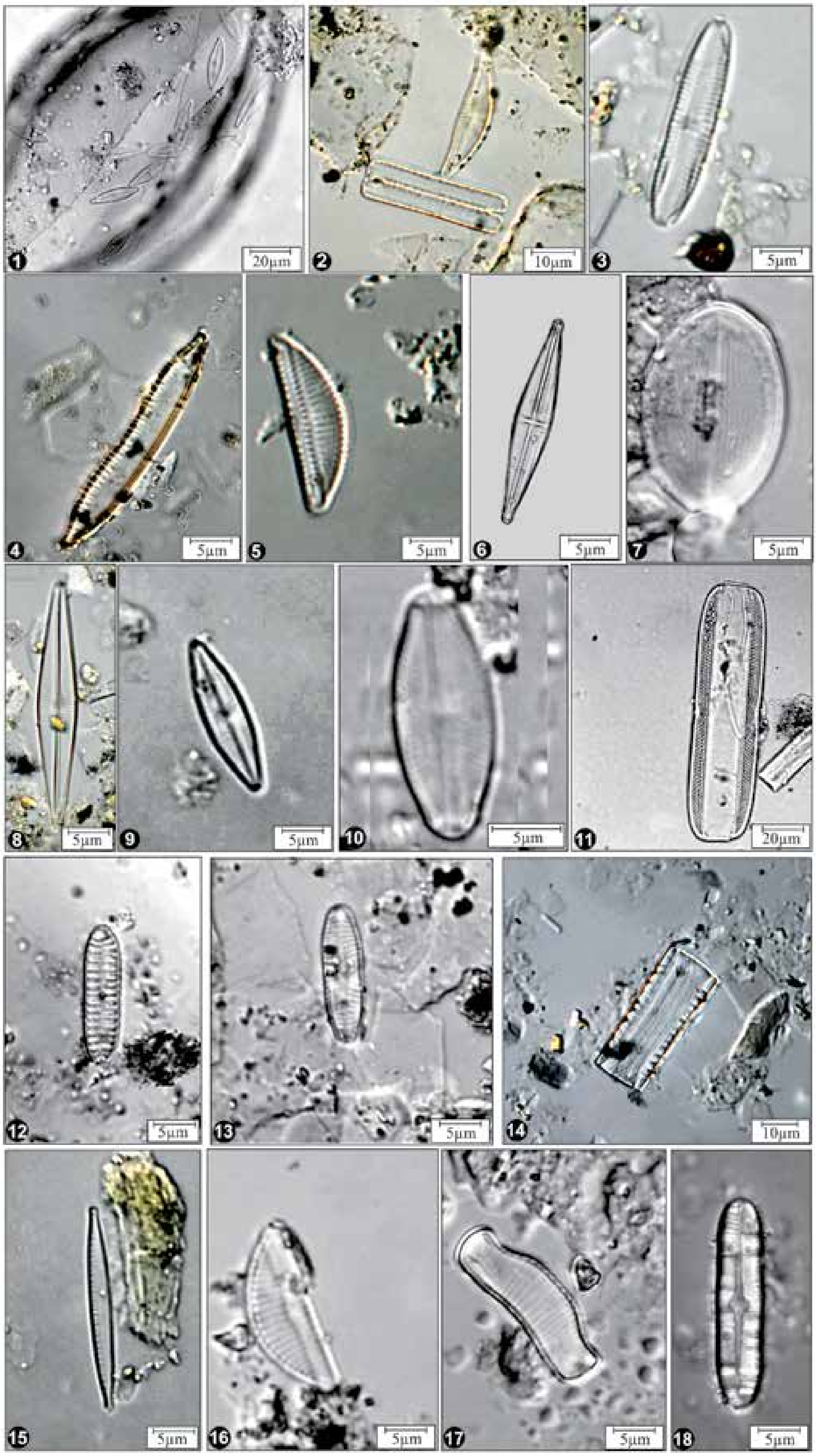

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Fig. 2. Field photograph taken facing west of the Penzi-la lake at an altitude of ~4450 m.

again centrifuged at 1000 rpm for 10 minutes for dehydration process. The glacial acetic acid was removed by decantation. The residue was treated with acetolytic mixture (acetic anhydride + Conc. H_2SO_4 in 9:1 ratio) for cleaning the valves of the diatom frustules. After cleaning with acetolytic mixture, the residue is again treated with glacial acetic acid and centrifuged and removed by decantation. The residue was washed thrice by distilled water using centrifugation method. The slides were prepared using standard techniques (Battarbee and Kneen, 1982; Battarbee, 1986). The identification, classification and counting of diatom frustules were followed as per standard procedure (Round *et al.,* 1990; Jacob, 2012; Karthick *et al.,* 2013) and other taxonomic literature.

It is relevant to mention here that out of 24 samples only 21 samples yielded, the diatoms response in lake samples was excellent, however, the river samples did not yield rich assemblage of diatoms (<50 cells) and three samples did not yielded any result. Hence for convenience and better representation the diatoms frequency distribution was used and the statistical analysis was run on TILIA 1.7 (Table 1). TILIA and TILIA graph software was used for preparation of range chart and CONISS was applied for cluster analysis (Grimm, 1987; 1990) (Fig. 3).

RESULTS AND DISCUSSION

Diatom proxy are frequently used as a reliable tool for environmental studies. In the present study also the high altitude region (~4500 m asl) coupled with stressful conditions show occurrence of diatoms both in lentic (lacustrine) as well as lotic (riverine) environments (Cabrol *et al.,* 2007). It has been demonstrated, on a broad geographic scale, that planktons (diatoms) are mainly influenced by the water chemistry and trophic state (Margalef *et al.,* 1976; Sabater and Nolla, 1991; Riera *et al.,* 1992; De Hoyos *et al.,* 2004). The TDS and EC are two major factors in the distribution of diatoms and it depends on bedrock geology and climate (Margalef *et al.,* 1976; Sabater *et al.,* 1991; Riera *et al.,* 1992). The diatom assemblages in the lacustrine environment show diverse population of diatoms representing about 20 genera (more than 200-300 counts), however, in riverine samples, the counts and the genera are relatively very low (<100 counts). The diatom population in the lacustrine environment contributes about 88%, while the riverine samples yielded only about 11% (in few cases lower than 1%) of the total assemblage. It is observed that the lake samples are dominated by benthic forms viz. *Navicula erifuga*, *Navicula* spp., *Pinnularia virdis*, *Nitzschia linearis*, *N. palea*, *N. intermedia*, *Frustulia* sp., *Encyonema hustedtii,* however, low occurrence of *Hantzschia amphioxys*, *Achnanthidium minutissium*, *Craticula* sp., *Eunotia*, *Gomphonema* etc. is also noticed (Plate 1). The diatoms in the riverine environment are dominated by species like *Surirella*, *Encyonema hustedtii*, *Achnanthidium minutissium,* which indicate moderate nutrient load in the water and differential energy levels in the flow regime. It is found that conductance has been one of the key factors other than salinity, temperature and pH in deriving diatom assemblages (Juttner *et al.,* 2000). The correlation of *Navicula* species with conductance has shown strong correlation (r = -0.71) which implies that high conductance is not suitable for the species of *Navicula* and thus this diatom is either absent of negligible in riverine samples.

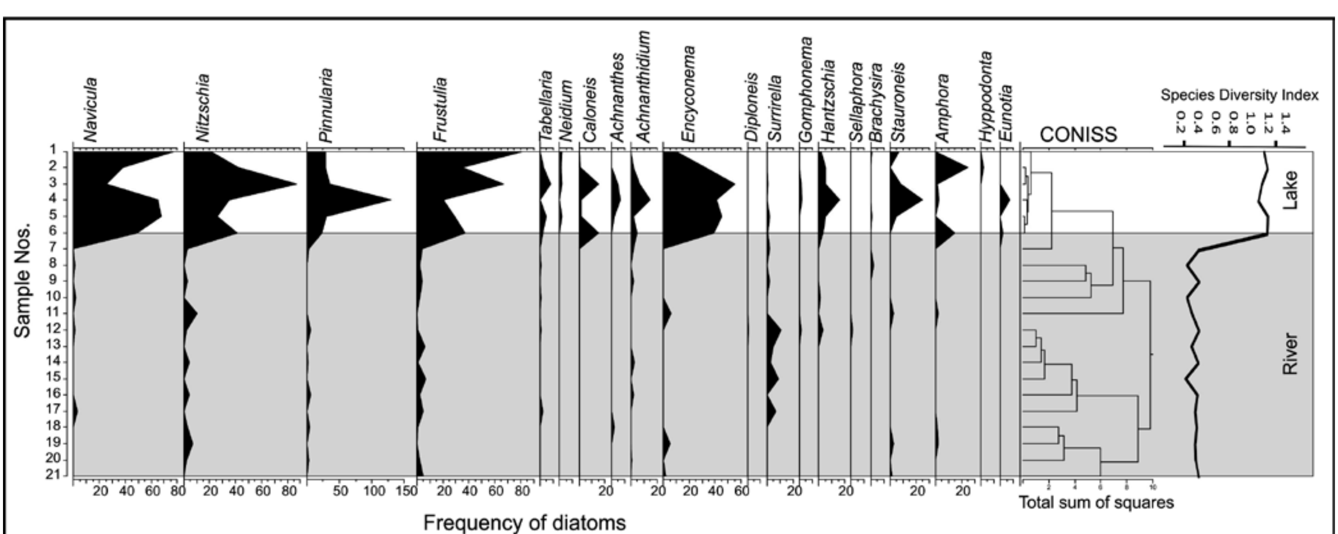

Fig. 3. Diatom frequency, CONISS and species diversity index.

Table 1. Diatoms frequency and species diversity of the samples from Zanskar valley, Ladakh

sample	code	*Navicula*	*Nitzschia*	*Pinnularia*	*Frustulia*	*Tabellaria*	*Neidium*	*Caloneis*	*Achnanthes*	*Achnanthidium*	*Encyconema*	*Diploneis*	*Surrirella*	*Gomphonema*	*Hantzschia*	*Sellaphora*	*Brachysira*	*Stauroneis*	*Amphora*	*Hyppodonta*	*Eunotia*	Species Diversity
Penzi D3	1	77	21	28	81	0	2	0	0	0	10	0	0	0	2	0	1	7	0	0	0	**1.18**
Penzi D2	1	38	42	28	35	3	1	1	0	2	32	0	0	0	5	0	0	0	25	2	0	**1.23**
Penzi D1	1	25	87	35	67	8	2	15	5	7	55	0	1	1	5	0	0	8	1	0	0	**1.16**
Penzi D6	1	65	35	130	20	0	0	2	7	15	41	0	0	2	16	0	0	25	3	0	7	**1.13**
Penzi D4	1	68	26	30	29	5	2	2	2	2	45	0	2	0	5	0	1	5	0	0	0	**1.23**
Penzi D5	1	49	41	23	37	2	0	15	0	5	39	0	1	0	3	0	0	0	15	0	2	**1.23**
R-1	2	0	3	3	4	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	**0.44**
R-2	2	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	**0.31**
R-3	2	0	3	0	4	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	**0.44**
R-4	2	2	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**0.31**
R-5	2	0	10	0	0	0	0	0	0	0	6	0	0	0	0	0	0	3	2	0	0	**0.37**
R-6	2	1	2	5	1	1	0	0	0	0	0	1	11	1	3	1	0	0	0	0	0	**0.44**
R-8	2	0	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	**0.36**
R-9	2	0	4	2	1	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	**0.44**
R-10	2	0	0	0	7	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	**0.30**
R-11	2	0	4	5	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	**0.44**
R-12	2	3	0	0	5	2	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	**0.41**
R-13	2	0	3	4	1	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	**0.43**
R-14	2	0	7	0	0	0	0	0	0	0	5	0	0	0	0	0	0	3	2	0	0	**0.41**
R-15	2	0	2	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**0.41**
MR-1	2	0	0	0	5	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	**0.44**

Abbreviations for Code: 1-Lake, 2-River

In the similar manner the species of *Nitzschia* (r = -0.68), *Pinnularia* (r = -0.55) and *Frustulia* (r = -0.68) have negative correlation with high conductance and as such these diatoms are found in abundance in lacustrine samples rather than riverine ones (Juttner *et al.,* 2000) (see Table 2). The results of the present study have also been plotted using TILIA 1.7 and cluster analysis by CONISS for differentiating and grouping the diatom population of two different environments (Fig. 4). The cluster analysis shows several groups; however, the assemblage can be categorized broadly into two major groups i.e. lacustrine and the riverine. This is also supported by the Shannon-Weaver Diversity Index (SWDI), which shows that the lacustrine environment have SWDI values ranging between 1.0 to 1.25, while in the riverine environment the SWDI value is less than 0.5. The cluster analysis is also supported by the SWDI values, which shows clear differentiation of lentic and lotic environments and the degree of primary productivity.

In order to understand the relationship between diatom (both abundance and species diversity) and the environmental variables, the variance in the diatom data set was first quantified and then its relationship with the environmental variables was studied using constrained ordination analysis. 20 diatom species and the species diversity (SWDI) were used as biotic response variable and 4 abiotic (pH, salinity, electrical conductivity and total dissolved solids) environmental parameters were considered to explain the variance among the biotic data. Detrended correspondence analysis (DCA) was done to choose the kind of constrained ordination analysis to be employed. The gradient lengths were 2.663 and 2.662 for DCA axes 1 and 2 respectively, which suggests a linear response model and hence redundancy analysis (RDA) was used (Ramette 2007). Since TDS (total dissolved solids) and EC (electrical conductivity) are in significant correlation, only EC was considered as one of the explanatory variables. So pH, salinity and EC were used as abiotic explanatory variables. As the units of response variables (abundance) and explanatory variables (pH, salinity and EC) are different, the scaled data set were used in the analysis. All these three environmental parameters account for 41% variance in the data set and this will become 49% if the category (whether it is Penzi-La lake or fluvial diatom species) is included in the explanatory variable list (Fig. 4). Among the 3 environmental parameters, EC and salinity account for 89 % (*F*-ratio and *p*-values: 4.5 and 0.025) and 10.9% (*F*-ratio and *p*-values: 3.5 and 0.070) respectively. It is also observed from the plot that the salinity is apparently controlling the diatom abundance, while the pH and EC (and TDS) control diatom species diversity (at least in the lacustrine environment)

Table 2. Correlation chart for selected diatoms and physical parameters

Matrix (Pearson correlation coefficient):

	Navicula	*Nitzschia*	*Pinnularia*	*Frustulia*	*Caloneis*	*Achnanthes*	*Achnanthidium*	*Encyconema*	*Surrirella*	*Stauroneis*	*Amphora*	pH	Salinity (PPT)	Conductivity (us)	TDS (PPM)
Navicula	1.00	**0.65**	**0.78**	**0.67**	**0.48**	**0.61**	**0.69**	**0.89**	-0.23	**0.63**	**0.46**	**0.61**	0.09	**-0.72**	**-0.689**
Nitzschia	**0.65**	1.00	**0.54**	**0.97**	**0.83**	**0.64**	**0.62**	**0.92**	-0.28	**0.47**	**0.46**	**0.62**	**0.68**	**-0.68**	**-0.655**
Pinnularia	**0.78**	**0.54**	1.00	**0.46**	0.28	**0.87**	**0.94**	**0.69**	-0.23	**0.94**	0.22	0.49	0.13	**-0.56**	**-0.542**
Frustulia	**0.67**	**0.97**	**0.46**	1.00	**0.84**	**0.55**	**0.53**	**0.92**	-0.17	0.34	**0.47**	**0.57**	**0.65**	**-0.69**	**-0.658**
Caloneis	**0.48**	**0.83**	0.28	**0.84**	1.00	0.39	**0.46**	**0.74**	-0.16	0.20	0.33	0.44	**0.61**	**-0.51**	**-0.489**
Achnanthes	**0.61**	**0.64**	**0.87**	**0.55**	0.39	1.00	**0.85**	**0.68**	-0.23	**0.90**	-0.06	0.40	**0.49**	-0.43	-0.411
Achnanthidium	**0.69**	**0.62**	**0.94**	**0.53**	**0.46**	**0.85**	1.00	**0.68**	-0.27	**0.89**	0.17	**0.51**	0.26	**-0.55**	**-0.540**
Encyconema	**0.89**	**0.92**	**0.69**	**0.92**	**0.74**	**0.68**	**0.68**	1.00	-0.28	**0.59**	0.45	**0.68**	**0.47**	**-0.76**	**-0.729**
Surrirella	-0.23	-0.28	-0.23	-0.17	-0.16	-0.23	-0.27	-0.28	1.00	-0.23	-0.25	-0.44	-0.20	0.01	0.003
Stauroneis	**0.63**	**0.47**	**0.94**	0.34	0.20	**0.90**	**0.89**	**0.59**	-0.23	1.00	-0.03	0.42	0.18	-0.45	-0.441
Amphora	**0.46**	**0.46**	0.22	**0.47**	0.33	-0.06	0.17	0.45	-0.25	-0.03	1.00	0.41	-0.10	**-0.47**	-0.455
pH	**0.61**	**0.62**	**0.49**	**0.57**	0.44	0.40	**0.51**	**0.68**	-0.44	0.42	0.41	1.00	0.13	**-0.67**	**-0.674**
Salinity (PPT)	0.09	**0.68**	0.13	**0.65**	**0.61**	**0.49**	0.26	**0.47**	-0.20	0.18	-0.10	0.13	1.00	0.00	0.030
Conductivity (us)	**-0.72**	**-0.68**	**-0.56**	**-0.69**	**-0.51**	-0.43	**-0.55**	**-0.76**	0.01	-0.45	**-0.47**	**-0.67**	0.00	1.00	**0.998**
TDS (PPM)	1.00	**0.65**	**0.78**	**0.67**	**0.48**	**0.61**	**0.69**	**0.89**	-0.23	**0.63**	**0.46**	**0.61**	0.09	**-0.72**	1.000

In bold, significant values (except diagonal) at the level of significance alpha=0.050 (two-tailed test)

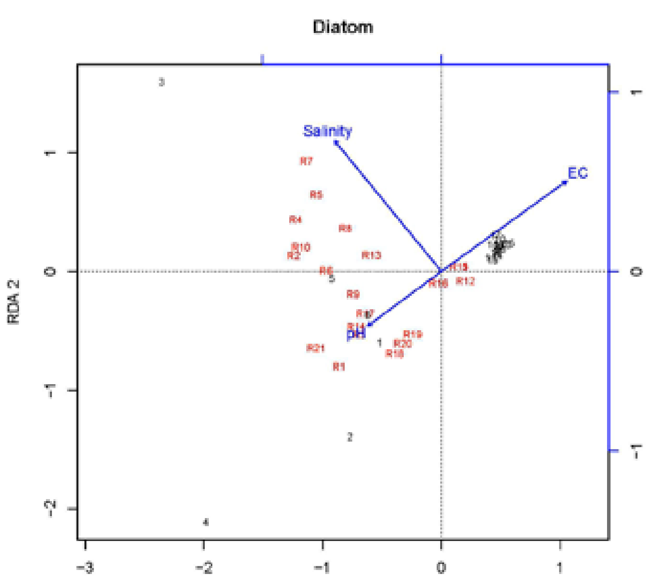

Fig. 4: Redundancy analysis (RDA).

positively and adversely respectively. It is clear from Fig. 3 that EC (TDS and pH) and salinity are independent as they are orthogonal to each other. All the analyses were done in R platform (R Core Team, 2014) using Vegan package from CRAN project (Oksanen *et al.,* 2015).

CONCLUSIONS

The present study gives some important insights on the diversity of diatoms in two different environmental settings under extreme/harsh climatic conditions. The main conclusion drawn out from this study are as follows:

Lake samples show high diversity of diatoms indicating high primary productivity even in high altitudinal regions experiencing harsh climatic conditions with low to moderate nutrient supply.

Low turnout of diatoms both in number as well as species diversity in riverine samples point to high runoff/ low nutrient supply and seems to be the limiting factor to allow diatom proliferation.

The statistical tests RDA and cluster analysis point towards role of physical parameters controlling the diatom distribution and diversity under high altitude stressed conditions.

The varying diatom population under extreme climatic conditions having low to moderate nutrient supply may also be attributed to geologic, geomorphologic and environmental setup (governing physical parameter as well) rather than vegetation or land use dynamics.

The present study points to adaptation of proxy (diatoms) for detailed picture of a macro- to microscale diversity in habitats and life emerging through the study of these extreme lakes in extreme environments.

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