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Zooplankton diversity and potential indicator species for assessment water quality of high altitude wetland, Dodi Tal of Garhwal Himalaya, India

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Abstract: The present study deals with the zooplankton density and identification of potential bioindicator for assessing the water quality of high altitude wetland, Dodi Tal over a period of one annual cycle (November 2014-2015). A total 32 species including the potential indicator belonging to four groups were recorded from Dodi Tal during the year. Over all contribution to zooplankton diversity was made by Rotifera (62%), Cladocera (16%), Copepoda (13%), and Protozoa (9%). Maximum density (353.00±35.69 ind.l^{-1}) of zooplankton was recorded in summer season and minimum (24.00±2.00 ind.l^{-1}) in monsoon season in Dodi Tal. Water quality and health of the wetland was assessed based on Shannon Wiener diversity index, physico-chemical parameters of water and potential indicator species of zooplankton. Some of the potential indicator species were identified *Brachionus caudatus, B. patulus, Cephalodella gibba* and *Colurella obtuse.* While, *Ascomorpha ovalis, Lrcane hastate, Trichocera, alona guttatta, Bosmina longirostris, Dephnia catwaba, Acanthocyclops vernalis and Arcella vulgaris* were found most tolerant species among zooplankton dwelling Dodi Tal. The present investigation revealed that the density of zooplankton species depended upon the physico-chemical parameters of the lacustrine environment. This was confirmed by Karl Pearson correlation coefficient and bioplotting Canonical Correspondence Analysis (CCA) between physico-chemical parameters and the zooplankton species.

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Keywords Water quality, High Altitude wetland, Zooplankton, Shannon Wiener index, Canonical Correspondence Analysis

Introduction

High altitude wetlands of the Himalaya are of paramount importance for providing drinking water to large number of trekkers, hikers, tourists, shepherds and the wild animals. To have a safe drinking water is one of the human rights (WHO 2004). Nearly 4 billon cases of acute gastrointestinal diseases are reported annually worldwide, of 88% are attributed to unsafe water and inadequate sanitation (WHO 2004). Changes in the freshwater environment accompanying an anthropogenic degradation of water quality are a cause of growing concern and require environmental monitoring of the surface water and the organisms inhabiting them (Vandysh, 2004).

Zooplankton are the most sensitive organisms that respond quickly to any change in the ecological condition. Hence, they can be used as ecological indicators. Zooplankton can flourish even at high altitude in comparison to other biodiversity components (Kumar et al. 2012). Zooplankton populations have also been used as pollution indicators (Pejler 1983; Nogrady et al. 1993; Okogwu 2010, Palmer 1969). Zooplankton are the important biotic component of aquatic ecosystems, As these are the intermediate link between phytoplankton and fish and play a key role in cycling of organic materials in an aquatic ecosystem (Schriver et al. 1995, Tatrai et al. 1997). Zooplankton communities are very sensitive to environmental changes and thus are of considerable potential value as water quality indicators (Gannon and Stemberger, 1978) Zooplankton association, richness, abundance, variation and diversity can be used for the assessment of water quality and for management practices (Kar and Kar 2013). Some workers have reported that the zooplankton as indicator of water quality of aquatic ecosystem. Zooplankton can also be used as a tool for assessing eutrophication (Vandysh, 2004; Webber et al., 2005). Thakur et al. (2013) studied plankton diversity for assessing the water quality of three freshwater lakes of Mandi, Himachal Pradesh. For understanding the health of the water bodies, zooplankton are very useful, as these are very sensitive to pollutants and they act as bio indicator of water quality (Vaidya, 2017).

The changes in species density and population size abundance result from either direct or indirect environmental stressors. Hence changes in biota may be used to elucidate changes in the aquatic environment. Thus, indicator species are those which by their presence or abundance provide some indication of the prevailing environmental conditions (Hellawell 1978). In the multidimensional space (ecological niche), the occurrence of aquatic organisms is affected by various physico-chemical environmental variables (Shurin et al. 2000, Lampert and Sommer 2001). Thus, environmental monitoring and water quality assessment will be instrumental for assessing the health of the high altitude wetland Dodi Tal of Garhwal Himalaya.

The aim of the present investigation was to test the hypothesis that changes within the communities of zooplankton may provide the basis for determining the water quality status of the high altitude wetland Dodi Tal. Based on the presence, absence, density and diversity of potential indicator species of zooplankton, the environmental status of the wetland was determined.

Study area

The Dodi Tal is one of the most important high altitude wetlands (3,075 m above m.asl) of the Garhwal Himalaya (latitude 30°52'31.99" N and longitude 78°31'12.47" E), India. The famous temples dedicated to Goddess Annapurna and Good Dhundiraj (Ganesha) are located at the bank of this lake. The high altitude wetland Dodi Tal receives heavy snowfall during winter season. The approximate length of the lake is about 248 m and width about 152 m at its broadest points with maximum depth of 19.97 m and average depth of 9.98 m. The lake is a destination for large number of trekkers, hikers, tourists and shepherds round the year except February and March (Figure 1).

Characteristic of sampling sites

Four sampling sites (S_1-S_4) were identified at the high altitude wetland, Dodi Tal. The sampling site S_1 was identified close to the inlet at an altitude of 3,104 m above sea level between latitude 30°53'56.85 N and longitude 78°31'34.47 E. This site is devoid of any anthropogenic activity. Therefore, this site is treated as reference site. The sampling site S_2 was identified towards the Forest Rest House (outlet) at an altitude of 3,083 m.asl between latitude 30°53'51.12 N, 78°31'38.95 E. This site was recognized as less disturbed site. The sampling site S_3 was identified close to the temple at an altitude of 3,068 m.asl between latitude 30°53'48.98 N and longitude 78°31'34.52E. This site was moderately disturbed site. Dumping of worship materials (sacred tree leaves, flowers, fruits sweets, etc.) garbage and trash by the tourists is very common here. The sampling site S_4 was identified close to the dense forest patch at 3,061 m.asl. (Latitude 30°53'52.99 N and 78°31'33.82 E).This site was the highly disturbed site.

Materials and methods

Physico-chemical analyses

Some of the physico-chemical parameters required for water quality analysis like pH, air temperature, water temperature and dissolved oxygen were measured at each sampling site of the wetland. Water temperature was recorded with the help of the Digital Thermometer was (-50 ^{0}C to +300 ^{0}C) thermometer; Electrical conductivity and pH of the samples were measured with the help of the Toshcon Multiparameter Analyser (Model No. TPC-17). The concentration of Nitrates, phosphates and sulphates were determined by using Spectrophotometer (Model –UV-VIS Systronics). Dissolved Oxygen, total hardness, BOD, alkalinity, Calcium and Magnesium were measured followed the method outlined in Wetzel and Likens (1991) and APHA (1998).

Zooplankton diversity analysis

Zooplankton were sampled monthly during one annual cycle at all the four sites. Zooplankton were sampled by towing plankton net of 35µm vertically in the wetland water to the maximum depth of 10 cm. All the samples were immediately fixed with 4% formalin solution. Identification was made with the help of the Inverted Compound Microscope Olympus CH 20*i.* Density of zooplankton was recorded in individual per liter (ind.l^{-1}). Standard manual of Michael and Sharma, (1988); Ward and Whipple, (1992); APHA (2005), and Munshi *et al.* (2010) were used for identification of zooplankton.

Statistical analysis

Species diversity index ($\overline{H}$) was calculated using the Shannon Wiener information function (Shannon and Wiener 1964). Canonical Correspondence Analysis (CCA) was used to determine the relationship between zooplankton species distribution and physico-chemical variables of the water of the wetland. The Canonical Correspondence Analysis was performed using P Aleonotological Statistics (PAST) Software version 2.10.

Results and discussion

The use of the physico-chemical properties of the water to assess the water quality of a water body gives a good impression of the status, productivity and sustainability of such water body. Considerable number of studies have shown marked differences in the composition, abundance and diversity of zooplankton of different trophic status of water bodies; and various species of zooplankton have been identified as indicators of the health status of the water body (Hutchinson 1967; Verma and Munshi 1987). The presence of these zooplankton is indicative of the degradation of the water bodies and can be used as a reliable tool for assessing the water quality of high altitude wetland, which has been supported by the physico-chemical analysis of water, diversity index and Cannonical Correspondance Analysis (CCA).

Physico-chemical parameters: Seasonal fluctuations in the various physico-chemical parameters at four selected sites of the Dodi Tal during the period of study are shown in Table 1. A maximum water temperature (10.65±1.050^{0}C) was recorded in monsoon at S_4 and minimum (6.37±2.819^{0}C) at S_1 in winter season. These range of variation (6°C to 18°C) has also been observed in Suraj Tal and Sissu Lake, Himachal Pradesh (Singh et al.2014). Gokyo lake, Kathmandu, Nepal (Ghimire et al. 2013). Turbidity was found to be maximum (1.44±0.160 NTU) at S_2 in monsoon season and minimum (0.14±0.056NTU) at S_1 in winter season. Total Dissolved Solids (TDS) were found to be maximum (172.00±47.00 mg l^{-1}) at S_4 in monsoon season and minimum (36.23±13.99 mg l^{-1}) at S_1 in winter season. 120±4.5 mg l^{-1} to 286±14.5 mg l^{-1} of TDS were observed in Deepak Tal and 98±5.0 mg l^{-1} to 245.5±12.6 mg l^{-1} in Sissu lake, Himachal Pradesh (Singh et al. 2014, 2016). Conductivity was recorded maximum (369.50±70.500 µScm^{-1}) at S_4 in monsoon season and minimum (64.00±15.513 µScm^{-1}) at S_1 in winter season. Same ranges of conductivity (212 ± 2.3) µS/cm was observed in Chandra Tal, Himachal Pradesh (Singh et al. 2016); 130±5.5 µS/cm in Deepak Tal and 200±12.6 µS/cm in Sissu Lake of Himachal Pradesh (Singh et al. 2014). Thus, high turbidity, NTU, TDS and conductivity during monsoon is the indication of degraded water quality. Alkalinity was recorded maximum (46.00±1.500 mg l^{-1}) at S_4 in monsoon season and minimum (32.50±7.427 mg l^{-1}) at S_1 in winter season. Free CO_2 was found to be maximum (3.85±0.770 mg l^{-1}) at S_4 in monsoon season and minimum (2.93±0.452 mg l^{-1}) at S_1 in winter season. Dissolved Oxygen (DO) was recorded maximum (12.07±0.525mg l^{-1}) at S_1 in winter season and minimum (9.55±0.050 mg l^{-1}) at S_4 in monsoon season. The same range of dissolved oxygen (6.85 mg l^{-1} -13.21 mg l^{-1}) was reported in Prashar Lake, Himachal Pradesh (Jindal et al. 2014). pH was recorded maximum (7.65±0.17) at S_1 in winter season and minimum (6.95±0.030) at S_4 in autumn season. Similar range (6.85-7.10) of pH was found in Satopanth lake, Uttarakhand (Sharma and Kumar 2017), and Deoria Tal, Uttarakhand (Chaudhary et al. 2018). Chlorides were found to be maximum (12.07±0.710mg l^{-1}) at S_4 in monsoon season and minimum (5.68±1.159 mg l^{-1}) at S_1 in winter season. Almost same range (2.98-5.68mg/l) was found in Nachiketatal Tal, Uttarakhand (Sharma and Tiwari 2018). Total hardness was found to be maximum (36.00±2.800mg l^{-1}) at S_4 in monsoon season and minimum (21.07±7.173 mg l^{-1}) at S_1 in winter season. Similar range of variation (35 mg/l - 37 mg l^{-1}) was observed in Sheshnag Lake, Kashmir (Yaqoob et al. 2008). Calcium was recorded maximum (6.13±0.760 mg l^{-1}) at S_4 in monsoon season and minimum (4.70±0.590 mg l^{-1}) at S_1 in winter season. Magnesium was found to be maximum (5.065±0.195 mg l^{-1}) at S_1 in monsoon season and minimum (2.27±1.394 mg l^{-1}) at S_1 in winter season. Nitrates were found maximum (0.22±0.010 mg l^{-1}) at S_4 in monsoon season and minimum (0.02±0.004 mg l^{-1}) at S_1 in winter season. Similar findings (0.06 mg l^{-1} -0.31 mg l^{-1}) were reported from high altitude lake in Khumbu and Imja Kola valleys, Nepal (Tartari et al. 1998b). Phosphates were found to be maximum (0.20±0.010 mg l^{-1}) at S_4 in monsoon season and minimum (0.02±0.004mg l^{-1}) at S_1 in winter season. Higher values of nitrates and phosphates were found in S_3 and S_4 (0.02 mg l^{-1}; 0.099 mg l^{-1}). Both these sites are disturbed and receive pressure of several anthropogenic activities. Human wastes (excreta) and solid waste disposal are the major sources of nitrogen and phosphorous in water bodies. Minimum concentration of phosphorus is the characteristic of high altitude wetlands (Pandit 1999).

Sodium was found maximum (1.06±0.087 mg l^{-1}) at S_4 in monsoon season and minimum (0.81±0.227 mg l^{-1}) at S_1 in winter season. Potassium was found to be maximum (1.45±0.010 mg l^{-1}) at S_4 in monsoon season and minimum (0.86±0.207 mg l^{-1}) at S_1 in winter season. The same range of concentration of Potassium (0.29±0.05 mg l^{-1} to 2.70±0.5 mg l^{-1}) was reported from Deepak Tal and Sissu Lake, Himachal Pradesh.

A marked difference in the values of BOD and nitrates were found in the sampling sites S_3 & S_4 than S_1 & S_2. However, a distinct difference in seasonal variations was recorded in the water quality of high altitude wetland Dodi Tal (Table 1). Water quality was most degraded during monsoon season in Dodi Tal.

A negative correlation between DO and temperature, turbidity, TDS, (r= -0.762, p<0.05; (r = -0.692, p< 0.05; r= -0.929, p<0.01; r= -0.636, p<0.05) was found. Significant negative correlation of dissolved oxygen with water temperature (r =-0.904) in Wular lake, Kashmir was found (Ganai and Parveen, 2014). Free carbon dioxide was inversely correlated with dissolved oxygen (r= -0.256, p<0.05) (Table 4.17). Similar inverse relationship has also been reported by other workers in different wetlands

(Pearsall 1923; Shastree et al. 1991; Thakur et al. 2013; Singh et al. 2017).

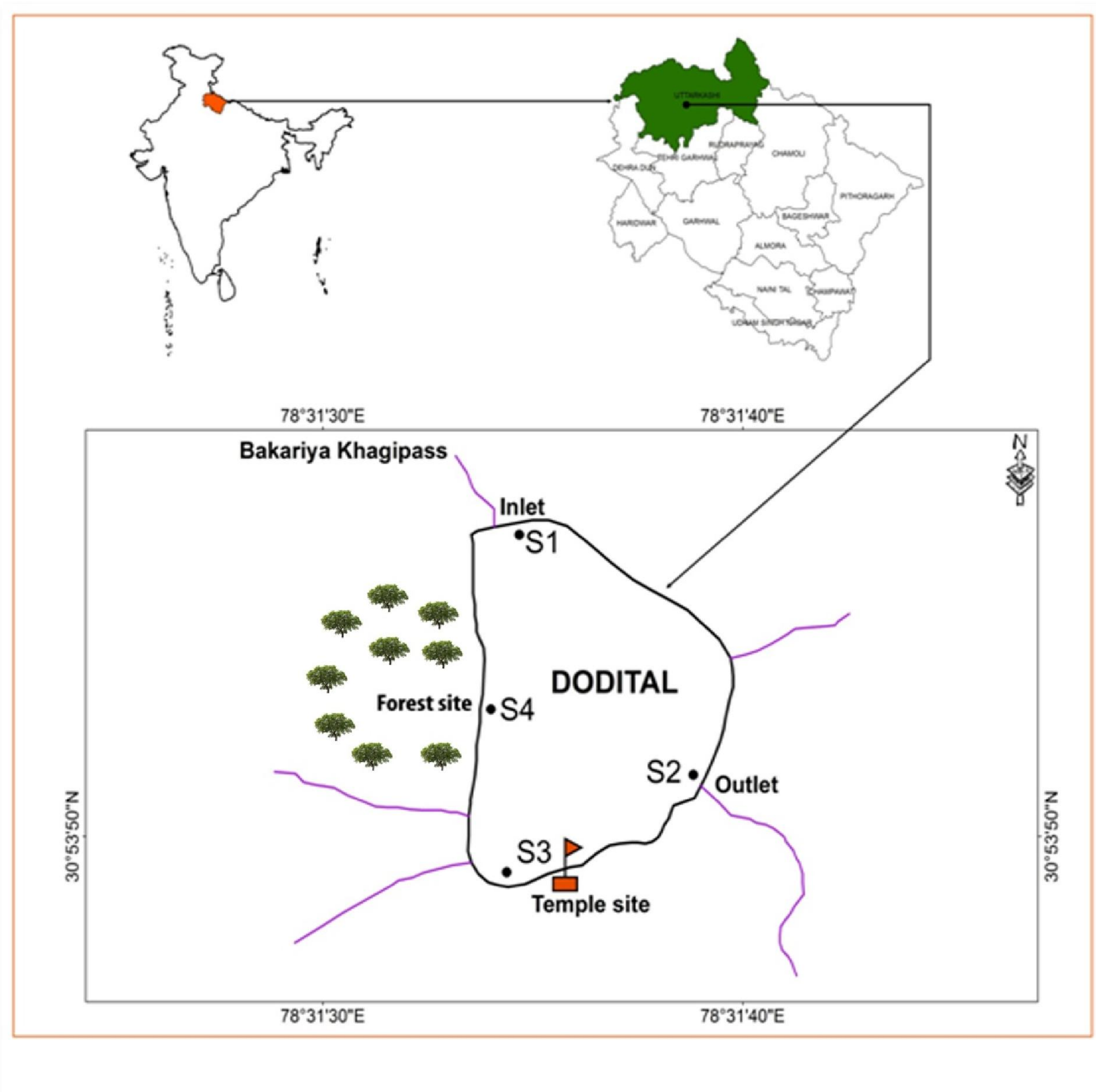


Fig. 1 Location of the sampling sites (S_1, S_2, S_3 and S_4) at Dodi Tal, a high altitude wetland, Garhwal Himalaya

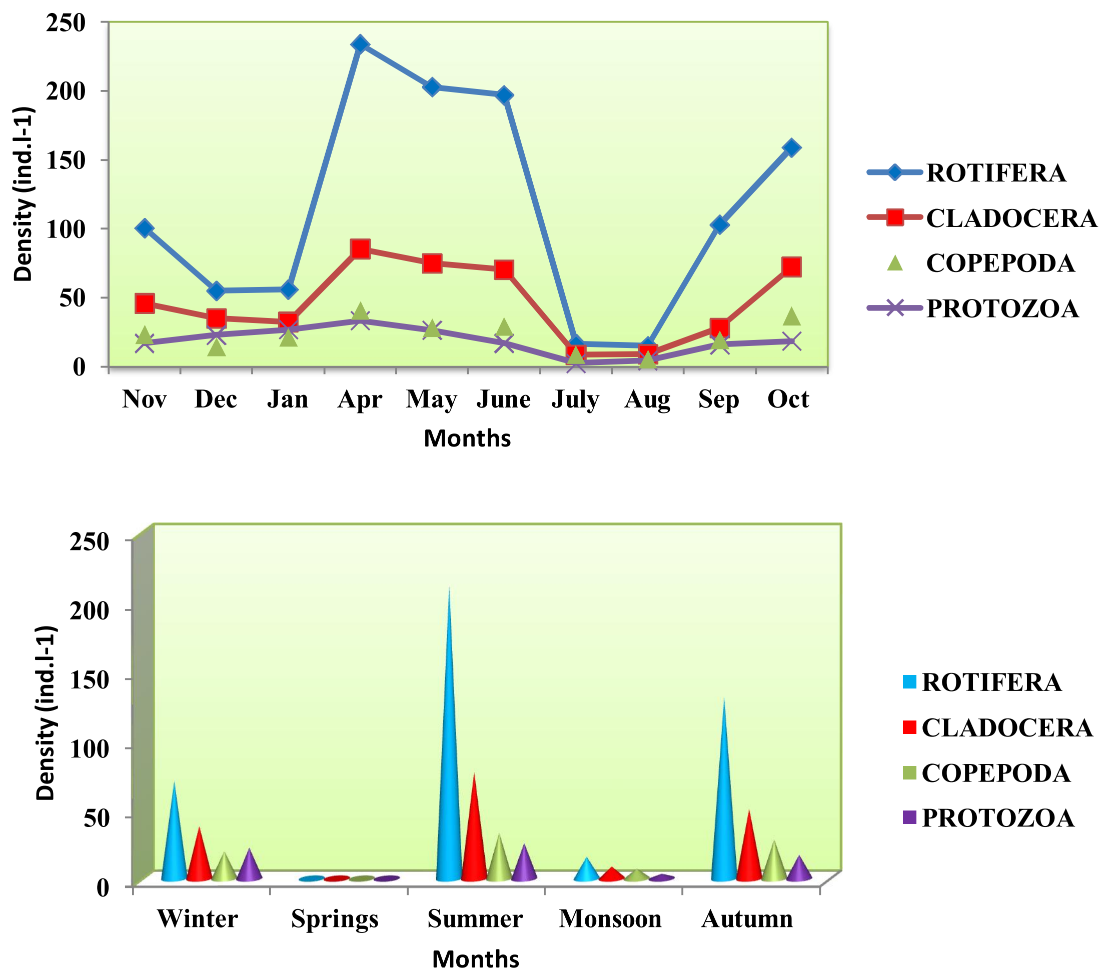


Fig 2. Distribution pattern of zooplankton community of High altitude wetland, Dodi Tal

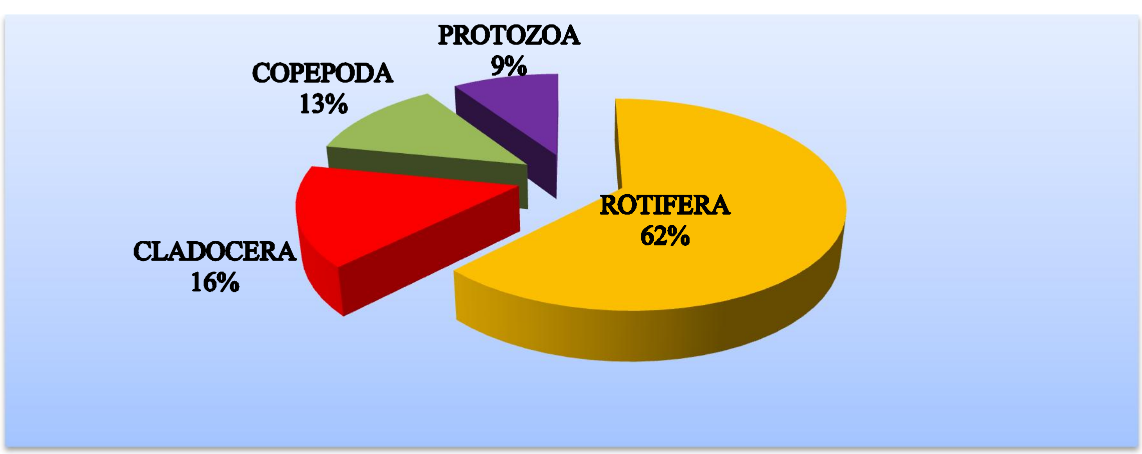
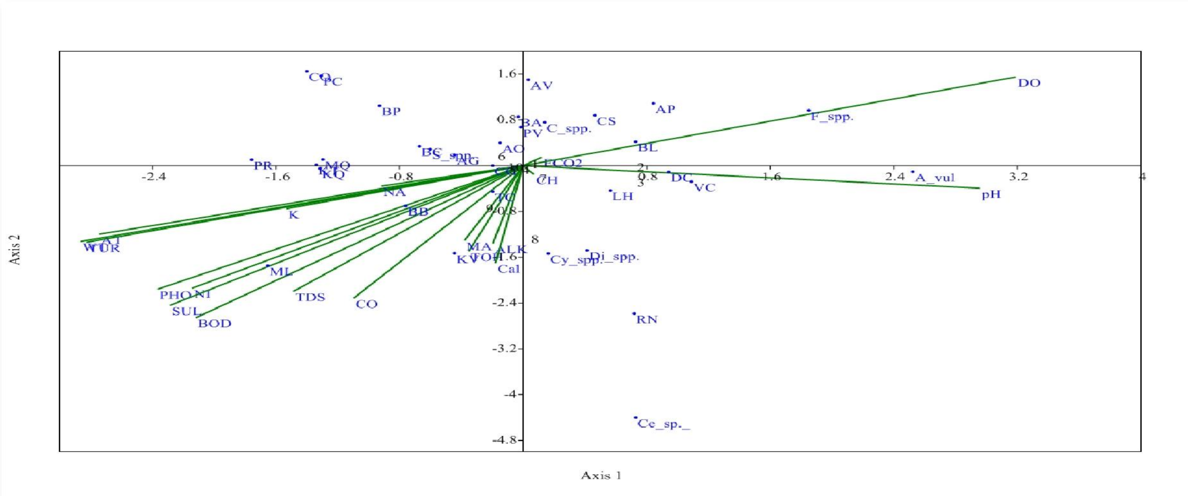


Fig. 3 Percentage composition of Zooplankton community in Dodi Tal, Garhwal Himalaya (November 2014-October 2015



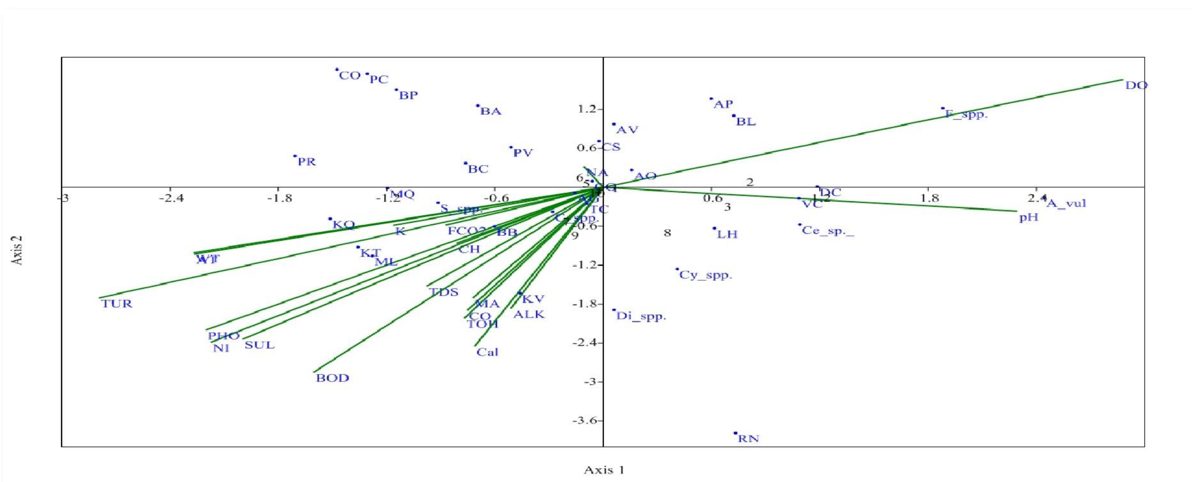
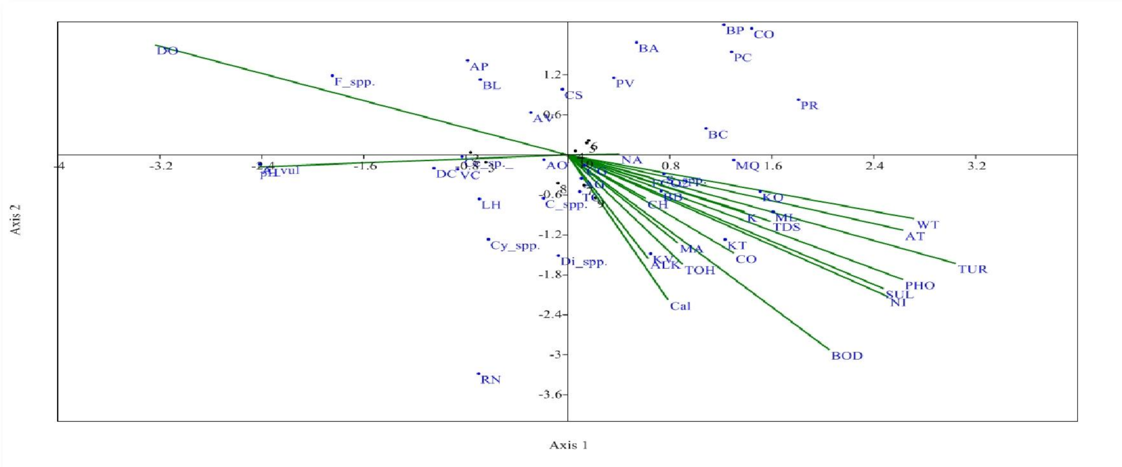


Figure 5: CCA biplot at site 2 between physiochemical parameters and zooplankton species (Physico-chemical parameters: AT: Air temperature; WT: Water temperature; TUR: Turbidity; TDS: Total Dissolved Solid; CO: Conductivity; ALK: Alkalinity; FCO_2: Free CO2; DO: Dissolved Oxygen BOD: Biological Oxygen Demand; pH:; CH: Chlorides; TOH: Total Hardness; CA: Calcium; MA: Magnesium; NI: Nitrates; PHO: Phosphates; SUL: Sulphates; NA: Sodium; K: Potassium); (Zooplankton species: AO: *Ascomorpha ovalis*; AP: Asplanchana pridonata; *BA: Brachionus angularis: BB: B bidentata; BC: B caudatus; BP: B patulus; CG: Cephalodella gibba; CO: Colurella obtuse; F spp: Filinia spp. KT: keratella tropiaca; KV: K vulga; KQ: K quadrata; LH: Lecane hastate; ML: Monostyla lunaris; MQ: Monostyla quadridentata; PC: Philodina citrine; PR: Philodina rosea; PV: Polyarthra vulgaris; RN: Rotaoria naptunia; TC: Trichocera cylindrical; AG: Alona guttatta; BL: Bosmina longirostris; CS: Chydorus spaericus; DC: Daphnia catwaba; Sc spp: Scapholebris spp.; AV: Acanthocyclops vernalis; C spp: Canthocamptus spp; Cy spp: Cyclops spp.; Di spp: Diaptomus spp. Ce sp.: Centropyxis sp.; A vul: Arcella vulgaris; VC: Vorticella campanula*



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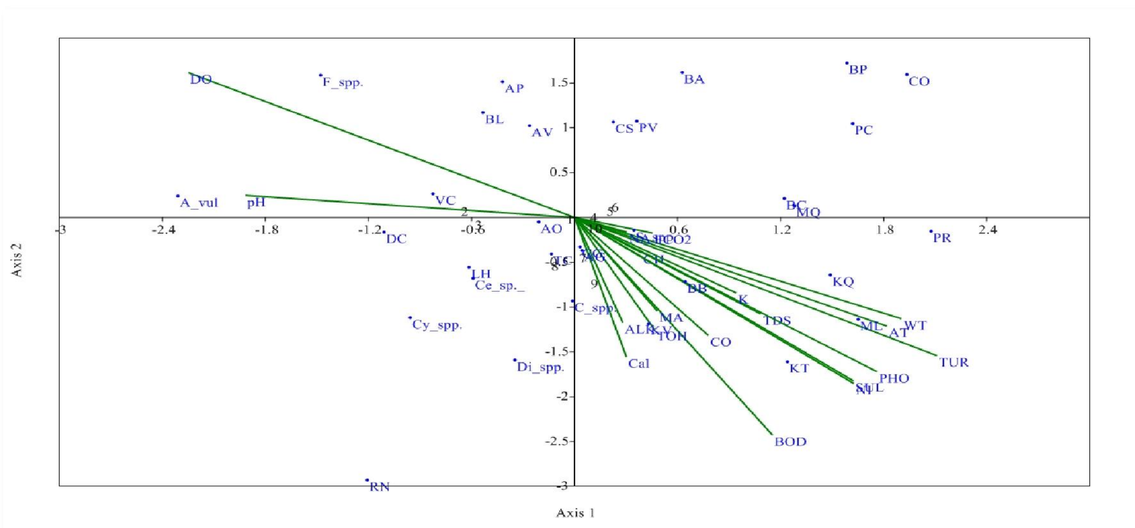

Fig. 7: CCA biplot at site 3 between physiochemical parameters and zooplankton species (Physico-chemical parameters: AT: Air temperature; WT: Water temperature; TUR: Turbidity; TDS: Total Dissolved Solid; CO: Conductivity; ALK: Alkalinity; FCO_2: Free CO2; DO: Dissolved Oxygen BOD: Biological Oxygen Demand; pH:; CH: Chlorides; TOH: Total Hardness; CA: Calcium; MA: Magnesium; NI: Nitrates; PHO: Phosphates; SUL: Sulphates; NA: Sodium; K: Potassium); (Zooplankton species: AO: *Ascomorpha ovalis*; AP: Asplanchana pridonata; *BA: Brachionus angularis: BB: B bidentata; BC: B caudatus; BP: B patulus; CG: Cephalodella gibba; CO: Colurella obtuse; F spp: Filinia spp. KT: keratella tropiaca; KV: K vulga; KQ: K quadrata; LH: Lecane hastate; ML: Monostyla lunaris; MQ: Monostyla quadridentata; PC: Philodina citrine; PR: Philodina rosea; PV: Polyarthra vulgaris; RN: Rotaoria naptunia; TC: Trichocera cylindrical; AG: Alona guttatta; BL: Bosmina longirostris; CS: Chydorus spaericus; DC: Daphnia catwaba; Sc spp: Scapholebris spp.; AV: Acanthocyclops vernalis; C spp: Canthocamptus spp; Cy spp: Cyclops spp.; Di spp: Diaptomus spp. Ce sp.: Centropyxis sp.; A vul: Arcella vulgaris; VC: Vorticella campanula*

Table 1- Seasonal variations ($\overline{X}$ ± SD) in physico-chemical environmental variables of high altitude wetland, Dodi Tal, Garhwal Himalaya recorded for the period of November 2014 - October 2015

Environmental variables	Sites	Winter	Summer	Monsoon	Autumn
Air temp (^{0}C)	**S1**	8.00±2.174	10.07±2.980	11.95±0.650	11.45±0.350
	S2	7.87±2.347	9.80±2.934	11.75±0.650	11.40±0.500
	S3	7.90±2.273	9.93±2.963	11.85±0.650	11.50±0.400
	S4	7.90±2.325	10.07±2.980	11.95±0.650	11.45±0.350
Water temp. (^{0}C)	**S1**	6.40±2.670	8.77±3.126	10.25±1.450	9.90±1.000
	S2	6.33±2.562	8.77±3.284	10.35±1.550	9.65±1.250
	S3	6.50±2.592	8.70±3.159	10.25±1.550	9.80±1.000
	S4	6.57±2.546	8.77±3.126	10.25±1.450	9.90±1.000
Turbidity (NTU)	**S1**	0.12±0.056	1.14±0.264	1.60±0.190	1.12±0.105
	S2	0.13±0.052	0.96±0.213	1.50±0.185	1.07±0.075
	S3	0.18±0.063	1.08±0.272	1.55±0.190	1.10±0.090
	S4	0.21±0.070	1.14±0.264	1.60±0.190	1.12±0.105
TDS (mg l^{-1})	**S1**	35.80±14.961	128.43±68.076	189.50±51.500	65.40±39.600
	S2	36.83±14.575	117.13±62.300	169.00±46.000	61.50±36.600
	S3	37.53±14.539	125.37±67.443	186.00±50.000	62.45±37.250
	S4	38.63±15.071	128.43±68.076	189.50±51.500	65.40±39.600
Conductivity (µScm^{-1})	**S1**	63.43±15.333	166.10±87.877	386.00±63.000	94.15±32.850
	S2	64.33±15.633	158.90±84.332	368.50±67.500	85.05±25.950
	S3	65.23±15.608	161.70±85.847	378.00±66.000	87.60±28.405
	S4	66.20±15.650	166.10±87.877	386.00±63.000	94.15±32.850
Alkalinity (mg.l^{-1})	**S1**	31.50±7.427	36.50±7.874	46.00±2.500	34.00±3.500
	S2	32.00±7.427	35.40±7.582	44.25±2.250	32.75±3.750
	S3	32.50±7.427	35.83±7.641	44.75±2.250	33.50±4.000
	S4	33.00±7.427	36.50±7.874	46.00±2.500	34.00±3.500
Free CO_2 (mg l^{-1})	**S1**	2.73±0.437	3.59±0.452	4.29±0.550	2.75±0.110
	S2	2.80±0.535	3.39±0.223	3.74±0.660	2.64±0.000
	S3	2.87±0.634	3.52±0.359	3.96±0.660	2.75±0.110
	S4	2.95±0.735	3.59±0.452	4.29±0.550	2.75±0.110
Dissolved oxygen (mg.l^{-1})	**S1**	11.93±0.499	9.93±0.125	9.15±0.050	9.50±0.600
	S2	11.73±0.499	10.23±0.125	9.60±0.000	10.10±0.500
	S3	11.57±0.464	10.17±0.047	9.40±0.000	9.80±0.600
	S4	11.33±0.419	9.93±0.125	9.15±0.050	9.50±0.600
B.O. D	**S1**	0.33±0.094	0.53±0.094	1.00±0.100	0.85±0.050
	S2	0.33±0.094	0.40±0.082	0.85±0.050	0.75±0.050
	S3	0.40±0.082	0.50±0.082	0.95±0.050	0.85±0.050
	S4	0.40±0.082	0.53±0.094	1.00±0.100	0.85±0.050
pH	**S1**	7.66±0.169	7.15±0.246	7.57±0.145	6.89±0.100
	S2	7.64±0.163	7.27±0.232	7.68±0.110	7.01±0.090
	S3	7.60±0.166	7.22±0.234	7.60±0.115	6.93±0.065
	S4	7.54±0.154	7.15±0.246	7.57±0.145	6.89±0.100
Chlorides (mg l^{-1})	**S1**	4.73±0.669	12.78±1.159	7.81±3.550	6.39±2.130
	S2	8.05±1.771	12.78±1.159	7.81±3.550	6.39±2.130
	S3	8.05±1.771	12.78±1.159	7.81±3.550	6.39±2.130
	S4	8.05±1.771	12.78±1.159	7.81±3.550	6.39±2.130
Total Hardness (mg l^{-1})	**S1**	20.93±6.979	27.00±4.490	36.30±2.500	24.50±1.300
	S2	21.20±7.073	25.53±5.076	35.50±2.500	22.30±2.500
	S3	21.80±7.073	25.93±5.076	35.90±2.500	23.60±1.600
	S4	22.13±6.979	27.00±4.490	36.30±2.500	24.50±1.300
Calcium (mg l^{-1})	**S1**	4.62±0.590	5.34±0.553	7.09±0.120	5.01±0.525
	S2	4.70±0.590	5.13±0.523	6.85±0.040	4.85±0.525
	S3	4.78±0.590	5.23±0.537	6.97±0.080	4.93±0.525
	S4	4.86±0.590	5.34±0.553	7.09±0.120	5.01±0.525
Magnesium ion (mg l^{-1})	**S1**	2.29±1.343	3.33±1.101	4.54±0.535	2.93±0.005

Environmental variables	Sites	Winter	Summer	Monsoon	Autumn
	S2	2.31±1.366	3.10±1.313	4.49±0.635	2.49±0.290
	S3	2.41±1.368	3.13±1.295	4.51±0.560	2.76±0.075
	S4	2.44±1.345	3.33±1.101	4.54±0.535	2.93±0.005
Nitrates (mg l^{-1})	**S1**	0.02±0.005	0.11±0.027	0.21±0.015	0.10±0.026
	S2	0.03±0.005	0.08±0.008	0.10±0.006	0.08±0.011
	S3	0.03±0.004	0.09±0.007	0.14±0.020	0.09±0.013
	S4	0.04±0.007	0.11±0.027	0.21±0.015	0.10±0.026
Phosphates (mg l^{-1})	**S1**	0.01±0.004	0.07±0.074	0.09±0.001	0.07±0.009
	S2	0.02±0.004	0.07±0.010	0.06±0.001	0.07±0.010
	S3	0.03±0.000	0.07±0.000	0.09±0.003	0.07±0.001
	S4	0.03±0.004	0.08±0.00	0.09±0.004	0.08±0.012
Sulphates (mg l^{-1})	**S1**	0.01±0.004	0.05±0.016	0.08±0.001	0.06±0.007
	S2	0.01±0.004	0.06±0.060	0.06±0.002	0.07±0.011
	S3	0.02±0.000	0.06±0.006	0.09±0.003	0.07±0.001
	S4	0.02±0.003	0.07±0.01	0.09±0.002	0.07±0.015
Sodium (mg l^{-1})	**S1**	0.75±0.230	1.02±0.096	0.95±0.110	1.00±0.190
	S2	0.79±0.221	0.82±0.113	0.77±0.075	0.81±0.180
	S3	0.91±0.135	0.92±0.094	0.88±0.090	0.91±0.170
	S4	1.05±0.111	1.02±0.096	0.95±0.110	1.00±0.190
Potassium (mg l^{-1})	**S1**	0.83±0.197	1.32±0.054	1.40±0.015	1.24±0.255
	S2	0.95±0.121	1.00±0.084	0.94±0.030	0.98±0.165
	S3	1.01±0.112	1.06±0.073	1.07±0.005	1.07±0.145
	S4	1.16±0.056	1.32±0.054	1.40±0.015	1.24±0.255

Table 2. Seasonal variation in density (ind.l^{-1}) of Zooplankton of the High altitude wetland, Dodi Tal, Garhwal Himalaya during November 2014- October 2015

Zooplankton	Winter	Springs	Summer	Monsoon	Autumn
ROTIFERA					
Ascomorpha ovalis	11.33±3.86	**NA**	20.67±1.70	3.50±0.50	12.50±1.50
Asplanchana pridonata	7.33±0.47	**NA**	14.33±1.89	0.50±0.50	5.50±5.50
Brachionus angularis	3.67±2.87	**NA**	12.00±2.45	0.50±0.50	0.00±0.00
B bidentata	6.00±5.35	**NA**	11.67±3.86	1.00±1.00	10.00±1.00
B caudatus	1.67±1.70	**NA**	9.00±1.41	0.00±0.00	6.00±1.00
B patulus	1.33±1.89	**NA**	9.33±2.05	0.00±0.00	1.00±1.00
Cephalodella gibba	5.00±3.74	**NA**	10.67±2.05	0.00±0.00	9.00±0.00
Colurella obtuse	0.00±0.00	**NA**	7.33±1.25	0.00±0.00	3.50±3.50
Filinia spp.	6.33±2.49	**NA**	10.67±1.25	0.00±0.00	2.50±2.50
keratella tropiaca	1.33±1.89	**NA**	7.67±5.79	1.50±0.50	8.50±0.50
k vulga	3.33±1.89	**NA**	10.00±0.82	0.50±0.50	8.50±0.50
k quadrata	2.33±3.30	**NA**	11.33±2.05	2.50±2.50	10.00±3.00
Lecane hastate	7.33±0.47	**NA**	11.67±0.47	0.50±0.50	10.00±1.00
Monostyla lunaris	0.00±0.00	**NA**	11.00±1.41	2.50±0.50	8.00±1.00
Monostyla quadridentata	2.67±3.09	**NA**	11.00±0.00	0.50±0.50	9.00±2.00
Philodina citrine	1.67±2.36	**NA**	7.00±5.35	1.50±0.50	4.50±4.50
Philodina rosea	0.00±0.00	**NA**	8.33±2.36	0.50±0.50	4.00±1.00
Polyarthra vulgaris	3.33±1.25	**NA**	13.33±3.09	1.00±0.00	4.50±4.50
Rotaoria naptunia	4.00±3.27	**NA**	2.33±2.62	2.50±0.50	6.50±0.50
Trichocera cylindrical	6.00±0.82	NA	10.00±0.82	0.50±0.50	8.50±0.50
Total	74.67±20.04		209.33±16.11	19.50±0.50	132.00±27.00
CLADOCERA					
Alona guttatta	10.00±2.83	**NA**	19.33±2.05	2.00±1.00	16.50±0.50
Bosmina longirostris	8.33±0.94	**NA**	17.00±1.41	1.00±1.00	5.50±5.50
Chydorus spaericus	5.33±3.77	**NA**	13.00±2.16	1.00±0.00	6.50±6.50
Daphnia catwaba	9.67±1.25	**NA**	12.33±1.89	2.50±0.50	11.50±3.50

Scapholebris spp.	6.33±2.05	**NA**	15.67±2.87	2.50±2.50	12.50±4.50
Total	39.67±4.50	**NA**	77.33±8.22	9.00±1.00	52.50±20.50
COPEPODA					
Acanthocyclops vernalis	7.33±0.47	**NA**	15.00±4.55	2.00±2.00	8.00±8.00
Canthocamptus spp.	2.67±1.89	**NA**	6.67±4.78	2.00±1.00	6.50±1.50
Cyclops spp.	7.00±0.82	**NA**	8.67±6.13	1.50±0.50	8.50±0.50
Diaptomus spp.	5.00±1.63	**NA**	7.67±2.87	4.00±0.00	9.00±0.00
Total	22.00±3.27	**NA**	38.00±5.72	9.50±2.50	32.00±10.00
PROTOZOA					
Centropyxis sp.	3.67±2.87	**NA**	6.33±4.50	1.50±1.50	3.50±3.50
Arcella vulgaris	14.00±2.16	**NA**	10.00±0.82	1.00±1.00	10.00±3.00
Vorticella campanula	8.33±0.47	**NA**	12.00±2.45	1.50±0.50	6.50±2.50
Total	26.00±5.10	**NA**	28.33±7.04	4.00±0.00	20.00±2.00
Grand Total	**162.33±22.57**	**NA**	**353.00±35.69**	**42.00±4.00**	**236.50±59.50**

NA: Not Accessible

Table 3. Seasonal variation in diversity index (Shannon-Wiener, 1964) for Zooplankton of high altitude wetland, Dodi Tal, Garhwal Himalaya for the period November 2014-October 2015

Sites	**Winter**	**Spring**	**Summer**	**Monsoon**	**Autumn**
2014-2015					
S1	3.26	NA	3.88	2.54	3.68
S2	3.33	NA	3.90	2.71	3.69
S3	3.38	NA	3.91	2.81	3.72
S4	3.47	NA	3.92	2.67	3.75
$\bar{x}$ **Diversity Index**	**3.36**	**NA**	**3.90**	**2.68**	**3.71**

Table 4. CCA biplot scores of physico- chemical parameters for zooplankton at four sites of high altitude wetland, Dodi Tal, Garhwal Himalaya for the period November 2014-October 2015

Parameters	S_1		S_2		S_3		S_4	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**
Air temp (^{0}C)	-0.686	-0.299	-0.567	-0.258	0.658	-0.282	0.606	-0.404
Water temp. (^{0}C)	-0.717	-0.331	-0.568	-0.252	0.679	-0.239	0.634	-0.376
Turbidity (NTU)	-0.707	-0.335	-0.699	-0.426	0.761	-0.407	0.703	-0.514
TDS (mg l^{-1})	-0.372	-0.549	-0.245	-0.381	0.398	-0.249	0.361	-0.359
Conductivity (µScm^{-1})	-0.274	-0.579	-0.189	-0.475	0.326	-0.368	0.260	-0.439
Alkalinity (mg.l^{-1})	-0.049	-0.340	-0.128	-0.467	0.158	-0.390	0.093	-0.391
Free CO_2 (mg l^{-1})	0.030	0.037	-0.219	-0.146	0.161	-0.084	0.151	-0.058
Dissolved oxygen (mg.l^{-1})	0.797	0.387	0.720	0.416	-0.810	0.413	-0.750	0.539
B.O. D	-0.530	-0.664	-0.401	-0.713	0.513	-0.731	0.384	-0.810
pH	0.739	-0.098	0.574	-0.092	-0.607	-0.045	-0.639	0.082
Chlorides (mg l^{-1})	0.018	-0.038	-0.203	-0.216	0.153	-0.164	0.130	-0.132
Total Hardness (mg l^{-1})	-0.088	-0.374	-0.193	-0.505	0.225	-0.410	0.155	-0.417
Calcium (mg l^{-1})	-0.045	-0.426	-0.178	-0.613	0.197	-0.544	0.101	-0.518
Magnesium ion (mg l^{-1})	-0.095	-0.327	-0.181	-0.427	0.216	-0.330	0.161	-0.348
Nitrates (mg l^{-1})	-0.536	-0.535	-0.544	-0.597	0.629	-0.532	0.542	-0.618
Phosphates (mg l^{-1})	-0.592	-0.540	-0.551	-0.550	0.657	-0.467	0.587	-0.574
Sulphates (mg l^{-1})	-0.572	-0.610	-0.499	-0.585	0.620	-0.502	0.541	-0.608
Sodium (mg l^{-1})	-0.229	-0.089	-0.027	0.080	0.101	0.003	0.101	-0.054
Potassium (mg l^{-1})	-0.384	-0.188	-0.291	-0.147	0.347	-0.213	0.314	-0.281
Eigen value	0.073	0.065	0.734	0.059	0.073	0.0531	0.065	0.053
Percentage of variance	23.4%	21.02%	25.91%	20.80%	27.49%	19.85%	26.92%	22.14%
P value	0.970	0.415	0.405	0.703	0.148	0.673	0.653	0.534

Zooplankton

Zooplankton of Dodi Tal was represented by four major groups – Rotifera, Cladocera, Copepoda and Protozoa. A total 32 taxa belonging to these four groups were recorded from Dodi Tal during the period of study (Table 2). Seasonally, the density of total zooplankton was found to be maximum (353.00±35.69 ind.l^{-1}) in summer and minimum (24.00±2.00 ind.l^{-1}) in monsoon during the study period of Dodi Tal (Table 2; Figure 2). This may be due to the most degraded water quality during monsoon season. Similar findings was reported by Jeelani and Kaur (2014) and Jeelani et al. (2005) in Dal lake, Kashmir. The most abundant rotifera species were found during winter and summer season. These species were absent or less abundant during monsoon season. Similar findings were reported by Garcia et al. (2009) in maxican high mountain wetland.

Malik and Shikha (2015) have observed maximum density and diversity of rotifera in Bhimtal lake of Kumaun region, Uttarakhand. Rotifera are represented by *Ascomorpha ovalis* (Bergendal, 1892), *Asplanchana pridonata* (Gosse, 1850), *keratella tropiaca* (Apstein, 1907), *K. vulga* (Ehrenberg, 1834), *Lecane hastate* (Murray, 1913), *Monostyla lunaris* (Ehrenberg, 1832), *Monostyla quadridentata* (Ehrenberg 1832), *Philodina rosea* (Var. nivalis Voigt, 1841), *Trichocera cylindrical* (Imhof, 1891), *Rotaoria naptunia* (Ehrenberg,1830), *Brachionus angularis* (Gosse, 1851), *Filinia spp., Colurella obtuse* (Gosse, 1886), *B. caudatus* (Barrois & Daday, 1894), *B. bidentata* (Anderson, 1889), *K. quadrata* (O. F. Müller, 1786) in Dodi Tal. Pandit (2008) reported the rotifera community constituted by (*Keratella sp., Brachionus sp., Lecane sp., Monostyla lunaris, Filina opliensis, Cephalodella sp., Trichocera sp.*) in freshwater wetlands of Kashmir (Nowgam, Malgam, Hiagam, Mirgund and Hokarsar). Raina and Vass (1993) reported 24 taxa of rotifera in Dal lake, Kashmir. Pandit (1999) reported 141 species of zooplankton, of which 29 belonged to Rotifera in Kashmir wetlands. Pandit and Yousuf (2003) reported 98 species of rotifera in Kashmir Himalayan lakes. Jeelani and Kaur (2014) have reported 40 taxa of zooplankton out of which Rotifera were most dominant group (27) in Dal Lake, Kashmir. Sharma and Kumari (2018) recorded 27 species of zooplankton belonging to five groups Rotifers were the most dominant group in Prashar lake, Himachal Pradesh. The most dominant Rotifera species in Dodi Tal were *Keratella tropiaca, K. vulga, K. quadrata*, *Monostyla lunaris*, *Monostyla quadridentata*, *Philodina rosea*, *Brachionus angularis*, B. *caudatus*, *B. bidentata*, *Filinia spp., Bosmina longirostris, Daphnia catwaba, Polyarthra vulgaris* and *Lecane hastate.* Raina and Vass (1993) recorded *Keratella sp. Filinia sp. Lecane sp. Polyarthra vulgaris* in Dal Lake, Kashmir. Balkhi et al. (1984) reported that *Polyarthra vulgaris* is the cold stenothermal species in Anchar lake, Kashmir. Kar and Kar (2013) reported *Brachionus* sp., *Keratella tropica. Filinia sp. Lecane sp. Polyarthra sp.* from Madhura anua lake, Assam. Thakur et al. (2013) reported *Brachionus spp. Keratella tropica, Polyarthra sp.* and *trichocera sp.* from Prashar lake, Himachal Pradesh.

Rotifers play an important role in nutrient cycling and energy transfer in freshwater lakes (Makarewicz and likens 1979). They are often used as bioindicator of water pollution (Nogrady et al. 1993). The role of the rotifers as biomonitoring tool and an important food source in the aquatic food chains are also other important aspects of the ecology of rotifers (Shah et al. 2015). According to Pejler (1983) rotifers respond more quickly to environmental changes than Crustacean plankton and appear to be more sensitive indicators of changes in water quality.

Seasonally, the density of Rotifera was found to be maximum (209.33±16.11ind.l^{-1}) in summer and minimum (19.50±0.50 ind.l^{-1}) in monsoon. *Brachionus caudatus, B. Patulus, Cephalodella gibba, Colurella obtuse* and *Filinia spp.* were found absent in monsoon season. Hence these species are very sensitive to seasonal change in water quality and can be considered as bioindicator species of high altitude wetland. *Brachionus spp.*, *Cephlodella gibba* and *Filinia spp.* were also absent in the highly polluted ponds in the vicinity of Badrinath temple (Kumar et al.2012). *B. angularis* and *Rotatoria sp.* have been reported as bioindicator of eutrophic condition (Sladecek 1983, Thakur et al. 2013). Hance, B. *angularis* and *Rotatoria sp.* were found in the highly disturbed site S_3 and S_4 due to anthropogenic activities. It may be due to high anthropogenic activities at these sites which leads to degradation in water quality and consequently affecting the zooplankton diversity. Water quality at particular site influences zooplankton abundance and biomass (Suresh et al. 2011).

The Cladocera contributed 16% to the total zooplankton of the high altitude wetland, Dodi Tal (Figure 3). Cladocera were represented by *Alona guttatta* (Sars 1862), *Bosmina longirostris* (O.P. Muller, 1776), *Chydorus spaericus* (O.P. Muller, 1776), *Daphnia catwaba* (William Chambers Coker 1926), *Scapholebris spp. is zooplankton of Dodi Tal.* Brehm (1937) has recorded (*Dephnia pulex* and *D. magna* from Kashmir Himalayan lakes. Das, *et al.* (1969) reported *Daphnia Catwaba* and *D. kounsurnugensis, D.mugna, D. longiremis* and *D. schodleri* from high mountain lakes in Kashmir. Naik et al. (2017) observed physico-chemical parameters of water influencing the distribution of cladocerans. Hence any type of environmental change has a direct effect on cladocerans diversity and abundance. Kar and Kar (2016) stated that they are good bio-indicator of environmental pollution as they response quickly to any changes in water quality.

Seasonally, the density of Cladocera was found to be maximum (77.33±8.22ind.l^{-1}) in summer and minimum (9.00±1.00 ind.l^{-1}) in monsoon. *Alona guttatta, Bosmina longirostris and Daphnia catwaba.* Were found to be highly tolerant species in Dodi Tal wetland. Jha and Barat (2003) undertake a qualitative analysis of zooplankton dwelling Mirik Lake in Darjeeling, Eastern Himalaya, and concluded *Moina* and *Daphnia sp.*, are the pollution indicators. Abundance of *Chydorus sp.* was found to be very low in Dodi Tal.

The Copepods contributed 13% to the total zooplankton of the Dodi Tal. These were represented by *Acanthocyclops vernalis* (Fisher, 1853), *Canthocamptus spp., Cyclops spp. and Diaptomus spp.* Seasonally, the density of copepoda was found to be maximum (38.00±5.72 ind.l^{-1}) in summer and minimum (9.50±2.50 ind.l^{-1}) in monsoon season. Low density of *Cyclops sp.* was recorded in monsoon season and high in winter season in Dodi Tal. Copepods prefer a more stable environment and are generally regarded as water pollution sensitive taxa as they disappear in severely contaminated waters especially turbid water in monsoon season (Das et al. 1996). The Protozoa contributed 9% to the total zooplankton of Dodi Tal. Protozoa were represented by *Arcella vulgaris* (Eheberg 1930) and *Vorticella campanula* (Ehernberg 1831). Seasonally, the density of Protozoa was found to be maximum (28.33±7.04ind.l^{-1}) in summer and minimum (4.00±0.00 ind.l^{-1}) in monsoon season. Abundane of *Arcella vulgaris* was very low in monsoon season in Dodi Tal. Hance, this species can be considered as an indicator species which is sensitive to degraded water quality in monsoon season.

Karl's Pearson's Correlation

Karl's Pearson's Correlation between major physico-chemical parameters and density of Zooplankton dwelling high altitude wetland, Dodi Tal has been calculated. Rotifera showed a significant positive correlation with water temperature (r =0.547), conductivity (r = 0.533) and chlorides (r = 0.536). Similar relationship between of temperature and chlorides (r= 0.532; r = 0.560) were found value the study on Prashar Lake, Himachal (Thakur et al. 2013). Cladocera have positive correlation with dissolved oxygen (0.509) and negative correlation with water temperature (-0.521). Copepoda showed a positive correlation (0.511) with dissolved oxygen and negative with water temperature (-0.519). The Protozoa have positive correlation with dissolved oxygen (r = 0.554, p< 0.05); and negative correlation with the water temperature (r = -0.611, p< 0.05), turbidity (r = -0.612, p< 0.05), conductivity (r = -0.713, p< 0.05), alkalinity (r = --0.507, p< 0.05). BOD (r = -0.855, p< 0.01) nitrates (r = -0.548), phosphates (r=-0.560) and sulphates (r=-0.507). Similar findings reported from the study on Prashar Lake (Thakur et al. 2013).

In the present study on Dodi Tal Rotifera showed a significant positive correlation with water temperature, turbidity, chlorides and a negative correlation with dissolved oxygen and pH. Thus the water temperature, dissolved oxygen and turbidity are playing an important role in regulating the abundance and density of zooplankton of Dodi Tal. The species of zooplankton are limited by DO, temperature and other physico-chemical factors (Kar and Kar 2013). Water temperature is one of the most prominent factors governing the chemistry of surrounding environment (Sommer et al. 1986).

Shannon Wiener Diversity index:

Shannon wiener diversity index can serve as a good indicator for assessing the health of high altitude lake. Shannon Wiener diversity index value greater than 3 indicates clean water. A value range of 1 to 3 indicates moderately polluted condition and value less than 1.0 indicates heavy polluted condition (Wilhm and Dorris 1968; Masson 1998). Shannon – Wiener diversity index of zooplankton of Dodi Tal ranged from 2.54-3.92 (Table 3) indicating moderately polluted to clean water of Dodi Tal.

Cannonical Correspondance Analysis (CCA):

The CCA plots were drawn between zooplankton species and physico-chemical variables indicating regulation of abundance of zooplankton by most of the physico- chemical parameters. Transparency, pH, dissolved oxygen, hardness and Calcium have been found to have strong influence on the distribution of zooplankton abundance (Allan 1976; Wetzel 1983).

CCA plot at S_1 revealed that temperature, conductivity, turbidity, nitrates, phosphates, sulphates, have close relation with each other. These physico – chemical parameters showed negative correlation with axis 2 and affects the distribution of *Keratella vulga, Brachionus angularis, Trichocera cylindrical, and Keratella quadrata. Monostyla quadridentata* showed *negative* correlation with axis 1. Dissolved oxygen affects the distribution of *Filinia spp. Bosmina longirostris, B. angularis and Asplanchana pridonata* of had positive correlation with Axis 1. pH showed a strong positive correlation with Axis 1 and affects the distribution of *Arcella vulgaris, vorticella campanula* and *Daphnia catwaba*. (Figure 4). Whereas, at S_2, nitrates, phosphates, sulphates, TDS showed negative correlation and affecting the distribution of *Monostyla lunaris* and *Brachionous angularis* with Axis 1. Dissolved oxygen showed a positive correlation with Axis 1 and affecting the distribution of *Bosmina longirostris* and *Filinia spp*. Distribution of *Arcella vulgaris*, *Daphnia catwaba* and *Vorticella campanula* was influenced by pH with Axis 1. (Table. 4; Figure 5).

Dissolved oxygen and pH showed negative correlation with Axis 1 at S_3 affecting the *filinia spp*. and *Polyarthra vulgaris, vorticella and Daphnia catawaba.* Water temperature, turbidity TDS, chlorides and free CO_2 showed a positive correlation with Axis 1 and affecting the distribution of *Keratella quadrata*, *Monostyla lunaris* and *Brachionus angularis* (Table 4; Figure 6). Dissolved oxygen and pH showed negative correlation with Axis 1 at S_4. and influencing the distribution of *Filinia spp.* and *Vorticella campanula*. Alkalinity and Calcium affect the distribution of *Canthocamptus spp*. conductivity had a positive correlation with Axis 2. Abundance of *Colurella obtuse, Philodina citrine, Chydorus spaericus* and *Cyclops spp*. were not influenced much in Dodi Tal (Table 4; Figure 7). Thus, these species were found most tolerant.

Conclusion

The present study on the seasonal fluctuation in physiochemical parameters and the diversity and density of zooplankton of high altitude wetland Dodi Tal revealed that there are few species of Rotifera, Cladocera, Copepoda and Protozoa are very sensitive to any environmental change of the high altitude wetland can be considered as potential bioindicators. These species are *Brachionus caudatus, B. Patulus, Cephalodella gibba* and *Colurella obtuse* (Rotifera) indication towards the degradation of water quality of these sites. While *Ascomorpha ovalis, Lecane hastate, Trichocera cylindrical* (Rotifera), *Alona guttatta, Bosmina longirostris, Dephnia catwaba* (Cladocera), *Acanthocyclops vernalis* (Copepoda) *and Arcella vulgaris* (Protozoa) for assessing the health of the high altitude wetland Dodi Tal.

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Water quality, High Altitude wetland, Zooplankton, Shannon Wiener index, Canonical Correspondence Analysis.

References

1. Allan, J.D. (1976). Life history patterns in Zooplankton. *Am. Nat. 110*: 165-180.
2. APHA, (2005). *Standard Methods for the Examination of Water and Wastewater.* 21st Ed. American Public Health Association, APHA, AWWA, WEF, Washington, D. C. pp: 1170.
3. Balkhi, M.H., Yousuf, A.R. and Qadri, M.Y. (1984). Rotifera of Anchar lake during winter and summer season. *Geobios New Rep 3*:163 165.
4. Brehm, V. (1937). *Freshwater fauna of India* Pt.11. - Rec. Ind. Mus. *48*: 9-28.
5. Chaudhary, S. Sharma, R.C. and Kumar, R. (2018). Physico-chemical and microbiological assessment of surface water quality of a Himalayan wetland Deoria Tal, India. *Civil and Environmental Research*. *10*(5): 59- 75.
6. Das, P.K., Michael, R,g., & Gupta, A. (1996). Zooplankton community in Lake Tasek, a tectonic lake in Garo Hills, India. *Tropical Ecology*, *37(2)*, 257-263.
7. Das, S.M. (1969). Studies of organic production in high altitudes of lakes of India Pert I. The general ecology and zooplankton of Kashmir lakes. *Kashair Science*, Kashmir University, Srinagar *7* (1): 1–22.
8. Ganai, A.H., & Parveen, S. (2014). Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir. *International Journal of Biodiversity and Conservation, 6*(1): 71- 84.
9. Gannon, J.E., & Stemberger, R.S. (1978). Zooplankton (especially crustaceans and rotifers) as indicatots of water quality. *Transactions of the American Microscopical Society, 97*, 16-35.
10. Garcia, C.E. Nandini, S. and Sharma, S.S.S. (2009). Seasonal dynamics of zooplankton in Lake Huetzalin, Xochimilco (Mexico City, Mexico). *Limnologica., 39*: 283–29.
11. Ghimire, N.P., Jha, P.K. and caravello, G. (2013). Water quality of high-altitude lakes in the Sagarmatha (Everest) National Park, Nepal. *Journal of Environmental Protection, 4*: 22-28.
12. Hellawell, J. M. 1978. *Biological Surveillance of Rivers.* Medmenham and Stevenage Water Research Centre.
13. Hutchinson, G.E. (1937). Limnological studies in Indian Tibet. *lnternationale Revue der Gesamten Hydrobiologie and Hydrographie*. *35*: 134-177.
14. Jeelani, M., & Kaur, H. (2014). Comparative Studies on Zooplankton in Dal Lake, Kashmir, India. *Journal of Academia and Industrial Research*, *2*: 9.

15. Jeelani, M., Kaur, H. and Sarwar, S.G. (2005). Distribution of Rotifers in the Dal Lake, Kashmir, India. *Poll. Res. 24*(1): 79-82.
16. Jha, P., & Barat, S. (2003). Hydrobiological study of lake Mirik Darjeeling Himalayas. *Journal of Environmental Biology*, *24*(3); 339-344.
17. Jindal, R., Thakur, R.K., Singh, U.B. & Ahluwalia, A.S. (2014). Phytoplantons dynamics and water quality of Prashar Lake, Himachal Pradesh. *Sustainability of water Quality and Ecology*, 3-4: 101-113.
18. Kar, S., & Kar, D. (2016). Zooplankton diversity of a Freshwater wetland of Assam, India. *International Journal of Advanced Biotechnology and Research* (IJBR), *7*(2): 614-620.
19. Kar. S., & Kar D. (2013). Studies on zooplankton diversity of an oxbow lake of south assam, india. *International Journal of Current Research*, *5*(12): 3652-3655.
20. Kaur, K.S., Bath, G., Monder and Dhilon, S. (1999). Aquatic invertebrate diversity of Kuji lake, Punjab. *Indian J. Env. Ecoplan*. *2*:37-41.
21. Kumar, P., Wanganeo, A., Sonaullah, F. and Wanganeo, R. (2012). Limnological study on two high altitude Himalayan Ponds, Badrinath, Uttarakhand. *The International Journal of Ecosystem.* 2(5): 103–111.
22. Lampert, W., & Sommer, U. (2010). *Elologia Wod Srodladowych* (*Ecology of Inland waters*). PWN, Warszawa: Wyd. Nauk.
23. Malik D.S., & Shikha P. (2015). Zooplankton diversity, species richness and their distribution pattern in Bhimtal Lake of Kumaun Region, (Uttarakhand). *Hydrology Current Res*., *7(1),* 1-7.
24. Mararewicz, J.C. & Likens, G.E. (1979). Structure and function of the zooplankton community of Mirror Lake, New Hampshire. *Ecological Monographs,* 109-127.
25. Masson, C.F. (1998). *Biology Freshwater Pollution*. 3rd (Edn). Harlow (Essex): Longman.
26. Michael, R.G. & Sharma, B.K. (1988). *Fauna of India and Adjacent Countries: Indian Cladocera (Crustacea: Branchiopoda: Cladocera)*. Zoological survey of India. *Surv*. India, Kolkata, 1- 262.
27. Munshi, J.D., Roy, S.P. and Munshi, J.S. (2010). *Manual of Freshwater Biota*. Narendra Publishing House, Delhi, India. 1-435.
28. Naik, G., Balkhi M.H, Bhat F.A and Rashid, M. (2017). Comparative study of present and past Cladoceran diversity in Manasbal Lake of Kashmir (India). *Journal of Fisheries Sciences*, *11*(1): 062-061.
29. Nogrady, T., Wallace, R. and Snell, T. (1993). Rotifera: biology, ecology and systematics. In: Dumont H (ed) *Guides to the Identification of the Micro-invertebrates of the continental waters of the World Vol. 1.* SPB Academic Publishing, The Hague, 1–142.
30. Okogwu, I.O. (2010). Seasonal variations of species composition and abundance of zooplankton in eboma lakea Floodplain Lake in Nigeria. *Rev. Biol. Trop. 58*(1), 171-182.
31. Palmer, G. (1969). A composite rating of algae tolerating organic pollution. *Journal of Phycology*, *5*, 78-82.
32. Pandit, A.K. & Yousuf, A.R. (2003). Rotifer community in some Kashmir Himalayan lakes of varied trophic status. *Journal of Research and Development, 2*: 1–12.
33. Pandit, A.K. (1999). Trophic structure of plankton community in some typical wetlands of Kashmir, India. In: Mishra SR (ed) *Limnological Research in India*. Daya Publishing House, Delhi- 110035 p 190–224.
34. Pandit, A.K. (2008). Biodiversity of wetlands of Kashmir Himalaya. *Proc Natl Acad Sci* India, *78*: 29–51.
35. Pearsall, W.H. (1923). A theory of diatom periodicity. *Ecology.* 11-12: 165-183.
36. Pejler, B. (1983). Zooplanktonic indicators of trophy and their food. *Hydrobiologia,* 101: 111-114.
37. Raina, H.S. & Vass, K.K. (1993). Distribution and species composition of zooplankton in Himalayan ecosystems. *Internationale Revue der gesamten Hydrobiologie, 78*(2): 295–307.
38. Schriver, P., Bogestrand, J., Jeppesen, E. and Sondergaard, M. (1995). Impact of submerged macrophytes on fish- Zooplankton-phytoplankton interactions. large-scale enclosure experiments in a shallow eutrophic lake. *Freshwater Biology. 33*: 255-270.
39. Shah, J.A., Pandit, A.K. & Shah, G.M. (2015). A research on rotifers of aquatic ecosystems of Kashmir Himalaya for documentation and authentication. *Proceedings of the National Academy of Sciences, Section B, Biological Sciences*, *85(1):* 13-19.
40. Shannon, C.E., & Wiener, W. (1964). *The mathematical Theory of Communication*. University of Illinois Press. Urbana, U.S.A.
41. Sharma R.C., & Tiwari, V. (2018). Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya. *Biodiversity International Journal. 2(2):*128-136.

42. Sharma, B.K. (1986). Assessment of pollution indicators in Indian Rotifera. *Journal of the Meghalaya Science Society 9*: 47–49.
43. Sharma, R.C. & Kumar R. (2017). Water quality assessment of sacred glacial Lake Satopanth of Garhwal Himalaya, India. *Applied Water Science*. *7*(8): 4757-4764.
44. Sharma, R.C. & Kumari, R. (2018). Seasonal variations in zooplankton community and environmental variables of sacred Lake Prashar Himachal Pradesh, India. *International Journal of Fisheries and Aquatic Studies, 6*(2): 207-213.
45. Shastree, N.K., Islam, M.S., Pathak, S. and Afshan, M. (1991). Studies on the physicochemical dimensions of the lentic hydrosphere of Ravindra Sarovar 285 (Gaya). ln: N.K.Shastree (ed.) *Current Trends in Limnology-*1.Narendra Publishing House Delhi: 133-152.
46. Shurin, J. B., Havel, J.H., Leibold, M.a., & Pinel-Alloul, B. (2000). Local and regional zooplankton species richness: a Scale – independent test for saturation. *Ecology*, *81*: 3062-3073.
47. Singh, D., Rawat, M.S., Bantwan, B. and Gusain, O.P. (2017). Water quality status of high altitude lake Nachiketa Tal, Garhwal Himalaya, Uttarakhand, India. *Journal of Global Biosciences*., *6*(5): 5012-5021.
48. Singh, V.B., Ramanathan, A.L. and Mandal, A. (2016). Hydrogeochemistry of high-altitude lake: a case study of the Chandra Tal, Western Himalaya, India. *Arabian Journal of Geosciences*, *9*: 308.
49. Singh, Y., Khattar, J.I.S., Singh, D.P., Rahi, P. and Gulati, A. (2014a). Limnology and cyanobacterial diversity of high altitude lakes of Lahaul-Spiti in Himachal Pradesh, India. *J Biosci.,* 39: 643–657.
50. Siraj, S. (2011). *Micro and Macro-zoobenthos of Three Different Water bodies of Kashmir*. Ph.D thesis. University of Kashmir.
51. Sladecek, V. (1983). Rotifera as indicatots of water quality. *Hydrobiologia*. *133,*127-141.
52. Sommer, U., Gliwicz, Z.M., Lampert, W. and Duncan, A. (1986). The PEG-model of seasonal succession of planktonic events in fresh waters. *Arch Hydrobiol*., *106*: 433–471.
53. Subla, B.A., Zutshi, D.P., Khan, M.A., Vishan, N., Wanganeo, A. and Raina, R. (1984). Distribution and ecology of zooplankton communities from Kashmir. *Bull. Env. Sci. 1*:30-34.
54. Suresh, G., Ramasamy, V., Meenakshisundaram, V., Venkatachalapathy, R., Ponnu- samy, V., (2011a). A relationship between the natural radioactivity and miner- alogical composition of the Ponnaiyar river sediments, *India. J. Environ. Radioact. 102*: 370–377.
55. Tartari, G.A., Tartari, G. and Mosello, R. (1998b) "Water chemistry of high altitude lakes in the Khumbu and Imja Kola Valleys (Nepalese Himalayas)," In: A. Lami and G. Gius- sani, (Eds.,) *Limnology of High Altitude Lakes in the Mt Everest Region (Nepal)*, *Memorie delllstituto Italiano di Idrolnologia*, *57*: 51-76.
56. Tatrai, I., Olah, J., Paulovits, G., Matyas, K., Kawieka, B. J., Jozsa, Y. and Pekar, F. (1997). Biomass dependent interactions in pond ecosystems: Responses of lower trophic levels to fish manipulation. *Hydrobiologia. 345*: 117-129.
57. Thakur R.K, Jindal R, Singh U. B, Ahluwalia A.S. (2013). Plankton diversity and water quality assessment of three freshwater lakes of Mandi (Himachal Pradesh, India) with special reference to planktonic indicators. *Environ Monit Assess 185*: 8355-8373.
58. Trisal, C.L. (1985). Trophic status of Kashmir Lakes. In: Misra, S.D., Sen, D.N. and Ahmad, I. (eds.) *Proc. Nat. Symp. Evalu. Environ.,* Geobios Supplement, 164-170. Jodhpur, India.
59. Vaidya, S. R. (2017). Biomonitoring of zooplankton to assess the quality of water in Nagpokhari of Kathmandu Valley. *International Journal of zoology studies*, *2(1),* 61-65.
60. Vandysh O. I. (2004). Zooplankton as an indicator of state of Lake ecosystems polluted with mining wastewater in Kola Peninsula. *Russian J Ecol*.; *35(2):*110-116.
61. Vass, K.K., (1980). On the trophic status and conservation of Kashmir lakes. *Hydrobiologia 61*:9-15.
62. Vass, K.K., Wanganeo, A., Raina, H.S., Zutshi, D.P and Wanganeo, R. (1989). Summer limnology and fisheries of high mountain lakes of Kashmir Himalayas. *Archiv für Hydrobiologie*, *114* (4): 603-619.
63. Verma, P.K., & Munshi, D. (1987). Plankton community structure of Badua Reservoir, Bhagalpur (India). *Tropical Ecology*, *28*,200-207.
64. Wanganeo, A., & Wanganeo, R. (2006). Variation in Zooplankton population in two morphologically dissimilar rural lakes in Kashmir Himalaya. *Nat. Acad. Sci*., *76*(B) III: 222-239.
65. Wanganeo, A., Mir, A.R., Yousuf, A.R. and Wanganeo, R. (2008). Seasonal variation of Rotifera population in relation to physico-chemical factors. In: Chishti MZ, Fayaz Ahmad (eds) *Science for Better Tomorrow*. University of Kashmir, Srinagar: 231–236.

66. Ward, H. B. & Whipple, G.C. (1992). *Freshwater Biology*. John Wiley and Sons (2nd edn). New York. 1-1248.
67. Webber Mona, Myers, Elecia Edwards, Cambell C, Webber D. (2005) Phytoplankton and zooplankton as indicators of water quality in Discovery Bay Jamaica. Hydrobiologia, *545*, 177-193.
68. Wetzel, R.G. & Likens, G.E. (1991). *Limnological Analyses*. 2nd edn. Springer, New York. 1-175.
69. Wetzel, R.G. (1983). *Limnology.* 2nd ed. Holt, Rinchart and Winston, 1-650.
70. Wilhm, J.L. & Dorris, T.C. (1968). Biological parameters for water quality criteria. *BioScience, 18*: 477-81.
71. World Health Organization (WHO) (2004). *Guidelines for Drinking water Quality*, 3rd edn. World Health Organization (WHO), Geneva.
72. Yaqoob, K.U., Pandit A.K., Wani, S.A. (2008). Comparative physicochemical limnology of three lakes of Kashmir Himalaya. *Proceedings of Taal 2007*: The 12th World Lake Conference: 1922-1927.
73. Yousuf, A.R., & Mir, M.F. (1994). Vertical distribution of Rotifera in warm monomictic lake of Kashmir. *J Freshwater Biol 6*(2):143–149.
74. Zutshi, D.P., Kaul, V. and Vass, K.K. (1972). Limnology of high altitude Kashmir lakes. *Verh. Internat. Verein. Limnol.*, *18*: 599-604.

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