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An Assessment of Phytoplankton Distribution in the Different Altitudinal Lakes of Arunachal Himalayan Region, India

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ABSTRACT
An assessment of plankton distribution along with physical and chemical parameters was undertaken in different altitudinal lakes of Arunachal Pradesh. The sampling and data analysis was performed following standard methods. Out of the total 66 species recorded, 15 species commonly occurred namely *Amphora* sp., *Bulbochaete* sp., *Closterium* sp., *Cymbella* sp., *Lyngbya* sp., *Mougeotia scalaris*, *Navicula* sp., *Nitzschia* sp., *Oedogonium* sp., *Pinnularia* sp., *Spirogyra* sp., *Stauroneis* sp., *Surirella* sp., *Synedra* sp. and *Zygnema* sp. Ganga Lake recorded the highest 33 species while Bone Lake recorded the lowest 7 species. Bacillariophyceae was dominant representing 22 species while Chrysophyceae, Dinophyceae, Euglenophyceae and Klebsormidiophyceae recorded only 1 species each. We found slight variations in physical and chemical properties due to altitude. The conductivity ranged between 4µS/cm (Kyalem) to 60µS/cm (Bone); total dissolved solid ranged between 5mg/L (Sela) to 22mg/L (Mehao); pH between 6.8 (Mehao) to 9.3 (Hireng); dissolved oxygen ranged between 4.77 mg/L (Kyalem) to 15.4 mg/L (Hireng); free carbon dioxide between 0.23 mg/L (Ganga) to 1.2 mg/L (Nagula); alkalinity between 3.4 mg/L (Mehao) to 8.2 mg/L (Hireng) and hardness recorded was between 3.7 mg/L (Mehao) to 17 mg/L (Pegu). The present findings provide baseline data on phytoplankton distribution and water quality of different altitudinal lakes in the Arunachal Himalayan Region.

Key words: Altitude, Lake, Physico-chemical parameters, Plankton, Seasonal abundance.

INTRODUCTION

The phytoplankton are unicellular organisms that drift with the water currents, carry out oxygenic photosynthesis and live in the upper illuminated waters of all aquatic ecosystems (Marañón 2009). They are the major aquatic primary producers, responsible for about half of global primary productivity each year (Field et al. 1998). The commonly found phytoplankton in freshwaters includes all suspended microalgae under the class chlorophyceae (green algae), bacillariophyceae (diatoms) and cyanophyceae/myxophyceae (blue-green algae). Plankton encountered in the water body reflects existing ecological characteristics and therefore, plankton organisms may be used as indicators of water quality (Bhatt et al. 1999, Saha et al. 2000). Plankton are very sensitive to change in environmental conditions of aquatic ecosystem. Any alteration would reflect on the existing status of ecological and biological characteristics especially in hill streams. Lakes are dynamic lentic ecosystems and possess significant resources of inland water to meet the increasing water demand (Sharma and Tiwari 2018a). The physical, chemical and biological characteristics of water play an important role in plankton productivity and final yield of aquaculture products (Poongodi et al. 2009, Radhakrishnan et al. 2009, Shanthi et al. 2010).

The important contributions on phytoplankton diversity and water quality of different mountain lakes of India include diversity of phytoplankton in Wular Lake, Kashmir (Ganai et al. 2010); ecology and biodiversity of Pangong Lake, Ladakh (Bhat et al. 2011); diversity of freshwater algae in Arunachal Pradesh (Das and Adhikary 2012); glacial lakes of Sikkim (Raj et al. 2013); phytoplankton dynamics, species diversity and water quality of Prashar Lake, Himachal Pradesh (Jindal et al. 2014a,b); hydrogeochemistry of high altitude lake Chandra Tal,

Western Himalaya (Singh et al. 2014); phytoplankton diversity in relation to abiotic factors of Nainital Lake, Kumaon Himalyas, Uttarakhand (Negi and Rajput 2015); ecology of Loktak Lake, Manipur (Kangabam et al. 2015); limnology and cyanobacterial diversity of high altitude lakes of Lahaul-Spiti, Himachal Pradesh (Singh et al. 2016); physical and chemical properties of a Himalayan lake of Uttarakhand (Pant et al. 2017) and phytoplankton diversity in relation to physical and chemical environmental variables of Nachiketa Tal, Garhwal Himalaya (Sharma and Tiwari 2018b). Recently, Hazarika and Kalita (2020) carried out limnological investigation in relation to plankton and fishes of Tasek Lake of East Garo Hills, Meghalaya. Abujam et al. (2021) studied the spatial variation of soil and water qualities of mountain lakes in Arunachal Pradesh.

However, there is dearth of studies in relation to phytoplankton distribution and physical and chemical properties of glacier-fed, spring-fed and rain-fed lakes of Arunachal Pradesh. Therefore, the present work contributes to the baseline data of phytoplankton distribution and water quality in different altitudinal lakes of Arunachal Himalayan region. It can be used as a reference dataset for further monitoring and conservation strategies.

MATERIALS AND METHODS

A preliminary survey was carried out in the lakes situated at different altitudes of Arunachal Pradesh on seasonal basis from March, 2020 to April, 2021. The lakes have been selected from low i.e. 274 to 445 m above mean sea level (MSL), mid (1661 to 1738 m above MSL) and high (3705 to 4230 m above MSL) altitude. The low altitude lakes were Ganga (27° 04' 26" N latitudes and 93° 34' 05" E longitudes) from Papum Pare district and Pegu (28° 34' 57" N latitudes and 95° 03' 50" E longitudes), Hireng (28° 34' 57" N latitudes and 95° 16' 23" E longitudes) and Bone (28° 36' 28" N latitudes and 95° 02' 52" E longitudes) from Upper Siang district. The mid altitude lake included 4 sample sites of Mehao (28° 08' 33" N to 28° 09' 12" N latitudes and 95° 56' 22" E to 95° 56' 38" E longitudes) in Lower Dibang Valley district and the high altitude lakes comprised of Kyalem (27° 40' 34" N latitudes and 91° 52' 26" E longitudes), Nagula (27° 39' 16" N latitudes and 91° 51' 48" E longitudes), Ptso (27° 38' 13" N latitudes and 91° 51' 23" E longitudes), Sela (27° 30' 22" N latitudes and 92° 06' 22" E longitudes) and Shungatser (27° 43' 20" N latitudes and 91° 49' 37" E longitudes) from Tawang district (Fig. 1). The Mehao Lake with the water spread area of 400 hectares of surface area is the largest lake in the state which is situated 14 km away from the Roing town. The lakes of Tawang district are about 5 to 14 hectares in water spread area and are mostly located within a radius of 12 to 25 km from Tawang town. The Ganga Lake is a medium-sized lake which is located about 6 km away from Itanagar, the capital of Arunachal Pradesh. The Pegu, Hireng and Bone are comparatively smaller lakes located in a radius of 6 to 12 km from Yingkiong town.

The phytoplankton samples were collected during early hours of the day (8:00 to 10:00 am) using plankton net of bolting silk No. 20 (75-p mesh size) to filter 50 litre surface water for obtaining 100 ml of the net plankton concentration (Fig. 2). The samples were immediately fixed in water sample bottle containing 5% formalin solution for further examination in the laboratory. Olympus CH 20i Microscope was used for identification and photography. The enumeration of phytoplankton was recorded as individuals per liter (ind/l) by using the Sedgewick Rafter counting cell of 1.0 ml capacity. The primary taxonomic references used for identification of phytoplankton were Adoni et al. (1985), Bellinger and Sigee (2010) and Munshi et al. (2010). The water parameters like conductivity, total dissolved solid (TDS), pH, dissolved oxygen (DO), free carbon dioxide (FCO_2) and hardness were estimated by following the scheme of Trivedy and Goel (1986) and APHA (1998).

RESULTS

The study recorded a total of 65 different phytoplankton species belonging to 8 classes and 41 families (Table 1). Out of which, 15 species were recorded in all the lakes, 13 species were common in high and low altitude lakes, 8 species were common in high and mid altitude lakes while 3 species were common in mid and low altitude lakes. Besides, 14 species were recorded only in the high

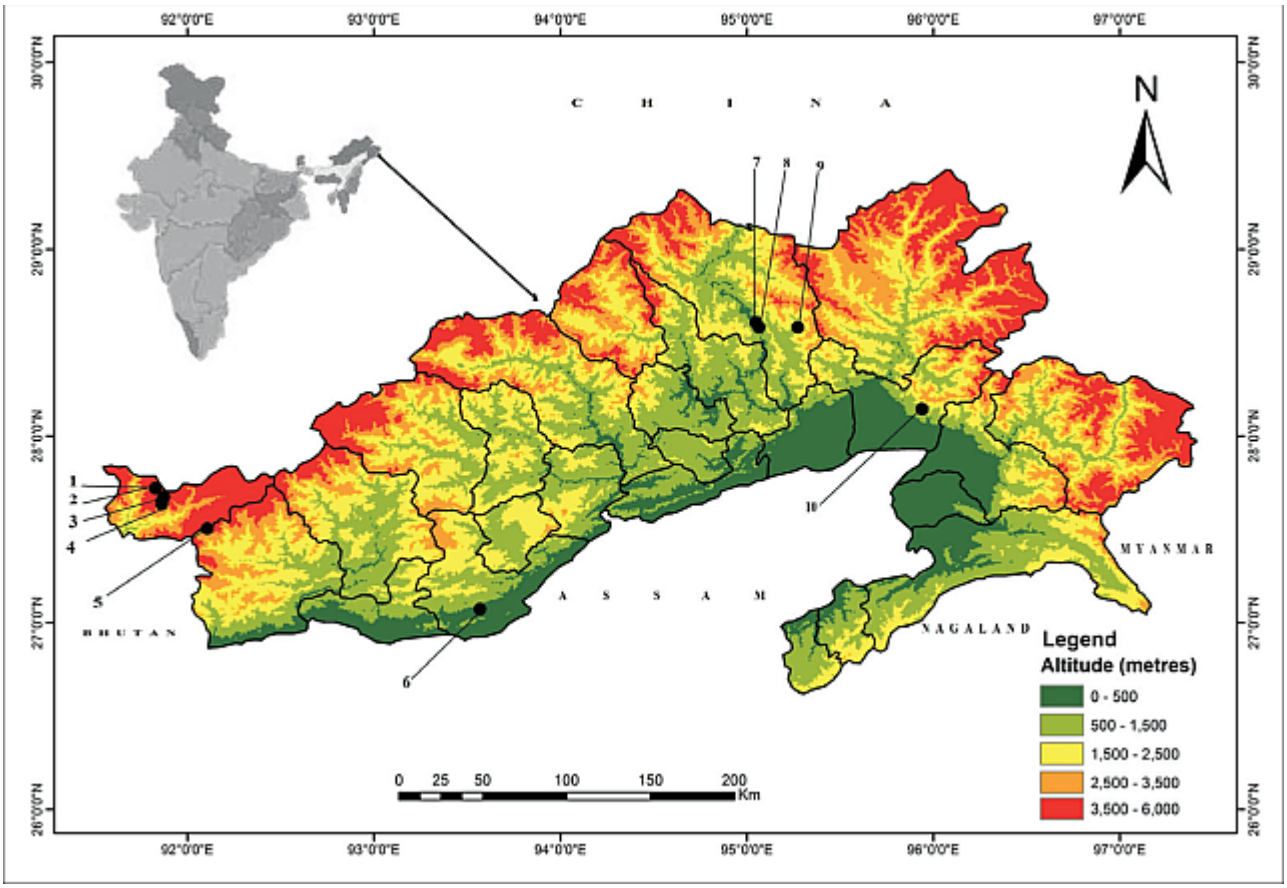

Figure 1. Location of the lakes (Redrawn from Abujam et al. 2021) Note: 1 = Shungaster, 2 = Kyalem, 3 = Nagula, 4 = Ptso, 5 = Sela, 6 = Ganga, 7 = Hireng, 8 = Bone, 9 = Pegu, and 10 = Mehao

Figure 2. Sample collections (plankton and water) from different altitudinal lakes

altitude lakes, 12 species in low altitude lakes and a lone species in mid altitude. *Amphora* sp., *Bulbochaete* sp., *Closterium* sp., *Cymbella* sp., *Lyngbya* sp., *Mougeotia scalaris*, *Navicula* sp., *Nitzschia* sp., *Oedogonium* sp., *Pinnularia* sp., *Spirogyra* sp., *Stauroneis* sp., *Surirella* sp., *Synedra* sp. and *Zygnema* sp. (Fig. 3a, b) were recorded from all the lakes. Overall, 50 different phytoplankton species were recorded in the high altitude lakes, 43 species in low altitude lakes and 27 species in mid altitude lake (Table 2). The high altitude lakes recorded 95 phytoplankton individuals, out of which Ptso recorded the highest 25 individuals (6 class & 18 family), followed by Nagula 22 individuals (4 class & 18 family), Shungatser 19 individuals (4 class & 14 family), Sela 16 individuals (5 class & 15 family) and Kyalem 13 individuals (3 class & 11 family). In the order of dominance, Bacillariophyceae recorded the highest 36 species, followed by Zygnematophyceae (22), Chlorophyceae (17),

Table 1. List of phytoplankton recorded from different altitudinal lakes

Class	Species	Family
Bacillariophyceae		
1.	*Amphora* sp.	Catenulaceae
2.	*Caloneis* sp.	Naviculaceae
3.	*Cyclotella* sp.	Stephanodiscaceae
4.	*Cymbella* sp.	Cymbellaceae
5.	*Denticula* sp.	Bacillariaceae
6.	*Diatoma* sp.	Fragilariaceae
7.	*Diploneis* sp.	Diploneidaceae
8.	*Eunotia* sp.	Eunotiaceae
9.	*Fragilaria* sp.	Fragilariaceae
10.	*Gomphonema* sp.	Gomphonemataceae
11.	*Gyrosigma* sp.	Pleurosigmataceae
12.	*Navicula* sp.	Naviculaceae
13.	*Nitzschia* sp.	Bacillariaceae
14.	*Pinnularia biceps*	Pinnulariaceae
15.	*Pinnularia grunowii*	Pinnulariaceae
16.	*Pinnularia* sp.	Pinnulariaceae
17.	*Rhopalodia* sp.	Rhopalodiaceae
18.	*Stauroneis* sp.	Stauroneidaceae
19.	*Staurosirella* sp.	Fragilariaceae
20.	*Surirella* sp.	Surirellaceae
21.	*Synedra* sp.	Fragilariaceae
22.	*Tabellaria* sp.	Tabellariaceae
Chlorophyceae		
23.	*Ankistrodesmus* sp.	Selenastraceae
24.	*Bulbochaete* sp.	Oedogoniaceae
25.	*Chlamydomonas* sp.	Chlamydomonadaceae
26.	*Chlorella* sp.	Chlorellaceae
27.	*Cladophora* sp.	Cladophoraceae
28.	*Closteriopsis* sp.	Chlorellaceae
29.	*Hydrodictyon* sp.	Hydrodictyaceae
30.	*Kirchneriella* sp.	Selenastraceae
31.	*Microspora* sp.	Microsporaceae
32.	*Oedogonium* sp.	Oedogoniaceae
33.	*Chlorococcum* sp.	Chlorococcaceae
34.	*Pediastrum* sp.	Hydrodictyaceae
35.	*Scenedesmus* sp.	Scenedesmaceae
36.	*Schizoclamys* sp.	Schizochlamydaceae
37.	*Ulothrix* sp.	Ulotrichaceae
38.	*Ulothrix zonata*	Ulotrichaceae
39.	*Volvox* sp.	Volvocaceae
Cyanophyceae		
40.	*Anabaena* sp.	Nostocaceae
41.	*Calothrix* sp.	Rivulariaceae
42.	*Chroococcus* sp.	Chroococcaceae
43.	*Eucapsis* sp.	Merismopediaceae
44.	*Komvophoron* sp.	Gomontiellaceae
45.	*Lyngbya* sp.	Oscillatoriaceae
46.	*Merismopedia* sp.	Merismopediaceae
47.	*Nostoc* sp.	Nostocaceae
48.	*Oscillatoria* sp.	Oscillatoriaceae
49.	*Phormidium* sp.	Oscillatoriaceae
Chrysophyceae		
50.	*Dermatochrysis* sp.	Chrysocapsaceae
Dinophyceae		
51.	*Peridinium* sp.	Peridiniaceae
Euglenophyceae		
52.	*Phacus* sp.	Phacaceae
Klebsormidiophyceae		
53.	*Klebsormidium* sp.	Klebsormidiaceae
Zygnematophyceae		
54.	*Cosmarium* sp.	Desmidiaceae
55.	*Euastrum* sp.	Desmidiaceae
56.	*Hyalotheca* sp.	Desmidiaceae
57.	*Micrasterias* sp.	Desmidiaceae
58.	*Mougeotia scalaris*	Zygnemataceae
59.	*Mougeotia* sp.	Zygnemataceae
60.	*Netrium digitus*	Mesotaeniaceae
61.	*Netrium* sp.	Mesotaeniaceae
62.	*Spirogyra* sp.	Zygnemataceae
63.	*Spondylosium* sp.	Desmidiaceae
64.	*Staurastrum* sp.	Desmidiaceae
65.	*Closterium* sp.	Closteriaceae
66.	*Zygnema* sp.	Zygnemataceae

Cyanophyceae (16), Chrysophyceae (1), Dinophyceae (1), Euglenophyceae (1) and Klebsormidiophyceae (1).

The species belonging to Bacillariophyceae, Chlorophyceae, and Cyanophyceae were present in all the high altitude lakes while Zygnematophyceae was absent in Kyalem. The species belonging to Chrysophyceae, Euglenophyceae and Klebsormidiophyceae were found only in Ptso while only one species belonging to Dinophyceae was recorded from Sela.

In the mid-altitude Mehao Lake (Lower Dibang Valley district), a total of 27 phytoplankton species (5 class & 21 family) were recorded. Bacillariophyceae comprised of 14 species followed by Zygnematophyceae (6), Chlorophyceae (3), Cyanophyceae (3), and Dinophyceae (1). A total of 65 species were recorded in the low altitude lakes. Ganga (Papum Pare district) recorded the highest 33 species (5 class & 25 family), followed by Hireng (Upper Siang) with 15 species (4 class & 13 family), Pegu (Upper Siang) with 10 species (4 class & 9 family), and Bone (Upper Siang) with 7 species (3 class & 6 family). Bacillariophyceae recorded 23 species, followed by Chlorophyceae (20), Cyanophyceae (12), Zygnematophyceae (9), and Euglenophyceae (1). Bacillariophyceae,

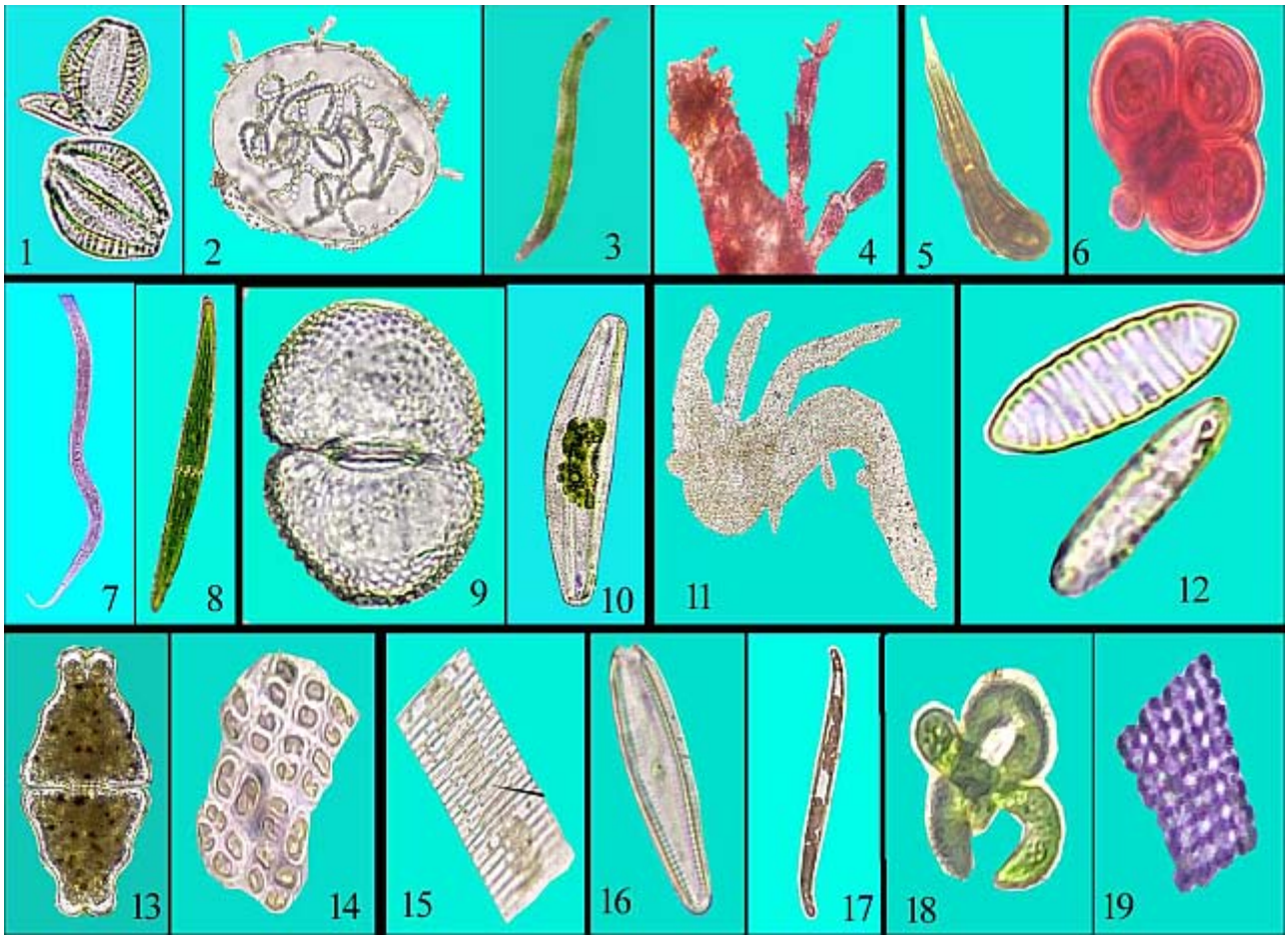

Figure 3a. Certain common phytoplankton species. (1) *Amphora* sp., (2) *Anabaena* sp., (3) *Ankistrodesmus* sp., (4) *Bulbochaete* sp., (5) *Calothrix* sp., (6) *Chroococcus* sp., (7) *Closteriopsis* sp., (8) *Closterium* sp., (9) *Cosmarium* sp., (10) *Cymbella* sp., (11) *Dermatochrysis* sp., (12) *Diatoma* sp., (13) *Euastrum* sp., (14) *Eucapsis* sp. (15) *Fragilaria* sp., (16) *Gomphonema* sp., (17) *Gyrosigma* sp., (18) *Kirchneriella* sp., and (19) *Merismopedia* sp.

Chlorophyceae, and Cyanophyceae species were found in all the low altitude lakes while Zygnematophyceae was not represented in Bone lake of Upper Siang district. One species belonging to Euglenophyceae was also recorded from Ganga.

The results of the physical and chemical parameters of the lakes studied show marked fluctuations (Table 3). Highest conductivity (60 µS/cm) was recorded from the low altitude lake (Bone) and the lowest (4 µS/cm) from high altitude lake (Kyalem). The highest total dissolved solid (TDS) of 22mg/L was observed in the mid-altitude lake (Mehao) while the lowest with 5mg/L in high altitude lake (Sela). The highest pH (9.3) was found in the low altitude lake (Hireng) while the lowest (6.8) in the mid-altitude lake (Mehao, site 4). The highest dissolved oxygen (DO) of 15.4 mg/L was found in the low altitude lake (Hireng) while the lowest with 4.77 mg/L from high altitude lake (Kyalem). The highest free carbon dioxide (FCO_2) of 1.2 mg/L was observed in the high altitude lake (Nagula) while the lowest with 0.23 mg/L from the low altitude lake (Ganga). The highest alkalinity (8.2 mg/L) was found in the low altitude lake (Hireng) while the lowest (3.4 mg/L) from mid-altitude lake (Mehao, site 4). Lastly, the highest hardness (17 mg/L) was found in the low altitude lake (Pegu) while the lowest (3.7 mg/L) from mid-altitude lake (Mehao).

DISCUSSION

A total of 187 phytoplankton species were recorded

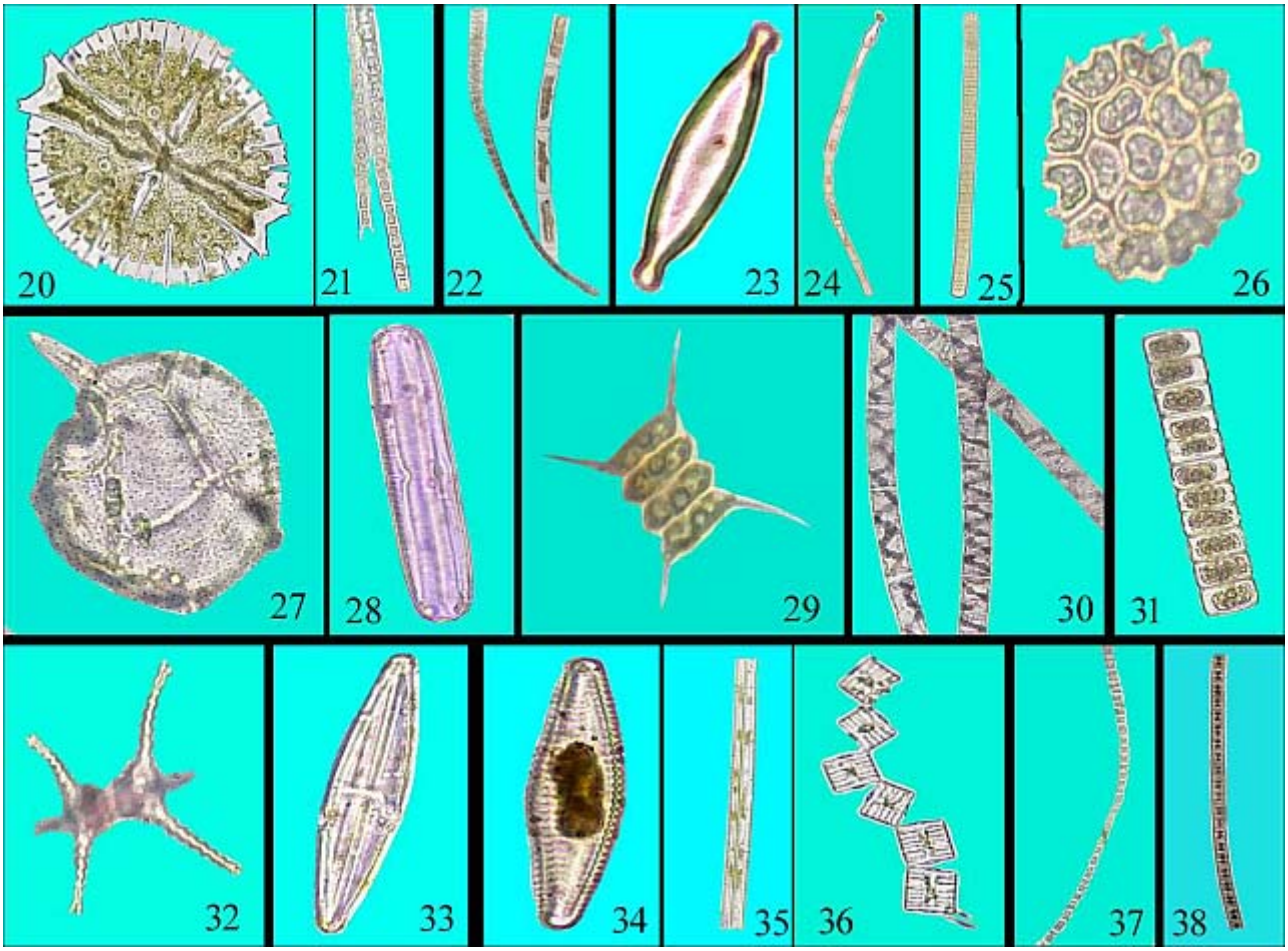

Figure 3b. Certain common phytoplankton species. (20) *Micrasterias* sp., (21) *Microspora* sp., (22) *Mougeotia* sp., (23) *Navicula* sp., (24) *Oedogonium* sp., (25) *Oscillatoria* sp., (26) *Pediastrum* sp., (27) *Peridinium* sp., (28) *Pinnularia* sp., (29) *Scenedesmus* sp., (30) *Spirogyra* sp., (31) *Spondylosium* sp., (32) *Staurastrum* sp., (33) *Stauroneis* sp., (34) *Surirella* sp., (35) *Synedra* sp., (36) *Tabellaria* sp., (37) *Ulothrix* sp., and (38) *Zygnema* sp.

from all the studied lakes. Ganga Lake recorded the highest 33 species, followed by Mehao (27), Ptso (25), Nagula (22), Shungatser (19), Sela (16), Hireng (15), Kyalem (13), Pegu (10), and Bone (7). The larger sized lakes such as Ganga, Mehao, Ptso, and Nagula showed comparatively higher number of phytoplankton species than the smaller sized lakes. Bacillariophyceae was found to be the dominant class representing 22 species followed by Chlorophyceae (17 species), Zygnematophyceae (13 species), Cyanophyceae (10 species), Chrysophyceae, Dinophyceae, Euglenophyceae, and Klebsormidiophyceae (1 species each). Similar observations of the dominance of Bacillariophyceae were also reported from Dodi Tal of Garhwal (Sharma and Singh, 2018); Nainital Lake of Uttarakhand (Negi and Rajput, 2015) and high altitude Himalayan ponds of Badrinath (Kumar et al. 2012).

Some of the Bacillariophyceae species like *Fragilaria* sp., *Navicula* sp., *Nitzschia* sp., *Gomphonema* sp., *Cymbella* sp. and *Diatoma* sp. were abundant and more common throughout the year in all the lakes studied while *Amphora* sp., *Eunotia* sp., *Pinnularia* sp., *Synedra* sp. and *Tabellaria* sp. were found to be discontinuously distributed and sometimes absent during collection throughout the year. On the other hand, the occurrence of species like *Cyclotella* sp., *Denticula* sp., *Diploneis* sp. *Gyrosigma* sp., *Stauroneis* sp., and *Surirella* sp. were found to be rare. These species were also recorded from Badrinath ponds (Kumar et

Table 2. Seasonal abundance of phytoplankton (+++ = Abundant, ++ = Common, + = Rare, and – = Absent) Wi = Winter (December 2020 - February 2021), Prm = Pre-monsoon (March - May 2020). Mo = Monsoon (June - August 2020) and Pom = Post-monsoon (September - November 2020)

Lakes	Class	Family	Species	Seasonal Abundance			
				Wi	Prm	Mo	Pom
High altitude **Kyalem**	Bacillariophyceae	Catenulaceae	*Amphora* sp.	+	+	-	+
		Eunotiaceae	*Eunotia* sp.	+	+	-	+
		Fragilariaceae	*Fragilaria* sp.	++	+++	++	++
		Stauroneidaceae	*Stauroneis* sp.	+	+	+	+
	Chlorophyceae	Cladophoraceae	*Cladophora* sp.	++	+	-	+
		Microsporaceae	*Microspora* sp.	++	-	++	+
		Ulotrichaceae	*Ulothrix* sp.	+	+	-	-
		Volvocaceae	*Volvox* sp.	+	++	+++	+
	Cyanophyceae	Nostocaceae	*Anabaena* sp.	-	+	+	+
			Nostoc sp.	-	+	+	-
		Oscillatoriaceae	*Lyngbya* sp.	++	+	+	+
			Oscillatoria sp.	++	-	-	+
		Rivulariaceae	*Calothrix* sp.	+++	++	+	+
High altitude **Sela**	Bacillariophyceae	Catenulaceae	*Amphora* sp.	++	+	-	+
		Diploneidaceae	*Diploneis* sp.	++	+	-	-
		Eunotiaceae	*Eunotia* sp.	++	+	-	+
		Fragilariaceae	*Fragilaria* sp.	++	+++	++	++
		Pinnulariaceae	*Pinnularia* sp.	++	+	+	+
		Surirellaceae	*Surirella* sp.	++	+	-	+
		Tabellariaceae	*Tabellaria* sp.	++	+	-	+
	Chlorophyceae	Oedogoniaceae	*Oedogonium* sp.	+	++	++	+
		Scenedesmaceae	*Scenedesmus* sp.	+	-	-	+
	Cyanophyceae	Nostocaceae	*Anabaena* sp.	-	++	+	+
		Merismopediaceae	*Merismopedia* sp.	+	+	-	-
		Oscillatoriaceae	*Oscillatoria* sp.	+	++	+++	+
	Dinophyceae	Peridiniaceae	*Peridinium* sp.	+	+	+	-
	Zygnematophyceae	Desmidiaceae	*Cosmarium* sp.	++	++	+++	++
		Zygnemataceae	*Mougeotia scalaris*	+	++	+++	++
			Spirogyra sp.	+	+	++	+
High altitude **Nagula**	Bacillariophyceae	Fragilariaceae	*Diatoma* sp.	+++	++	-	-
		Naviculaceae	*Navicula* sp.	+	+++	+++	+
		Bacillariaceae	*Nitzschia* sp.	+++	+	+	-
		Pinnulariaceae	*Pinnularia* sp.	++	+	+	+
		Rhopalodiaceae	*Rhopalodia* sp.	++	+	-	+
		Stauroneidaceae	*Stauroneis* sp.	++	+	-	+
		Tabellariaceae	*Tabellaria* sp.	++	+	-	+
	Chlorophyceae	Oedogoniaceae	*Bulbochaete* sp.	+	+	-	-
		Chlorellaceae	*Closteriopsis* sp.	+	+	-	-
		Hydrodictyaceae	*Pediastrum* sp.	+++	+	++	++
		Schizochlamydaceae	*Schizoclamys* sp.	+	+	-	-
		Ulotrichaceae	*Ulothrix* sp.	-	+	+	+
			Ulothrix zonata	-	+	+	+

Lakes	Class	Family	Species	Seasonal Abundance			
				Wi	Prm	Mo	Pom
	Cyanophyceae	Rivulariaceae	*Calothrix* sp.	+	++	++	+
		Chroococcaceae	*Chroococcus* sp.	+	-	+	+
		Oscillatoriaceae	*Lyngbya* sp.	++	++	+	+
			Oscillatoria sp.	+	++	+++	+
	Zygnematophyceae	Closteriaceae	*Closterium* sp.	+	++	+++	+
		Desmidiaceae	*Cosmarium* sp.	+	++	+++	+
			Euastrum sp.	++	++	+++	++
			Hyalotheca sp.	++	++	+++	++
		Zygnemataceae	*Mougeotia scalaris*	+	++	+++	+
High altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	++	+	-	+
Ptso		Eunotiaceae	*Eunotia* sp.	++	+	-	+
		Gomphonemataceae	*Gomphonema* sp.	+++	+	++	-
		Naviculaceae	*Navicula* sp.	+	+++	+++	+
		Pinnulariaceae	*Pinnularia* sp.	++	+	+	+
		Surirellaceae	*Surirella* sp.	++	+	-	+
		Fragilariaceae	*Fragilaria* sp.	++	+++	++	++
			Staurosirella sp.	++	+	-	+
			Synedra sp.	++	++	+	+
		Tabellariaceae	*Tabellaria* sp.	++	+	+	+
	Chlorophyceae	Oedogoniaceae	*Bulbochaete* sp.	+	+	-	-
			Oedogonium sp.	+	++	++	+
		Ulotrichaceae	*Ulothrix* sp.	-	+	+	+
	Cyanophyceae	Nostocaceae	*Anabaena* sp.	-	++	+	+
		Chroococcaceae	*Chroococcus* sp.	+	-	+	+
	Euglenophyceae	Euglenaceae	*Phacus* sp.	++	++	+	+
	Chrysophyceae	Chrysocapsaceae	*Dermatochrysis* sp.	+	+	-	-
	Klebsormidio-phyceae	Klebsormidiaceae	*Klebsormidium* sp.	+	+	-	-
	Zygnematophyceae	Closteriaceae	*Closterium* sp.	+	++	+++	+
		Desmidiaceae	*Cosmarium* sp.	+	++	+++	+
			Micrasterias sp.	+++	++	+	+
		Zygnemataceae	*Mougeotia scalaris*	+	++	+++	+
			Mougeotia sp.	-	+	++	+
			Spirogyra sp.	++	+	-	+
			Zygnema sp.	+	-	-	+
High altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	++	+	-	+
Shungatser		Naviculaceae	*Caloneis* sp.	++	++	+	+
		Cymbellaceae	*Cymbella* sp.	+++	++	+	+
		Bacillariaceae	*Denticula* sp.	+	+	-	-
		Fragilariaceae	*Diatoma* sp.	+++	++	-	-
		Gomphonemataceae	*Gomphonema* sp.	+++	+	++	+
		Pinnulariaceae	*Pinnularia* sp.	++	+	-	+
		Stauroneidaceae	*Stauroneis* sp.	++	+	+	+
	Chlorophyceae	Oedogoniaceae	*Bulbochaete* sp.	+	+	-	-
		Ulotrichaceae	*Ulothrix* sp.	-	+	+	+
	Cyanophyceae	Oscillatoriaceae	*Lyngbya* sp.	++	+	+	+

Lakes	Class	Family	Species	Seasonal Abundance			
				Wi	Prm	Mo	Pom
			Oscillatoria sp.	+	++	+	+
	Zygnematophyceae	Closteriaceae	*Closterium* sp.	+	++	+++	+
		Desmidiaceae	*Cosmarium* sp.	+	++	+++	+
			Hyalotheca sp.	++	++	++	+
		Zygnemataceae	*Mougeotia scalaris*	+	++	+++	+
			Spirogyra sp.	++	+	-	+
		Desmidiaceae	*Spondylosium* sp.	+	+	-	-
		Zygnemataceae	*Zygnema* sp.	+	-	-	+
Mid-altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	+	+	+	+
Mehao		Naviculaceae	*Caloneis* sp.	++	+	+	-
		Cymbellaceae	*Cymbella* sp.	+	++	+	+
		Fragilariaceae	*Diatoma* sp.	+++	++	-	+
		Eunotiaceae	*Eunotia* sp.	+	+	+	+
		Fragilariaceae	*Fragilaria* sp.	+	++	++	+
		Gomphonemataceae	*Gomphonema* sp.	+++	+	++	+
		Naviculaceae	*Navicula* sp.	+++	+	-	+
		Bacillariaceae	*Nitzschia* sp.	+++	+	-	+
		Pinnulariaceae	*Pinnularia* sp.	+	+	+	+
		Stauroneidaceae	*Stauroneis* sp.	+	+	+	+
		Surirellaceae	*Surirella* sp.	+	+	+	+
		Fragilariaceae	*Synedra* sp.	+	++	+	-
		Tabellariaceae	*Tabellaria* sp.	++	+	+	+
	Chlorophyceae	Oedogoniaceae	*Bulbochaete* sp.	+	+	-	+
			Oedogonium sp.	+	++	-	+
		Hydrodictyaceae	*Pediastrum* sp.	+++	+	++	++
	Cyanophyceae	Merismopediaceae	*Eucapsis* sp.	+	+	-	-
		Oscillatoriaceae	*Lyngbya* sp.	+	-	-	+
			Phormidium sp.	+	-	-	+
	Zygnematophyceae	Closteriaceae	*Closterium* sp.	+	++	+	-
		Zygnemataceae	*Mougeotia scalaris*	-	+	+	+
		Mesotaeniaceae	*Netrium digitus*	++	++	+++	++
		Zygnemataceae	*Spirogyra* sp.	+++	++	+	++
		Desmidiaceae	*Staurastrum* sp.	+	+	-	+
		Zygnemataceae	*Zygnema* sp.	+	+	-	+
	Dinophyceae	Peridiniaceae	*Peridinium* sp.	++	++	+	+
Low altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	+	+	+	-
Ganga		Stephanodiscaceae	*Cyclotella* sp.	+	-	-	+
		Cymbellaceae	*Cymbella* sp.	+	+++	++	+
		Naviculaceae	*Gyrosigma* sp.	-	+	+	+
			Navicula sp.	++	++	+++	++
		Bacillariaceae	*Nitzschia* sp.	+	+++	++	+
		Pinnulariaceae	*Pinnularia biceps*	+	++	++	+
			Pinnularia grunowii	+	++	++	+
		Stauroneidaceae	*Stauroneis* sp.	+	+	+	+
		Surirellaceae	*Surirella* sp.	+	+	+	+
		Fragilariaceae	*Synedra* sp.	+	+	++	-

Lakes	Class	Family	Species	Seasonal Abundance			
				Wi	Prm	Mo	Pom
	Chlorophyceae	Selenastraceae	*Ankistrodesmus* sp.	+	+	+	+
		Chlamydomonadaceae	*Chlamydomonas* sp.	++	++	++	+++
		Chlorellaceae	*Chlorella* sp.	++	++	++	+
		Chlorococcaceae	*Chlorococcum* sp.	+	+	-	-
		Chlorellaceae	*Closteriopsis* sp.	++	+	+	+
		Selenastraceae	*Kirchneriella* sp.	+	+	+	-
		Oedogoniaceae	*Oedogonium* sp.	+	++	-	+
		Scenedesmaceae	*Scenedesmus* sp.	+	-	-	+
		Ulotrichaceae	*Ulothrix* sp.	++	++	-	+
		Volvocaceae	*Volvox* sp.	+	++	+++	++
	Cyanophyceae	Merismopediaceae	*Eucapsis* sp.	+	+	-	-
		Gomontiellaceae	*Komvophoron* sp.	+	+	-	-
		Merismopediaceae	*Merismopedia* sp.	+	+	-	-
		Oscillatoriaceae	*Oscillatoria* sp.	++	++	+++	+
			Phormidium sp.	+	-	-	+
	Zygnematophyceae	Chlorellaceae	*Closterium* sp.	+	++	+	-
		Zygnemataceae	*Mougeotia scalaris*	-	+	+	+
		Mesotaeniaceae	*Netrium* sp.	+	++	+++	++
		Zygnemataceae	*Spirogyra* sp.	++	++	-	+
		Desmidiaceae	*Staurastrum* sp.	+	+	+	-
		Zygnemataceae	*Zygnema* sp.	++	-	-	+
	Euglenophyceae	Euglenaceae	*Phacus* sp.	+++	++	++	+
Low altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	++	+	+	-
Hireng		Cymbellaceae	*Cymbella* sp.	+	+++	+	+
		Diploneidaceae	*Diploneis* sp.	+	+	-	-
		Naviculaceae	*Navicula* sp.	++	++	+++	++
		Stauroneidaceae	*Stauroneis* sp.	+	+	+	+
		Fragilariaceae	*Synedra* sp.	+	+	++	-
	Chlorophyceae	Cladophoraceae	*Cladophora* sp.	++	++	+++	+
		Microsporaceae	*Microspora* sp.	+	+	++	+
		Oedogoniaceae	*Oedogonium* sp.	+	++	++	+
		Scenedesmaceae	*Scenedesmus* sp.	+	-	+	++
	Cyanophyceae	Nostocaceae	*Anabaena* sp.	+	++	+	-
			Nostoc sp.	-	++	+	-
		Oscillatoriaceae	*Oscillatoria* sp.	+	++	+++	++
	Zygnematophyceae	Zygnemataceae	*Mougeotia scalaris*	-	+	+	+
			Spirogyra sp.	+	++	++	-
Low altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	+	+	-	-
Pegu		Naviculaceae	*Navicula* sp.	++	++	+++	++
		Pinnulariaceae	*Pinnularia* sp.	-	+	+	+
	Chlorophyceae	Cladophoraceae	*Cladophora* sp.	+	++	+++	+
		Chlorellaceae	*Chlorella* sp.	+	++	++	+
		Oedogoniaceae	*Oedogonium* sp.	+	++	++	+
	Cyanophyceae	Nostocaceae	*Anabaena* sp.	+	++	+	-
		Oscillatoriaceae	*Lyngbya* sp.	-	++	++	+
			Oscillatoria sp.	+	++	+++	++

Lakes	Class	Family	Species	Seasonal Abundance			
				Wi	Prm	Mo	Pom
	Zygnematophyceae	Zygnemataceae	*Spirogyra* sp.	+	++	++	-
Low altitude	Bacillariophyceae	Catenulaceae	*Amphora* sp.	+	+	-	-
Bone		Naviculaceae	*Navicula* sp.	++	++	+++	++
		Bacillariophyceae	*Rhopalodia* sp.	-	+	+	+
	Chlorophyceae	Oedogoniaceae	*Bulbochaete* sp.	-	+	+	+
			Oedogonium sp.	+	++	++	+
		Hydrodictyaceae	*Hydrodictyon* sp.	-	+	+	-
	Cyanophyceae	Oscillatoriaceae	*Oscillatoria* sp.	+	++	+++	++

Table 3. Water quality parameters in different altitudinal lakes (March 2020 – February 2021)

District	Name of Lakes	Altitude (m)	Conductivity (μS/cm)	TDS (mg/l)	pH	DO (mg/l)	FCO_2 (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)
Upper Siang	Pegu	274	49	10	9.2±0.3	11.5± 0.60	0.25±0.13	7.9±1.50	17.0±4.20
	Hireng	383	13.51	13	9.3±0.5	15.4±0.35	0.38±0.22	8.2±2.40	6.40±1.50
	Bone	445	60	12	7.8±0.2	7.80±1.20	0.59±0.25	6.1±1.04	8.40±1.60
Papum Pare	Ganga	341	19	12	7.4±0.4	8.60±0.52	0.23±0.40	4.2±0.95	5.80±2.70
Tawang	Sela	4164	5	5	8.2±0.5	5.25±0.50	0.56±0.12	7.5±2.52	6.50±2.02
	Kyalem	4230	4	6.4	8.1±0.3	4.77±0.51	0.81±0.42	7.5±2.53	12.3±3.13
	Nagula	4122	7	7	7.9±0.3	5.08±0.28	1.20±0.53	6.8±2.01	11.1±4.02
	Shungatser	3705	14	8	7.9±0.4	6.44±1.05	0.52±0.21	5.1±1.29	5.60±1.06
	Ptso	3904	26	13	7.9±0.3	5.52±1.23	0.49±0.23	6.4±1.03	8.50±2.12
Lower Dibang	Mehao Site 1	1671	26	22	7.3±0.3	10.3±1.62	0.50±0.2	4.9±2.46	3.7±0.90
Valley	Mehao Site 2	1738	22	21	7.6±0.2	8.0±1.02	0.32±0.3	5.2±1.06	5.5 ±1.24
	Mehao Site 3	1680	18	20	7.6±0.1	7.8±1.13	0.33±0.1	5.0±1.08	3.7±1.02
	Mehao Site 4	1661	20	21.97	6.8±0.2	9.6±2.15	0.36±0.1	3.4±0.91	4.0±1.00

al. 2012), Nainital lake of Uttarakhand (Negi and Rajput 2015), Rewalsar Lake of Himachal Pradesh (Jindal and Thakur 2013) and Wular Lake of Kashmir (Ganai and Parveen 2014).

Among the Chlorophyceae class, species like *Microspora* sp., *Chlorella* sp., *Chlamydomonas* sp., *Cladophora* sp., *Oedogonium* sp., *Pediastrum* sp. and *Volvox* sp. were abundant and more common throughout the year while the species like *Ankistrodesmus* sp., *Bulbochaete* sp., *Chroococcus* sp., *Closteriopsis* sp., *Hydrodictyon* sp., *Kirchneriella* sp., *Ulothrix* sp., *Scenedesmus* sp. and *Schizoclamys* sp. occurred rarely.

The abundant species under Cyanophyceae were *Calothrix* sp., *Lyngbya* sp. and *Oscillatoria* sp. while *Anabaena* sp., *Chroococcus* sp., *Eucapsis* sp., *Komvophoron* sp., *Merismopedia* sp., *Nostoc* sp., and *Phormidium* sp. occurred rarely and sometimes absent. *Oscillatoria* sp. was found mostly abundant in the low altitude lakes. These species have been also reported in Nainital Lake of Uttarakhand (Negi and Rajput 2015); Rewalsar Lake of Himachal Pradesh (Jindal and Thakur 2013); Chandra Tal, Suraj Tal, Deepak Tal and Sissu Lake of Western Himalaya, Himachal Pradesh (Singh et al. 2016).

In case of Zygnematophyceae, *Closterium* sp., *Cosmarium* sp., *Euastrum* sp., *Hyalotheca* sp., *Mougeotia scalaris*, *Netrium digitus* and *Spirogyra* sp. were abundant and more common throughout the year in all the lakes except mid and low altitude lake (Mehao, Ganga, Hireng) while *Zygnema* sp., *Spondylosium* sp. and *Staurastrum* sp. occurred rarely and sometimes absent. *Netrium* sp. was mostly abundant in low altitude lake (Ganga). *Peridinium* sp. (Dinophyceae) was rare and sometimes absent in high altitude lake (Sela) but it was common and

rare in mid altitude lake (Mehao). *Phacus* sp. (Euglenophyceae) was common in Ganga while *Dermatochrysis* sp. (Chrysophyceae) and *Klebsormidium* sp. (Klebsormidiophyceae) rarely occurred in the high altitude lake (Ptso).

In the present investigation, there were prominent variations in seasonal abundance of phytoplankton in all the lakes with comparatively higher number of phytoplankton during the winter and pre-monsoon seasons probably due to low/ moderate temperature, high pH, relatively high amount of dissolved oxygen and low hardness. The study revealed that the phytoplankton thrive well in different temperatures because water temperature is a critical parameter that control aquatic biota (Wetzel 1983). There is considerable evidence from Indian waters that maximum diatoms are produced during the summer or winter or both (Dhanapathi 2000).

The physical and chemical properties of the lake water were found to vary in different altitude zones. The pH, total solids, calcium, nitrate, phosphate and organic matter are important factors influencing the growth of algae (Cairns and Dickinson 1971). Also the usual temperature, nitrates, phosphate and angiosperm association are often cited as important factors influencing the abundance and spatio-temporal distribution of diatoms (Kumara et al. 2018). The pH is a key factor that decides the suitability of water for various purposes. The pH values of the lakes mostly lies in the range of 6.5-8.5 in accordance with the World Health Organization (WHO) standards. High pH values promote the growth of algae and results in heavy bloom of phytoplankton (Nandan and Patel 1992). Similar range of pH has been reported also from Satopanth Lake of Garhwal Himalaya (Sharma and Kumar 2017). The dissolved oxygen is a vital parameter for natural health of aquatic ecosystem (Chang 2002). Additionally, it is the most reliable criterion for assessing the trophic status i.e. eutrophication (Edmondson 1966). The mean value of dissolved oxygen (except Kyalem) reached above the critical values of 5.0 mg/L as per the WHO standards in conformity with earlier findings in different lakes of the Himalayan region (Saini et al. 2008, Sharma and Kumar 2017, Abujam et al. 2021). The mean value of alkalinity was less than the permissible level of 200 mg L^{-1} as recommended by the WHO. The mean value of total hardness was also less than the WHO standards (200 mg/L). The low values of total hardness may be attributed to the fewer amounts of cation dissolved in water. Saini et al. (2008), Sharma and Kumar (2017) and Abujam et al. (2021) also reported similar results from the Himalayan lakes.

CONCLUSION

The distribution of phytoplankton in the lakes fairly varied due to the altitude factor. The highest number of phytoplankton was observed in the high altitude lakes while lowest in the mid-altitude lake. The presence of plankton community indicated a healthy lake ecosystem and the status of pollution. The present investigation revealed that the lakes have no pollution load and no significant impacts of anthropogenic activities were observed so far. The findings also showed slight variations in physical and chemical properties among the different altitudinal lakes. However, most of the water quality parameters were found good and were within the range of WHO standards and Bureau of Indian Standards (BIS). The present baseline findings can be a reference for further studies in managing the lakes of the Himalayan region for sustainable development.

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