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# Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya

## Abstract

The study deals with the assessment of physico-chemical parameters and phytoplankton diversity of Nachiketa Tal. The lake was monitored for one annual cycle (May 2014-April 2015). A total of 71 taxa of phytoplankton belonging to 57 genera were recorded. Phytoplankton in the lake are represented by six major families, *Bacillariophyceae* (22), *Chlorophyceae* (37), *Cyanophyceae* (6), *Xanthopyceae* (2), *Dinophyceae* (2) and *Euglenophyceae* (2). The overall phytoplankton density was found to be abundant (1401±325.60 ind. $l^{-1}$) in winter season, declined in monsoon season (457.50±17.83 ind. $l^{-1}$) but the population of *Cyanophyceae* and *Euglenophyceae* was found to be high (174.33±37.09 ind. $l^{-1}$) and (24.33±5.89 ind. $l^{-1}$) respectively in summer season. Results showed that the increases in turbidity, TDS in monsoon season are the driving factors for decreasing the phytoplankton density in the lake. Pearson's correlation and CCA calculated between environmental variables and phytoplankton diversity showed that the distribution of phytoplankton in the lake is dependent on the variabilities of physico-chemical variables.

**Keywords:** phytoplankton, himalaya, lake, physico-chemical

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## Introduction

Lakes are the important natural resources present on the Earth. These are the type of productive ecosystem important for any geographical region, as they play significant role in its ecological stability.[1] The Nachiketa Tal is an important lake of Garhwal Himalaya. This lake is surrounded by dense forest of *Querecus, Abies, Rhododendron* and *Myrica, etc*. and receives its water from the watershed. The variations and distribution of phytoplankton in freshwater lake depend on its physiochemical features.[2] Phytoplanktons are the primary producer and play a vital role in food chain of aquatic ecosystem.[3,4] Due to this reason, phytoplanktons are usually used as an ecological indicator to assess the ecological health and the stress effects of chemical contaminants on aquatic ecosystems and they are also necessary to sustain a healthy aquatic ecosystem.[5–8] Dynamics in the phytoplankton biomass are the result of the complex interaction of physical, chemical and biological processes. The availability of nutrients influences the diversity of the phytoplankton. From the past few decades, there is much interest to study various factors influencing the development of phytoplankton in relation to the physico-chemical attributes.[9–12] Changes in the phytoplankton community of different types of lakes also assessed the trophic status and environmental quality of the lakes. Algae (Phytoplankton) are photoautotrophic organisms having chlorophyll 'a' and unicellular reproductive structures. It is highly diverse group, which are important for aquatic habitats.[13]

A preliminary study on the primary productivity of Nachiketa Tal has been done by Singh et al.[14] A factual report of the water quality of the lake is also available.[15] So the present study was carried out in order to determine the composition, density and diversity of Phytoplankton of Nachiketa Tal and the influence of physico-chemical variables on them.

## Materials and methods

Nachiketa Tal is located between latitude N 30°38.666' N and longitude E 078°28.362' E at an altitude of 2,453m above m.s.l. in Garhwal Himalaya. The area of Nachiketa Tal is 0.49 ha. It is elliptical in shape, measuring about 132 m in length and 58 m width (Figure 1). The lake remains occasionally covered with thin sheet of ice during the winter months of January and February. The lake depth varies from season to season and attains its maximum depth during rainy season and has no noticeable inlet as well as outlet. During the major part of the year, Nachiketa Tal remains shallow. The runoff from the forest deposited sediments in the lake bed. Monthly sampling was undertaken at 08:00 to 10:00 hrs during the one annual cycle (May 2014 to April 2015).

Four sampling sites ($S_1$, $S_2$, $S_3$, $S_4$) were identified for covering the entire ecosystem for collecting data on the physico-chemical parameters and phytoplankton community of the Nachiketa Tal. For physico-chemical parameters, five replicates of samples from each sampling site were taken for each parameter and their mean value was computed. Water temperature was recorded with the help of the Centigrade (0-110°C) thermometer; electrical conductivity and pH of the sample were measured with the help of the Toshcon Multiparameter Analyser. Nitrates, phosphates, sulphates were determined by using Spectrophotometer (Model –UV-VIS Systronics 117 series). Dissolved Oxygen, total hardness, BOD, alkalinity, calcium, magnesium *etc.* were measured followed the method outlined in Wetzel and Likens,[16] APHA.[17]

For phytoplankton, from each sampling site, five liter of sample was passed through silk plankton net of mesh size 20 µm and was fixed through 4% formalin solution into sample bottles. Enumeration

of density of phytoplankton (ind. $l^{-1}$) was done by using Sedgwick Rafter counting cell. The identification of phytoplankton was done by using the Olympus CH 20*i* Microscope and was identified with the help of Ward & Whipple,[18] Bellinger & Sigee[19] and Munshi et al.[20] The Pearson's correlation coefficient was used to determine the relationship among the various physico-chemical parameters and different phytoplankton. The correlation coefficient was performed using SPSS version 16.0. CCA was performed using P Aleonotological Statistics (PAST) Software version 2.10.

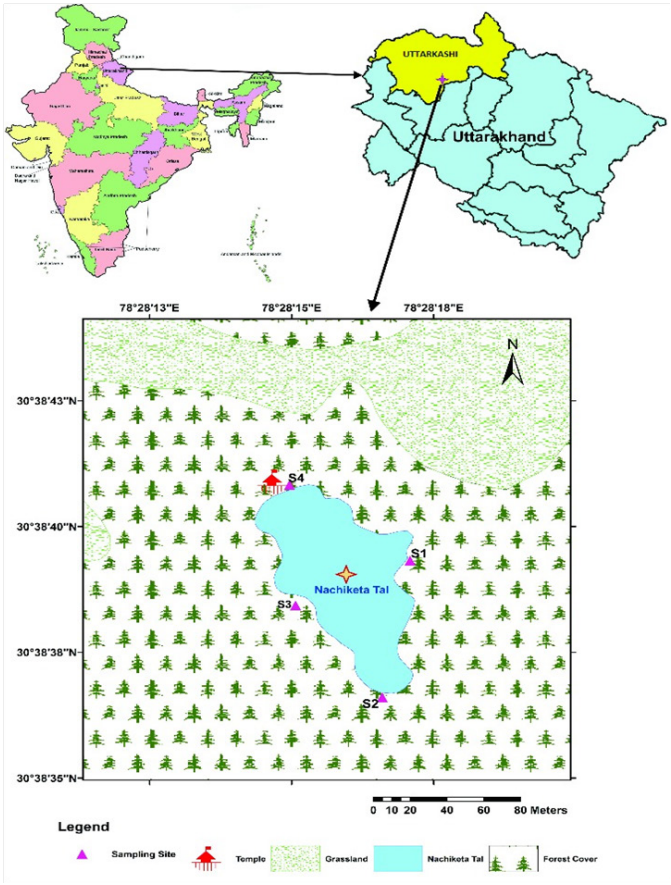


**Figure 1** Location map of Nachiketa Tal with sampling sites.

## Results and discussion

### Physico-chemical environmental variables

The high altitude lakes are sensitive indicators of environmental changes. The water qualities of such lakes are greatly influenced by the variations in parameters like temperature and pH.[21] The physico-chemical parameters were determined in order to observe their influence on phytoplankton density (Table 1-4). Air temperature was found maximum (22.13±1.53°C) at $S_4$ in summer season and minimum (10.43±2.58°C) at $S_2$ in winter season. Water temperature was found to be maximum (20.77±1.72°C) in summer season at $S_4$ and minimum (8.7±1.9°C) in winter at $S_2$. Electrical conductivity was highest (69.9±2.4µScm$^{-1}$) in monsoon season at $S_2$ and lowest (34.57±2.99µScm$^{-1}$) in winter at $S_1$. pH is an important parameter and has a significant role in the biological process of all aquatic organisms.[22] pH was found maximum(7.280.07) at $S_4$ in winter season and lowest (6.59±0.01) was recorded in monsoon season at $S_2$. TDS in Nachiketa Tal was found maximum (36.75±0.35 mg.$l^{-1}$) at $S_2$ in monsoon season and minimum (16.3±1.27mg. $l^{-1}$) at $S_3$ in spring season. Turbidity was found maximum in monsoon (7.97±0.97 NTU) at $S_2$ and minimum in spring (2.96±1.15 NTU) at $S_4$. Maximum TDS and turbidity in monsoon season is due to the rain which transports soil and other organic matter from the watershed to the lake. The availability of dissolved oxygen is one of the most critical factors for the survival of the aquatic organisms.[23] DO was found maximum (8.57±0.45 mg.$l^{-1}$) at winter season at $S_4$ and minimum (6.5±0.71 mg.$l^{-1}$) at $S_1$ in monsoon season. Higher dissolved oxygen in winter season is also reported by Garg et al.[24] BOD was found to be maximum (1.5±0.14 mg.$l^{-1}$) in monsoon season at $S_4$ and minimum (0.57±0.12 mg.$l^{-1}$) in winter season at $S_3$. Similar finding was recorded by Bordoloi & Baruah.[25] Free $CO_2$ was found maximum (2.38±0.62 mg.$l^{-1}$) and minimum (1.01±0.19 mg.$l^{-1}$) at $S_2$ in monsoon and spring season respectively. Higher free $CO_2$ was also recorded in monsoon season.[25] Maximum water temperature in the Nachiketa Tal was recorded high in the month of summer followed by months of monsoon. Raised temperature in the monsoon season could increase the microbial decomposition of the organic matter carried out by the rain in to the lake ecosystem which in turn reduce the DO level into the water body.[25–28] Due to the microbial decomposition, there is an increased demand of DO, resulting in the high BOD value in the monsoon season.[29] High microbial activities in the monsoon season also raise the level of $CO_2$ into the water, which is also one of the reasons of maximum $CO_2$ level in monsoon season. Maximum free $CO_2$ decreases the pH level in monsoon season.[30] Total alkalinity was found maximum (82.73±3.68 mg.$l^{-1}$) and minimum (53.50±11.43 mg.$l^{-1}$) in summer season and winter season respectively at $S_1$. Similar trend was also reported by Fathi and Flower.[31] Calcium was found maximum (8.28±2.02 mg.$l^{-1}$) in summer season at $S_1$ and minimum (4.01±1.13 mg.$l^{-1}$) in monsoon at $S_2$. Magnesium was found to be maximum (3.82±0.11 mg.$l^{-1}$) at $S_3$ in summer season and minimum in monsoon season at $S_1$, $S_3$ and in autumn season at $S_3$. Chlorides were found maximum (5.68±0.8 mg.$l^{-1}$) in monsoon at $S_2$ and minimum (2.98±0.2 mg.$l^{-1}$) in autumn season at $S_3$. Total hardness was found to be maximum (34.67±6.11 mg.$l^{-1}$) in summer season at $S_1$ and minimum (21±1.41 mg.$l^{-1}$) in monsoon at $S_2$ and $S_3$. Nitrates were found to be maximum (0.372±0 mg.$l^{-1}$) in monsoon season at $S_2$ and minimum (0.256±0.01 mg.$l^{-1}$) in winter season at $S_4$. Similar finding was reported by Panigrahi et al.[32] Phosphates were found maximum (0.086±0.01mg.$l^{-1}$) in monsoon season at $S_1$ and minimum (0.057±0 mg.$l^{-1}$) in spring season at $S_3$. Sulphates were found to be maximum (7.85±0.28 mg.$l^{-1}$) in monsoon at site $S_3$ and minimum (5.38±0.39 mg.$l^{-1}$) in $S_3$ at autumn.

The water system in Nachiketa Tal was mainly influenced by rainfall. So, it is estimated that any variation, whether seasonal or monthly in physico-chemical variables of Nachiketa Tal may be influenced by climatic factors and the characteristics of its catchment. The high seasonal variations in electrical conductivity in Nachiketa Tal in monsoon season were may be because of the rains which export the ions from the catchment area to the lake ecosystem. Similar trend was reported by Burna et al.[33] The nutrient like phosphates, nitrates and sulphates increases in the monsoon because the rains brought these nutrients from the catchment. The decrease of nutrients during the winter season may be due to the phytoplankton population.

**Table 1** Seasonal variation in physico-chemical parameters at sampling stations $S_1$ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

| Parameters | Summer | Monsoon | Autumn | Winter | Spring |
|---|---|---|---|---|---|
| Air temp (0C) | 21.77±1.53 | 21.65±1.2 | 19.15±0.49 | 11±2.71 | 13±7.78 |
| Water temp. (0C) | 20.5±1.87 | 19.75±1.06 | 16.9±0.99 | 9.17±1.8 | 11.85±7 |
| Conductivity ($\mu Scm^{-1}$) | 58.47±5.03 | 68.45±2.76 | 56.4±2.55 | 34.57±2.99 | 48.5±2.83 |
| Alkalinity ($mg.l^{-1}$) | 82.73±3.68 | 78.2±2.83 | 67.9±10.47 | 53.5±11.43 | 63.25±6.72 |
| TDS ($mg\ l^{-1}$) | 27.67±6.71 | 36.25±1.77 | 17.2±1.98 | 16.7±0.44 | 16.35±1.63 |
| Free $CO_2$ ($mg\ l^{-1}$) | 1.58±0.77 | 2.24±0.68 | 1.06±0.12 | 1.76±0.88 | 1.06±0 |
| Dissolved oxygen ($mg.l^{-1}$) | 7±0.4 | 6.5±0.71 | 6.7±0.42 | 8.4±0.72 | 8.3±0.71 |
| BOD ($mg.l^{-1}$) | 1.3±0.26 | 1.35±0.21 | 1.05±0.21 | 0.7±0.1 | 1±0.28 |
| pH | 6.76±0.04 | 6.73±0.06 | 6.86±0.06 | 7.27±0.06 | 7.11±0.36 |
| Turbidity (NTU) | 5.47±0.87 | 7.78±0.91 | 5.15±1.27 | 3.2±0.06 | 3.12±1.04 |
| Chlorides ($mg\ l^{-1}$) | 3.6±0.87 | 5.4±0.4 | 3.55±0.2 | 3.22±0.91 | 3.98±0.4 |
| Hardness($mg\ l^{-1}$) | 34.67±6.11 | 22±2.83 | 23±1.41 | 26.73±1.1 | 25±1.41 |
| Calcium($mg\ l^{-1}$) | 8.28±2.02 | 5.21±0.57 | 5.61±0 | 6.84±0.74 | 6.01±0.57 |
| Magnesium ($mg\ l^{-1}$) | 3.4±0.48 | 2.18±0.34 | 2.19±0.34 | 2.35±0.18 | 2.43±0 |
| Nitrates ($mg\ l^{-1}$) | 0.322±0.01 | 0.355±0.01 | 0.334±0.03 | 0.271±0.03 | 0.287±0.03 |
| Phosphates ($mg\ l^{-1}$) | 0.064±0.01 | 0.086±0.01 | 0.078±0 | 0.066±0.01 | 0.06±0 |
| Sulphates ($mg.l^{-1}$) | 6.02±0.8 | 7.72±0.57 | 5.38±0.59 | 6.48±0.62 | 5.73±0.66 |

**Table 2** Seasonal variation in physico-chemical parameters at sampling stations $S_2$ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

| Parameters | Summer | Monsoon | Autumn | Winter | Spring |
|---|---|---|---|---|---|
| Air temp (°C) | 21.37±0.85 | 21.25±1.06 | 18.6±0.57 | 10.43±2.58 | 12.6±7.92 |
| Water temp. ($^0C$) | 19.67±1.04 | 19.55±0.64 | 16.55±0.78 | 8.7±1.9 | 11.35±6.86 |
| Conductivity ($\mu Scm^{-1}$) | 59.37±6 | 69.9±2.4 | 58.1±3.25 | 35.87±2.95 | 49.5±3.25 |
| Alkalinity ($mg.l^{-1}$) | 81.6±5.72 | 80±3.54 | 68.15±10.82 | 53.77±11.23 | 62.5±3.54 |
| TDS ($mg\ l^{-1}$) | 29.6±6.16 | 36.75±0.35 | 17.85±2.33 | 17.37±0.72 | 17.75±2.62 |
| Free $CO_2$ ($mg\ l^{-1}$) | 1.67±0.69 | 2.38±0.62 | 1.14±0.12 | 1.61±0.67 | 1.01±0.19 |
| Dissolved oxygen ($mg.l^{-1}$) | 6.83±0.35 | 6.65±0.49 | 6.9±0.14 | 8.43±0.4 | 8.3±0.42 |
| BOD ($mg.l^{-1}$) | 1.33±0.31 | 1.35±0.21 | 0.8±0.14 | 0.63±0.15 | 0.85±0.21 |
| pH | 6.62±0.07 | 6.59±0.01 | 6.8±0.07 | 7.13±0.06 | 7.06±0.37 |
| Turbidity (NTU) | 5.69±0.95 | 7.97±0.97 | 5.24±1.36 | 3.35±0.18 | 3.34±1.11 |
| Chlorides ($mg\ l^{-1}$) | 3.88±0.43 | 5.68±0.8 | 3.41±0 | 3.12±0.85 | 3.83±0.6 |
| Hardness($mg\ l^{-1}$) | 33.33±5.03 | 21±1.41 | 22.4±2.26 | 26.83±1.44 | 25±1.41 |
| Calcium($mg\ l^{-1}$) | 7.48±1.85 | 4.01±1.13 | 4.81±1.13 | 6.41±1.61 | 5.61±1.14 |
| Magnesium ($mg\ l^{-1}$) | 3.56±0.74 | 2.67±1.03 | 2.52±0.14 | 2.63±0.69 | 2.67±0.35 |
| Nitrates ($mg\ l^{-1}$) | 0.335±0.01 | 0.372±0 | 0.355±0.05 | 0.268±0.02 | 0.296±0.04 |
| Phosphates ($mg\ l^{-1}$) | 0.065±0 | 0.084±0.01 | 0.076±0 | 0.065±0.01 | 0.06±0 |
| Sulphates ($mg.l^{-1}$) | 6.29±0.68 | 7.74±0.3 | 5.69±0.33 | 6.66±0.58 | 5.95±0.75 |

**Citation:** Sharma RC, Tiwari V. Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya. *Biodiversity Int J.* 2018;2(2):102-110. DOI: 10.15406/bij.2018.02.00052

**Table 3** Seasonal variation in physico-chemical parameters at sampling stations $S_3$ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

| Parameters | Summer | Monsoon | Autumn | Winter | Spring |
|---|---|---|---|---|---|
| Air temp (°C) | 21.87±1.52 | 21.2±1.41 | 19±0.71 | 10.93±2.58 | 12.75±7.85 |
| Water temp. ($^0$C) | 20.67±1.46 | 19.75±0.64 | 16.9±0.57 | 8.9±1.85 | 11.65±6.72 |
| Conductivity (μScm$^{-1}$) | 57.87±4.71 | 67.2±3.25 | 57.05±3.46 | 34.63±3.36 | 48.35±2.62 |
| Alkalinity (mg.l$^{-1}$) | 80.4±7.29 | 78.35±2.62 | 67.7±10.61 | 53.63±11.83 | 64±5.66 |
| TDS (mg l$^{-1}$) | 27.57±6.19 | 36.35±1.63 | 17.05±1.63 | 16.87±0.55 | 16.3±1.27 |
| Free CO2 (mg l$^{-1}$) | 1.55±0.79 | 2.2±0.62 | 0.97±0.12 | 1.53±0.57 | 1.06±0.12 |
| Dissolved oxygen (mg.l$^{-1}$) | 7.07±0.31 | 6.7±0.71 | 6.85±0.21 | 8.37±0.85 | 8.1±0.14 |
| BOD (mg.l$^{-1}$) | 1.13±0.12 | 1.2±0.28 | 0.9±0.14 | 0.57±0.12 | 0.8±0.28 |
| pH | 6.71±0.11 | 6.69±0.05 | 6.85±0.07 | 7.17±0.15 | 7.05±0.35 |
| Turbidity (NTU) | 5.28±0.93 | 7.75±0.77 | 5.16±1.35 | 3.17±0.05 | 3.03±1.1 |
| Chlorides (mg l-$^{1}$) | 3.6±0.71 | 5.25±0.6 | 2.98±0.2 | 3.22±0.91 | 3.98±0.4 |
| Hardness(mg l$^{-1}$) | 32±4 | 21±1.41 | 22±2.83 | 26.67±1.15 | 25.2±1.7 |
| Calcium(mg l$^{-1}$) | 6.52±1.45 | 4.81±0 | 5.21±0.57 | 6.68±0.46 | 5.93±1.13 |
| Magnesium (mg l$^{-1}$) | 3.82±0.11 | 2.18±0.34 | 2.18±0.34 | 2.43±0 | 2.53±0.27 |
| Nitrates (mg l$^{-1}$) | 0.324±0.01 | 0.36±0.01 | 0.334±0.01 | 0.263±0.02 | 0.291±0.04 |
| Phosphates (mg l$^{-1}$) | 0.065±0 | 0.084±0 | 0.077±0.01 | 0.062±0 | 0.057±0 |
| Sulphates (mg.l$^{-1}$) | 6.2±0.92 | 7.85±0.28 | 5.38±0.39 | 6.51±0.55 | 5.82±0.7 |

**Table 4** Seasonal variation in physico-chemical parameters at sampling stations $S_4$ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

| Parameters | Summer | Monsoon | Autumn | Winter | Spring |
|---|---|---|---|---|---|
| Air temp (°C) | 22.13±1.53 | 21.8±1.41 | 19.3±0.71 | 11.13±2.52 | 13.15±7.99 |
| Water temp. (°C) | 20.77±1.72 | 19.7±0.99 | 17.25±0.64 | 9.27±1.87 | 11.75±6.72 |
| Conductivity (μScm$^{-1}$) | 58.37±5.15 | 67.35±4.03 | 56.2±3.39 | 34.7±3.46 | 48.4±3.11 |
| Alkalinity (mg.l$^{-1}$) | 80.57±4.38 | 78.5±2.83 | 67.6±10.75 | 54.27±11.87 | 65±4.24 |
| TDS (mg l$^{-1}$) | 26.97±6.47 | 36.7±1.84 | 17.2±1.7 | 16.93±0.51 | 16.35±1.2 |
| Free $CO_2$ (mg l$^{-1}$) | 1.55±0.79 | 2.24±0.56 | 1.06±0 | 1.53±0.57 | 1.06±0.12 |
| Dissolved oxygen (mg.l-$^{1}$) | 6.97±0.4 | 6.7±0.42 | 7±0.28 | 8.57±0.45 | 8.3±0.14 |
| BOD (mg.l$^{-1}$) | 1.4±0.17 | 1.5±0.14 | 1±0.28 | 0.6±0.1 | 0.95±0.21 |
| pH | 6.7±0.03 | 6.69±0.04 | 6.75±0.07 | 7.28±0.07 | 7.09±0.37 |
| Turbidity (NTU) | 5.53±1 | 7.77±0.83 | 5.15±1.34 | 3.19±0.05 | 2.96±1.15 |
| Chlorides (mg l$^{-1}$) | 3.5±0.71 | 5.11±1.2 | 3.41±0 | 3.31±0.82 | 3.55±0.2 |
| Hardness(mg l$^{-1}$) | 34±6 | 22±0 | 22±2.83 | 26.67±1.15 | 25±1.41 |
| Calcium(mg l$^{-1}$) | 8.02±1.61 | 4.97±0.23 | 4.41±1.7 | 6.41±0 | 6.01±0.57 |
| Magnesium (mg l$^{-1}$) | 3.4±0.48 | 2.33±0.14 | 2.67±0.34 | 2.59±0.28 | 2.43±0 |
| Nitrates (mg l$^{-1}$) | 0.334±0 | 0.357±0 | 0.323±0 | 0.256±0.01 | 0.287±0.04 |
| Phosphates (mg l$^{-1}$) | 0.064±0.01 | 0.086±0 | 0.08±0 | 0.066±0 | 0.061±0 |
| Sulphates (mg.l$^{-1}$) | 6.24±0.96 | 7.84±0.55 | 5.49±0.33 | 6.5±0.65 | 5.8±0.82 |

**Citation:** Sharma RC, Tiwari V. Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya. *Biodiversity Int J.* 2018;2(2):102-110. DOI: 10.15406/bij.2018.02.00052

## Plankton community

Physico-chemical parameters of any water body alone do not provide an ideal picture of the ecological condition of the water body. The biotic community of any water body is outcome of interaction between the chemical, physical and geo-morphological characteristics of any water body.[34,35] The study of physico-chemical parameter is important to know their impact on phytoplankton and *vice-versa.* A total of 71 taxa belonging to 57 genera were recorded in the lake Nachiketa Tal. The phytoplankton in the lake is represented by six major families, *Bacillariophyceae* (22), *Chlorophyceae* (37), *Cyanophyceae* (6), *Xanthopyceae* (2), *Dinophyceae* (2) and *Euglenophyceae* (2). The percentage compositions (Figure 2) of these six families were *Bacillariophyceae* (31%), *Chlorophyceae* (52%), *Cyanophyceae* (8%), *Euglenophyceae* (3%), *Xanthophyceae* (3%) and *Dinophyceae* (3%). Overall, maximum density (1501 ind. $l^{-1}$) of phytoplankton was observed in January at $S_1$ and minimum (443 ind.$l^{-1}$) phytoplankton density was observed in July at site $S_3$. Seasonally the maximum density 1401±325.60 ind. $l^{-1}$ of phytoplankton was observed in winter season at $S_1$ and minimum (457.50±17.83 ind. $l^{-1}$) in monsoon season at $S_2$ (Figure 3). Dissolved oxygen is produced by phytoplankton biomass due to their photosynthetic activity. Therefore, dissolved oxygen was found higher, where phytoplankton count was high.[12] Density of *Cyanophyceae* and *Euglenophyceae* was found high in summer season. The present study also recorded higher dissolved oxygen and the phytoplankton during winter season and lowest during monsoon season. During the monsoon season there was an increased amount of turbidity in Nachiketa Tal due to runoff from the watershed, which transports soil and other plant and animal debris into the lake. During the period of high turbidity in the outflow zone, the nutrient concentration increased and the transparency decreased. It was found that the phytoplankton density decreased during this period. Thus, the light is an important factor for the growth of phytoplankton through the process of photosynthesis.[13,36] The *Chlorophyceae* was recorded as the dominant group in the lake ecosystem of Nachiketa Tal followed by *Bacillariophyceae* and *Cyanophyceae*. Similar findings were reported by Tyagi & Malik.[37]

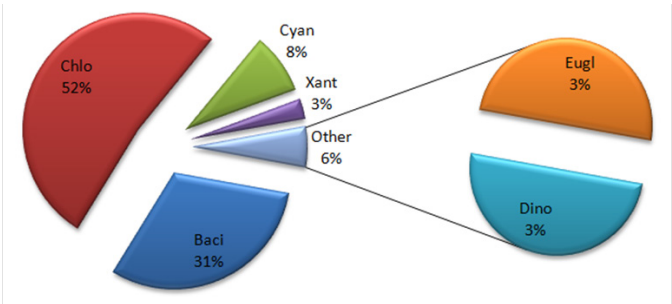


**Figure 2** Percentage composition of phytoplankton in Nachiketa Tal (Chlo, *Chlorophyceae*; Baci, *Bacillariophyceae*; Cyan, *Cyanophyceae*; Xant, *Xanthophyceae*; Eugl, *Euglenophyceae*; Dino, *Dinophyceae*).

### *Chlorophyceae*

Chlorophyceae has been recorded as the dominant component of phytoplankton followed by *Bacillariophyceae*, *Cyanophyceae*, *Xanthophyceae*, *Dinophyceae* and *Euglenophyceae* respectively. Hinder et al.[38] also recorded *Chlorophyceae* as a dominant groups over the other groups in Jöri lakes, Swiss Alps; Bhat et al.[39] also recorded *Chlorophyceae* as a dominant group in Bhoj wetland, a Ramsar Site. Sharma[40] also reported *Chlorophyceae* as dominant group in Loktak Lake. The dominating species of this group were *Staurastrum manipurense, Scendesmus quardicauda, Spirogyra* sp., *Ankistrodermus falcatus,* and *Chlorella vulgaris*. A total of 37 species were recorded from the Nachiketa Tal. The maximum density of Chlorophyceae (710 ind. $l^{-1}$) at $S_1$ in January and lowest (211 ind. $l^{-1}$) in July at $S_4$. Seasonally, the population of *Chlorophyceae* was recorded maximum (663.67±158.15 ind. $l^{-1}$) in winter season and minimum (221.5±86.97 ind. $l^{-1}$) in monsoon season. Maximum density of Chlorophyceae was recorded in winter season by Tiwari & Chauhan.[41]

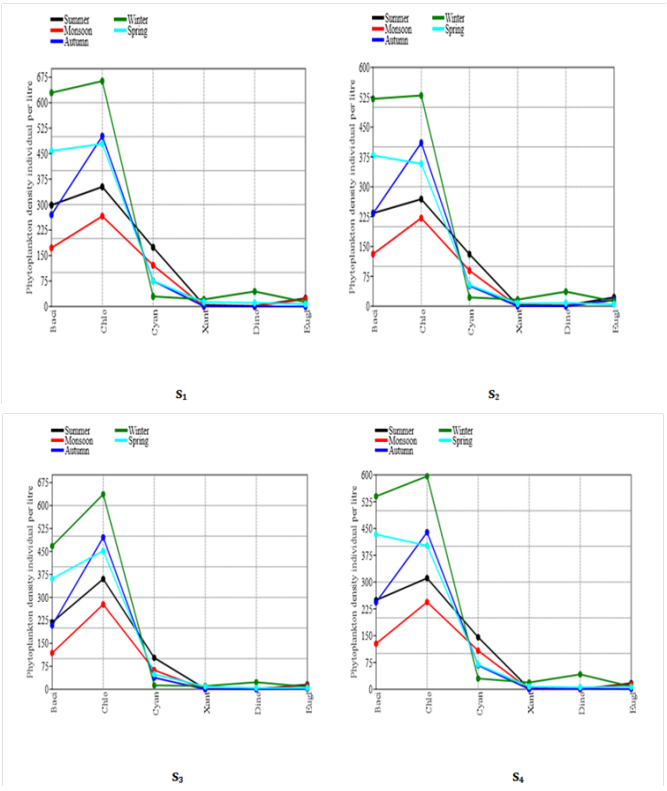


**Figure 3** Seasonal density of phytoplankton at all the four sites ($S_1$-$S_4$) of Nachiketa Tal.

### *Bacillariophyceae*

The second most abundant group recorded during the present study was *Bacillariophyceae*. The dominant species were *Cymbella* sp., *Navicula* sp., *Nitzschia* sp, and *Synedra* sp. similar results were reported by Kumar et al.[42] in the ponds of Badrinath. The maximum (703 ind. $l^{-1}$) density was recorded at $S_1$ in January and lowest (116 ind. $l^{-1}$) in August at $S_3$. Seasonally, the population of *Bacillariophyceae* was recorded maximum (629.33±126.09 ind. $l^{-1}$) in winter season and minimum (118.5±41.72ind. $l^{-1}$) in monsoon season.

### *Cyanophyceae*

The third group dwelling Nachiketa Tal was *Cyanophyceae*. The dominating species were *Chroococcus* sp. *Gloeocapsa* sp., *Oscillatoria* sp., *Microcystis* sp. Density of *Cyanophyceae* was found maximum (184 ind. $l^{-1}$) in June and minimum (11 ind. $l^{-1}$) in December at $S_3$. Seasonally, it was found maximum (174.33±37.09 ind. $l^{-1}$) during summer season and minimum (12.67±8.08 ind. $l^{-1}$) during winter season. Similar findings were reported by Tiwari & Chauhan[41] and Rosińska et al.[43] Increased temperature and long photoperiod in summer supports the increased *Chlorophyceae* diversity.[39] After the summer season, second highest density of *Cyanophyceae* was seen in monsoon season (121.5±20.5 ind. $l^{-1}$) in Nachiketa Tal. Jarousha[44]

reported that the high concentration of nitrates in monsoon season attributed higher member of *Cyanophyceae*. The concentration of nitrates was found maximum in monsoon season in the lake.

Two genera of each family of *Xanthophyceae*, *Dinophyceae* and *Euglenophyceae* were encountered in Nachiketa Tal. The maximum density of *Xanthophyceae* (27 ind. $l^{-1}$) in December at $S_4$. Density of *Dinophyceae* was found maximum (52 ind. $l^{-1}$) during November and December at $S_1$ and at $S_4$ in November *Euglenophyceae* were found maximum (31 ind. $l^{-1}$) in June at site $S_1$. Seasonally, the maximum density of *Xanthophyceae* (21±7 ind. $l^{-1}$) and *Dinophyceae* (43.33±1 ind. $l^{-1}$) was found to be in winter season at $S_1$. *Euglenophyceae* were found maximum (24.33±5.89 ind. $l^{-1}$) in summer season at site $S_1$. The Shannon-Wiener diversity index was recorded maximum (3.950) in winter at $S_2$ and minimum (3.750) in monsoon at $S_4$ and the Jaccard evenness was recorded maximum (0.067) in autumn at $S_1$ and $S_3$ and minimum (0.057) in summer at $S_1$, $S_2$ and $S_4$ during the present study. The pollution indicating taxa *like Navicula, Oscillatoria, Nitzschia, Euglena, Cymbella* were encountered in almost all the four sites with varied numbers in Nachiketa Tal.[42,45] Numbers of these taxa were less at $S_3$ in comparison to other sites.

## Statistical treatment of data

Pearson's correlation coefficient calculated between various physico-chemicals attributes and density of phytoplankton dwelling Nachiketa Tal have been presented in Table 5. Water temperature and pH have negative correlation (r=-989, p<0.05). TDS has positive correlation with the water temperature (r=0.719, p<0.01) and electrical conductivity (r=0.771, p<0.01). Abundance of *Bacillariophyceae*, Chlorophyceae, *Xanthophyceae*, *Dinophyceae* is negatively correlated with water temperature (r=-0.898, p<0.01); (r=-845, p<0.01); (r=-875, p<0.01) and (r=-0.761, p<0.01) respectively. However, the abundance of Cyanophyceae and *Euglenophyceae* were positively correlated with water temperature (r=0.881, p<0.01) and (r=0.619, p<0.01) respectively. Turbidity is negatively correlated with *Bacillariophyceae* (r=-0.882, p<0.01), Cholorophyceae (r=-0.802, p<0.01) and *Xanthophyceae* (r=-0.721, p<0.01). However, it is positively correlated with Cyanophyceae (r=0.625, p<0.05).Turbidity may be the one of the reasons of lower phytoplankton density in the monsoon season. DO was positively correlated with *Bacillariophyceae* (r=0.919, p<0.01), Cholorophyceae (r=0.766, p<0.01), *Xanthophyceae* (r=-0.883, p<0.01) and *Dinophyceae* (r=0.751,p<0.01). However, it was negatively correlated with Cyanophyceae (r=-668, p<0.05). Cyanophyceae showed positive correlation with nitrates (r=-0.686, p<0.05). Phosphates are negatively correlated with the density of *Bacillariophyceae* (r=-0.686, p<0.05).

## Canonical correspondence analysis

Canonical Correspondence Analysis **(**CCA) method was used to found the relationship between the physico-chemical variables and phytoplankton. It is a direct gradient analysis technique,[46] it extracts synthetic gradient from the biotic and environmental matrices and quantitatively represented by arrows in graphical biplots.[47] In the present study, the eigenvalues and the percentage of variance for each site were found to be high for axis 1 than axis 2. CCA was drawn between the 17 physico-chemical parameters and 42, 37, 41, 40 dominant phytoplankton species from $S_1$, $S_2$, $S_3$ and $S_4$ respectively.

At the sampling site $S_1$, (Figure 4). The Eigen values were 0.124 and 0.042 for axis 1 and axis 2 respectively. The axis 1 shows 56.86 % correlation and axis 2 shows 19.26 % correlation with the physico-chemical parameters and dominant phytoplankton species. The species like *Microspora* sp., *Staurastrum manipurense*, *Pinnularia* sp., *Synedra ulna*, *Chlorella vulgaris*, *Cymbella affinis*, *Frustulia* sp., *Scenedesmus quardicauda* are strongly related with axis 1. *Nitzschia* sp., *Navicula radiosa*, *Navicula* sp., *Ankistrodesmus falcatus*, *Cymbella affinis*, *Frustulia* sp., *Diatoma* sp., *Monoraphidium* sp., *Synedra ulna* are positively related with the dissolved oxygen and pH. Water temperature, BOD, alkalinity, TDS, electrical conductivity, and nitrates were found to have in positive correlation with *Gloeocapsa* sp. and *Chroococcus* sp.

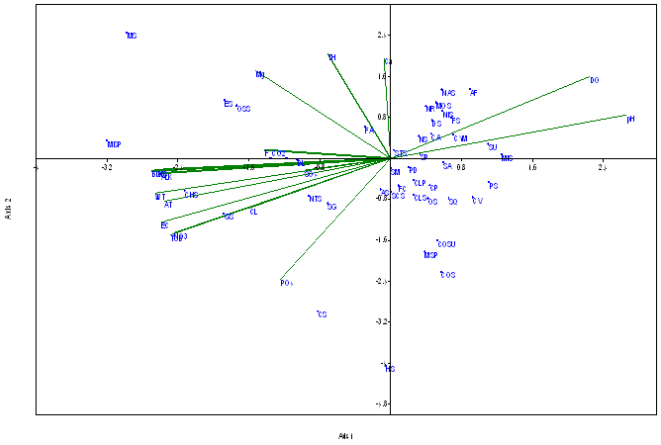

**Figure 4** CCA biplot between physico-chemical parameters and species of phytoplankton at $S_1$ (Dominant phytoplankton species: CLP, *Closterium pseudodianae*; CLS, *Closterium* sp. COS, *Cosmarium* sp.; COSU, Cosmarium subtumidium; DL, *Dimorphococcus lunatus*; HS, *Hormidium* sp.; MS, *Mesotaenium* sp.; MIS, *Microspora* sp.; MOS, *Monoraphidium* sp.; MSP, *Mougeotia* sp.; OS, *Odegonium* sp.; CA, *Cymbella aequalis*; CYM, *Cymbella affinis*; ES, *Euglena* sp.; OSS, *Oscillatoria* sp.; NTS, *Nostoc* sp.; MISP, *Microcystis* sp.; GS, *Gloeocapsa* sp.; CHS, *Chroococcus* sp.; SM, *Staurastrum manipurense*; STS, *Staurastrum* spp.; SP, *Spirogyra* sp.; SG, *Selenastrum gracile*; SCS, *Scenedesmus* sp.; SQ, *Scenedesmus quadricauda*; SA, *Scenedesmus accuminatus*; PD, *Pediastrum duplex*; DS, *Diatoma* sp.; FA, *Fragilaria arcus*; FC, *Fragilaria capucina*; FS, *Frustulia* sp.; NR, *Navicula radiosa*; NS, *Navicula* sp.; NAS, *Navicula subtilissima*; NIS, *Nitzschia* sp.; PS, *Pinnularia* sp.; SU, *Synedra ulna*; AF, *Ankistrodesmus falcatus*; AS, *Ankistrodesmus spiralis*; CS, *Chlamydomonas* spp.; CV, *Chlorella vulgaris*; CP, *Closterium parvulum*

Eigen values of 0.122 explained 53.58% correlation with axis 1 for the $S_2$ (Figure 5) Eigen value (0.041) explained 18% correlation with axis 2. Axis 1 was strongly related with the species like *Cymbella affinis*, *Synedra ulna*, *Pinnularia* sp., *Microspora* sp., *Diatoma* sp., *Navicula subtilissima*, *Nitzschia* sp., *Gonatozygon* sp., *Closterium parvulum*. Whereas, *Oscillatoria* sp., *Ankistrodesmus falcatus*, *Microcystis* sp., *Fragilaria arcus*, *Gloeocapsa* sp. were positively correlated with the axis 2. Dissolved oxygen and pH were positively correlated with the genera of *Bacillariophyceae* (*Cymbella affinis*, *Synedra ulna*, *Navicula subtilissima*, *Nitzschia* sp.). *Bacillariophyceae* was reported high in the winter season, when dissolved oxygen and pH were found maximum. Although the seasonal variations in water temperature, electrical conductivity, TDS, free $CO_2$, turbidity, nitrates negatively influence these species.

Eigen value (0.101) explained 46.68% for axis 1 and Eigen value (0.040) explained 18.77 % for axis 2 at $S_3$ (Figure 6). Alkalinity, TDS, water temperature, nitrates, turbidity, BOD are positively related to axis 1 and positively related with Cyanophyceae member like *Gloeocapsa* sp. and *Chroococcus* sp., which increases in summer to monsoon season, when there is an increase in water temperature, Nitrates were found in maximum concentration in monsoon season

due to surface runoff in Nachiketa Tal. The dissolved oxygen and pH are negatively related with the axis 1. Phosphates were positively correlated with the *Scendesmus* sp. The Eigen value (0.113) explained by 50.66% of correlation at $S_4$ (Figure 7). Eigen value (0.046) for axis 2 explained 20.83 % correlation. Dissolved oxygen and pH were strongly related with the axis 1. *Nitzschia* sp., *Frustulia* sp., *Navicula radiosa, Microspora* sp., *Pinnularia* sp., *Synedra ulna* and *Ankistrodesmus falcatus* are positively correlated with dissolved oxygen and pH but the parameters like water temperature, turbidity, electrical conductivity, BOD and nitrates influences these species.

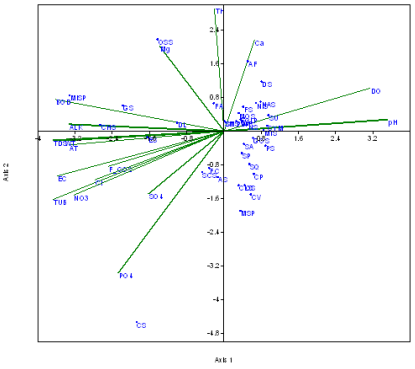

**Figure 5** CCA biplot between physico-chemical parameters and species of phytoplankton at $S_2$ (Dominant phytoplankton species: CLP, *Closterium pseudodianae*; CLS, *Closterium* sp.; DL, *Dimorphococcus lunatus*; GOS, *Gonatozygon* sp.; HS, *Hormidium* sp.; MIS, *Microspora* sp.; MOS, *Monoraphidium* sp.; MSP, *Mougeotia* sp.; OS, *Odegonium* sp.; CA, *Cymbella aequalis*; CYM, *Cymbella affinis*; ES, *Euglena* sp.; OSS, *Oscillatoria* sp.; MISP, *Microcystis* sp.; GS, *Gloeocapsa* sp.; CHS, *Chroococcus* sp.; SM, *Staurastrum manipurense*; STS, *Staurastrum* spp.; SP, *Spirogyra* sp.; SCS, *Scenedesmus* sp.; SQ, *Scenedesmus quadricauda*; SA, *Scenedesmus accuminatus*; PD, *Pediastrum duplex*; DS, *Diatoma* sp.; FA, *Fragilaria arcus*; FC, *Fragilaria capucina*; FS, *Frustulia* sp.; NR, *Navicula radiosa*; NS, *Navicula* sp.; NAS, *Navicula subtilissima*; NIS, *Nitzschia* sp.; PS, *Pinnularia* sp.; SU, *Synedra ulna*; AF, *Ankistrodesmus falcatus*; AS, *Ankistrodesmus spiralis*; CS, *Chlamydomonas* spp.; CV, *Chlorella vulgaris*; CP, *Closterium parvulum*

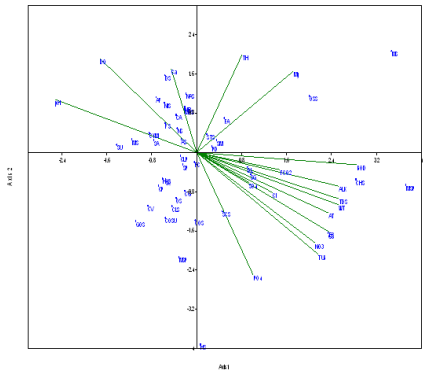

**Figure 6** CCA biplot between physico-chemical parameters and species of phytoplankton at $S_3$ (Dominant phytoplankton species: CLP, *Closterium pseudodianae*; CLS, *Closterium* sp.; COS, *Cosmarium* sp.; COSU, *Cosmarium subtumidium*; DL, *Dimorphococcus lunatus*; HS, *Hormidium* sp.; MS, *Mesotaenium* sp.; MIS, *Microspora* sp.; MOS, *Monoraphidium* sp.; MSP, *Mougeotia* sp.; OS, *Odegonium* sp.; CA, *Cymbella aequalis*; CYM, *Cymbella affinis*; ES, *Euglena* sp.; OSS, *Oscillatoria* sp.; MISP, *Microcystis* sp.; GS, *Gloeocapsa* sp.; CHS, *Chroococcus* sp.; SM, *Staurastrum manipurense*; STS, *Staurastrum* spp.; SP, *Spirogyra* sp.; SG, *Selenastrum gracile*; SCS, *Scenedesmus* sp.; SQ, *Scenedesmus quadricauda*; SA, *Scenedesmus accuminatus*; PD, *Pediastrum duplex*; DS, *Diatoma* sp.; FA, *Fragilaria arcus*; FC, *Fragilaria capucina*; FS, *Frustulia* sp.; NR, *Navicula radiosa*; NS, *Navicula* sp.; NAS, *Navicula subtilissima*; NIS, *Nitzschia* sp.; SU, *Synedra ulna*; AF, *Ankistrodesmus falcatus*; AS, *Ankistrodesmus spiralis*; CV, *Chlorella vulgaris*; CP, *Closterium parvulum*; CG, *Cosmarium granatum*; GOS, *Gonatozygon* sp.; HYS, *Hydrodiction* sp.

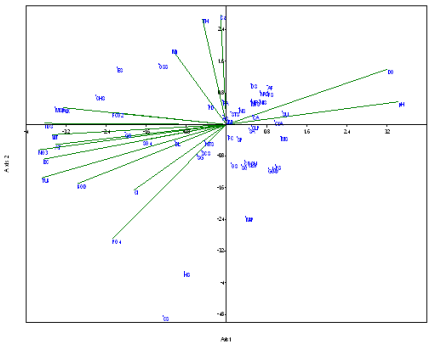

**Figure 7** CCA biplot between physico-chemical parameters and species of phytoplankton at $S_4$ (Dominant phytoplankton species: CLP, *Closterium pseudodianae*; CLS, *Closterium* sp.; COS, *Cosmarium* sp.; COSU, *Cosmarium subtumidium*; DL, *Dimorphococcus lunatus*; HS, *Hormidium* sp.; MIS, *Microspora* sp.; MOS, *Monoraphidium* sp.; MSP, *Mougeotia* sp.; OS, *Odegonium* sp.; CA, *Cymbella aequalis*; CYM, *Cymbella affinis*; ES, *Euglena* sp.; OSS, *Oscillatoria* sp.; NTS, *Nostoc* sp.; MISP, *Microcystis* sp.; GS, *Gloeocapsa* sp., CHS, *Chroococcus* sp.; SM, *Staurastrum manipurense*; STS, *Staurastrum* spp.; SP, *Spirogyra* sp.; SG, *Selenastrum gracile*; SCS, *Scenedesmus* sp.; SQ, *Scenedesmus quadricauda*; SA, *Scenedesmus accuminatus*; PD, *Pediastrum duplex*; DS, *Diatoma* sp.; FA, *Fragilaria arcus*; FC, *Fragilaria capucina*; FS, *Frustulia* sp.; NR, *Navicula radiosa*; NS, *Navicula* sp.; NAS, *Navicula subtilissima*; NIS, *Nitzschia* sp.; PS, *Pinnularia* sp.; SU, *Synedra ulna*; AF, *Ankistrodesmus falcatus*; AS, *Ankistrodesmus spiralis*; CS, *Chlamydomonas* spp.; CV, *Chlorella vulgaris*; CP, *Closterium parvulum*; GOS, *Gonatozygon* sp.

## Conclusion

Phytoplanktonic density and diversity have significant correlation with the physico-chemical variables in Nachiketa Tal. The growth of phytoplankton was directly or indirectly dependent on the environmental variables of the Lacustrine ecosystem. The environmental attributes like dissolved oxygen, pH, turbidity, TDS, BOD and nutrients influenced the population of the phytoplankton dwelling in the Nachiketa Tal. *Navicula*, *Cymbella*, *Nitzschia*, *Oscillitoria*, *Nostoc*, *Microcystis* etc. were recorded indicators of the pollution under the present study. It is evident from the results that the lake is progressing from the Oligotrphic to the Mesotrophic state.

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## Conflict of interest

There is no conflict of interest to declare regarding the publication of this paper.

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