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Trophic status of Tilitso, a high altitude Himalayan lake

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Abstract

The trophic status and water quality of Lake Tilitso (4920 m above sea level) in a high altitude region in central Nepal were surveyed in September, 1984. The lake is rather large with a maximum depth of 95 m and a surface area of 10.2 km^2. The lake water was turbid due to glacier silt and the euphotic layer was only 5 m deep. The nutrient concentration was very low with total phosphorus concentration 1–6 μg l^{-1}, and DTN concentration 0.10–0.22 mg l^{-1}. The phytoplankton biomass and chlorophyll-a concentration were also low. Primary production was estimated to be about 12 mg C m^{-2} d^{-1}. The concentrations of particulate matter and most cations and bacterial number were higher in the epilimnion than in the hypolimnion. The trophic status of this lake was estimated as ultraoligotrophic.

Introduction

The Himalayan region is considered one of the most un-polluted areas in the world. The trophic status of high altitude lakes in this area is expected to be the basal trophic status of lakes. Although a limnological survey of high altitude lakes in this region was carried out by Löffler (1969) in 1964, there is little information on biological and physico-chemical limnology in this area.

Lake Tilitso is located on the north side of Mt. Annapurna in central Nepal. We surveyed this lake in 1984. There was no information on this lake before our survey including the maximum water depth. The present paper describes the results of the limnological investigation for trophic status and related factors in this lake.

Description of the surveyed lake

Lake Tilitso is located on the north side of Mt. Annapurna in central Nepal (Fig. 1). The altitude of the surface water of the lake is 4920 m above sea level. The surface area is 10.2 km^2. We found the maximum depth to be 95 m with most of the lake being deeper than 60 m (Fig. 2). The south-east side of the lake was dammed by an end moraine while the west side was covered by glacier. There were several inlet streams on the east and north sides, and no surface outlet stream was found. The glacier shelved directly down into the lake. Study sites are indicated in Fig. 2. Station 1 was located on the windward side and sta. 3 was on the leeward side. A strong south wind blew every afternoon. The maximum air temperature was about 13 °C and the minimum was about −8 °C during the survey.

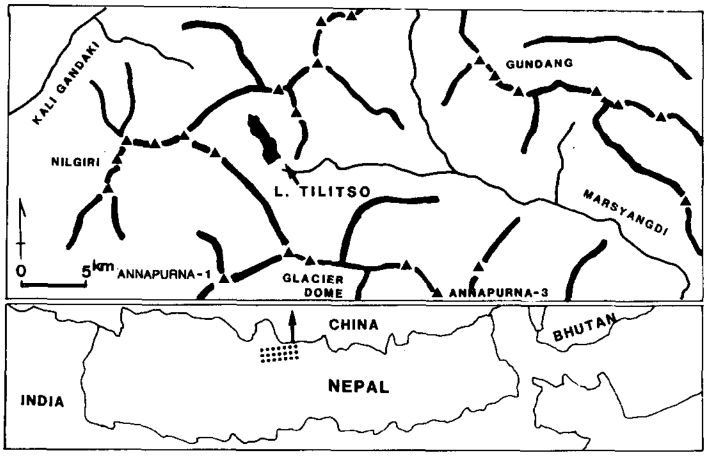

Fig. 1. Map of the central part of Nepal and surveyed lake.

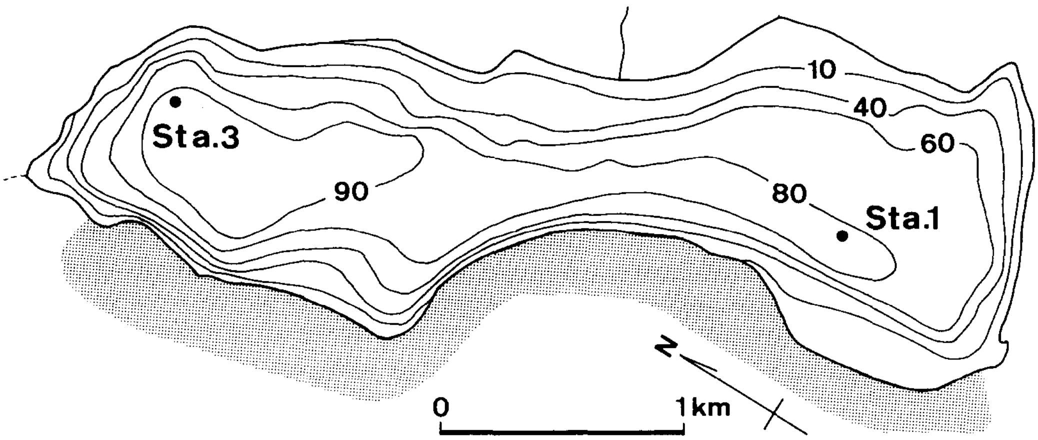

Fig. 2. Bathymetric map of Lake Tilitso. (●), sampling site. Hatched part indicates the glacier.

Material and methods

The survey was carried out from the 22nd to the 30th of September, 1984. An echo sounder with a recorder was used to draw a bathymetric map. Water temperature, pH, electroconductivity (EC), Secchi disk transparency and concentration of dissolved oxygen (DO) were measured in the field. Water samples were taken with a 3-liter Van-Dorn bottle and subsamples were poured into separate bottles for determination of total phosphorus (TP), cations and total inorganic carbon (IC) concentrations, total bacterial number and algal species composition. Residual water samples were filtered through Whatman GF/C glass fiber filters pretreated at 450 °C and the particulate material on the filters were used for the analyses of SS dry weight, total particulate carbon (TPC), total particulate nitrogen (TPN) and chlorophyll-a concentrations. Filtrates were also used for determination of concentrations of anions and dissolved total nitrogen (DTN). These samples were taken back to Japan and analyzed. Zooplankton samples were collected with a NXX13 plankton net. Photosynthetic activities were measured by the *in situ* ^{13}C-technique (Hama *et al.*, 1983) using 500 ml glass bottles. These bottles were incubated at each depth for about 6.6 hrs in the day-time. The total number of bacteria was measured by the acridine orange direct count technique (Aizaki, 1985).

Chemical analyses were made by the following methods: TP and DTN with an autoanalyzer (Technicon AA2) after persulfate digestion (Otsuki *et al.*, 1984), TPC and TPN by CHN corder (Yanagimoto, MT.3), chlorophyll-a by the method of SCOR/UNESCO, cations by ICP emission spectrochemical analysis (Nojiri *et al.*, 1985) after dissolution of particulate materials by the addition of hydrochloric acid, sulfate-S and chlorine by ion chromatography (Yokokawa Co.), IC by an infrared gas analyzer (Oceanography Co.) and dissolved oxygen by the Winkler method.

Results

Physical and chemical water qualities

Figure 3 shows vertical profiles of water temperature at the stations. Surface water temperatures were about 8 °C. The depths of the thermoclines were different at the two stations, being about 20 m at sta. 1 and about 15 m at sta. 3. The water temperatures under the thermocline were about 4.4 °C at both stations. Secchi disk transparency was relatively low, being 1.5 m at sta. 1 and 1.35 m at sta. 3.

Figure 4 shows vertical profiles of pH, EC and DO concentration. The values of pH ranged from 8.7 to 9.2 at sta. 1 and 8.3 to 8.4 at sta. 3. The values of EC (E_{18}) ranged from 130 to 150 μS cm^{-1} at sta. 1 and 134 to 157 μS cm^{-1} at sta. 3. The concentrations of DO ranged from 5.4 to 6.0 mg l^{-1} at sta. 3. The values of DO concentrations seemed almost at the saturation value for the altitude of this lake.

Figure 5 shows vertical distributions of total phosphorus and dissolved total nitrogen concentrations. The concentrations of the former were from 2 to 6 μg l^{-1} in the whole layer. These values were very small and almost detection level. The concentrations of the latter varied from 0.10 to 0.22 mg l^{-1} except the value from 40 m at sta. 1. These values were also low.

Figure 6 shows vertical distributions of cation concentrations at sta. 1. Several elements showed chemical stratification. The concentrations of Al and Fe were higher in the epilimnion than in the hypolimnion, and Na, S, Mg and Si were higher in the hypolimnion than in the epilimnion. These

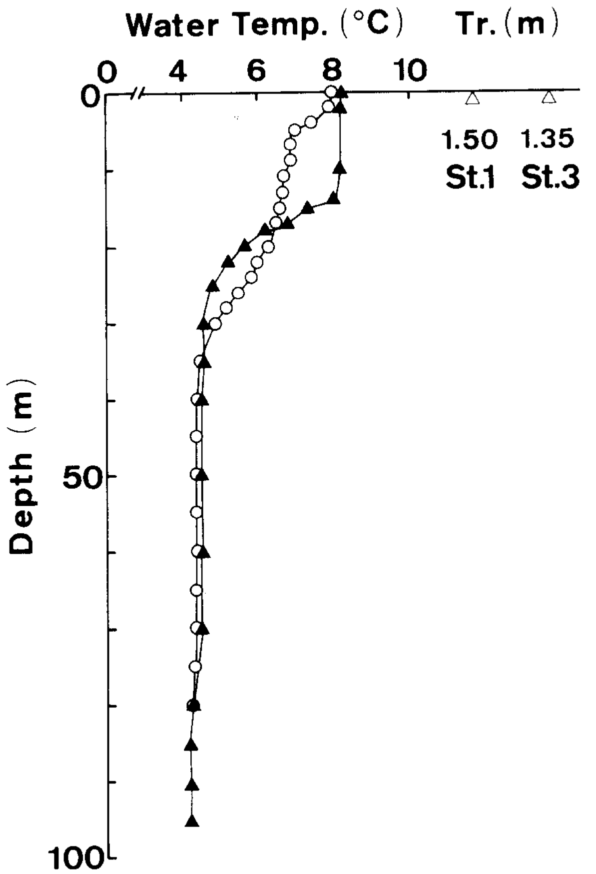

Fig. 3. Vertical profiles of water temperature and Secchi disk transparency. (o), sta. 1; (▲), sta. 3.

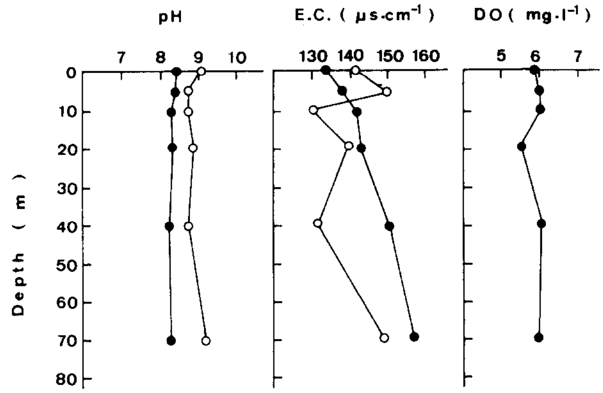

Fig. 4. Vertical profiles of pH, EC and DO values. (o), sta. 1; (●), sta. 3.

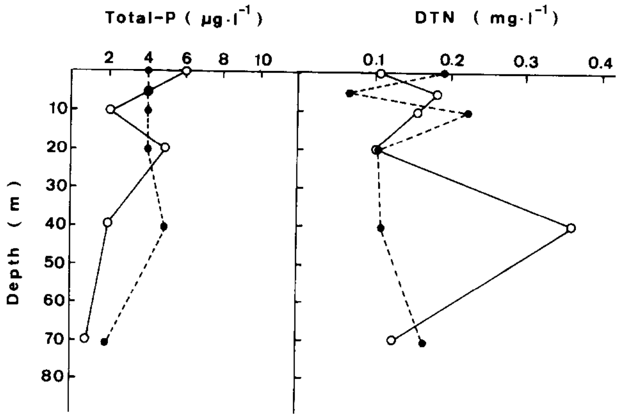

Fig. 5. Vertical distributions of total phosphorus and dissolved total nitrogen (DTN) concentrations. (o), sta. 1; (●), sta. 3.

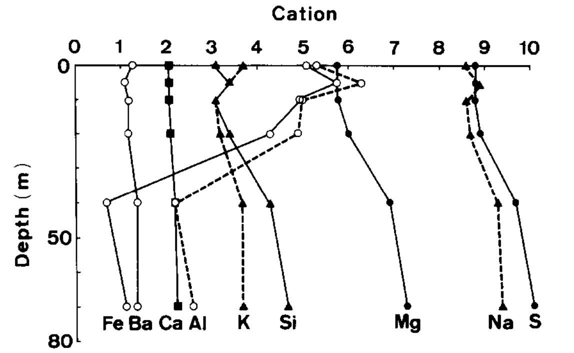

Fig. 6. Vertical distributions of cation concentrations at sta. 1. Units: Ca, × 10 mg l^{-1}; Mg and S, mg l^{-1}; Na, K and Si, × 0.1 mg l^{-1}; Fe, Ba and Al, × 0.01 mg l^{-1}

facts indicate that the mixing of epilimnion and hypolimnion waters scarcely occurs in the summer period. The concentration ranges of each element at both stations are shown in Table 1. No large differences in these concentrations were found between the two stations.

Table 2 shows anion concentrations. The SO_4-S concentrations ranged from 8.1 to 9.8 mg l^{-1} and weak chemical stratifications were observed. Since total sulfur concentrations determined by ICP analysis were 8.8–10.6 mg l^{-1}, sulfur usually existed in the sulfide form. Chlorine ions were almost undetectable. Inorganic carbon concentrations were relatively high, being 19–22 mg l^{-1} in the epilimnion (Table 2).

Table 2. Concentrations of anions and inorganic carbon at the stations.

Sampling site	SO_4-S (mg l^{-1})	Cl (mg l^{-1})	Inorganic-C (mg l^{-1})
sta. 1 – 0m	8.1	N.D.	19
5	8.1	0.72	17
10	8.1	N.D.	21
20	8.2	0.51	22
40	9.1	N.D.	-
70	9.2	N.D.	-
sta. 3 – 0	8.1	N.D.	-
10	8.2	N.D.	-
20	8.6	N.D.	-
40	9.1	N.D.	-
70	9.8	4.19	-

Table 1. Ranges of cation concentrations at the stations.

	Na (mg l^{-1})	K (mg l^{-1})	Ca (mg l^{-1})	Mg (mg l^{-1})	Sr (µg l^{-1})	Ba (µg l^{-1})	Li (µg l^{-1})
Sta. 1	0.86–0.94	0.31–0.37	20.7–22.5	5.75–7.30	123–130	11.0–13.9	1.8–2.2
Sta. 3	0.87–0.95	0.37–0.43	20.6–22.1	5.63–7.25	115–119	12.5–14.5	2.0–2.4

	B (µg l^{-1})	Si (mg l^{-1})	S (mg l^{-1})	Al (µg l^{-1})	Ti (µg l^{-1})	Mn (µg l^{-1})	Fe (µg l^{-1})
Sta. 1	2	0.31–0.47	8.8–10.1	22–63	2	0.6–1.1	7.0–57.5
Sta. 3	2	0.33–0.50	9.1–10.6	33–87	2	0.6–1.6	13.9–75.5

Biomass

Figure 7 shows vertical distributions of SS dry weight and TPC concentrations, TPC/SS and C/N ratios. These concentrations and ratios were significantly different in epilimnion and hypolimnion except for the TPC concentration. The concentrations of SS dry weight ranged from 5.5 to 6.5 mg l^{-1} in the epilimnion and 1.4 to 4.2 mg l^{-1} in the hypolimnion. The TPC concentrations ranged from 0.12 to 0.3 mg l^{-1} in the whole layer. As a result, TPC/SS ratios were lower in the epilimnion than in the hypolimnion. The ratios ranged from 3.6 to 4.7% in the former and 5.7 to 9.0% in the latter. C/N ratios were also lower in the epilimnion than in the hypolimnion. The ratios ranged from 18 to 27 in the former and 23 to 31 in the latter. These values are very high for phytoplankton.

Figure 8 shows vertical distributions of the chlorophyll-a concentrations and total numbers of bacteria. The chlorophyll-a concentrations ranged from 0.12 to 0.25 $\mu g\ l^{-1}$ at sta. 1 and 0.14 to 0.26 $\mu g\ l^{-1}$ at sta. 3. The concentrations were somewhat higher in the epilimnion than in the hypolimnion. The total numbers of bacteria were very low compared with other lakes, especially in the hypolimnion. These numbers were different in the epilimnion and the hypolimnion, being $0.95-1.2 \times 10^5$ cells ml^{-1} in the former and $3.2-6.4 \times 10^4$ cells ml^{-1} in the latter.

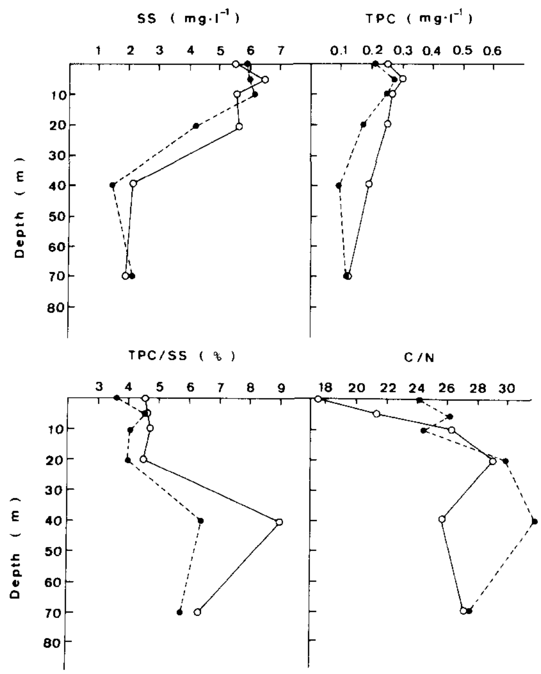

Fig. 7. Vertical distributions of concentrations of SS dry weight, TPC and ratios of TPC/SS and C/N. (○), sta. 1; (●), sta. 3.

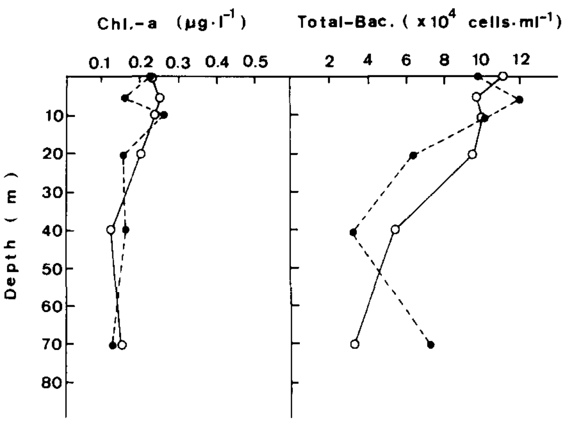

Fig. 8. Vertical distributions of concentrations of chlorophyll-a and total number of bacteria. (○), sta. 1; (●), sta. 3.

Table 3 shows the species composition of phytoplankton. *Cyclotella comensis* dominated. However, the maximum number of this species was only 155 cells ml^{-1}, at the 5 m depth. *Scenedesmus* sp. and *Dictyochlorella globosa* were also observed, but their density was very low.

Table 4 shows the vertical distribution of zooplankton. The Calanoid copepod, *Arctodiaptomus altissimus*, and one kind of rotifer, *Hexarthra bulgarica nepalensis* were observed. The density of the rotifer was very low. Since we collected only adults of the copepod, this species seems to have only one generation per year in this lake. The maximum number of the copepod was 543 individuals m^{-3}, in the surface layer (0 m – 5 m). The number

Table 3. Species composition of phytoplankton (cell·ml^{-1}).

	0 m	5 m	10 m	20 m	40 m	70 m
Cyclotella comensis	60	155	75	70	80	40
Scenedesmus sp.	4	15	8	12	0	3
Dictyochlorella globosa	+	–	–	–	–	–

Table 4. Zooplankton numbers in each layer at Sta. 3 (individuals m^{-3}).

	0–5 m	5–10 m	10–20 m	20–40 m	40–70 m
Arctodiaptomus altissimus	543	127	33	1	2
Hexarthra bulgarica nepalensis	+				

in the hypolimnion was almost negligible.

No fish could be collected from this lake in spite of our efforts.

Photosynthesis

Table 5 shows photosynthetic rates and activities. The chlorophyll concentrations were almost the same from the surface to 20 m deep. The photosynthetic rate ($\mu g\ C\ l^{-1}\ h^{-1}$) ranged from 0.11 to 0.27 in the upper 1–5 m layer and was not detected under 5 m deep. Since Secchi disk transparency was about 1.5 m at this station, the compensation depth was about 5 m. Therefore, light must be limiting below 5 m. Daily photosynthetic production was estimated as 12.3 mg C $m^{-2}\ d^{-1}$. Photosynthetic activity (mg C mg chl-a^{-1} h^{-1}) ranged from 0.44 to 1.1 in the euphotic layer.

Discussion

According to Löffler (1969), most high altitude Himalayan lakes are rather small with the maximum depth not exceeding 30 m. Lake Tilitso is probably one of the largest lakes in comparison with other surveyed high altitude lakes. Very little information is available on the water budget of this lake. It is probably frozen over from December to June, and during the summer monsoon, abundant rainfall and meltwater from the glacier may flow into it. In Lake Tsola Tso located on the south-west side of Mt. Everest, the water level increased about 3.6 m from 6th to 24th July, 1964 (Löffler, 1969). The same phenomenon probably occurs at Lake Tilitso. At the end of September, the water level of this lake seemed to be at its highest. Table 6 shows the concentrations of nutrients, particulate materials, cations and anions in an inflowing stream. In our survey, strong chemical stratification was observed in the lake. The reason for the formation of this stratification seemed to be the inflow of abundant water containing a high concentration of glacier silt into the epilimnion during the summer monsoon.

Photosynthetic activity in high altitude lakes has been measured by several investigators and the reported values range from low to relatively high. Rodhe *et al.* (1966) reported production rates of 0.2–27.2 mg C $m^{-3}\ d^{-1}$ in Swedish lakes; Fabris and Hammer (1975) reported values of 6–601

Table 5. Photosynthetic rates and activities at sta. 1.

Depth (m)	Chl.-a ($\mu g\ l^{-1}$)	Photosynthesis	
		($\mu g\ C\ l^{-1}\ h^{-1}$)	(mg C mg chl.-a^{-1} h^{-1})
0	0.28	0.27	0.96
1	0.29	0.19	0.65
3	0.23	0.25	1.1
5	0.25	0.11	0.44
10	0.24	N.D.	N.D.
20	0.23	N.D.	N.D.

Table 6. Concentrations of nutrients, particulate matter, cations and anions in an inflowing stream of Lake Tilitso.

T-P (mg l^{-1})	DTN (mg l^{-1})	T-Bac. (cells ml^{-1})	SS (mg l^{-1})	TPC (mg l^{-1})	TPN (μg l^{-1})	Na (mg l^{-1})
0.040	0.115	1.1×10^6	152.3	3.31	100	9.93

K (mg l^{-1})	Ca (mg l^{-1})	Mg (mg l^{-1})	Sr (μg l^{-1})	Ba (μg l^{-1})	Li (μg l^{-1})	B (μg l^{-1})	Si (mg l^{-1})
1.92	42.9	16.7	499	547	16.0	20.7	5.93

S (mg l^{-1})	Al (μg l^{-1})	Ti (μg l^{-1})	Mn (μg l^{-1})	Fe (μg l^{-1})	SO_4-S (mg l^{-1})	Cl (mg l^{-1})	IC (mg l^{-1})
32.1	3170	112	57.9	2800	31.7	N.D.	25

mg C m^{-2} d^{-1} in four small lakes in the Canadian Rocky Mountains; Massey (1981) reported values of 0.18–1.80 mg C chl-a^{-1} h^{-1} in a tropical alpine lake in Hawaii; Löffler (1969) reported values of 3–15 mg C m^{-2} d^{-1} in the high altitude lakes in the Mt. Everest region of Nepal.

The phytoplankton biomass in high altitude lakes has also been surveyed by several investigators. Löffler (1969) reported values of 2500 cells l^{-1} of a *Cyclotella* sp. and 2000 cells l^{-1} of other species in lakes in the Mt. Everest region; Martinez-Silvestre (1975) reported a phytoplankton concentration of $2-10 \times 10^5$ cells l^{-1} in alpine lakes in Spain; Stout (1969) reported values of 0.22–5.43 μg l^{-1} of chlorophyll-a concentration in lakes in the mountain region of New Zealand.

The algal biomass of 0.16–0.25 μg l^{-1} in chlorophyll-a and 60–155 cells ml^{-1} of phytoplankton number, and a photosynthetic activity of 0.44–1.1 mg C mg chl-a^{-1} h^{-1} in the euphotic layer in Lake Tilitso are relatively low in comparison with other data for high altitude lakes. Algal biomass and photosynthetic activity depend on nutrient concentration, light conditions, water temperature and other related factors. In Lake Tilitso, nutrient concentration was very low as total phosphorus concentration was 1–6 μg l^{-1} and the DTN concentration was 0.10–0.22 mg l^{-1}. The surface lake water was turbid due to glacier silt, and the euphotic layer was estimated as only 5 m deep. Low primary production and low algal biomass in Lake Tilitso can be explained by the above reasons. The existence of zooplankton in this lake in spite of such low primary productivity is of interest for an understanding of ecosystems in high altitude lakes.

A trophic state index has been developed by Carlson (1977) and other investigators. Aizaki *et al.* (1981) modified Carlson's index and examined the relationships between it and other parameters related to the trophic status of lakes. An index value of zero was assumed by them to correspond to chlorophyll-a concentration of 0.1 μg l^{-1} and concentrations of other parameters at this index value were estimated as follows: Secchi disk transparency, 46 m; total phosphorus, 0.4 μg l^{-1}; POC, 0.02 mg l^{-1}; PON, 3 μg l^{-1}; total number of bacteria, 4.6×10^4 cells ml^{-1}. The trophic status in Lake Tilitso appeared near an index value of zero, because chlorophyll-a concentration, TPN concentration and total number of bacteria in this lake were almost the same as the above values, especially in the hypolimnion. It was concluded from this survey that Lake Tilitso is very important as an example on non-polluted lake.

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