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Basic limnological study in an alpine Lake Puma Yumco, the pre-Himalayas, China

Osamu MITAMURA[1], Yasushi SEIKE[2], Kunio KONDO[3], Naoshige GOTO[1], Kaori ANBUTSU[1], Tetsuji AKATSUKA[1], Masaki KIHIRA[1], Tsering QIONG[4] and Mitsugu NISHIMURA[5]

[1] Limnological Laboratory, School of Environmental Science, University of Shiga Prefecture
[2] Department of Material Science, Faculty of Science and Engineering, Shimane University
[3] Institute for Environmental Sciences
[4] Faculty of Science, Tibet University
[5] School of Marine and Science Technology, Tokai University

ABSTRACT: Lake Puma Yumco is a typical alpine lake (altitude; 5,030 m) located in the pre-Himalayas of Tibet, China. This study was the first limnological investigation. Puma Yumco (28°34'N, 90°24'E) has the following morphometric properties: maximum length of 31 km; maximum width of 14 km; mean width of 9 km; shoreline of 90 km; surface area of 280 km^2; shoreline development of 1.5. Transparency was approximately 10 m. Dissolved oxygen was 7 mg O_2 L^{-1} and showed saturated values. Salinity was 360 mg L^{-1}. The chemical type of the lake water was Mg-Ca-HCO_3-SO_4. Total nitrogenous nutrients and phosphate were extremely low at 1 μM and 0.02 μM, respectively. Chlorophyll-a concentration was 0.2 mg chl.a m^{-3}. Phytoplankton and zooplankton were dominated by *Aphanocapsa* sp. and Diaptomidae. The grain size of lake sediment was that of silt in most cases.

Key Words: pre-Himalayas alpine lake, lake morphometry, physical, chemical and biological characteristics, grain size of sediment;

Introduction

The Limnology of alpine lakes has been extensively studied (Anderson, 1972; Blumthaler and Ambach, 1990; Felip et al., 1995; McKnight et al., 1997; Sommaruga et al., 1997; Vinebrooke and Leavitt, 1998; McNaught et al., 1999). We also have considerable data from lakes located in the Titan Plateau, China (Kato et al., 1987; Kawashima and Nishiyama, 1989). However, the limnological knowledge of lake systems in extremely high-altitude mountain areas has been quite limited. The lake chosen for this study was a typical alpine lake (28°34'N, 90°24'E; altitude of 5,030 m) formed by fault action and located in the pre-Himalayas in the southern part of the Tibetan Plateau, China. Puma Yumco is classified as a dimictic lake.

Thermal stratification is established during a short summer season or lengthy ice-covered winter season. During this investigation period the lake was about to begin a circulation phase just after the thawing season.

This is the first report of a limnological investigation in a large lake over 5,000 m in altitude. In this paper, we describe the morphometric properties of the lake basin, the physical, chemical and biological characteristics of the lake water, and the grain size of the lake sediment.

Materials and Methods

Field investigations of the horizontal and vertical distributions of some limnological parameters were carried out in Lake Puma Yumco on April 5 to 22, 2001 during the circulation phase just after the ice-covered season but before the monsoon season (Fig.1). During the investigation period, the lake surface was almost frozen over. Therefore, investigations were made at open water sites near the base camp. The physical, chemical and biological parameters of the lake were observed at stations parallel to the shore line and at transect stations from the shore to the offshore site.

Water samples were collected at nine stations with a plastic water sampler from the surface to the bottom layer. The samples were then used for the measurement of major cation (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anion elements (Cl^-, SO_4^{2-}). The values of water temperature, pH, dissolved oxygen, and electric conductivity were taken with a Water Quality Monitoring System. The concentrations of six major elements were determined with an Ion Chromatograph.

For a determination of the biogeochemical constituents and chlorophyll-a concentrations in lake water, the waters were immediately filtered through glass fiber filters (Whatman GF/F) which were freed of organic matter by ignition at 420°C. Then the filters and filtrates were frozen solid until chemical analyses

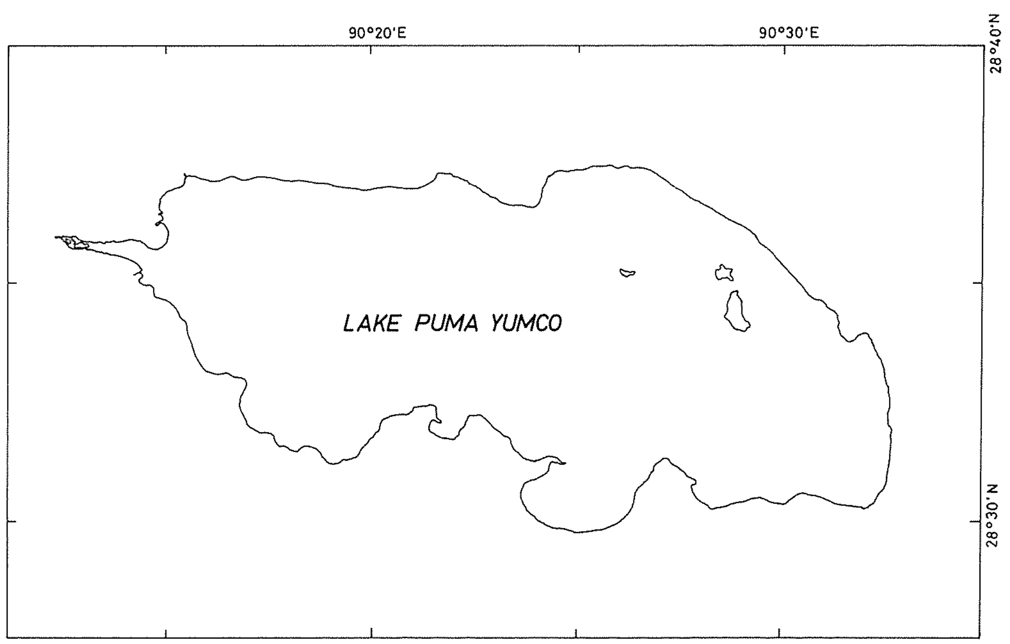

Fig.1. Map of Lake Puma Yumco in the pre-Himalayas.

in the laboratory. Ammonia concentration was determined by the method of Sagi (1966), nitrite after Bendschneider and Robinson (1952), nitrate after Mitamura (1997), and phosphate after Murphy and Riley (1962). Urea was determined by the method of Newell et al. (1967). Chlorophyll-a and phaeopigments were determined with a Fluorometer.

Phytoplankton samples were collected at Station 6 with a water sampler from several depths and deposited on 10 μm mesh screen. Zooplankton, on the other hand, were collected with a plankton net (94 μm) by hauling vertically at Station 6. After collection, the phyto- and zooplankton were immediately preserved by adding concentrated formaldehyde solution.

Lake sediments for measurements of grain size were collected at the transect stations using a standard Ekman-Birge grab sampler. Grain size distribution was measured with a Laser Diffraction Particle Size Analyzer.

Results and Discussion

Lake morphometry

Morphometric properties of the basin are shown in Table 1. The location of this lake is 28°34'N and 90°24'E. Altitude of the lake surface was 5,030 m. The maximum length of the lake surface was 31.1 km. The maximum width was 14.1 km, and the mean width was calculated as 9.0 km. The length of shoreline was 90.3 km and the shoreline development was calculated as 1.5. The lake surface was a simple unindented oval shape. The area of the lake surface was 281 km^2. The catchment area of Puma Yumco was 1,700 km^2, and the area ratio of catchment to lake surface was calculated as 6.2.

Table 1. Morphometric properties of Lake Puma Yumco basin.

Location	28°34'N, 90°24'E
Altitude	5,030 m
Maximum length	31.1 km
Maximum width	14.1 km
Mean width	9.0 km
Shore line	90.3 km
Area	281 km^2
Catchment area	1,700 km^2
Catchment area:Surface area	6.2
Shore line development	1.5

Physico-chemical features

The physico-chemical characteristics of the lake are shown in Table 2. Water temperature ranged from 3.3 to 3.7°C. The water exhibited slightly alkaline properties. Dissolved oxygen was 5.3 to 8.6 mg O_2 L^{-1}. The lake waters were almost completely saturated with dissolved oxygen from the surface to the bottom layer. Electric conductivity was 45 to 48 mS m^{-1}. The vertical distribution of these physico-chemical

Table 2. Distribution of physico-chemical parameters in Lake Puma Yumco. SD and CV indicate standard deviation and coefficient of variation.

	Tr (m)	WT (°C)	pH*	DO (mg O_2 L^{-1})	DO (%)	Turbidity (NTU)	EC (mS m^{-1})
Range	8.5 – 10.5	3.3 – 3.7	8.3 – 8.7	5.3 – 8.6	77 – 126	180 – 277	45 – 47
Average	9.4	3.6	8.5	7.5	109	230	46
SD	0.6	0.1	0.1	0.5	8	28	0.3
CV (%)	6	2	1	7	7	12	1

*Average, SD and CV was arithmetically calculated from the pH value.

parameters showed almost no change. There were no differences among the nine stations. Transparency with a Secchi Disc was 8.5 to 10.5 m. The extinction coefficient of lake water was calculated as 0.15 m^{-1}. Turbidity in water was 180 to 277 NTU. A high value was obtained at littoral Station 1, apparently caused by inorganic clay and silt materials from the shore or littoral sediment. The water was a clear-blue color even in the thawing season with silty particles in suspension. A large biomass of Charophyta was observed at the stations with water depths of 28 m or less. Thus, the annual average Secchi Transparency can be roughly estimated as 30 m or more from the depth of the *Chara* zone, making Puma Yumco one of the clearest lakes in the world.

Composition and concentration of major ionic elements

The concentrations of each ionic element were for Na^+ 20.4 ± 0.4 mg L^{-1} as an average value, K^+; 4.3 mg L^{-1}, Mg^{2+}; 32.9 mg L^{-1}, Ca^{2+}; 25.0 mg L^{-1}, Cl^-; 2.3 mg L^{-1}, and SO_4^{2-}; 28.9 mg L^{-1} (Table 3). High concentrations of Mg^{2+} and SO_4^{2-} were observed. The concentration of HCO_3^- was estimated as 199 ± 7 mg L^{-1}. The chemical type of the lake water was Mg-Ca-HCO_3-SO_4, based on 25% or more of cation or anion equivalence. The water was characterized by a high concentration of Mg. These values showed a uniform vertical distribution due to the absence of thermal stratification. Average salinity was estimated as 363 mg L^{-1} Kawashima and Nishiyama (1989) indicated that the salinity was lower in the south than in the arid north of the plateau, and that of the chemical type of lake waters was Na-Cl and/or Na-SO_4 in the north but Na-HCO_3 (with the one exception of Ca-HCO_3) in the south. Our results showing a high Mg concentration in Puma Yumco, however, revealed a considerably different chemical type.

Table 3. Concentration of major ionic elements in Lake Puma Yumco. HCO_3^- was estimated from ion balance of cation and anion equivqlent values. Percentages of equivalence show the value in each total cation and anion equivalence.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
Range (mg L^{-1})	19.8 – 21.3	4.2 – 4.4	31.5 – 33.8	22.4 – 26.4	2.2 – 2.4	77.0 – 80.9	186 – 208
Average (mg L^{-1})	20.6	4.3	32.9	25.0	2.3	78.9	199
SD (mg L^{-1})	0.4	0.1	0.6	1.1	0.1	1.3	6.5
CV (%)	2	2	2	5	2	2	3
Equivalence (%)	17.7 – 18.5	2.2 – 2.3	54.1 – 55.9	23.3 – 25.9	1.2 – 1.3	31.9 – 35.0	63.7 – 66.8

Table 4. Concentration of ammonia, nitrite, nitrate, urea nitrogen and phosphate phosphorus (DIP) in Lake Puma Yumco.

	Ammonia	Nitrite	Nitrate	Urea	Phosphate	DIN/DIP	TNN/DIP
Range (mM)	0.2 – 0.3	0.13 – 0.17	0.3 – 0.5	0.1 – 0.2	0.01 – 0.03	30 – 63	36 – 77
Average (μM)	0.2	0.2	0.4	0.2	0.02	38	45
SD (μM)	0.03	0.01	0.09	0.03	0.004		
CV (%)	13	7	23	21	20		
Contribution in DIN (%)	24 – 37	15 – 25	41 – 59				
Contribution in TNN (%)	20 – 31	12 – 21	34 – 48	14 – 22			

DIN and TNN mean dissolved inorganic nitrogen (sum of ammonia, nitrite and nitrate nitrogen) and total nitrogenous nutrient (sum of DIN and urea nitrogen).

Distribution of biogeochemical parameters

Distributions of ammonia, nitrite, nitrate, urea and phosphate concentrations in Puma Yumco are shown in Table 4. The concentration of ammonia was 0.25 μM, as an average value. Low concentration of nitrite was observed. The nitrate concentrations, on the other hand, were 0.39 μM. The concentrations of dissolved inorganic nitrogenous nutrients (DIN) were extremely low, compared with those generally observed in natural lakes in temperate and tropical regions. This indicates that the loading of these nitrogenous compounds from the lake watersheds is considerably low. There were no appreciable differences in the level of these inorganic nitrogenous nutrient concentrations among stations. The variations in these parameters showed an almost uniform vertical distribution. The present results indicate that Puma Yumco during the investigation period was in its circulation phase. The dissolved oxygen in the deep layer is supplied from the upper layer through diffusion. It is tempting to suggest that in the deep layer the nitrite and nitrate are supplied from the oxidation of ammonia.

Urea nitrogen in the lake ranged from 0.12 to 0.22 μM. Low concentrations of urea were obtained. The urea concentration displayed no change horizontally or vertically. Urea nitrogen was lower than ammonia and nitrate, but comparable to nitrite. An appreciable amount of urea nitrogen in the total nitrogenous nutrient (TNN; as sum of ammonia, nitrite, nitrate and urea nitrogen) was observed, ranging from 13 to 22% of TNN. In freshwater lakes, urea makes an appreciable contribution to the nitrogenous nutrients (Satoh et al., 1980; Mitamura and Saijo, 1981; Mitamura and Hino, 1997). Moreover, the importance of urea as a nitrogen source for phytoplankton has been pointed out by several studies of freshwater lakes (McCarthy et al., 1982; Mitamura and Saijo, 1986; Mitamura et al., 1995; Mitamura, 2001). The present results indicate that the urea in the euphotic zone of Puma Yumco is one of the principal nitrogenous compounds serving as a nitrogen source for phytoplankton.

The phosphate (DIP) concentration was limited. There was no appreciable change by either stations or depths. The molar ratios of DIN to DIP and TNN to DIP were calculated as 30 to 63 and 36 to 77. This seems to indicate that both nitrogen and phosphorus nutrient compounds were the limiting parameters for phytoplankton growth during the investigation period.

Chlorophyll-a amounts were 0.15 to 0.34 mg chl.a m^{-3} (Table 5). Low concentrations of phaeopigments, on the other land, were obtained. Uniform distributions in the concentrations of these parameters were observed both horizontally and vertically. The ratios of phaeopigments to chlorophyll-a concentration ranged from 0.09 to 0.15. Low ratios indicate that the phytoplankton in Puma Yumco during the investigation period possessed a high potential for photosynthetic activity, although the primary productivity seemed to be limited by low concentrations of nitrogen and phosphorus nutrients.

Table 5. Concentration of chlorophyll-a and phaeopigments, and the ratio of phaeopigments to chlorophyll-a amount in Lake Puma Yumco.

	Chl.a	Phaeo.	Phaeo/Chl.a
Range (mg m^{-3})	0.14 – 0.34	0.02 – 0.04	0.09 – 0.15
Average (mg m^{-3})	0.22	0.03	0.12
SD (mg m^{-3})	0.05	0.01	
CV (%)	24	28	

Composition and distribution of phyto- and zooplankton

A varied community of three species of Cyanophyceae, eight or more species of Bacillariophyceae, twelve or more species of Chlorophyceae, and one species of Dinophyceae, was observed (Table 6). Predominant among the epilimnetic phytoplankton were a blue-green alga *Aphanocapsa* sp. and a green alga *Oocystis borgei.* The vertical profile of phytoplankton seemed to reveal the existence of preferential depths foe each species, although most species distributed at whole depths. Two species of Copepoda and two of Branchiopoda, on the other hand, comprised our zooplankton sample. The zooplankton were dominated by free-living copepods Diaptomus sp. (first dominant) and Nauplii (second dominant). Very little biomass of the Cladocera species was observed. The composition of zooplankton as shown by the present results confirms the oligotrophic character of Puma Yumco.

Table 6. Frequency distribution of sediment grain size from Lake Puma Yumco. SD indicate standard deviation.

	Sta.6	Sta.7	Sta.8
Range (φ)	1 – 10	1 – 9	1 – 8
Average (μm)	44	53	74
SD (μm)	0.5	0.5	0.4
Median (μm)	49	63	88

Lake sediment

Visual observation of samples taken from the Ekman-Birge grab sampler showed that the sediments of transect Stations 5, 6, 7 and 8 had the grain size of sand with clay, while at littoral Station 9 it was mainly composed of pebble-cobble gravel with sand and clay. Sediments from the shallow stations of 30 m depth or less were covered with a macrophyte, *Chara* sp. At Stations 8 (10 m depth) and 9 (4 m) the large biomass was verified. The benthic animals (including shellfish) in the bottom sediment taken in the single grab collection could not be identified.

The physical and chemical characteristics of the interstitial waters in the upper sediments were as follows. Water temperature ranged from 3.3 to 3.7°C (almost the same values as those of the lake water). The pH values were 7.4 to 7.9. It is worthy noting that the pH values in the contact/interstitial water on the sediments were low compared with those of the lake water (8.3 to 8.7). The concentrations of dissolved oxygen varied from 1.8 to 7.0 mg O_2 L^{-1} (27 to 106% of saturated value), showing that the surface sediments in Puma Yumco showed an anoxic character, despite their large grain size and low levels of organic matter.

Table 6 shows the frequency distribution of grain size in sediments taken from three stations along the transect line. These sediments were generally of silt and sand size particles. At pelagic Station 6, the average grain size diameter was 44 μm, whereas at inshore Station 8 a larger size was observed. The median diameter was 49 μm of silt size at Station 6, 63 μm of sand at Station 7, and 88 μm of sand at Station 8. Even at Station 6 with its smaller size sediments, the clay size was only 3 % in total (sum of clay, silt and sand percentages). Generally the sediments consisted of large grain size, compared with those observed in temperate and tropical lakes. The present results indicate that the supply of allochthonous organic matter from the Puma Yumco their watershed was extremely low, and that the sedimentation of autochthonous organic matter originating from primary productivity was also poor due to the low photosynthesis of phytoplankton.

Wetzel (2001) established a trophic classification of lakes and reservoirs in relation to nitrogen and phosphorus concentrations in water, based on the relationship of lake productivity and the biogeochemical parameters demonstrated by Vollenweider (1968). Lakes with low concentrations of DIN (<200 mg N m^{-3}) and total phosphorus (<5 mg P m^{-3}) are defined as ultra-oligotrophic (Wetzel, 2001). In our study, extremely low concentrations of nitrogenous, phosphorus nutrients and chlorophyll-a were obtained. This seems to confirm that Lake Puma Yumco can be classified as a harmonic ultra-oligotrophic lake.

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