LIMNOLOGICAL RECONNAISSANCE OF LAKE NUKABIRA, A RESERVOIR IN HOKKAIDO

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Lake Nukabira, located in Nukabira, Kamishihoro, Eastern Hokkaido, is a body of water impounded by a dam constructed in connection with a hydro-electric generation plant. This reservoir was filled up with water in September, 1955; in June of the next year Eguchi and Fujioka (1956) made a preliminary observation on the general limnology of this lake. The present investigations attempting also a general survey of the limnology of the present reservoir were carried out on November 15–17, 1956.

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Outline of Physiographic Features of the Lake

The dam as constructed is 76 meters in height and 287 meters in length; the reservoir occupies an area of 8.1 km^2; the volume of impounded water is 19.4 km^3 (Fig. 1). The long axis of the lake extends about 8 km from north-west to south-east, the greatest width measuring about 3 km in the southern part of the lake. The shoreline shows a high degree of irregularity. The deep basin is generally found along the long axis from north-west to south-east above the old bed of the River Otofuke. The maximum depth of 75 m occurs in the southern part of the lake near the dam. In the present observation, though no exact topographic measuring was done, the depth of the lake was recorded as 12 m at St. 1, 19 m at St. 2, 38 m at St. 3 and St. 4, 48 m at St. 5, 50 m at St. 6 and 73 m at St. 7 respectively (Fig. 1).

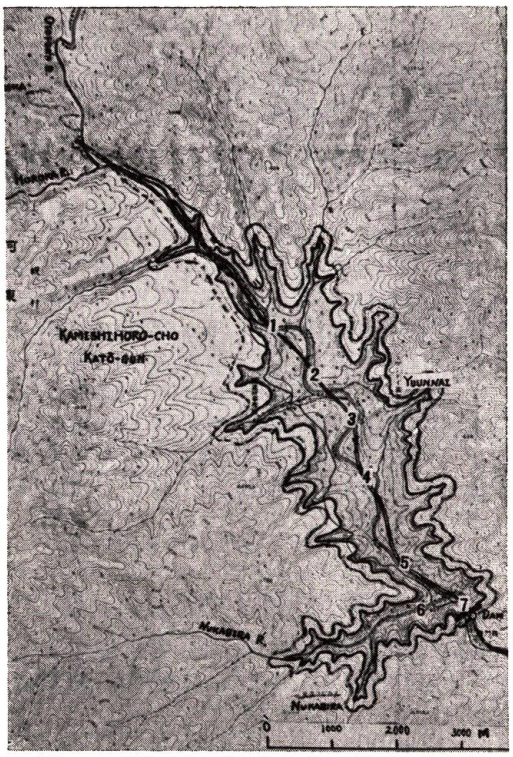

Fig. 1. Map showing location of Lake Nukabira and the stations at which observations were made

There are several rivers flowing into the lake basin; and they drain a total area of 378 km^2. Of these, the Otofuke River on the northern-most shore is of considerable importance as one of the sources of the lake water.

Physical and Chemical Properties of the Lake Water

Field observations were made at seven stations, but observations on physical and chemical properties of the lake water were made only at St. 2 and 6.

Station	Date	Hour	Air temp. (°C)	Weather
1	Nov. 15, '56	2:50–3:00 p. m.	−3	Snow showers
2	〃	3:30–5:30 p. m.	−3	〃
3	Nov. 16, '56	10:30–10:50 a. m.	−4	Overcast with lower clouds
4	Nov. 17, '56	10:20 a. m. – 12:00 m.	−2	Snow
5	Nov. 16, '56	11:20–11:30 a. m.	−4	Snow showers
6	〃	11:50 a. m. – 12:20 p. m.	−4	〃
7	〃	1:25–3:00 p. m.	−3	Overcast with lower clouds

Temperature of water: The temperature of water from the surface to near the bottom ranged vertically from 6.67 °C to 7.47 °C at St. 2 and from 7.05 °C to 7.88 °C at St. 6 as shown in Table 1 and Fig. 2. The difference of temperature between the

Table 1. Physical and chemical properties of the water observed on Nov. 15–16, 1956

Depth (m)	Temp. of water (°C)		Dissolved oxygen (cc/l)		Dissolved oxygen (%)		pH		Chlorine (mg/l)		Half-bound carbon dioxide (mg/l)		$KMnO_4$ consumption (mg/l)		Silicate-Si (μg-atoms/l)		Phosphate-P (μg-atoms/l)	
	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6	St.2	St.6
0	6.67	7.57	6.11	6.52	76.8	79.6	6.9	6.8	6.5	6.5	18	19	1.4	1.3	30.3	50.0	0	0
2	7.49	7.70	6.48	5.83	83.1	75.0	7.2	6.8	—	6.0	—	—	—	1.4	35.7	50.0	0	0
4	7.71	7.83	6.03	6.00	77.6	77.4	6.9	6.8	6.0	6.5	—	—	1.5	1.4	31.6	44.4	0	0
6	7.28	7.64	6.01	5.90	76.7	75.7	6.9	6.8	—	—	—	—	—	—	40.0	48.9	0	0
8	7.20	7.88	6.25	5.71	79.5	73.9	6.9	6.8	6.5	5.6	—	—	1.6	1.3	44.0	47.0	0	0
10	7.40	7.69	7.54	5.75	95.8	74.0	6.9	6.8	—	—	—	—	—	—	44.4	47.0	0	0
12	7.42	7.88	6.98	5.90	89.3	76.3	6.85	6.8	7.0	6.0	—	—	1.6	1.3	40.0	54.8	0	0
14	7.49	7.70	7.99	5.61	102.4	72.2	6.8	6.8	—	—	—	—	—	—	40.0	51.3	0	0
16	7.47	7.88	6.40	5.97	82.1	77.2	6.8	6.8	7.0	5.6	17	17	1.6	1.3	40.0	57.1	0	0
18		7.70		5.82		74.9		6.8		—		—		—		57.1		0
20		7.78		5.66		73.0		6.8		6.0		—		1.3		51.3		0
25		7.86		5.74		74.3		6.9		—		—		—		51.3		0
30		7.81		5.55		71.6		6.9		5.6		—		1.3		32.0		0
35		7.70		5.74		73.9		6.9		—		—		—		28.0		0
40		7.05		5.11		64.8		6.7		6.0		—		1.3		30.0		0
45		7.62		4.11		52.8		6.7		6.0		17		1.4		26.0		0
50																		
	Transparency (m)		3.0	3.0	Color of water (No.)		10	10										

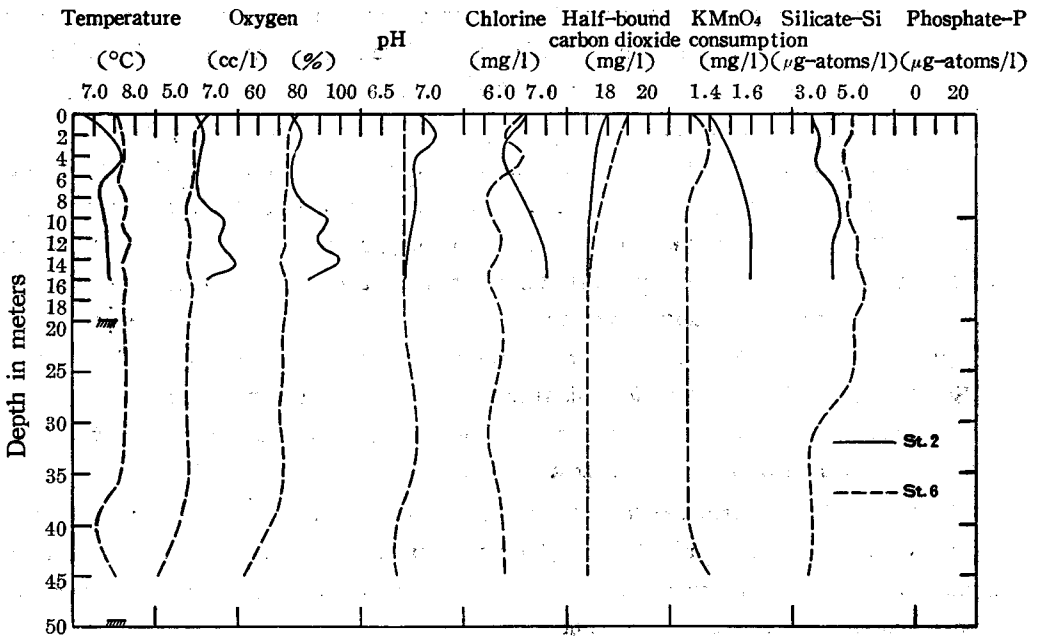

Fig. 2. Hydographic conditions at St. 2 and St. 6

surface and the bottom water was very small, no thermocline being formed. In detail, however, a slightly poikilothermic condition was formed possibly on acount of partial circulation which had occurred with the decrease of surface temperature.

As is expected from the figure of the vertical distribution of water temperature, at the present time the bottom water in the deep region (St. 6) would not be subjected to any influence by the water of upper layers.

Horizontal differences of the water temperature, though very small, were found between the two stations, 2 and 6; the temperature of water showed lower values at St. 2 through all layers. Such a low temperature at that station was possibly caused by the inflow of water of low temperature from the Otofuke River.

Color and transparency of water: The color of lake surface as read by Forel's scale was very high, showing No. 10 at both stations. The lake water presented the yellow brown color probably due to the tint of the suspended materials, but the lake water filtered by filter paper was very transparent. The present lake will be disignated from its color as a lake of common type such as is widely formed in Japan.

The transparency of water was comparatively low, being 3 meters of Secchi's disc reading at the two stations. The low transparency of this lake seems to be brought about by the large crop of plankton, mainly composed of *Asterionella formosa.*

Dissolved oxygen: The content of dissolved oxygen ranged vertically from 7.99 cc to 6.01 cc at St. 2 and from 6.52 cc to 4.11 cc at St. 6. The oversaturated oxygen was

found only at 14 meters layer at St. 2; as a whole, the oxygen was dissolved in the range of 70-80% saturation. This fact is very different from the condition of such a bog lake as the Uryu Reservoir, in which there is only 30% saturation of oxygen at 2 meters depth (Motoda, 1950).

In some mountain lakes of northern Japan a complete mixing of lake water often does not occur even in the autumnal circulation period according to their morphological patterns. The gradient of vertical distribution of oxygen in the present lake offers proof of fact that deeper layer was not influenced yet by a complete circulation of the upper water in the period of autumnal overturn.

pH value: The pH value showed a range of 7.2 to 6.8 at St. 2 and of 6.9 to 6.7 at St. 6 respectively. The vertical distribution of the pH value was almost uniform from the surface to the bottom, with exception at St. 6. The pH value at St. 2 was somewhat higher than that of St. 6 in the upper layers.

There exists a brimstone-mine at the upper course of the Horoka River, one of the branch streams of the Otofuke River. Therefore, it is possible that SO'_4 coming out from the soil makes the river water acidic by the action of H_2SO_4, and, in turn that causes the lake water also to be acidic.

Chlorine: It was expected that the water of this lake would contain a comparatively large amount of chlorine because there are the Nukabira and the Yuunnai Hot Springs near the shore of the lake, but the measurement showed such comparatively low chlorinity as 7.0-6.0 mg/l at St. 2 and 6.5-5.6 mg/l at St. 6. These values are somewhat small as compared with those of other lakes in northern Japan.

Half-bound carbon dioxide: Half-bound carbon dioxide measured from 18 mg/l to 17 mg/l at St. 2 and from 19 mg/l to 17 mg/l at St. 6. The vertical distribution of this substance was almost uniform from the surface to the bottom, but, in detail, a slightly large amount was found in the upper layer. The quantity of the half-bound carbon dioxide in the present observation corresponds to a quarter of that of the underground water of Akiyoshidai, Yamaguchi Pref. which is a famous example for containing a large amount of this substance in Japan. The present lake will rank as moderate type in Japan in respect of the content of this substance.

Potassium permanganate consumption: $KMnO_4$ consumption of lake water ranged from 1.4 mg/l to 1.6 mg/l at St. 2 and from 1.3 mg/l to 1.4 mg/l at St. 6 respectively. Such relatively small values of $KMnO_4$ consumption of the lake water may be essentially a prominent feature. Eguchi and Fujioka (1956) also reported the value as small as 2.0 mg/l in June, 1956.

Yoshimura (1937) has reported the following classification as a scale in determining the trophic types of lakes on the basis of potassium permanganate consumption.

Oligotrophic type ····· under 10 mg/l ····· Mountain lake

Eutrophic type ..... 10 to 20 mg/l ..... Low land lake
Destrophic type ..... over 20 mg/l ..... Bog lake

Judging from this classification, the present lake is suggested to be not a bog lake, but a mountain lake with respect to the nature of the water.

Silicate and phosphate: The dissolved silicate-Si was 30.3-44.4 μg-atoms/l at St. 2 and 26.0-57.1 μg-atoms/l at St. 6 respectively; phosphate-P came to zero at both stations. The vertical distribution of silicate-Si tended to be present in maximum quantity in the middle layer at both stations. The local difference of these nutrient substances was clear; a considerably small value was observed at St. 2 as compared with that of St. 6. Such a local difference is supposed to have resulted in a remarkable growth of phytoplankton at St. 2 (*Asterionella formosa*). Silicate-Si had declined to but about one-eleventh the content obtained in June of this same year (Eguchi & Fujioka, 1956).

Plankton

Method of collection: Plankton net of ordinary type, with anteriorly tapering canvas cone, 16 cm in diameter at anterior opening, 32 cm in large diameter of the proper filtering portion and 1 m in length of the filtering bolting cloth, was used by hauling vertically from near the bottom to the surface in all stations. In addition, a specially designed quantitative sampler corresponds to 20 liters of water. The collection of plankton with the special sampler was made to ascertain vertical distribution of plankton in detail only at St. 4, which is located at the approximate center of the lake.

Plankton species: The plankton collected represented only 8 species in total. The species identified were as follows:

Cyclops vicinus	r r r
Daphnia longispina	r
Bosmina coregoni	c
Asplanchna priodonta	r
Asterionella formosa	c c c
Volvox aureus	r r
Pandorina morum	+
Eudorina elegans	r

Of these, the dominant species was *Bosmina coregoni* in zooplankton and *Asterionella formosa* in phytoplankton. Above all, the latter species occurred in abundance.

According to the previous observation, the total number of plankton species in this lake counted 6 in June, 1956 (Eguchi & Fujioka, 1956). A copepoda of *Acanthodiaptomus* sp., which appeared in small number in the former observation, was not found at all in the present sampling. The high concentration of phytoplankton comprised of three species of diatoms, of which *Synedra ulna* was dominant, was reported in the former observation,

but these species did not occur at all in the present observation.

The plankton in this lake showed a noticeable difference from other reservoirs in Hokkaido such as the Uryu and the Takadomari. In the Uryu Reservoir filled with water in 1943 the number of species of plankton counted 18 in August, 1946 (Motoda, 1950), and in the Takadomari Reservoir impounded in October, 1953 it was represented by 38 species in October, 1955 and 20 species in October, 1956 respectively (Kurohagi, 1956).

Some investigators (Uèno, 1952; Shiraishi *et al.*, 1953; Round, 1956) stated that a reservoir when impounded by dam construction generally contains a relatively small number of species, but a certain species occasionally grows vigorously, showing nearly monotonous composition. However, the plankton species usually becomes larger with the passage of time as in ordinary lakes. Unusual increase of plankton in the reservoir of a certain time after construction may be induced by the certain nutrient or promoting substances derived from the bottom.

Many observations have shown that a bog lake differs from lakes of ordinary type, eutrophic or oligotrophic, regarding both plant and animal plankton populations. The plankton organisms in bog lakes are usually represented by preponderance of dismids, a small number of diatom species, an abundant occurrence of rotifera and a poverty of copepoda species. Hada (1956) proved the abundance of rotifera in several bog lakes in Hokkaido. The plankton community of this lake observed in the present observation does not show a positive feature of a bog lake.

Among the species observed, the six prevalent species, *Cyclops vicinus*, *Daphnia longispina*, *Bosmina coregoni*, *Asterionella formosa*, *Asplanchna priodonta* and *Pandorina morum* are known as cold-water forms or eurythermal forms. It has been stated that in habit *Cyclops*, *Bosmina*, *Asplanchna* and *Pandorina* occur mainly in cold-water condition of lake, and *Daphnia* and *Asterionella* are known to be eurythermal species. *Asterionella* adjusts to a wide range of temperature of water, showing two types of colony according to the temperature of environment, that is, the cross-shaped forms occur mainly in the cold-water condition. In the present observation the colonies of *Asterionella* were dominantly represented by such cross-shaped individuals.

Vertical distribution of plankton: The vertical distribution of three species of plankton is shown in Fig. 3. *Asterionella formosa*, *Bosmina coregoni* and *Asplanchna priodonta* inhabited all depths. Of these, the former two species were uniformly distributed throughout the layers observed, while *Asplanchna* disappeared entirely at 30 meters layer. The maximum populations were present in the shallow layers, in detail, at the surface in *Asterionella* and *Asplanchna* species and 6 meters layer in *Bosmina*. From this depth downwards, these species decreased in number with depth to the middle layer, though there was some irregularity. Below the middle layer, they commenced to increase and then again decreased near the bottom.

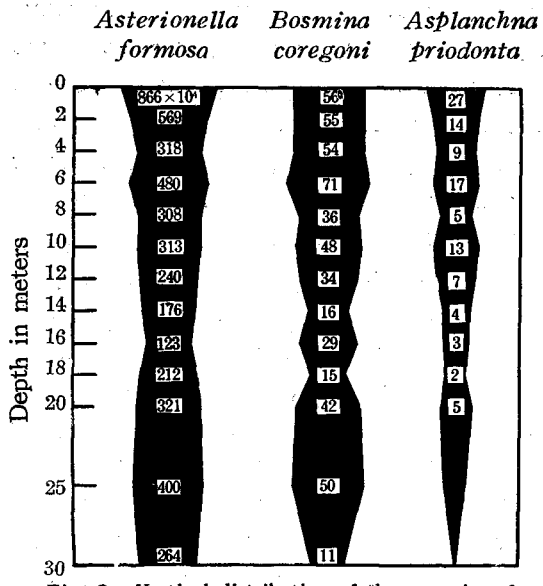

Fig. 3. Vertical distribution of three species of plankton at St. 4

Standing crop of net plankton: The standing crop of net plankton at each station was determined by measuring dry weight and chlorophyll content of the organisms on the samples obtained by the vertical haul with plankton net. The volume of water filtered through the plankton net was calculated by reading of the flowmeter set at the center of the anterior opening of the net. The results are shown in Table 2.

The dry weight of net plankton per cubic meter of lake water ranged from 67 mg to 860 mg. The mean was calculated as 234.5 mg per cubic meter; it corresponds to 561.3 kg per hectare. The organic matter as represented by the weight of ash of plankton organisms was 252.6 kg per hectare (Table 3). The dry weight of plankton somewhat increased to the center region from the north and from the south shore.

Table 3 indicates the dry weight and the weight of organic matter of plankton in several lakes of eutrophic type in Japan.

Table 2. Dry weight and chlorophyll content of plankton observed on Nov. 15–17, 1956

Station	Dry weight of plankton (mg/m^3)	Chlorophyll content (mg/m^3)
1	77	0.52
2	245	1.36
3	184	—
4	860	2.20
5	95	0.14
6	113	0.33
7	67	0.36
Mean	234.5	0.81

Table 3. Comparison of dry weight of organic matter of plankton in eutrophic lakes in Japan

Lake	Dry weight of plankton (mg/m^3)	Dry weight of plankton (kg/ha)	Weight of organic matter of plankton (kg/ha)	Investigator
Suwa	11500–2500		336–24	Hogetsu *et al.*, 1952
Nakanuma	1330–840			Ichimura, 1956
Koikuchinoike	881	125.4	69.0	Kawamura, 1956
Nukabira	234.5	561.3	252.6	Kawamura & Anraku, 1956

Several authors (Hogetsu *et al.*, 1952; Rawson, 1953; Ichimura, 1956; Kawamura, 1956) gave figures on the measurement of plankton standing crops in lakes; the volume was 10–20 kg in dry weight per hectare in oligotrophic lakes (western Canada), 50–100 kg per hectare in moderate lakes, about 150 kg per hectare in very eutrophic lakes. The production of the present lake which yields a crop of 234.5 mg per cubic meter or 561.3 kg per hectare seems to rank as a lake of eutrophic type, though the value here reported is concerned only with the time of observation, not annual mean.

The amount of chlorophyll of plankton in the present lake ranged from 0.1 mg to 2.2 mg per cubic meter through all stations. Local difference of chlorophyll content of plankton was generally parallel to that of the dry weight of plankton. Ichimura (1956) stated that on the basis of summer observations, the eutrophic lakes such as Lake Suwa, Lake Nakanuma, *etc.* contain plankton chlorophyll in the range from 10 mg to 50 mg per cubic meter of water, while in the oligotrophic lakes such as Lake Aoki, Lake Motosu, *etc.* it is less than 1 mg per cubic meter. Other lakes showing intermediate values between them indicates that they are mesotrophic. From this classification, the present lake is assumed to be of oligotrophic type. It is general fact that the amount of chlorophyll of plankton in a lake varies greatly from season to season, so that the annual mean of chlorophyll content in this lake may be larger than the above estimation (0.81 mg/m^3) obtained in November. The present lake will possibly come within the range of the mesotrophic lakes at the present time.

Summary

1) A preliminary limnolgical survey of Lake Nukabira, a body of fresh water impounded as a reservoir about one year previously, was carried out in November, 1956.

2) The character of a bog lake in respect to physical and chemical properties was not recognized. The plankton species are confined to 8, among which *Bosmina coregoni* and *Asterionella formosa* are dominant.

3) Such nutrient substances for the growth of phytoplankton as silicate-Si and phosphate-P in the lake water are remarkably reduced by the vigorous growth of the diatom, *Asterionella formosa.*

4) The dry weight of plankton is calculated to be 561.3 kg per hectare, indicating that the lake is eutrophic to a certain extent, but the quantity of plankton chlorophyll is rather low, corresponding to that of usual oligotrophic lakes.

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