JOUR. FAC. SCI., SHINSHU UNIV. Vol. 2, No. 3, pp. 139–148 Dec. 1967

*Dissolved Oxygen, Bloom of Microcystis and "Susu-mizu" of Summer-autumn Season in Lake Suwa**

By HIROSHI YAMAGISHI

Suwa Hydrobiological Station, Faculty of Science,
Shinshu University

and TOKIO OKINO

Department of Biology, Faculty of Science,
Tokyo Metropolitan University

(Received Sept. 30, 1967)

Abstract

Vertical distribution of dissolved oxygen and chlorophyll in summer-autumn season were determined in the offshore of Osaka in Lake Suwa. In mid-summer, when whole the surface of the lake was covered with blooming *Microcystis*, dissolved oxygen in the surface water layer could attain over-saturation to the utmost extent (160%). Late in August the amount of dissolved oxygen markedly decreased less than 90% saturation, in spite of a large amount of *Microcystis* existed. It might be related to the declining of the photosynthetic activity of the alga. Moreover, if drifting of the upper water containing a great part of *Microcystis* by wind ("Susu-mizu") occurred, serious decrease of dissolved oxygen (less than 50% saturation) was observed. Wind and waves usually were not favorable to increase oxygen into the surface water. In such a situation carps cultured in the floating nets may be exposed to danger of asphyxia unless a large amount of dissolved oxygen is supplied from surrounding water outside of the nets during the night. There was a relationship between the pH value and the saturation percentage of dissolved oxygen in the water of 0 to 2 m depth.

Introduction

Lake Suwa (N 36° 03′, E 138° 05′) is located in Nagano Prefecture at the altitude of 759 m. It is an eutrophic lake with the surface area of 14.45 km², the maximum depth of 6.5 m and the mean depth of 4.1 m. Into the lake 25 rivers

*Contributions from the Suwa Hydrobiological Station, Shinshu University, No. 1.

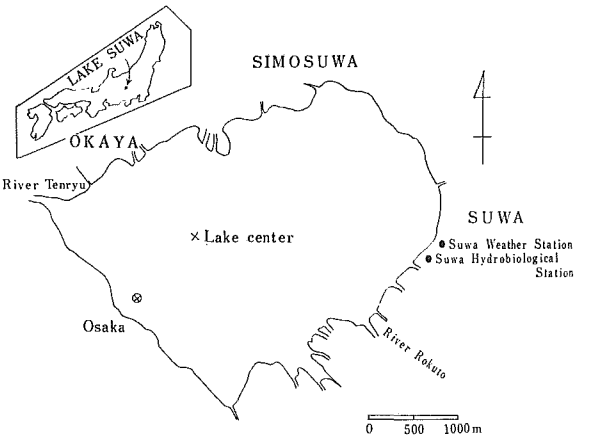

Fig. 1 Maps showing the position of Lake Suwa and the station (⊗) at which the observations were made.

and brooks flow in, but from the lake only one river (River Tenryu) flows out (Fig. 1). Three cities and one town lie around and near the lake. In the lake the culture of carps within large floating nets has developed.

Concerning Lake Suwa, a large number of biological and limnological studies have appeared up to present. Among them those on the biological production of Lake Suwa made during 1947—1951 by HOGETSU, KITAZAWA, KURASAWA, SHIRAISHI and ICHIMURA (KITAZAWA and KURASAWA, 1951, 1952, 1952a; KURASAWA, KITAZAWA and SHIRAISHI, 1952, 1952a; HOGETSU, 1953; HOGETSU and ICHIMURA, 1954; KURASAWA and SHIRAISHI, 1954, 1955) are valuable.

In summer the bloom of *Microcystis aeruginosa* is usually observed in the lake. Recently, the bloom shows a tendency to begin in early summer and to last longer, sometimes toward the close of autumn. It seems to be related to increasing pollution of the lake water accompanied with the development of industry and human population around the lake (KURASAWA and AOYAMA, 1967).

It must be pointed out that late in summer the carps cultured in the floating nets used to be killed in a large number with oxygen deficiency suddenly occured over night. At that time the colour of the lake water turns to brown from green (the colour of *Microcystis*) usually. This phenomenon called "Susu-mizu" (summer kill) by local people, is supposed to be caused when the surface water is carried away by wind and the bottom water with little amount of dissolved oxygen rises to the surface. Dissolved oxygen in the bottom water of the profound region decreases to the utmost extent if the weather is kept calmly for several days in summer.

On the other hand, there are some opinions regarding the toxicity of *Micro-*

cystis aeruginosa on freshwater fishes (PRESCOTT, 1948; INGRAM and PRESCOTT, 1954; SCHELUBSKY, 1951). However, according to AHMAD (1966, 1967) the investigations made in India have shown that the alga is not toxic to freshwater fishes.

Apart from this question, the present authors have made some invesitgations on the vertical distribution of dissolved oxygen and chlorophyll of summer-autumn season of 1967 in Lake Suwa. The obtained results were enough to show some features of oxygen condition and possible influence of it on the fish culture in the lake.

Locality and Methods

All the field observations were made at a station in the offshore of Osaka with the depth of 5.3 m. Near the station, some area was occupied by several floating nets for the carp culture in the course of our observation. The sample of the lake water from the depth of 1, 2, 3, 4 and 5 m was taken with Van-Dorn's water sampler with 3000 cc volume.

The amount of dissolved oxygen was determined by Winkler's method. In order to collect organisms containing chlorophyll (phytoplankton) each sample water (200–1000 cc) was filtered through glass-fibre filter paper (1.2 μ mean pore size) which had been weighed dry. After the filtration each of the filter papers was again dried at 80° C longer than 24 hours and weighed. The increment of the dry weight of the filter paper before and after the treatment corresponds approxymately to the dry weight of the seston in sample water. The amount of chlorophyll (a + b) in the seston was determined by Strickland and Parson's method.

Results

The surveys were made on the 1st and 24th of August, 9th, 18th and 22nd of September and 11th of October in 1967. On the 1st of August the sampling was made four times and on the 9th of September two times.

In mid-July whole the surface of Lake Suwa was covered with yellow-green coloured *Microcyctis aeruginosa* already. Very little phytoplankton except *Microcystis* was seen in the water of surface layer on the 1st of August (KURASAWA ET AL., unpublished). *Microcystis* dominated late in September and even in October in surface water though it decreased in number and other algae were seen more frequently than in August. In Tables 1 to 6 water temperature, pH and amount of dissolved oxygen, seston and chlorophyll (a + b) at the depth of 0 to 5 m and weather on each observation were shown. Fig. 2 shows saturation percentage of dissolved oxygen and transparency on each day of observation.

The temperature of the water was maintained at 20–30°C in all the layer

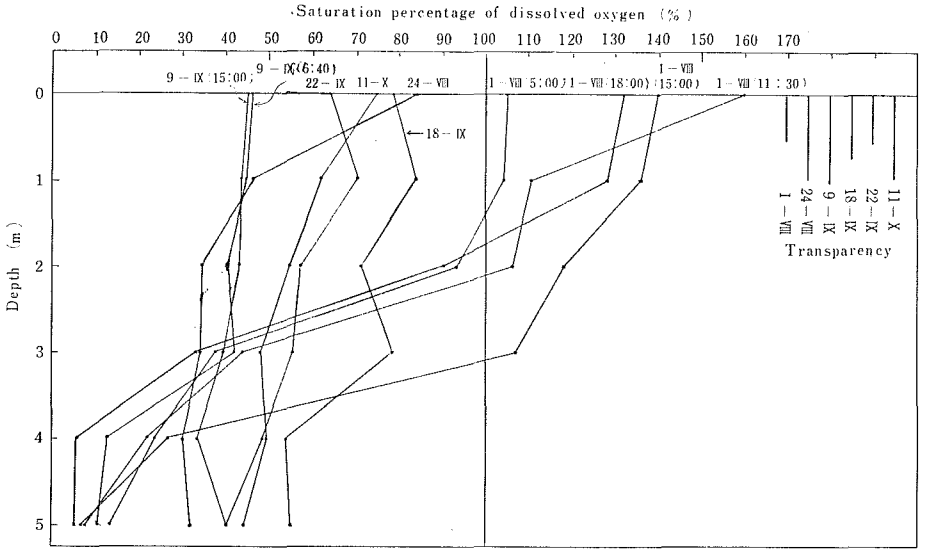

Fig. 2 Saturation percentage of dissolved oxygen of the water of 0 to 5 m depth and transparency in the offshore of Osaka on each day of observations.

until the 18th of September, but after the 22th of September it declined to less than 20°C. The maximum temperature in the surface water showed 29.4°C at half past eleven on the 1st of August. The thermocline seemed to be present at the depth of 2–3m on that day. It showed the decrease of the water temperature in the range of 2–3°C. The pH values were very high in the upper water (more than 9) on the 1st of August.

It is noticeable that dissolved oxygen was over-saturated in the surface water when *Microcystis* was found in excess (expressed in a great amount of seston and chlorophyll) even in the early morning (Table 1). But dissolved oxygen could not attain to 100% saturation late in August though considerable amount of chlorophyll was contained in the surface water (Table 2). This decrease of dissolved oxygen may be related to declining photosynthetic activity of *Microcystis* toward the end of summer.

As shown in Table 3 dissolved oxygen in upper water layer had decreased markedly (less than 50% saturation) in the morning of the 9th of September. It took place when wind (0–4.7 m/sec) had blown over night that followed several calm days. On the day the colour of the water turned brown and the declined amount of seston (accordingly, chlorophyll as well) was found in this area of the lake. The phenomenon expressed in drifting of upper water layer containing a great amount of *Microcystis* by wind may be taken as "Susu-mizu". In the

Table 1 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 1st of August.

Ranks in the weather column indicate weather, atmospheric temperature, wind speed and wind direction from the top to the bottom. Wind speed and wind direction depend on the data of Suwa Weather Station.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Weather
5.00 a.m.	0	26.3	9.6	9.48	32.5	183	Fine
	1	26.5	9.8	9.32	25.0	117	21.6°C
	2	26.0	9.6	8.38	12.0	66	1.5 m/sec
	3	23.7	8.3	3.54	6.6	17	SSE
	4	22.2	7.6	2.34	5.2	11	
	5	21.5	7.3	1.32	8.0	12	
	Mean			5.73	14.9	68	
11.30 a.m.	0	29.4	10.1	13.64	43.0	260	Fine
	1	26.8	9.7	9.85	9.2	61	28.2°C
	2	26.6	9.7	9.52	8.4	54	2.0 m/sec
	3	23.8	8.4	4.14	4.2	14	WSW
	4	22.2	7.5	2.14	4.0	8	
	5	21.2	7.2	0.97	12.2	12	
	Mean			6.68	13.5	68	
15.00 p.m.	0	27.9	9.9	12.26	17.6	83	Cloudy
	1	27.6	9.8	11.95	17.6	86	28.3°C
	2	27.3	9.7	10.20	16.0	82	4.8 m/sec
	3	24.4	9.4	10.00	10.8	35	SSE
	4	21.8	7.5	1.80	8.0	13	
	5	21.0	7.1	0.73	6.6	18	
	Mean			7.82	12.8	53	
18.00 p.m.	0	28.0	9.7	11.51	16.0	82	Cloudy
	1	28.0	9.7	11.20	16.0	73	23.0°C
	2	26.3	9.4	8.15	8.8	29	1.7 m/sec
	3	22.1	6.9	2.20	4.0	10	SSE
	4	20.9	6.7	0.57	8.6	12	
	5	20.9	6.7	0.51	13.8	17	
	Mean			5.69	11.2	37	

afternoon wind blew so strong (0.7–6.8 m/sec) that the lake waved highly. As a result the stratification of dissolved oxygen in the water which had been present in the morning was disturbed. But little increase of dissolved oxygen in the surface layer was observed though remarkable increase in the deep layer was found.

It is interesting that the relationship showing a sigmoid curve was present

Table 2 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 24th of August.
Description of the weather column is the same as in Table 1.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Weather
	0	28.4	8.6	7.32	24.7	131	Fine
	1	25.1	7.4	4.27	11.7	34	32.3°C
	2	24.4	7.0	3.23	7.9	24	1.8m/sec
14.00 p.m.	3	24.4	6.9	3.20	7.0	10	NW
	4	24.2	6.9	2.90	6.4	7	
	5	24.0	6.9	3.00	5.4	7	
	Mean			3.99	10.5	36	

Table 3 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 9th of September.
Description of the weather column is the same as in Table 1.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Wather
	0	23.6	7.0	4.35	7.4	6.5	Cloudy
	1	23.6	7.0	4.26	7.0	8.0	21.0°C
	2	23.6	7.0	3.78	6.2	8.3	2.8m/sec
6.40 a.m.	3	23.6	7.0	3.96	6.9	8.8	ESE
	4	23.4	6.8	1.20	8.3	5.1	
	5	23.2	6.8	0.96	11.0	6.6	
	Mean			3.09	7.8	7.2	
	0	23.8	7.1	4.29			Cloudy
	1	23.8	7.0	4.11			23.6°C
	2	23.7	7.0	4.05			4.7m/sec
15.00 p.m.	3	23.6	7.0	3.75			SE
	4	23.4	6.9	3.15			
	5	23.2	6.9	3.84			
	Mean			3.87			

between pH value and saturation percentage of dissolved oxygen only in the water of 0 to 2 m depth (above thermocline) during the season (Fig. 3).

Discussion

As mentioned above, when excessive *Microcystis* covered whole the surface of the lake dissolved oxygen attained to over-saturation to the utmost extent in

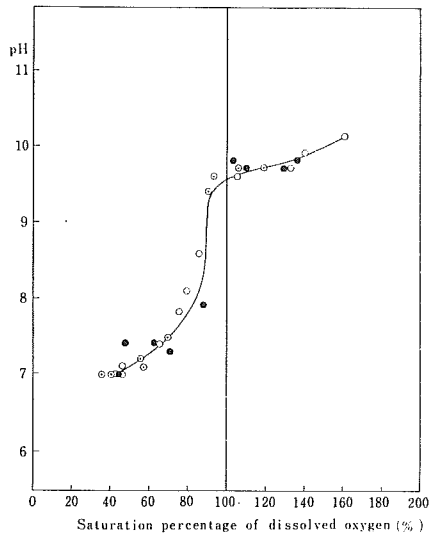

Fig. 3 Relationship between pH value and saturation percentage of dissolved oxygen of the water of 0 to 2 m depth during the summer-autumn season.
○ 0 m; ● 1 m; ◉ 2 m.

the daytime. Dissolved oxygen in the surface layer could remain in over-saturation until the next morning. According to the second author's experimental investigation oxygen consumption of *Microcystis* in darkness was very little (OKINO, unpublished). Moreover, *Microcystis* tends to be afloat on the water. These facts may be favorable to fish cultured in the floating nets as well as those in the ponds with blooming *Microcystis* as usually observed.

However, marked change in oxygen condition occurred late in summer. At that time *Microcystis* was not so active as to saturate the lake water with oxygen. Moreover, drifting of upper water containing a great amount of *Microcystis* by wind (so-called "Susu-mizu") was apt to take place. When the "Susu-mizu" occurred dissolved oxygen suddenly decreased to below 50% saturation. The wind and waves mixing the upper water with the bottom water might be useless to increase oxygen into the surface water. Strong wind may reduce the amount of dissolved oxygen if it blows when the dissolved oxygen is over-saturated in the upper water. In addition, the consumption of the dissolved oxygen by the polluted water flows into the lake by the inflow waters all the time may continue as before. As a result the balance of the dissolved oxygen in the lake will tend to be broken.

Such a situation will be menace to the fish cultured in the floating nets. If in a floating net with 121.5 m^3 water volume ($9 \times 9 \times 1.5$ m) are cultured 4000 carps with 500 g body weight (usual density in a net and average weight per fish) late in summer, they will cosume 150 g dissolved oxygen per hour at 25°C (oxygen consumption of carp was calculated based on the data of BEAMISH, 1964 as 75 mg O_2/kg/hr in standard oxygen consumption* at 25°C).

Supposing that oxygen supply in the net is shut off from the surroundings and oxygen consumption by algae is very little at night, dissolved oxygen in the

* According to BEAMISH (1964) standard oxygen consumption means oxygen uptake in the absence of spontaneous activity.

Table 4 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 18th of September.
Description of the weather column is the same as in Table 1.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Weather
	0	22.1	8.1	7.62	19.7	39.0	Rainy
	1	22.3	7.9	8.07	15.2	27.8	19.6°C
	2	22.2	7.5	6.90	15.1	19.0	0.7 m/sec
15.35 p.m.	3	21.9	7.5	7.65	16.1	23.9	WNW
	4	21.7	7.1	5.31	13.8	10.7	
	5	21.5	7.1	5.43	17.0	10.3	
	Mean			6.83	16.2	21.8	

Table 5 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 22th of September.
Description of the weather column is the same as in Table 1.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Weather
	0	20.0	7.4	6.48	16.2	17.2	Fine
	1	20.0	7.3	6.60	17.0	16.5	22.2°C
	2	19.7	7.2	5.82	15.0	20.0	3.5 m/sec
16.15 p.m.	3	19.1	7.2	5.70	15.9	18.7	SW
	4	19.1	7.1	5.01	14.5	16.6	
	5	18.3	7.0	4.23	20.5	13.7	
	Mean			5.64	16.6	17.2	

Table 6 Water temperature, pH and amount of dissolved oxygen, seston and chlorophyll in the water of 0 to 5 m depth in the offshore of Osaka on the 11th of October.
Description of the weather column is the same as in Table 1.

Time	Depth (m)	Water temperature (°C)	pH	Dissolved oxygen (mg/l)	Seston (mg/l)	Chlorophyll (mg/m³)	Weather
	0	19.1	7.8	7.70	12.2	19.0	Fine
	1	16.3	7.4	6.76	12.8	13.0	19.6°C
	2	16.0	7.2	6.00	14.0	16.6	4.7 m/sec
15.00 p.m.	3	15.9	7.1	5.31	12.2	14.8	SE
	4	15.7	7.0	5.44	12.1	14.5	
	5	15.5	7.0	4.90	19.7	18.6	
	Mean			6.02	13.8	16.1	

100% 0_2 saturated water (8.2 mg 0_2/1 at the altitude of Lake Suwa at 25°C) in the floating net will be entirely consumed by carps in the early course of 6.64 hours at night. That is to say, more than equal amount of existing dissolved oxygen is needed for life. This deficit of dissolved oxygen must be covered by the supply from the atmospheric oxygen and the dissolved oxygen in surrounding water outside of the net. However, the supply of oxygen into the water from the air is too little to be taken into account (0.034 g $0_2/m^2/hr$ in the still water of 0 % 0_2 saturation at 20–25°C) (Odum, 1956). Consequently, the fish in the net must depend on the supply of dissolved oxygen from surrounding water outside the net.

Based on our estimation, necessary amount of water containing oxygen in 100 % saturation in the rest course of 7.36 hours (supposing that effective duration of sunshine to the photosynthetic activity of algae is 10 hours) is equal to 135 m^3. The amount may be not so great. However, saturation percentage of dissolved oxygen in the upper water used to be far from 100% late in August and in September even when no "Susu-mizu" occured. On the other hand, fish are growing as before and they consume more dissolved oxygen at that time. It means that the carps in the floating net may be exposed to danger of asphyxia late in summer, if the net is equiped without any apparatus for the oxygen (air) supply.

As mentioned above, the relationship showing a sigmoid curve was present between the value of pH and the saturation percentage of dissolved oxygen in the water of 0 to 2 m depth during the season. The decrease of pH less than 8 may be regarded as a warning of oxygen deficiency in the upper water.

References

Ahmad, M. R (1966) *Hydrobiologia*, **28**, p. 88–90.

———— (1967) Ibid. **29**, p. 388–392.

Beamish, F. W. H. (1964) *Can. J. Zool.*, **42**, p. 177–188.

Hogetsu, K. (1953) *Misc. Rep. Res. Inst. f. Nat. Res.*, **30**, p. 4–9.

———— and Ichimura, S. (1954) *Jap. Journ. Bot.*, **14**, p. 280–303.

Ingram, W. M. and Prescott (1954) *Amer. Midl. Naturalist*, **52**, p. 75–87.

Kitazawa, Y. and Kurasawa, H. (1951) *Misc. Rep. Res. Inst. f. Nat. Res.*, **24**, p. 1–15.

———— (1951) Ibid. **25**, p. 1–13.

———— (1952a) Ibid. **27**, p. 1–6.

Kurasawa, H. and Aoyama, K. (1967) *Proceedings of the annual meeting of the Jap. Ecol. Soc.*, p. 85.

Kurasawa, H., Kitazawa, Y. and Shiraishi, Y. (1952) *Misc. Rep. Res. Inst. f. Nat. Res.*, **27**, p. 29–39.

———— (1952a) Ibid. **28**, p. 98–106.

KURASAWA, H. and SHIRAISHI, Y. (1954) **33**, p. 24–32.
———— (1955) Ibid. **37**, p. 49–57.
ODUM, H. T. (1956) *Limnol. Oceanog.*, **1**, p. 103–117.
PRESCOTT, G. W. (1948) *Hydrobiologia*, **1**, p. 1–13.
SCHELUBSKY, M. (1951) *Verh. Int. Verein. Limnol.*, **11**, p. 362–366.