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WATER QUALITY AND COMPOSITIONS OF THE PHYTOPLANKTON AND ZOOPLANKTON BEFORE AND AFTER BUILDING CONSTRUCTION IN LAKE FUKAMI-IKE, JAPAN

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ABSTRACT: Lake Fukami-ike is a small monomictic and eutrophic lake, located in southern Nagano Prefecture in central Japan. Water quality improvement was expected from maintenance of farm village drainage and waterfront function was carried out for town activation in 1992. However, no blue-green algal bloom outbreak had occurred before. We studied the water quality and compositions of the zooplankton and phytoplankton before and after building a bulkhead maintenance construction. Large decreased values for NO_3-N, NH_4-N and NO_2-N were 1.87→0.50 gNm^{-2} (26.7%), 1.49→0.78 gNm^{-2} (52.3%) and 0.085→0.030 gNm^{-2} (35.3%), respectively. *Aphanizomenon flos-aquae* (Cyanophyceae) were dominant in the summer; some species of the genus *Fragilaria* were dominant among phytoplankton during study periods. The dominant species of zooplankton during study periods were *Keratella cochlearis* (Rotatoria); smaller than *Cyclops vicinus* (Crustaceae) were dominant species of zooplankton before the construction.

Keywords: Building a Bulkhead maintenance construction, Water quality, Phytoplankton, Zooplankton

1. INTRODUCTION

Water pollution is worldwide problem, and control of river inflow that is the source of nitrogen and phosphorus is important for the water quality improvement [1]-[2].

Lake Fukami-ike is a small monomictic and eutrophic lake, located in southern Nagano Prefecture in central Japan. The studies in the lake were begun from 1978, and it is continuing now mainly about water quality roughly once a month.

Maintenance of farm village drainage and waterfront function and water quality expectations became better. However, although water color stays a dark green or brown, the transparency variation for 35 cm - 470 cm in the 1992 - 2010s was larger than that of 50 cm - 150 cm in the 1980s - 1992. Moreover, no blue-green algal bloom (*Microcystis aeruginosa*) outbreak had occurred before, and high chlorophyll-a concentration (357 μgL^{-1}) and low transparency (35 cm) was observed in June 2000.

We studied the water quality in the water column and compositions of zooplankton and phytoplankton before and after building a bulkhead maintenance construction.

2. METHODS

2.1 Study Area

Lake Fukami-ike is located in southern Nagano Prefecture in central Japan; north latitude 35°32′55″77, east longitude 137°81′93″56. The surface area of the lake is about 2.1 ha, with a maximum depth of 7.75 m, and volume 1.0 × 105 m^3 and with a small diameter: 150 m, 300 m. (Fig. 1 and Fig. 2) [3].

The lake is eutrophic lake because of having 12 units considering inflow nutrients from surrounding paddy fields. The maximum depth was reported 9.3 m in 1951 [4], 8.1 m in 1993 [5], and 7.75 m in recently [3].

The lake has five inflow rivers and the lake water exits from an outflow river. These rivers receive the runoff sewage water from around houses. The lake water is not dry up because there is a lot of spring water which become a source of inflow water having less than 30 cm wide.

Circulation periods were in November to March, and stagnation periods were in April to October; the dissolved oxygen concentration was zero in about the 4 m to 5 m deeper layer in mid-summer [6].

Water plants (such as *Phragmites australis*; Poales, *Typha latifolia*; Typhales) live around the lakeshore. Local residents mow these weeds on a regular basis.

Lake Fukami-ike has been described in previous studies about manganese, purple nonsulphur bacteria, microbial sulfur cycling, dial vertical migration of *Chaoborus flavicans* (Diptera) [3],[7]-[9]. It is interesting to note that the chlorophyll-a amount in the winter was higher than that of summer caused the interruption of upward nutrient transportation from the tropholytic layer due to distinct stagnation of water and the consumption of nutrients by photosynthetic sulfur bacteria (as bacteriochlorophyll-c) growing near the top of the anoxic layer in summer [10].

Chlorophyceae (classes of green algae) reached a rich “Vegetationstrübung” condition, and no water bloom occurred in the lake [11].

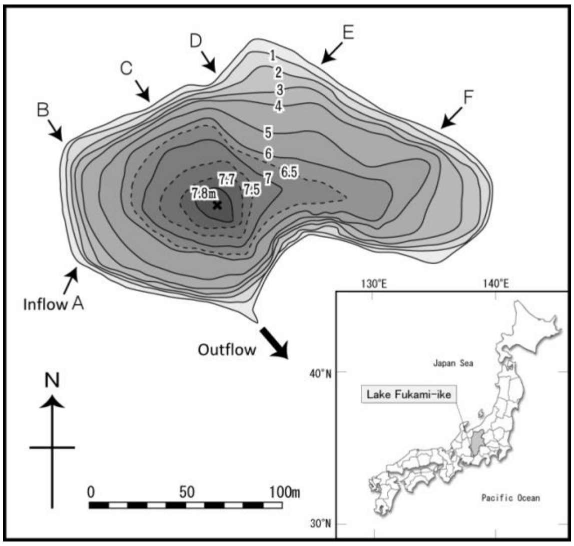

Fig. 1 Bathymetrical map of Lake Fukami-ike.

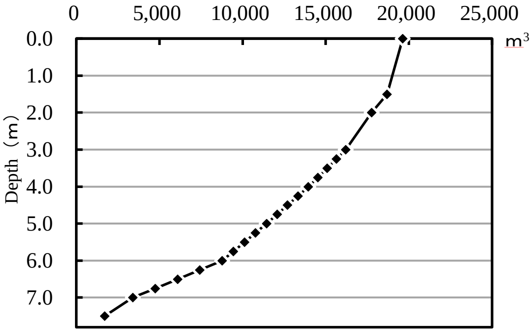

Fig. 2 Stratified volume amount of Lake Fukami-ike.

2.2 Sampling and analysis

Lake water samples were collected at the deepest point with a hand-operation water pump connected to a polyvinylchloride tube from every 0.25 m depth during the period of water stratification from April to October or from every 50 cm - 1 m depth in other months.

Part of the water samples was filtered through a glass fiber filter (Whatman, GF/F, 47 mm) immediately after the sampling. The samples were stored at -20℃ until chemical analysis in the laboratory.

The filtrate was used for the determination of inorganic nitrogen (NO_3-N, NH_4-N and NO_2-N) were measured by ion chromatography analysis (DKK-TOA CORPORATION, PCI-311S).

Total phosphorus and total dissolved phosphorus were measured by the molybdenum blue colorimetric method [12].

Chlorophyll-*a* was measured by the fluorometric method [13].

Water temperature was measured with a thermistor thermometer, and dissolved oxygen was determined with a DO meter (HORIBA DO Meter OM-12).

Plankton samples were taken with a Van Dorn water sampler (10L, Rigo Co., Ltd., Tokyo Japan) every 1 m from the upper to bottom layer. All samples were preserved in 1% formalin in the field immediately, then counted and identified using an optical microscope (BX51, OLYMPUS Optical Co., Ltd., Tokyo, Japan) in the laboratory.

3. RESULTS AND DISCUSSION

3.1 Inflow and Outflow rivers

The interannual variability of the inflow rate data were shown in Table 1. Before building the bulkhead maintenance, inflow data were 4 LS^{-1} in 1973, 9.9 LS^{-1} in 1979, 5.7 LS^{-1} in 1980. However, 0.52 LS^{-1} and 0.62 LS^{-1} in 2008 were measured after, the mean values were dramatically decreased from 6.5 LS^{-1} to 0.57 LS^{-1}. Outflow data 14.4 LS-1 in 1973, 19.5 LS-1 in 1979 and 7.7 LS-1 in 1980, 0.68 LS-1 and 0.46 LS-1 in 2008. Mean values were 13.8 LS-1 before construction, and 0.57 LS-1 after. Because the inflow river course had a bypass to avoid the lake for the bulkhead construction in 1992, inflow and outflow dramatically decreased one-twentieth and one twenty-fourth respectively.

Table 1 Mean abundance of flow rates in inflow and outflow rivers.

building construction	Observation day	Inflow (LS^{-1})	Outflow (LS^{-1})
Before	Nov 2, 1973	4	14.4
	Sep 15, 1979	9.9	19.5
	Feb 15, 1980	5.7	7.7
	Means (LS^{-1})	6.5	13.8
After	Feb 15, 2008	0.52	0.68
	Oct 22, 2008	0.62	0.46
	Means (LS^{-1})	0.57	0.57

3.2 Nutrients

3.2.1 *Nitrogen*

Seasonal depth-time diagram distribution of inorganic nitrogen from 1978 to 1980 and 1999 to 2000 was shown in Fig. 3 (NO_2-N), Fig. 4 (NO_3-N) and Fig. 5 (NH_4-N).

All inorganic nitrogen (NO_3-N, NH_4-N and NO_2-N) concentrations in the lake were decreased after maintenance construction than before it; in particular, NO_3-N concentrations from 0 m to 3 m in the epilimnion were much decreased.

The interannual mean values of NO_3-N, NH_4-N and NO_2-N in the water column before (1979-1992) and after (1992-2013) for NO_3-N, NH_4-N and NO_2-N were 1.87 → 0.50 gNm^{-2} (26.7 %), 1.49 → 0.78 gNm^{-2} (52.3 %) and 0.085 → 0.030 gNm^{-2} (35.3 %), respectively. In particular, NO_3-N value decreased one fourth before the maintenance construction. Because inflows contain from paddy fields and orchards (allochthonous inorganic matter) stop to significantly reduce, NO_3-N value decrease largely after the construction.

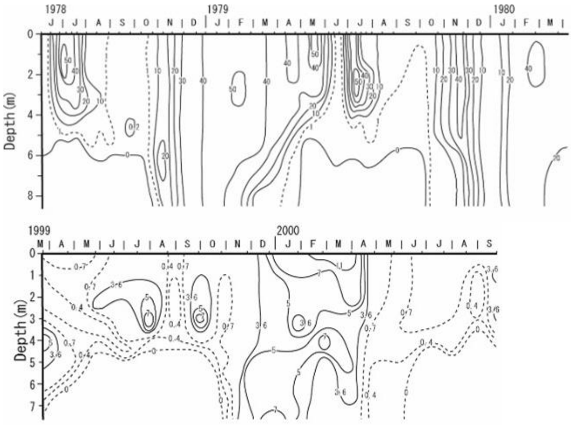

Fig. 3 Depth-time diagram distribution of NO_2-N (μg at. N l^{-1}) concentrations in 1978-1980 (above) and 1999-2000 (below). (Modified from [14].)

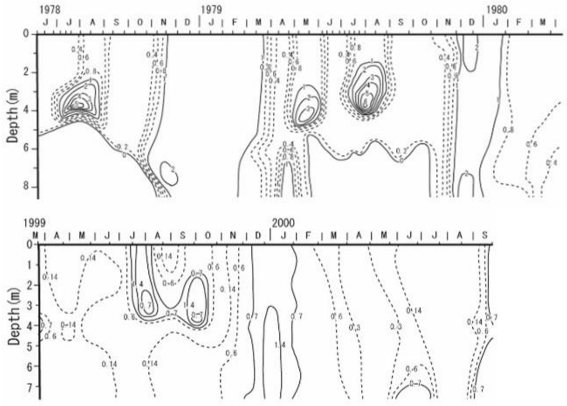

Fig. 4 Depth-time diagram distribution of NO_3-N (μg at. N l^{-1}) concentrations in 1978-1980 (above) and 1999-2000 (below). (Modified from [14].)

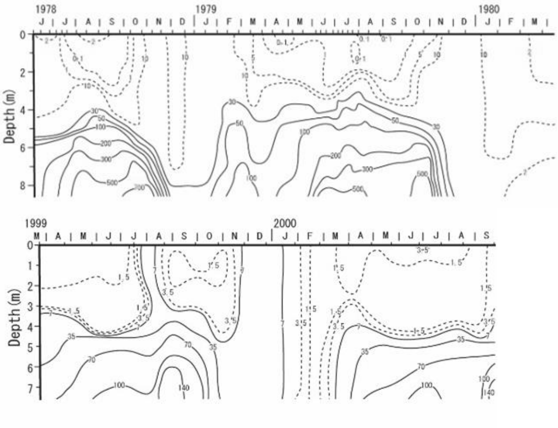

Fig. 5 Depth-time diagram distribution of NH_4-N (μg at. N l^{-1}) concentrations in 1978-1980 (above) and 1999-2000 (below). (Modified from [14].)

3.2.2 *Phosphorus*

The mean total phosphorus (TP) amounts in the lake before the construction (1979-1992) and after (1992-2013) were shown in Fig. 6.

TP in the oxic layer increased about 1.2 times from 0.95 gPm^{-2} (before) to 1.12 gPm^{-2} (after), and particulate organic phosphorus amounts were decreased from 0.28 gPm^{-2} (before) to 0.19 gPm^{-2} (after), respectively.

On the other hand, the mean TP amounts in the anoxic layer were almost equal to 1.84 gPm^{-2} (before) and 1.80 gPm^{-2} (after), and particulate organic phosphorus (POP) amounts were increased from 0.09 gPm^{-2} (before) to 0.45 gPm^{-2} (after). The POP amounts in the anoxic layer increased 5-fold because it was associated with the increase of photosynthesis sulphur bacteria.

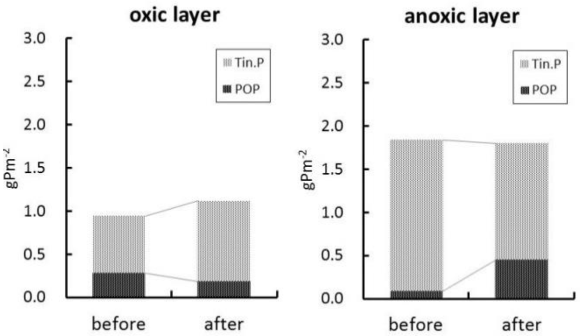

Fig. 6 Mean amount of total phosphorus in the oxic and anoxic layer of the water column before and after maintenance construction.

3.3 Chlorophyll-*a*

Monthly mean chlorophyll-*a* amounts in the oxic layer in the lake before (1979-1992) and after

(1992-2013). The values from April to November (stagnation periods) were 167.6 mg m^{-3} (maximum 321.5 mgm^{-3}, minimum 50.1 mgm^{-3}) before construction and 188.5 mg m^{-3} (max 378.0 mgm^{-3}, minimum 50.1 mgm^{-3}) after it.

The values from December to March (circulation periods) were 353.3 mg m^{-3} (maximum 642.9 mgm^{-3}, minimum 179.6 mgm^{-3}) before construction and 557.1 mgm^{-3} (maximum 730.1 mgm^{-3}, minimum 246.0 mgm^{-3}) after it. The values in the circulation periods after the construction were slightly higher before. The tendency the for values to be low in the stagnation period and high in the circulation period was the same before and after the maintenance construction.

3.4 Plankton

3.4.1 *Phytoplankton*

Seasonal changes in the abundance of phytoplankton found from April 2013 to March 2014 were shown in Fig. 7.

Bacillariophyceae were dominant from April to May, and from the beginning November to March. Chlorophyceae were dominant from spring to summer, and Cyanophyceae were dominant in July.

Aphanizomenon flos-aquae (Cyanophyceae) were dominant in July. Bacillariophyceae were included *Staurosira construens* and *Fragilaria crotonensis*, *Fragilaria rumpen*s and some species of the *Synedra*. Chlorophyceae were included *Gleocystis* sp., *Oocystis* sp. and *Crucigenia tetrapedia*.

The phytoplankton found in Lake Fukami-ike was previously reported [4],[15]-[16]. The dominant species of seasonal changes was reportedly, *Ulnaria acus* from middle of March to the middle of September, and *Aulacoseira ambigua* (Bacillariophyceae) from the end of September to the beginning of March, and others (Chlorophyceae and Bacillariophyceae) were found in 1978-1979 [16].

Chlorophyll-*a* amounts in the lake before and after the building construction did not change greatly previously; chlorophyll-a contents (phytoplankton) showed little change.

3.4.2 *Zooplankton*

Seasonal changes in the abundance of zooplankton found from April 2013 to March 2014 were shown in Fig. 8.

Rotatoria were dominant from April to May, from the beginning of July to the beginning of November, in January and March. Protozoa were dominant in June, and from the end of November to December, and February. As for the dominant Protozoa the end of November, the upwelling water from the bottom layer included Protozoa carried up from all layers, because observations were conducted and zooplankton were collected just at the beginning of circulation periods.

About *Keratella cochlearis* (Rotatoria) became dominant from April to May, followed by *Trichocerca similis* and *Keratella cochlearis* var. *tecta* (Rotatoria) in summer, *Tintinnopsis lacustris* (Protozoa) in autumn, and *Filinia longiseta* (Rotatoria) in winter. Crustaceae were found Nauplius of Cyclops in the beginning of July, *Bosmina longirostris* were found in January.

In 1978-1979, the dominant species were *Cyclops vicinus* in the beginning October to the middle of February. *Bosmina longirostris* (Cladocera), *Mesocyclops dissimilis* (Cyclopoida), and *Filinia longiseta* (Rotatoria) were found [16]. However, in 2013-2014, a few Crustaceae, larger than Rotatoria, were found.

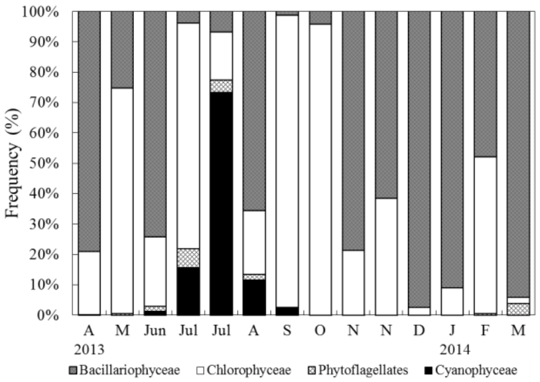

Fig. 7 Seasonal changes in the abundance of phytoplankton group found.

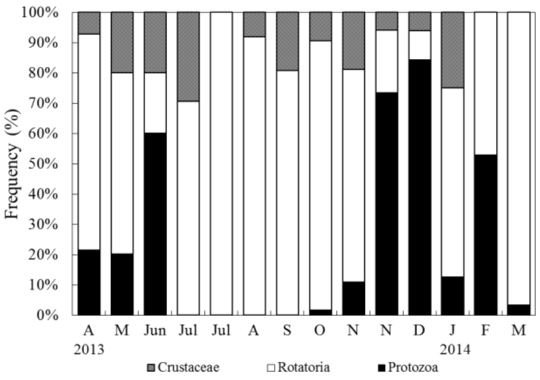

Fig. 8 Seasonal changes in the abundance of zooplankton group found.

4. CONCLUSION

NO_3-N amounts were largely reduced after the construction, this results suggested that the inflow water from paddy fields and orchards has stopped by the construction. However, chlorophyll-*a* amounts not changed before and after the construction. Phytoplankton it believed to using nitrogen (ammonium and phosphorus) which have accumulated in the bottom. Water quality is not improved even stop the inflow of nutrients because the nutrients have already accumulated in the bottom [17].

Recently, Cyanophyceae has dominant in early-midsummer, it seems that chlorophyll-a contents (phytoplankton species) only changed before and after the construction. One should consider the possibly that Cyanophyceae can make advantage the competition for nutrients (NO_3-N) to be used for growth [18].

Rotatoria were dominant recently because that they were released from predation pressure of large size (Cyclopoida). Fish predation has emphasized as a factor to determine the species composition of the zooplankton community [19]. These problem need more investigation and is still open to discuss. We found that there is significant difference for long-term changes of plankton in the Lake Fukami-ike.

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