

Lake Kasumigaura Database

Interpretations of observed data

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Remark:

This document provides measurement methods and interpretations of observed data, compiled from Lake Kasumigaura Database (CD-ROM) published in March 2001. Please refer to the following website for updated information.

Data list, Lake Kasumigaura Database

<http://db.cger.nies.go.jp/gem/moni-e/inter/GEMS/database/kasumi/contents/database/datalist.html>

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I. Weather

1. Monitoring system on meteorological and relating parameters (by Kazuo Matsushige)

1. Observation points

Observations of the surface temperature, humidity, wind direction, wind speed, and illuminance were measured on the roof of the Main Laboratory of the Kasumigaura Water Research Station of the National Institute of Environmental Studies (Oyama, Miho-mura, Inashiki-gun, Ibaraki: 35°00.14'N, 140°22.58'E). Precipitation and soil temperature were measured in an open space near the Main Laboratory building. Air temperature, humidity, wind direction and wind speed were measured on the roof of the intake tower of lake water, which is built 150 m offshore in the lake (36°00.22'N, 140°22.85'E). The water level was measured on the floor of the intake tower. Soil temperature was measured at the depths of 10 cm and of 30 cm below the surface. Water temperature was measured at depths of 20 cm, 75 cm and 150 m.

2. Sensors used for measurements

Wind direction: Anemoscope (synchronized type), manufactured by Ogasawara-keiki Co. Ltd. (1985-).

Wind speed: Wind-mill type anemometer (pulse type), manufactured by Ogasawara-keiki Co. Ltd. (1985-).

Temperature: Thermometer (crystal-oscillator type), manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), and thermometer (platinum-resistance type), manufactured by Yokogawa Weathac Co. Ltd. (1996-).

Humidity: Hygrometer (Vaisala type), manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), and Hygrometer (Vaisala type), manufactured by Yokogawa Weathac Co. Ltd. (1996-).

Precipitation: Reversal bucket rain gauge, manufactured by Ogasawara-keiki Co. Ltd. (1985-).

Atmospheric pressure: Auto-recording aneroid barometer, manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), and high accuracy anemometer, manufactured by Yokogawa Weathac Co. Ltd. (1996-).

Solar radiation: Neo Pyranometers, manufactured by Ogasawara-keiki Co. Ltd. (1985-).

Water level: Water level gauge (floating type), manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), Ultrasonic water level gauge, manufactured by Yokogawa Weathac Co. Ltd. (1996-), and Pressure type water level gauge, manufactured by Yokogawa Weathac Co. Ltd. (1997-).

Water temperature: Platinum resistance thermometer, manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), and platinum resistance thermometer, manufactured by Yokogawa

Weathac Co. Ltd. (1996-).

Soil temperature: Platinum resistance thermometer, manufactured by Ogasawara-keiki Co. Ltd. (1985-1996), and Platinum resistance thermometer, manufactured by Yokogawa Weathac Co. Ltd. (1996-).

3. Data recording system

Signals from sensors were converted to voltage change by a voltage converter, and then digitized by an AD converter of computer. The signals were stored in magnetic media. After 1996, the signals were arranged by using a Data Recorder, HR-2500E (Yokogawa Electric Co. Ltd.) at intervals of 20 sec., and transferred to a computer system. Recording of the signal was made at intervals of 1 min. for the period from 1985 to 1996, and of 10 min. after 1996.

Units of measured data and additional notes

Wind direction: sixteen sectors. If the wind speed averaged for 10 min. is less than 0.2 m, it is recorded as no observation.

Wind speed: m sec^{-1} , the running mean value for 10 min.

Temperature: $^{\circ}\text{C}$.

Humidity: %.

Precipitation: 0.5 mm unit.

Atmospheric pressure: hPa.

Solar radiation: $\text{MJm}^{-2} \text{hr}^{-1}$. Accumulated value for 1 hour. Resetting of accumulation is made every due hour.

Water level: m (YP).

Water temperature: $^{\circ}\text{C}$

Soil temperature: $^{\circ}\text{C}$.

II. Water Quality

2. Nutrients (by Yukihiro Nojiri)

1. Nutrients in fresh water lake

The most essential elements, which are important in material cycles of aquatic ecosystems, are the so called nutrients such as nitrogen, phosphorus and silicate. Silicate is not so important for fresh water lakes, due to sufficient supply from river water. The other two elements, nitrogen and phosphorus, are called as nutrients in limnological definition. Phytoplankton is the primary producer in the aquatic environment, and assimilates phosphorus, nitrogen, and carbon in the almost fixed

ratios, and creates organic materials. Secondary consumers, zooplankton and nekton, grow basically eating primary producer, phytoplankton.

Deep lakes in the mountainous areas are usually oligotrophic. The supply of nutrients from their intake area is limited, and production in lakes is limited. So, the lake water is kept to have high transparency. Shallow lakes in flat land like Lake Kasumigaura are usually eutrophic because large amounts of nutrients are supplied from their basins. So, the transparency of the lakes is decreased. Recent eutrophication problems of lakes have been caused by the tremendous increase of nutrients supply due to human activities in the intake area. Abnormal blooms of phytoplankton obstruct usage of lake water for various purposes, and severely influence the lake scenery. Various anti-eutrophication measures are being tried, but the most basic and efficient measure is to decrease the amount of inflowing nutrients. Especially for the case of usual fresh water lakes, suppression of inflowing nitrogen and phosphorus is essential. The concentration of silicate in Lake Kasumigaura shows large seasonal variations and special variations (see the section of dissolved elements in this data book). Silicate concentration appears to give considerable influence on species composition of phytoplankton, however, the total stock of phytoplankton depends mainly on nitrogen and phosphorus concentrations rather than silicate concentration.

The National Institute for Environmental Studies has conducted measurements on various phases of nitrogen and phosphorus from the beginning of its survey project on Lake Kasumigaura.

2. Various forms of nitrogen and phosphorus

Nitrogen exists in water in following phases:

- A. Nitrate-nitrogen
- B. Nitrite-nitrogen
- C. Ammonium-nitrogen
- D. Dissolved organic nitrogen (DON)
- E. Particulate nitrogen (PN)

Dissolved inorganic nitrogen (DIN) is defined as the sum of A, B, and C. Dissolved total nitrogen (DTN) is the sum of A, B, C, and D, and total nitrogen (TN) the sum of A, B, C, D, and E.

Various organics, such as dissolved amino acid, uric acid, proteins and so on, contain various forms of DON. So it is very difficult to determine the composition of these substances. Various forms of nitrogen included in the filtered sample are decomposed by oxidation, and changed into nitrate-nitrogen. From the concentration of this nitrate-nitrogen, DON is determined by subtracting DIN. PN is the total amount of nitrogen included in zooplankton, phytoplankton and other suspended solids. One of the methods to obtain PN is to measure nitrogen in the suspended solids left on filter paper after the filtration of the sample water. This type of value is shown in the chapter of "others" of the section of water properties in this data book. The values of PN shown here are obtained by the

indirect method. We digest all of the nitrogen in various forms in the unfiltered sample into nitrate nitrogen. Then, PN is obtained by subtracting DTN from TN. If there exists nitrogen compounds, which are hard to be digested, some difference may arise between the results of these two methods.

Phosphorus exists in water in following forms:

- A. Phosphate-phosphorus
- B. Dissolved organic phosphorus (DOP)
- C. Particulate phosphorus (PP)

Dissolved total phosphorus (DTP) is the sum of A and B, and total phosphorus (TP) is the sum of A, B, and C.

Various complex organic materials are included in DOP, and it is difficult to determine composition of these materials. As the direct measurement of DOP is difficult, all of various forms of phosphorus in the filtered sample are digested into phosphate-phosphorus, and the resultant phosphate-phosphorus is measured. Then, by subtracting the value of the phosphate-phosphorus of the original sample, DOP is determined. PP is the total amount of phosphorus included in phytoplankton, zooplankton and other suspended solids. One of the analytical methods is to measure the amount of phosphorus on filter paper after filtration of the sample water. However, this method requires a time-consuming digestion procedure, and it is not so popular in limnological studies. We measured PP from the subtraction of DTP from TP. Various forms of phosphorus in the unfiltered sample are digested by a wet oxidation method to change into phosphate-phosphorus. From the concentration of this phosphate-phosphorus, PP is obtained by subtracting DTP. One of the forms of phosphorus in fresh water is inorganic polyphosphate, in which more than two phosphates are bonded. It is not so clear that the substance might be reactive in the phosphate-phosphorus analysis in our measurement procedure. However, it is included in DOP even though it is not included in phosphate-phosphorus. Polyphosphate is a possible form of phosphorus in detergents, which is one of main pollutants of fresh water lakes.

3. Measurement

Lake water was collected by a column water sampler of 2 m length. Sampled water was well mixed in a stainless steel bucket, and aliquots were placed in polypropylene bottles. The sample bottles were kept with ice. They were carried to laboratory, and the sample water was filtered by Whatman GF/C glass filter (combusted under 450°C prior to the use) within a few hours after the sampling. Filtered waters were kept in dark and cool conditions prior to the analysis. Analysis of dissolved nutrients was usually conducted in the next day following the sampling. The sample waters, which are subjected to digestion, were subsampled into digestion bottles. Oxidation reagent was added on the day of sampling and the analysis was made in a few days.

AAII Auto-Analyzer of Technicon Co. Ltd. was used for the analysis of nutrients in this study.

The schemes of analysis of nutrients are detailed in Nojiri (1987) and Otsuki et al. (1993) (see Fig.1).

We measured following 8 items: a) nitrate+nitrite, b) nitrite, c) ammonium, d) total dissolved nitrogen, e) total nitrogen, f) phosphate, g) total dissolved phosphorus, and h) total phosphorus.

Filtered water sample with Whatman GF/C was used for the measurement of total dissolved nitrogen. While, unfiltered water was treated in an autoclave under 120°C for 30 min with potassium peroxodisulfate under alkaline pH for the measurement of total nitrogen. Filtered water sample with Whatman GF/C was used for the measurement of total dissolved phosphorus. While, unfiltered water was treated in an autoclave under 120°C for 30 min with potassium peroxodisulfate under acidic pH for the measurement of total phosphorus.

In this data book, analytical results are given for the following 7 items: nitrate+nitrite (a), nitrate (a-b), nitrite (b), ammonium (c), DON (d-a-c), DTN (d), TN (e), phosphate (f), DTP (g), and TP (h). As discussed above, each forms of nitrogen and phosphorus can be calculated from these.

In the period before February 1992, either of the total dissolved nitrogen or the total nitrogen was analyzed. However, both were analyzed after March 1992. The units used in this data book are $\mu\text{g l}^{-1}$ (ppb) for nitrogen and for phosphorus. For the case of nutrients, molarity (volume molarity μM or weight molarity $\mu\text{mol kg}^{-1}$ or gram equivalent ($\mu\text{atm l}^{-1}$ or $\mu\text{atm kg}^{-1}$)) were used case by case. mM and $\mu\text{atm l}^{-1}$ are equivalent, and it can be converted into $\mu\text{g/l}$ by multiplying the atomic weigh of nitrogen (14.01) or that of phosphorus (30.97).

AAII Auto-analyzer was replaced by a new type of analytical system (AACSII by Branluebbe Co. Ltd.) in July 1995. Until March 1997, both of the analyzers were used for the comparison. As there was no significant difference in the results of two analyzers, only the AACSII type was used after April 1997. Some of the reagents used for colorimetric analysis were changed with the changing of the analytical system.

4. Results

Monthly concentrations averaged for the 6 years period from April 1990 are also shown in Fig.2 (Utsumi et al., 1998). The amplitude of the seasonal variation of total nitrogen is small. The concentration of inorganic nitrogen is low from April through September, increases in October, and remains high by March. Inorganic nitrogen is mainly ammonium-nitrogen in summer, but is nitrate-nitrogen in other seasons. As for total phosphorus, clear seasonal variations are seen, and a high concentration occurs in summer. This is due to the elution of phosphate-phosphorus from the sediment in summer by the larger production in the lake and succeeding anaerobic conditions of the surface sediment layer. The ratio of phosphorus in Lake Kasumigaura exceeds the ratio of phytoplankton consumption in summer. So the phosphorus becomes over abundant, and the limiting nutrient becomes to be nitrate, and nitrate depletion occurs. Ammonium-nitrogen is supplied from

the bottom sediments together with phosphate, and then dominant inorganic nitrogen in summer is not nitrate but ammonium, but the concentration variability is very large. On the other hand, when the water temperature decreases in autumn, the anaerobic state hardly occurs the decrease of biological production and due to increase of oxygen supply by water mixing, and then the emission of phosphate from the sediments ceases. The limiting nutrient for phytoplankton becomes phosphorus, and then the concentration of nitrate increases (Takamura et al., 1992).

The emission of phosphate from the sediments in summer, and the high concentration of nitrate in winter show large year-to-year variations. It will be necessary to clarify these year-to-year variations in order to improve the lake environment by controlling the input of nutrients.

References

Nojiri, Y. (1987): Progress in water-quality analysis, J. Japanese Society of Ground Water, 29: 107-111 (in Japanese).

Takamura, N., A. Otsuki, M. Aizaki and Y. Nojiri (1992): Phytoplankton species shift accompanied by transition from nitrogen dependence to phosphorus dependence of primary production in Lake Kasumigaura, Japan, Arch. Hydrobiol., 124: 129-148.

Otsuki, A., H. Goma, M. Aizaki and Y. Nojiri (1993): Seasonal and spatial variations of dissolved nitrogenous nutrient concentrations in hypertrophic shallow lake, with special reference to dissolved organic nitrogen, Verh. Internat. Verein Limnol., 25: 187-192.

Utsumi, M., Y. Nojiri, T. Nakamura, T. Nozawa, A. Otsuki and H. Seki (1998): Oxidation of dissolved methane in a eutrophic, shallow lake: Lake Kasumigaura, Japan, Limnol., Oceanogr., 43: 471-480.

3. *In-situ* observations

3-1. pH (by Morihiro Aizaki)

1. Meaning of pH measurement

pH is the indicator of concentration of hydrogen ions. At the temperature of 25°C, pH7 corresponds to the neutral state. If pH is smaller than 7, it is acidic state, and, if pH is larger than 7, it is an alkaline state. There are many of acid lakes in Japan, relating to volcanic activity. pH value in harmonious lakes like Lake Kasumigaura is determined by the alkalinity and inorganic carbon concentration. Alkalinity is the indicator that represents the buffering ability protecting pH decrease against the addition of acid. So, its measurement is important relating to acid rains. As the variation of alkalinity is generally small in lake water, the pH value corresponds with inorganic carbon

concentration.

As phytoplankton uptake inorganic carbon during photosynthesis, the concentration of inorganic carbon decreases, and the pH increases. So, a daily variation of pH is seen in the lake. Inorganic carbon, which is essential for photosynthesis of phytoplankton, exist in four different states in water: namely, dissolved carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ion (CO_3^{2-}). The ratio of these four states depends on the pH (Fig.3). Bicarbonate ions prevails in high pH values. Dissolved carbon dioxide and carbonic acid can not exist in values larger than of pH8, and almost of inorganic carbon is the state of carbonate ion.

Some species of Chrysophyceae can utilize only dissolved carbon dioxide, and so the pH is one of important factors, which determines the species composition of phytoplankton. *Microcystis*, the dominant species of the heavy algal blooms by Cyanobacteria, have a high ability to uptake inorganic carbon under high pH conditions.

2. Method

In-situ measurements of pH were made by using pH meters. Though we used several types of glass electrode pH meters for the observations, measured values are treated as a single time series data.

3. Results and discussion

The annual changes of pH at the depth of 0.5 m are shown in Fig.4 for St.1, St. 3 and St. 9, respectively. The value of pH varies roughly between 6.5 and 10 at St. 1. It lies usually between 9 and 10 in summer, indicating that inorganic carbon is consumed due to active photosynthesis of phytoplankton. As to yearly variations, the pH value decreased from 1987 to 1994, and its value mainly lies between 8 and 9. Values smaller than 7, which are seen occasionally, would be caused by a large amount of inflow water due to heavy rainfall. It can be understood that pH increased in summer before 1987 due to heavy algal blooms of *Microcystis*, and that blooms did not occur for 7-8 years after that period.

A similar annual change is seen at St. 3, but pH rarely decreased below 7. No river inlets are found near St. 3, and the station does not have any severe direct influences of inflow river water. Low pH values can be frequently found in autumn. This would be caused by heavy rainfall due to typhoons. The value of pH frequently exceeds 9, indicating active photosynthesis. The as same as at St. 1, pH lies mainly between 8 and 9 for 7-8 years after 1987. This trend corresponds to the decrease of frequency of heavy algal blooms of *Microcystis*. At St. 9, the value of pH hardly exceeds 9, and lies between 8 and 9, in general. Low pH values of less than 7 occurred in the winters of 1982 and 1983, but their cause is not clear.

The annual change of pH at the depth of 4 m at St. 9 is shown in Fig.5. The values at the depth of

4 m are almost the same as those at 0.5 m. The transparency at St. 9 is of order of 1 m, and solar radiation hardly penetrates to 4 m depth. So, no photosynthesis would occur at this depth. The reason why the pH values at the depth of 4 m are of same order of those at 0.5 m would be attributed to vertical mixing. Vertical mixing due to wind action is very active in Lake Kasumigaura, and the vertical variation of water characteristics is generally very small.

The value of pH has a big influence on the species composition of phytoplankton in general. The variation of pH in Lake Kasumigaura described here would be resulted from phytoplankton species variations.

3-2. Water Temperature (by Takehiko Fukushima)

1. Method

Thermistor thermometer, Hydrolab 8000 (Toho Dentan Co. Ltd.), and thermistor thermometer attached to digital DO meter, model 58 (YSI Co. Ltd.) were used.

2. Results and discussion

A seasonal pattern like a sine curve is repeated every year. The lowest annual water temperature at the center of the lake (St. 9) is in the range 2-7°C, and the highest annual water temperature is 24-32 °C. The maximum temperature at St. 1 in shallow water is about 1 °C higher than at St. 9. No clear interannual trend has been observed, but the lowest annual temperature has gradually increased in the decade of 1990. Namely, the occurrence frequency of warm winters appears to be increasing. One of the peculiar phenomena is seen in the highest annual temperature in 1993: it was 22 °C at St. 1, and 23 °C at St. 3 and St. 9, indicating that an extremely cool summer occurred in 1993.

3-3. Electric conductivity (by Takehiko Fukushima)

1. Method

Water samples were brought back to our laboratory. The measurements were made by Electric Conductivity Meter with a 1 cm cell, manufactured by Toa-Dempa Co. Ltd., under the temperature of about 25 °C. The water temperature was measured in parallel, and the measured conductivity was corrected to that at 25 °C.

2. Results and discussion

The measured values of electric conductivity are in the range of 0.15-0.30 mScm⁻¹ at St. 1, 0.20-0.35 mScm⁻¹ at St. 3, and 0.25-0.40 mScm⁻¹ at St. 9, respectively. The conductivity tends to increase towards downstream. Temporal variation pattern that conductivity increases gradually and

decreases rapidly is frequently observed in the records at St. 3 and at St. 9. A rapid decrease of conductivity is caused by a large inflow of low conductivity river water just after heavy rainfall, and gradual increases during the period of low inflow would be caused by the release of substances affecting conductivity from the bottom sediments and by inflow of high conductivity water from the Hitachi River. There is clear tendency that the conductivity decreases with time before 1992, but it appears to increase after 1992. The decrease tendency during the former period would represent the general long-term tendency of desalinization of Lake Kasumigaura, but the cause of the increasing tendency is not clear.

3-4. Dissolved oxygen (by Takehiko Fukushima)

1. Method

Dissolved oxygen meter, Hydro lab 8000 (Beckman Co. Ltd.) and digital DO meter, model 58 (YSI Co. Ltd.) were used.

2. Results and discussion

The seasonal variation is clear at St. 9, with the dissolved oxygen concentration being low in summer and high in winter. The concentrations in the upper layer (0 m depth) in summer and in winter are 2-5 mg l^{-1} higher than the saturated values in summer and in winter, respectively. In the bottom layer (5 m depth), the highest annual concentration is as high as in the upper layer, but the lowest annual concentration is sometimes lowered to below 2 mg l^{-1} . This indicates that anoxic water is generated in the bottom layer during the period from spring to summer, due to the rather stable stratification in these seasons. There is no clear interannual trend. A low dissolved oxygen concentration was observed over all examined areas and depths of Lake Kasumigaura in July 1988 and in March 1989. The cause of this low concentration was not determined.

The dissolved oxygen concentrations both in the upper layer and in the bottom layer at St. 3 are higher than those at St. 9. The higher concentration at St. 3 would be caused by the higher primary production activities there. On the other hand, the deeper water depth would partly cause the lower concentrations at St. 9.

3-5. Secchi disc transparency and underwater light intensity (by Noriko Takamura)

1. Introduction

Transparency has been measured to investigate the turbidity of lake water since Secchi designated the Secchi disc in 1865. Therefore, the data of Secchi disc transparency has been used to study long-term variations of eutrophication in many lakes. We can approximate the depth of the euphotic

zone from the transparency, since the thickness of the euphotic zone is about 2-2.5 times of the transparency. In order to measure the precise depth of the euphotic zone, underwater light intensity should be measured directly with a quantum sensor. The underwater light intensity is an important parameter to determine the primary production in lakes.

2. Method

Transparency has been measured with a Secchi disc (Rigosha) at all 10 stations. Underwater light intensity was measured at Sts. 3, 7, 9 and 12. The underwater light intensity has been measured with an illuminometer (λ , LI-185) until 8 June 1981, and with a quantum sensor thereafter (Licor, LI-192S from 24 June 1981 to March 1983, Biosphaerical QSP-170 from April 1984 to March 1989, and LI-192SA/B and Licor LI-1000 since April 1989).

The extinction coefficient (k ; m^{-1}) is expressed as:

$$I_z = I_0 e^{-kZ}$$

where I_z and I_0 is underwater light intensity at Z m and 0 m, respectively.

3. Summary of results

The transparency at Sts. 1 and 6 (innermost sites of Takahamairi and Tsuchiurairi bays, respectively) showed only small seasonal variations and was always lower (about 50 cm) than values at other stations, where clear seasonal variations were observed, and was higher in the winter and lower in the summer. High transparency (2-4 m) had been often observed in the winter in most parts of lakes except at Sts.1 and 6 until 1989. The appearance of *Daphnia* concurrently occurs with this high transparency. However, such high transparency has not been recorded since 1989. Recently, the seasonal variation of transparency has hardly been observed at all stations.

The depth of the euphotic zone obtained by the extinction coefficient was well correlated with the transparency, and was approximately 2.1-2.7 times of transparency in Lake Kasumigaura.

The relationship between chlorophyll a and transparency in the main basin is shown as:

$$Tr = -123 \text{ Log (chl.a) } - 60,$$

where Tr is the transparency in cm and chl.a is the chlorophyll a in $mg L^{-1}$.

Therefore, the transparency is almost determined by the phytoplankton biomass in Lake Kasumigaura. The transparency, however, did not increase with a decrease of chlorophyll a concentrations at St. 7, probably because of the dredging activity near this station.

See Variation of transparency in 1990-1998 (Fig.6)

3-6. Water depth (by Tomiji Hagiwara)

Before 1996, water depths were measured using a rope with a lead attached to the end. After then an aluminum disk of 15.5 cm diameter was attached to the lead to prevent it from penetrating into the mud, and at the same time, water depths were also measured by a fishfinder using echo sounding.

3-7. Position of station (by Tomiji Hagiwara)

1. Method

Before March 1994, more than two landmarks were set on land along the lake bank, and the position was determined from the cross-point of lines drawn in the observed orientations from these landmarks.

Global Positioning System (GPS) were used after April 1994 and the two methods were used in the period from 1994 to 1995 in parallel, and the position determined by the former method was plotted against those determined by GPS. The position of the center of the scattered points was used as the position of observations in the present system.

2. Results and discussion

In Fig.7, the relationships between the water level and the water depth at St. 9 are shown for the periods before and after GPS was introduced. Before GPS was introduced (left figure), the measured water depth is scattered between 5 and 6.5 m, regardless of the water level. However, the water depth tends to increase with water level after GPS was introduced (right figure). This indicates that positions measured before March 1994 were not so accurate, and the measured depth seems to be affected by the depth changes near the station.

4. Other variables

4-1. COD (by Takanobu Inoue)

1. Method

(1) Sampling

The water was sampled by column water sampler.

(2) Treatment in advance of the sample preparation

Analysis is made for both filtered and not filtered water. Glass fiber filters (GF/F) were used for

filtration.

(3) Chemical analysis procedure

Enough volume of sample water is put into an Erlenmeyer flask (or conical flask) of volume 300 ml. The volume is increased to 100 ml by adding water.

A 100 ml sample or a suitable portion diluted to 100 ml is put into a 300 ml conical flask.

Add 10 ml sulfuric acid (1+2) and 10ml N/40 potassium permanganate.

After shaking the flask, the flask is immediately put in a boiling water bath, and is heated for 30 minutes. The liquid level of the sample in the flask should be below the surface of the boiling water, and the bottom of the flask should not touch the bottom of the bath. (Dilution of the sample should be enough that the 1/2 of the added N/40 potassium permanganate solution remains after this procedure.) Taking out the flask from the boiling water bath, 10 ml N/40 sodium oxalate is added, and the mixture is shaken. By keeping the solution temperature between 55 and 60°C, titration is conducted so as that the color of the solution turns slightly red due to the N/40 potassium permanganate solution (the color should be maintained for about 30 seconds.) In parallel, 100 ml of distilled or deionized water is filled in a conical flask, and the same procedure is conducted.

CODMn (mgO/l) is calculated by following equation:

$$\text{CODMn} = (a-b) \times f \times 1000 / V \times 0.2$$

Where

CODMn: Chemical Oxygen Demand by potassium permanganate at 100°C

a : volume of N/40 potassium permanganate solution required in titration (ml) used for sample

b : volume of N/40 potassium permanganate solution required in titration (ml) used for blank

f : factor of N/40 potassium permanganate solution

V : volume of the sample water (ml)

0.2 : equivalent oxygen value (0.025×8mg) of N/40 potassium permanganate solution

2. Results and discussion

(1) Distribution among measured stations

The mean value of T-COD in the period from April 1981 to March 1998 is 8.8 at St. 1, which is located in bay head of Takahama Inlet. This value is higher than the value of 7.7 at St. 7, which is located in bay head of Tsuchiura Inlet. In general, T-COD values at stations (St. 6-St. 8) in the Takahama Inlet are higher than those at the stations (St. 1 -St. 4) in the Tsuchiura Inlet. The water inflow from the Sakura River and the Koise River flows out from the water gate of the Hitachigawa River. T-COD value at St. 9 in the center of the lake and that off Edozaki are 7.9 and 8.1, respectively, and there is no significant decrease of the COD value during water movement. The averaged values over all the measuring stations range 6.8-9.4.

(2) Interannual variations

The mean values for each fiscal year from 1981 to 1998 were calculated for St. 1 at the bay head of Takahama Inlet and for St. 9 in the center of the lake.

T-COD at St. 1 was above 10 in the period from 1984 to 1987 fiscal years. Thereafter, T-COD was between 8.0 and 9.3 except in 1993 and in 1995 when the value was below 7. D-COD does not show significant variation after 1988 fiscal year, and varies between 3.0 and 4.7. Only T-COD data are available at St. 7, but it varies in the range between 6.5 and 8.1 after 1984 fiscal year except in 1995. Also at St. 9, T-COD is in the range between 6.7 and 8.9 and D-COD is between 3.8 and 5.1 after 1984 fiscal year except in 1995. The results indicate that an improvement in the water quality has not been seen during these 10 years. Although the water quality at St. 1 at the bay head of Takahama Inlet has improved after 1988, its influence does not reach to the central part of the lake.

(3) Seasonal variation

T-COD at St. 1 at the bay head of Takahama Inlet is high in the period from July to October and low in the winter season, though significant seasonal variation is seen. The same tendency can be seen at St. 9 in the center of the lake before 1994. This seasonal variation is caused by the seasonal growth and decay of algae, but a clear seasonal variation cannot be seen in the center part of the lake after 1996. Besides, there is some tendency that T-COD is increased in the spring season of April and May.

4-2. Pigment (by Kazuo Matsushige)

1. Sampling

By using a column water sampler of 2 m length and of 6 cm diameter, lake water at 2 m below the surface was collected. The sampled water was put into a stainless steel vat with a grip. After washing polyethylene bottles by this water, sampled water was filled and kept in an ice box with ice before being brought back to the laboratory.

2. Pretreatment

A suitable amount of the sample water was filtered by Whatman GF/F filter, and the filter paper was kept in a freezer under a temperature of -20°C .

3. Method of analysis

(1) Chlorophyll-a: 10 ml methanol was added on the glass filter on which the suspended substances had been filtered, and then soluble substances are extracted by keeping it for 12 hours under the temperature of 3°C . Then, concentration of chlorophyll-a is measured by absorption spectrum method. The obtained solution is once stirred, and subjected to centrifuge for 10min. under rotation

of 3,000 rpm. The supernatant clear part of the solution is applied to high quality spectrograph with slit width less than 1 nm. Cell of 1 cm is used, and absorption coefficients at 750 nm, 665 nm, 645 nm and 630 nm were measured. Concentration of chlorophyll-a is obtained by the following equation:

$$\text{Chl-a } (\mu\text{g l}^{-1}) = (11.6E_{665} - 1.31E_{645} - 0.14E_{630}) \times v / (V \times l),$$

where E_{665} , E_{645} and E_{630} are the values of the absorption coefficients at 665 nm, 645 nm and 630 nm subtracted from those at 750 nm, respectively. V is the filtered volume of sample water (l), l the length of the cell used (cm), and v the volume of methanol used (ml), respectively.

(2) Pheophytin: acetone of 90% was added to the glass filter on which the suspended substances had been collected, and the filter paper was grinded down into a milky solution. The solution was put into a centrifuge tube by washing out with acetone of 90%. The tube was kept for about 2 hours under cold and dark conditions. After applying to centrifuge for 10 min with 3,000 rpm, the amount of the top clear part was recorded. The absorption coefficients at wavelengths of 750 nm and 665 nm were read for 90% acetone solution. After leaving it for 3 min, the measurement was repeated. The concentration of pheo-pigment was determined using the following equation:

$$\text{Pheo-pigment } (\mu\text{g l}^{-1}) = 26.7(1.7E_{665a} - E_{665}) \times a / (V \times l),$$

Where E_{665} is the value of the absorption coefficient at 665 nm is subtracted from that at 750 nm. E_{665a} is the value of absorption coefficient at 665 nm subtracted from that at 750 nm for the solution, to which 2N hydrochloric acid has been added. V is the filtered volume of the sample water (l), l the length of the cell used (cm), and the total volume of acetone in the supernatant clear solution (ml), respectively.

(3) Phycocyanin: phosphoric acid buffer solution of 10 mM was added to the glass filter on which the suspended substances had been collected, and phycocyanin was extracted by keeping it for 12 hours under a temperature of 3°C. After applying to centrifuge for 10 min under 3,000 rpm, the supernatant clear part was subjected to the fluorescence detector. The high-performance liquid chromatograph system consisted of a Hitachi 655 Pump, Rheodyne Injector, Hitachi F-1000 fluorescence spectrophotometer and Shimazu C-RIA Inkdelator. We used a gel filter column (7.5 mm inner diameter and 60 cm lengths) of TSK-GelSW3000 or SW2000 (Tosoh Co., Ltd.). No special pretreatment was made, and the 200 μ l of the supernatant part of the extracted solution of phycocyanin was directly applied. As to the fluid phase, we used the 10 mM phosphoric acid buffer solution, which was used in the extraction of phycocyanin. The flow speed is 1.0 ml/min. The excitation and radiation wavelengths are used 605 nm and 640 nm. These wavelengths are near the maximum peaks of phycocyanin.

Extracted material (Sigma Chemical, USA) from the standard of phycocyanin_(*Spirulina*

platensis) was dissolved in 10 mM phosphoric acid buffer solution (pH 7.0). The solution is stable if the concentration is above 10 mg l⁻¹, and is unchanged for several months under temperatures lower than 5°C. However, if concentration is lower than 1 mg l⁻¹, is unstable, and fluorescence luminosity is lowered more than 20% 2 days after. When the samples including about 0.01 mg l⁻¹ Phycocyanin are kept under dark condition for 12 hours with a temperature of 3°C, radiation photo-intensity is kept unchanged. So, the standard was dissolved just before usage, and kept under the temperature of 3°C.

The peak value in the chromatograph has linear relationship with the amount of phycocyanin within the range of the applied amount between 0 and 5µg, when measured by using the excitation and radiation wavelengths mentioned above. The limit of measurement is 0.2 ng. When the applied amount is 200µl, and when 0.1 mg l⁻¹ concentration sample are used, the reproducibility is ±6.5%. Phycoerythrin and allophycosyanin were not detected, if measured with an excitation photo-wavelength of 605 nm and radiation photo-wavelength of 640 nm. Besides, phycoerythrin and allophycosyanin were not detected, when an excitation wavelength of 495 nm and radiation photo-length of 575 nm, which are suitable for the measurement of phycoerythrin. The retention times of phycoerythrin and phycocyanin are about 11 min and 12 min, respectively, when a SW3000 column is used, and when the flow speed is taken as 1 ml/min.

4-3. SS (Suspended Solid) (by Kazuo Matsushige)

1. Sampling

By using a column water sampler of 2 m length, lake water at 2 m below the surface was collected. The sampled water was put into a stainless steel vat with a grip. After washing polyethylene bottles by this water, sampled water was filled in the bottle so that the bottles were full and then covered by cap. The sample bottles were kept in an icebox with ice, and were brought back to the laboratory.

2. Pretreatment and method of measurement

Firstly, a suitable amount of the collected sample water was baked in an electric furnace for 4 hours under 450°C. The sample was filtered with Whatman GF/F filter, which had been pre-weighed. The sample was dried for 2 hours under a temperature of 105-110°C, and then was weighed. The weight of SS was obtained by subtracting the weight of the filter. The filter was used for the measurement of POC and PON after weighing.

3. Meaning

The composition of suspended solid (SS) in usual lakes is organic substances, living phytoplankton and the corps of dead organisms. However, as the depth of Kasumigaura Lake is

shallow, bottom sediments are easily entrained into the water column due to wind actions, and consist a part of SS. So, the amount of SS is very changeable day by day and depends on the wind condition just before the day of the survey. So, it is difficult to obtain concrete conclusions from the results.

4-4. POC, PON (by Kazuo Matsushige)

1. Sampling and pretreatment

The sampling procedure and pretreatment are the same as in the case for SS. Usually, the filter, which had been used for the weighing of SS, was used for this analysis.

2. Measurement

CO₂ and N₂ gases were produced from the sample filter by the dry combustion method. A YANAKO CHN-coder MT-5 was used. The amount of each gas was measured by the heat-conductivity detect method, and then the amounts of carbon and nitrogen were calculated.

3. Meaning

The amounts of organic carbon and organic nitrogen in the suspended solid (SS) are useful indicators to judge whether the SS originates from organisms or from minerals. The measured values are given as a concentration in water. The influence of minerals which has been entrained into the water column from the sediments can be estimated by the ratio of carbon in SS.

4-5. C/N (by Kazuo Matsushige)

Meaning

C/N is the value of the POC divided by the PON. It indicates generally the ratio of carbon to nitrogen in the organisms. However, in the case of Lake Kasumigaura, it is hard to obtain concrete conclusions, because of the influence of sediments that have been entrained from the bottom due to wind action. The influence is very variable day by day according to variation of wind speed as discussed in the section of SS.

5. Methane (by Yukihiro Nojiri)

1. Generation and release mechanism of methane in freshwater lakes

Methane is the most important greenhouse gas next to carbon dioxide. The concentration of methane in the atmosphere is rapidly increasing due to human activities after the Industrial Revolution (Nojiri, 1996). The anthropogenic increase of methane has resulted by human activities

relating to fossil fuel production and use, and human impacts to carbon cycles in the biosphere. The former methane is mainly emitted during mining processes of fossil fuels. The latter is due to rice paddy agriculture, animal husbandry, landfills, biomass burning and so on. In the case of methane, there are natural sources in addition to anthropogenic ones, and a significant level of methane concentration in the atmosphere had occurred even before human activities began to influence the atmospheric environment. Freshwater environments are much more important than marine environments, and natural wetlands including bogs, fens, swamps, marshes, floodplains, and freshwater lakes are the main contributors.

There are five types of lakes due to their water circulation pattern: meromictic lakes, oligomictic lakes, polymictic lakes, monomictic lakes, and dimictic lakes (Arai, 1980). Meromictic lakes are lakes where the density of the deep layer water is always higher than that of the surface layer water, for example, dense deep waters may be supplied from high salinity subterranean water, or be generated under influence of seawater. In such lakes, vertical mixing occurs only in the surface layer. The water in deep layer has no oxygen supply from the atmosphere, and the deep water has no oxygen. Typical examples of meromictic lakes can be seen for graven lakes in Africa. In these lakes, organic substances, which have been produced in the surface layer, sink to the deep layer, and are decomposed under anaerobic condition. So, the concentration of methane becomes extremely high in the sub-surface lake water. Oligomictic lakes have a lower density difference between the surface and subsurface waters, however, mixing occurs only occasionally. In this type of lakes, the bottom water tends to be anoxic and produces methane.

Shallow lakes, especially if there is no high salinity bottom water, are usually polymictic lakes, in which vertical mixing reaching to the bottom occurs frequently in any of seasons. The temperature difference and so the density difference between waters in surface and the deep layers is therefore kept small. Thus, wind driven lake water mixing frequently occurs, and a uniform temperature distribution is created from the surface to the bottom. The bottom water and the pore water of sediments are frequently supplied oxygen, and so anaerobic condition is rarely generated. On the other hand, in the case of deep lakes, the water temperature in the surface layer increases according to the increase of air temperature in early summer (heating period), and so the water density in the surface layer is lower than that of deep layer (direct stratification). The direct stratification is maintained until autumn. When the air temperature decreases from autumn to winter, the surface water of lakes is cooled, and the temperature gradually decreases (cooling period). Thus, a surface mixed layer of homogeneous temperature is formed, and its thickness (mixed layer depth) increases until the temperature becomes homogeneous down to the bottom. This period is called the mixing period, and mixing occurs over the whole depth of the lake. As the lowest temperature of subtropical lakes is generally 4°C or higher, the water temperature is lowest during the mixing period. The lake in this case becomes monomix. In the case of the lakes under a colder climate, the surface

temperature may be lowered below 4°C. The surface water density cooled below 4°C becomes lower than that of the deep waters, and the stratification becomes again stable (inverse stratification). In a cold climate, the lake surface may freeze. When the surface water is warmed in spring, and when its temperature reaches 4°C, vertical mixing occurs again, and the temperature becomes homogeneous over the whole depth. Thus, convection occurs twice a year, and the lakes are classified in dimictic lakes.

Generation of methane occurs mainly in the pore water of the bottom sediment. The reduction of organic substances into methane is made under absolute anaerobic conditions that all of the oxidative substances (oxygen, nitric acid, sulfate and etc.) in the pore water have been completely consumed. Methane producing bacteria get their energy by creating methane from organic substances. Concentration of sulfate is high in marine sediments, and organic substances are mainly consumed for reduction of sulfate. So, absolute anaerobic condition producing methane merely occurs in the surface sediment. Even if some of oxygen remains (aerobic conditions) in the surface layer of bottom sediments, subsurface layers of sediments may become absolute anaerobic conditions, as the oxygen supply from the lake water can easily be broken off. So, if the sediment surface is anaerobic, methane generation occurs also at the surface. However, if the sediment surface is aerobic, it occurs only in the subsurface layers of sediments. If the upper layer is aerobic and the subsurface layers are anaerobic, methane-oxidizing bacteria, which get their energy by oxidizing methane using dissolved oxygen, are predominant at the boundary. Methane-oxidizing bacteria need to have supplies of both methane and oxygen: namely methane is supplied from the deeper layers and oxygen from the upper layers. It is known that the supply of methane is balanced with the oxidization rate at the concentration of dissolved oxygen of about 0.5 mg/l, and that methane oxidization bacteria are most active at this dissolved oxygen level. If the bottom water is anaerobic, this boundary is located in the water column. When the sediment surface is aerobic and generation of methane occurs in deeper layers, a layer of methane oxidation exists in the subsurface layer.

Both in monomictic lakes and in dimictic lakes, stable stratification is generated in the lakes except for the mixing period. The concentration of dissolved oxygen in the deep layer decreases with time due to decomposition of organic substances. Whether bottom water and sediment surface reach anaerobic conditions or not depends on amount of organic substances supplied there. In eutrophic lakes, anaerobic condition may occur in the bottom water until the end of stratified period, as supplies of organic substances is abundant. On the other hand, in oligotrophic lakes, it never reaches to anaerobic conditions even at the end of stratified period. It is possible to estimate the emission of methane from the lake bottom sediments by considering the state of the lake water mixing and of the oxic-anoxic conditions of the lake sediments. In monomictic and dimictic lakes, having aerobic bottom sediments, methane flux through the sediment surface is limited because of the methane oxidation. Even if methane is generated in the deeper layers of sediments, methane needs to pass

through the sediment layer where methane oxidation occurs. On the other hand, when the bottom lake water becomes anaerobic, the oxidative layer of surface sediment disappears, and methane is easily emitted directly to the lake water. The concentration of methane in the bottom water becomes high. If dissolved oxygen is rich in water of the shallower layers of lake, methane oxidation occurs most actively at the boundary between the oxic and anoxic layers in the water column. We have conducted a survey of Lake Nojiri, as one of related investigations. Lake Nojiri is one of the typical examples of this case. All the layers of Lake Nojiri are mixed in December. At the time just before this mixing event, we found that the concentration of dissolved oxygen is higher than 1 mg/l down to a depth of 30 m and that of methane is low, and that the high concentration of methane is found in the layers deeper than 30 m (Utsumi *et al.*, 1998a). Namely, though methane generation is very active in the sediments, however, it is consumed by oxidation occurring at the sediment surface in the early stage of stratification period, and in the lake water in the late stage of stratification just before the mixing period. Thus, the concentration of methane is kept considerably low in the surface layer of water. At the time of vertical mixing in December, the concentration of methane is increased over the whole of the water column of the lake temporarily. However, the rate of methane oxidation is also increased in the lake, and the emission of methane to the atmosphere is considerably suppressed.

In the case of Lake Kasumigaura, mixing of the lake water occurs frequently through year, and its sediment surface does not become absolutely anaerobic for long periods. It might be reasonable to consider that the amount of methane generated in the sediment layers of Lake Kasumigaura is small, dissolved concentration in the lake water is not high, and the amount of methane emitted through the lake surface is also small. In order to confirm this assumption, we measured the concentration of methane in the water of Lake Kasumigaura on a monthly basis for 6 years. In addition, we measured the oxidation rate in the lake water, concentration of methane in the sediments layers, and tried to measure directly the methane flux by using a floating chamber. We made the investigation to clarify the total features of methane flow in the typical shallow and eutrophic lake, Lake Kasumigaura, by combining the results of various measurements mentioned above (Utsumi *et al.*, 1998b, Nakamura *et al.*, 1999).

2. Water sampling and analysis

Water sampling for the measurement of dissolved methane was made using a Go-Flo sampler (General Oceanic Co., Florida, USA) of sizes from 1.7 l to 10 l, because we need to use the sampler airtight type enough to keep the dissolved gasses. For sampling bottles, we used 50 ml serum bottles. The samples were immediately poisoned with 0.5 ml of 3.5 % HgCl₂ solution so as that concentration of Hg is 100 mg/l. Each bottle was capped with polyisoprene rubber stopper, had been pierced with a hypodermic needle to ensure that entrapped air bubbles were displaced. After the

hypodermic needle was removed, the bottles were further sealed with an aluminum crimp seal, and transported back to the laboratory in a cool box at 2°C. The samples can be kept more than 1 month, but we made analysis within two days after sampling. The measurement of methane concentrations were made by using an automated analyzer consisting of a purge and trap system and a gas chromatograph equipped with a flame ionization detector (FID). About 35 min is needed to analyze 10 ml samples from each serum bottle. The precision of analysis was within ± 1 % at 100nM, a typical concentration for the lake water.

In the earlier period, the measurements were made for Sts. 1, 3, 7, 9, and 12. In the later period, two Sts. 4 and 8 were added. The sampled depths were from the surface at Sts. 4, and 8, two depths from the surface and the bottom at Sts. 7 and 12, and three depths from the surface to the bottom at Sts. 3 and 9. The definition of the surface water is 0.5 m depth.

3. Results of measurements

The variation of methane concentration averaged for whole area of Lake Kasumigaura is shown in Fig.8 for the 6 years from April 1990 to March 1996. The variations of the methane flux through the lake surface, and of the water temperature are also shown in this figure in the same manner, these values will be discussed later. The monthly mean concentration of methane and its standard deviation are shown for each station in Fig.9. The methane concentration is highest at St. 1 in Takahama Inlet. The second highest value is found at St. 3. The concentrations at St. 7 in Tsuchiura Inlet and St. 12 at the lake end are a little smaller than that at St. 9 at the center of the lake. The concentration is highest from August through in the period from January to March, and relatively low values appear from April to June. Year-to-year variation is large in winter and in summer, and small in spring and autumn.

Methane flux through the lake surface in Fig.8 (b) is calculated from the methane concentration in the lake water and wind speed by using empirical gas exchange equation.

Measurement of the consumption rate of methane in the lake water was made continuously after 1991. The oxidation rate is lowest in winter, and the residence time of methane exceeds 100 hours. The oxidation rate starts to increase usually after July, and a high rate is maintained until about October. However, this period of high oxidation rate is very changeable year by year, and causes high year-to-year variation of the summer concentration of methane mentioned above.

The concentration of methane in the sediments was measured. The methane concentration at the depth of 10 cm below the sediment surface at St. 9 was considerably high value throughout the year, in the range between 0.5 and 2 mM. The maximum concentration appeared in the period from late summer to autumn, reflecting the high decomposition activity of plant material. The concentration at the depth of 2 cm was significantly lower than 0.5 m in winter and in spring, but it increased to almost the same as at the depth of 10 cm in summer. In the shallow Lake Kasumigaura, the

temperature difference between the surface layer and the bottom layer is small. Solubility of methane is lowest in the high temperature period of summer. It was shown that the methane concentration in the sediment surface reaches almost its saturated value under in-situ pressure in summer. The concentration at the shallower St. 3 is a little lower than at the deeper St. 9 and also increased in summer near to the saturation value.

These results suggest that the emission of methane may occur as bubble generation in the season from late summer to autumn, when the methane concentration at the surface of sediment is almost saturated. So, we set a floating chamber at the water surface, and tried to collect the gas emitted from the lake in bubble form. We found a good correlation between bubble flux through the lake surface and degree of saturation of methane in the surface layer of sediment (2 cm depth). The bubble flux changed considerably above and below 50 % degree of saturation of methane. The methane concentration in sediments by sampling of the sediments corresponds to the state after the methane bubbles have been emitted or the state after it has been partially oxidized. Thus, the bubble flux of methane is observed above a critical value in degree of saturation.

Generation, consumption, and emission rates of methane in Lake Kasumigaura was estimated for each month on the basis of the observed facts above mentioned and of the available information on the oxidation rate of methane in water, and are shown in Fig.10. In the season from winter to spring, the sediment surface is always aerobic, and most of the methane generated in the sediments is consumed by oxidation at the surface of the sediments. Dissolved methane in water is emitted without oxidation due to the low oxidation rate in the water column. The generation rate of methane increases after July, and the ebullition rate is significant from July to October. The oxidation rate at the sediment surface is decreased, but oxidation rate in water column is accelerated. So, the emission to atmosphere is rather suppressed. The methane concentration in the water is kept at a low level in the period from November to December, as the production rate is decreased and oxidation activity in water is kept at a high level.

The methane budget in Lake Kasumigaura is shown for annual averages in Fig.11. The generation rate of methane in sediments of Lake Kasumigaura is in the same order as in usual wetlands. However, about a half of the generated methane is decomposed in oxidation layer near the surface of sediment, and diffusion into the lake water is greatly suppressed. The amount of methane emitted into the lake water is about 13 % of the generated methane. Three fourths of the methane in the water is lost by oxidation in the water column. Thus, the methane flux diffusing to atmosphere is only 3 % of the generated methane in the sediment layer. Contribution of methane flux due to ebullition, which occurs only during a limited season (summer), is more significant, and about one third of the generated methane is transferred to the atmosphere. In general, the amount of methane supply to the atmosphere per unit area of inland-water lakes is considerably smaller than that of wetlands. This is a result of the oxidation phenomena at the sediment surface and in the lake water.

In the case of much shallower wetlands, in which many of plants are growing, methane generated in sediments is effectively transferred into atmosphere through the stems of plants.

References

- Arai, T. (1980): *Water of Japan – its natural feature and science –*, Sanseido Pub. Co. (in Japanese)
- Nakamura, T., Y. Nojiri, A. Otsuki, and N. Hashimoto (1994): The concentration of methane in the sea water of Tokyo Bay and its variation. *Geochemistry*, 28: 47-57. (in Japanese)
- Nojiri, Y. (1996): Generation, circulation and disappearance of greenhouse gas – methane – . In *Global warming from viewpoint of Hydrospheric-Atmospheric Sciences*, ed. N. Handa, Nagoya University Press, 97-116. (in Japanese)
- Utsumi, M., Y. Nojiri, T. Nakamura, T. Nozawa, A. Otsuki and H. Seki (1998): Oxidation of dissolved methane in a eutrophic, shallow lake: Lake Kasumigaura, Japan. *Limnol., Oceanogr.*, 43: 471-480.
- Utsumi, M., Y. Nojiri, T. Nakamura, T. Nozawa, A. Otsuki, N. Takamura, M. Watanabe and H. Seki (1998): Dynamics of dissolved methane and methane oxidation in dimictic Lake Nojiri, Japan. *Limnol., Oceanogr.*, 43: 10-17.
- Nakamura, T., Y. Nojiri, M. Utsumi, T. Nozawa and A. Otsuki (1999): Methane emission to the atmosphere and cycling in a shallow eutrophic lake, *Arch. Hydrobiol.*, 144: 383-407.

6. Heavy Metals

6-1. Heavy metals: Cu and Fe (by Kazuho Inaba)

1. Method

(1) Sampling

Monitoring was performed monthly at Sts. 1 and 9 (from April 1989 for copper and from June 1989 for iron), St. 3 (from April 1991 for copper and iron), and Sts. 7 and 12 (from April 1994 for both metals) in Lake Kasumigaura. Data for March 1992 were eliminated because of contamination. Surface water at each station was collected directly into a 1L stoppered polypropylene bottle, which was kept cool in an icebox and was brought back to the Institute. All bottles and glassware used were washed with 6 M nitric acid for at least 3 days and then rinsed by an excess of ion-exchanged distilled water just before use.

(2) Pretreatment

The samples were filtered with a 0.45- μm membrane filter, ultipor N₆₆ (Pall Trinity Micro Co.), as

soon as possible. 500 mL of the each sample was filtered in order to minimize the effect of contamination from the apparatus used. The filtered solution was placed into 30 mL stoppered polypropylene bottle; the solution was stocked in a refrigerator after being acidified by the addition of 0.5 M analytical grade nitric acid.

(3) Chemical analysis

The amounts of copper and iron in the sample solutions were determined using a Perkin-Elmer Z-5100A graphite furnace atomic absorption spectrometer using absorption lines at 248.3 nm for iron and 324.8 nm for copper with deuterium background correction. Usually, 10 μL of the sample was injected into the graphite tube, but several tens of μL of the sample was used when the metal concentration was low. The standard temperature-control program recommended by the manufacturer was utilized for the determination. The measurements were made at least in duplicates for each sample. The amounts of copper and iron in the samples were calculated using calibration curves obtained by sets of standard solutions containing up to 10.00 $\mu\text{g/L}$ copper and up to 100.0 $\mu\text{g/L}$ iron.

(4) Estimation of error in AAS determination

In order to estimate any error in the measurement of copper and iron by the present AAS method, the sensitivity and the accuracy of the present analysis were tested. Blank absorbances, measured using ion-exchanged distilled water, were almost zero and the values for standard deviation ($N = 10$) were 0.4 pg for copper and 0.8 pg for iron. The detection limits ($3 \times \text{SD}$) were therefore 1 pg for copper and 2 pg for iron, and the quantitative limits ($10 \times \text{SD}$) were 4 pg for copper and 8 pg for iron. Samples (usually 10 μL) were injected into the AAS, the limit concentrations for detection and quantification being 0.1 and 0.4 $\mu\text{g/L}$ for copper and 0.2 and 0.8 $\mu\text{g/L}$ for iron, respectively. The total concentration from the sample bottles and glassware during the whole sample treatment prior to AAS determination was estimated by a blank experiment. One L of ion-exchanged distilled water was stored overnight in an acid-washed polypropylene bottle and then filtered with a 0.45- μm membrane filter. The concentrations of copper and iron in the stored and the filtered solutions were determined ($N = 6$). The ion-exchanged distilled water before the treatment contained 0.03 ± 0.03 $\mu\text{g/L}$ copper and 0.2 ± 0.2 $\mu\text{g/L}$ iron, whilst the filtered 0.03 ± 0.04 $\mu\text{g/L}$ copper and 0.1 ± 0.2 $\mu\text{g/L}$ iron; no difference was observed in the values before and after the filtration. It was reported that the elution of copper and iron from the membrane filter used in the present study was negligible. Considering the above results, contamination from the apparatus and treatment was negligible.

2. Results and discussion

The metals reported here are not only dissolved species such as ionic metals and soluble complex

species, but include suspended materials such as hydroxide colloids that can pass through the 0.45- μm pores of the filter membrane. Hence, the meaning of the concentrations of the metals reported here is not on a “dissolved” basis but on a “filtered” one.

The concentrations of copper at all the sampling sites varied with the season, being higher in summer and lower in winter. The seasonal changes were clearly observed until 1994, however, became unclear after 1995. This tendency may indicate a change in chemical environment in the lake during the monitoring periods. The seasonal variation and the long-term change in copper concentrations shows similar variation pattern to the changes in concentrations of dissolved organic matter; indicating the formation of complex species between copper and the organic matter. The concentrations of copper did not vary among the sampling sites; it is possible to estimate that the stability of the complex species is high enough to avoid the decrease in copper concentration by formation of hydrolyzed species in the lake environment.

The concentrations of iron showed large variations at all the sampling sites, but there were no obvious seasonal changes. The concentration of iron in the lake, however, showed a clear decrease from the upstream site to the downstream site. This may indicate that iron in the lake water does not form a stable complex species and would quickly be oxidized, hydrolyzed and then polymerized. The polymerized iron should form colloids and precipitate; the concentrations of iron in the lake should decrease with the flow of water through the lake. These reactions are controlled not only by the chemical environment such as pH, oxidation-reduction potential, and coexisting materials, but also by mechanical forces such as changes in the flow rate or stirring and entrainment of lake sediments by rainfall, wind, and dredging. These are potential reasons why the iron concentration among sampling sites and dates become larger than that for copper. It was also observed that the concentration of iron in source area (St. 1) has shown a long-term changes; the highest value in a year was about 100 $\mu\text{g/L}$ until 1993 but it became about 50 $\mu\text{g/L}$. Such decreases in iron concentration in the source area may be due to the changes in its source and/or the chemical environment that controls the behavior of the metal in the lake water.

6-2. Main Elements (by Masataka Nishikawa, Reiko Kumata and Miyoko Takano)

1. Methods

(1) Measured elements and determination limits

Samples were filtered through a glass fibre filter paper immediately after being taken to the laboratory from the sampling site. The filtered samples were stored in a cool and dark room until ICP-AES analysis. This procedure allows measurement of dissolved elements in the surface water of Lake Kasumigaura. In the past 20 years, three types of ICP-AES have been used for this analysis: 1980 to 92, Plasma Atomcomp 975 (Jarrell-Ash), 1992-94, JY-48P (Daini Seiko-sha), and since 1995,

an ICAP-750 (Japan Jarrell-Ash). Analysts employed for the continuous analysis of samples include Masataka Nishikawa in the 1980's, Miyoko Takano in the first half of the 1990's, and Reiko Kumata in the second half of 1990's. Instrumental and operator errors causing variation in the analytical conditions and outcomes were minimised by utilising in-parallel measurements for six months when an instrument and/or an operator was changed over. The following 25 elements have routinely been looked for; Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Sr, Ti, V and Zn. Only the following elements were quantitatively determined for at least some part in the measurement period; Al, B, Ba, Ca, Fe, K, Mg, Mn, Na, Si, and Sr (see ref. 1 and ref. 2). The minimum determination limit for each element is influenced not only by the inherent instrument performance, but also by the conditions of the instruments on the day of measurement and the nature of the sample solution. Typical minimum determination limits are shown in Table.1. The determination limits were calculated as 15 times of the standard deviation of the "zero point" standard, which was obtained by repeat measurements ($n = 10$) of distilled water. The values below the determination limits are shown as 0.0 or 0.00 in the table of the monitoring results, for convenience. In order to compare with the high accuracy measurements of JP-48P, Al and Fe values were determined with the other instruments (before October 1992, and after January 1995) and these are given in parentheses up to the half of nominal determining accuracy.

(2) Quality Control

Since 1980, the quality of measurements have been checked by using the following protocol:

- a) To confirm that the conditions of the instruments are not significantly different from that of the previous operation. Ultra-pure water was analysed 10 times by following the measuring procedure of each element, and the standard deviation of the measured values was used to confirm the instrument conditions: the standard deviation should not be outside of the range expected for each element.
- b) Make calibration curves using standard solutions for which the elemental concentrations have been certified.
- c) Confirm zero point.
- d) Analyse samples twice, and take the averages of two as the measurement values.
- e) Analyse standard solutions before and after the measurement to ensure the stability of ICP-AES. If the analysed values of the standard solution are outside of ± 5 % of the certified concentration values of the standard solutions, the whole analysis is repeated from the first.

Whenever standard solutions were replaced, both the old and new standards were analysed, and assured that the difference between the two standards was below the detectable range of the ICP-AES. We also checked that the calibration curves of both standard solutions agreed with each other within the tolerance limits by analysing NIST (former NBS) reference materials 1643a, b

(Trace Elements in Water) and NIES reference materials No. 2 (Pond Sediment).

Results of analysis for 0 and 10 mg/l standard solutions for various periods are shown in Table.2 for several elements. The periods are defined according to the used instruments, and one type of instrument was used in each period. The status of the long-term stability of the ICP-AES instruments can be seen from this table. We used several types of ICP-AES, and the accuracy and allowable error range are different from instrument to instrument. The stability of ICP-AES used before 1992 appears poorer than those of the instruments used after 1992. However, the relative standard deviation (defined as the standard deviation divided by the average) for 10 mg/L standard solution never exceeded 3% even for the period before 1992. Three times of the standard deviation is equivalent to the 99.5% confidence limit if the distribution is Gaussian. As seen in Table.2, the value is considerably changed with the type of instrument. If the monthly variation of the measured values exceeds the allowable error range, the variation would be considered to be significant. It should be noted that the errors, which might be generated in sampling and pre-treatment procedures, are not included in the discussion here.

2. Results and discussion

Seasonal variations of the averaged concentration of three representative elements, Si, Na and Ca are shown in Fig.12 Monthly averages were obtained from the data taken in the period from 1980 to 1996. The monthly averaged levels of precipitation are cited from the report³⁾ of the Meteorological Observatory in Tsukuba, which is located about 10 km northwest of Lake Kasumigaura, and the levels are shown at the top of the figure. Two main rivers flow into Takahama Inlet and Tsuchiura Inlet, and St. 1 and St. 6 are situated in these inlets, respectively. St. 9 is located at the centre of Lake Kasumigaura, and St. 12 is off Asoh, which is located close to the place where the water of Lake Kasumigaura outflows into the Tone River. The Na concentrations at St. 9 are higher than those in the inlet area, St. 1 and St. 6. That at St. 12 is the highest among all the stations. Before a floodgate was constructed between Lake Kasumigaura and the Tone River, seawater often invaded into Lake Kasumigaura from the Tone River. From the high Na concentrations at St. 12 it can be understood that the influence of invaded seawater still remains. On the other hand, the Ca concentrations are the highest at St. 6, and the lowest at St. 1. Those at St. 9 and at St. 12 are comparative to each other, and have medium values (St. 6 > St. 12 = St. 9 > St. 1). This indicates that the origin of Ca is not the seawater. The Si concentrations of St. 1 and St. 6 are the highest amongst all the Stations. In contrast to the cases of Na and of Ca, significant differences are not seen between St.1 and St. 6. The Si concentrations tend gradually to decrease from the inlet areas (Sts.1 and 6) to the lake end (St. 12), through the lake centre (St. 9), indicating that the contribution of the inflowing river water is dominant.

In the variations of monthly concentrations of Na, Ca, and Si, averaged for 17 years period in

Fig.13, only the Si concentrations show a clear seasonal change. The seasonal change of Si concentrations cannot be explained only by meteorological factors such as precipitation. If it is caused only by the seasonal change of precipitation, similar seasonal changes would also be seen for Na and Ca. Other biological factors such as the proliferation and decay of diatom need to be considered.

The yearly precipitation averaged over the period from 1980 to 1996 is 1262 mm. The maximum precipitation was 1841 mm in 1991, which is followed by 1989 (1520 mm), 1982 (1443 mm) and 1993 (1380 mm). The yearly precipitation, which was considerably lower than the average, was observed in 1985 (719 mm), in 1987 (1098 mm), and three years from 1994 to 1996. The temporal variations of Na and Ca concentrations (monthly values) are shown for the period from April 1980 to March 1997 in Fig.13 together with that of the precipitation. There is some correlation among variations of precipitation, Na and Ca: the concentrations of Na and Ca tend to be low when precipitation is high, and to be high when precipitation is low. The curves of the Na and Ca concentrations sometimes show sudden drops to extremely low values. These drops usually occur just after heavy rainfall caused by typhoons or stationary fronts. A typical example of a sudden drop is seen just before August 1986, which was resulted by record-breaking rainfall due to the Typhoon No. 10, which passed over Ibaraki Prefecture on August 4-5, 1986. Another example of a drop is seen in October 1991, and low level concentrations persisted for 3 months. The cause of this event can be attributed to a long period of continued rainfall due to a stationary front. We had heavy rain from autumn to the beginning of winter in this year. The drops of the concentrations are most significant at stations in the inflow areas of river water (see the curves at St. 1 in Fig.13).

References

- Nishikawa, M., R. Kumata and M. Takano (1993): Particularities of ICP-AES analysis in routine work, *J. Environ. Chem.*, 3; 789-796. (in Japanese)
- Nishikawa, M., R. Kumata and M. Takano (1994): Availabilities of ICP-AES analysis with an ultra-sonic nebulizer for environmental water samples, *J. Environ. Chem.*, 4; 683-688. (in Japanese)
- Mito Meteorological Station Report; Monthly Report on Meteorology in Ibaraki Prefecture, in 1980-1996. (in Japanese)

7. Properties of bottom sediment (by Kuninori Otsubo)

1. Properties of the bottom sediment

(1) Sampling intervals of the bottom sediment core

Sample No. 1: 0-1 cm depth range, mean depth 0.5 cm;

Sample No. 2: 1-2 cm depth range, mean depth 1.5 cm;
Sample No. 3: 2-3.5 cm depth range, mean depth 2.75 cm;
Sample No. 4: 3.5-5 cm depth range, mean depth 4.25 cm;
Sample No. 5: 5-7 cm depth range, mean depth 6.0 cm;
Sample No. 6: 7-9 cm depth range, depth 8.0 cm;
Sample No. 7: 9-11 cm depth range, mean depth 10.0 cm;
Sample No. 8: 11-13 cm depth range, mean depth 12.0 cm;
Sample No. 9: 13-15 cm depth range, depth 14.0 cm;

Sample No. 10: 15-17 cm depth range, mean depth 16.0 cm; and below this, the core sample was sliced into 2 cm thickness samples, and the numbering was made in the same manner as shown above.

(2) Water Content

Water Content (%) is defined as follows:

Water Content

$$= (\text{weight of water in sample})/(\text{weight of solid phase of sample}) \times 100$$

(3) VSS (Ignition Loss)

VSS is an indicator of the organic components in the sediment, and defined as follows:

VSS

$$= (\text{weight of solid phase of sample} - \text{weight after burning})/(\text{weight of solid phase of sample}) \times 100$$

(4) Specific Gravity

Specific Gravity

$$= (\text{density of solid phase of sample at } 4^{\circ}\text{C})/(\text{water density at } 4^{\circ}\text{C})$$

2. Method

(1) Sampling method of the bottom sediment

A core-sampler of the self-weight type was used. This core sampler consists of an acryl sampling cylinder of 300 mm in length and 70 mm in internal diameter, metal wings and a 10-kg weight. In order to obtain undisturbed samples, a sampled core in the cylinder was pushed upward from the bottom of the core thorough a rubber tap attached to it. (The diameter of the tap was just smaller than the internal diameter of the cylinder.) After removing the overlaying water, the sediment core pushed out from the top of the cylinder was sliced at the intervals described above.

(2) Pretreatments

The samples were weighed at first. Then, the samples were dried by the freeze-drying method to avoid their deformation and shrinkage during the process of drying.

(3) Method of analysis

1) Water Content

The weight of the solid phase of the sample was determined after it was dried by the freeze-drying method. The weight of water in the sample was determined by the difference between the weight of the sample before and after drying.

2) VSS

The weight after burning was defined as that of the sample burned at 600°C for three hours.

3) Specific Gravity

Specific gravity was measured by use of specific-gravity bottles under the temperature of 4°C.

III. Biological Data

8. Bacteria (by Morihiro Aizaki and Noriko Takamura)

1. Meaning of bacterial number measurement

Organic substances in a lake are generated by photosynthesis of phytoplankton, or supplied from rivers, which flow into that lake. Organic substances serve as foods for zooplankton, fishes and other lives. Bacteria play the role to decompose organic substances to inorganic substances. Bacteria themselves may become foods for other organisms in the lake.

Two kinds of methods are used: one is to count the bacteria number under microscope, and the other is to count the bacteria, which have been cultivated in a culture medium. The number of bacteria obtained through microscope observation is called as total number of bacteria (direct count), and obtained through cultivation is called as total number of aerobic heterotrophic bacteria (viable count).

The total number of bacteria is an excellent index of water quality, and it gives the number, which distributes continuously from very low values for very clean water like Lake Mashu to high values for polluted water where no algae can grow. The number of viable bacteria shows high values in lakes where dissolved organic substances are abundant.

2. Method

In Lake Kasumigaura, the total number of bacteria has been measured from 1983, and number of viable bacteria from 1993. Sterilized 100ml glass water sampler was used, and the sampling was conducted at 0.5 m depth.

The total number of bacteria was counted by using fluorescence microscope, after the sample was dyed with acridine orange. Nuclepore-filters of 0.4 μ m were used from 1982, but that of 0.2 μ m were used thereafter.

The number of viable bacteria was measured by the pour plate count method using 1/10 nutrient agar medium following a 2-week incubation period at 20°C before 1982. Thereafter, the MPN method with 1/10 nutrient broth was used. Bacteria number obtained by the MPN method tends to be a little larger than the pour plate count method.

The measurement of the total number of bacteria was re-started at two observation stations, St.9 (the central part of the lake) and St. 3 (the central part of Takahamairi Bay) in June 1996. The water was sampled by a column water sampler of 2 m length and of 5 cm internal diameter. The water was kept in 100 ml plastic bottles, and glutaraldehyde was added promptly so as that the final concentration became to be 1%. The water samples were kept in a refrigerator.

The counting was conducted within two weeks using the following method: (1) 1-10ml distilled water, which was filtered by nuclepore filter of 0.1 μ m was added to the sample water, in order to collect bacteria uniformly on the filter surface. The sample water was filtered by nuclepore filter of 0.2 μ m having a diameter of 25 mm which was dyed with Sudanblack B. (2) Two or three drops of DAPI (4'6-diamino-2-phenylindole) were added so as to cover the whole area of the filter surface. A few minutes after, we removed the excess DPI solution. (3) This was placed under a fluorescence microscope of U-excitation system (Olympus BH2-RFC), and purple-blue light spots were counted by referring to the lattice grids attached to the ocular. More than 1000 cells are counted for each sample. Then, the obtained number was converted to the cell number per 1 ml.

3. Results and discussion

Variations of the total number of bacteria at St. 1 and St. 9 are shown in Fig.14. At both stations, the lower values are almost the same, and are about 2.0×10^6 cells/ml. Most of the values are below 5.0×10^6 cells/ml at St. 9, while the values at St. 1, which is located near a river mouth, are very variable and sometimes increase up to about 1.0×10^7 cells/ml.

The number of bacteria at St. 3 was $1-14 \times 10^6$ cells/ml in 1996, $9-21 \times 10^6$ cells/ml in 1997 and $7-23 \times 10^6$ cells/ml in 1998. At St. 9, it was $9-21 \times 10^6$ cells/ml in 1996, $8-20 \times 10^6$ cell/ml in 1997, and $6-18 \times 10^6$ cells/ml in 1998. The numbers are relatively low at both stations in 1996, while they are high and stable in 1999. Generally, the numbers are low before 1996, and relatively high thereafter. The difference in analyzing method before and after 1996 might partly be a cause of this difference.

Variations of number of viable bacteria are shown in Fig.15. Numbers are 10^4-10^5 MPN/ml at St. 1, and the values are one order of magnitude higher than at St. 9. As similar to the case of total number of bacteria, it can be understand because large amount of biologically-decomposable (labile) organic substances are supplied in the area near the river mouth (St. 1). At the station in the center of

the lake (St. 9), abnormally low values of bacterial number are found occasionally. At the center of the lake, most of the dissolved organic substances are not-biologically-decomposable (refractory organic substance) biologically-decomposable substances are few. This gives the reason why bacteria number is small at St. 9. It should be noted that the value of order of 10^2 is found in clean and not-polluted streams in mountain areas.

9. Protozoa (by Noriko Takamura)

1. Introduction

Protozoans have been recognized not only to be important primary consumers of bacteria and picophytoplankton, but themselves to be grazed by cladocerans, copepods and rotifers. Therefore protozoans play important roles linking the ecological elements in pelagic freshwaters. However, they have been ignored mainly because of methodological and taxonomic problems. Free-living protozoans have been counted since 1996 with an epifluorescence microscope in Lake Kasumigaura.

2. Method

Water samples were taken from the surface to 2.0 m depth with an acrylic column sampler at Sts. 3 and 9. The water sample (100ml) for counting ciliates was fixed with a few drops of Lugol's iodine solution. The sample was put in a 10ml of sedimentation chamber (Utermöhl 1958). The upper water was removed after the sample was kept for 24 hours. 40 cells of ciliates were counted for each sample with an inverted microscope. The number per one ml was converted as follows:

$$\text{Cells*ml}^{-1} = \frac{\text{Counted number (cells)*area of sedimentation chamber (mm}^2\text{)}}{\text{total counted areas (mm}^2\text{)/volume of sedimentation (ml)}}$$

Counting procedures were completed within three months.

The water sample (100 ml) for counting nanoflagellates was fixed with glutaraldehyde (final concentration, 1%) and then it was kept cool (4-6°C) until it was counted (up to 1 week). The water sample (approx. 5 ml) was filtered with nuclepore filters (pore size; 1.0µm), previously dyed with Sudan Black B. The filter was put in FITC solution (2 g of FITC powder dissolved in 50ml phosphate buffer) for one minute, and then rinsed with phosphate buffer. The filter was placed onto a clean slide, a small drop of the immersion oil added, and a coverslip was mounted on the top of the filter.

100 cells of flagellates were counted for each sample with an epifluorescence (BV-filter) microscope. The number per one ml was converted as follows:

$$\text{Cell number (cells*ml}^{-1}\text{)} = \frac{\text{Counted number (cells)*area of filtration (mm}^2\text{)}}{\text{total counted areas (mm}^2\text{)/volume of filtration (ml).}}$$

Counting procedures were completed within two weeks.

3. Summary of results

The densities of ciliates and flagellates irregularly varied from 12-228 cells*ml⁻¹ and 362-27584 cells*ml⁻¹, respectively during 1996-1998. The highest density of heterotrophic nanoflagellates was recorded in February 1997, and that of ciliates was recorded in April 1997. The mean density of ciliates and nanoflagellates in the lake were in the second order and the fourth order per ml, respectively.

The free-living protozoans in Lake Kasumigaura consume bacteria and picophytoplankton, and themselves are grazed by cladocerans, copepods and rotifers. Sun et al. (1999) indicated recently that the production of protozoans in Lake Kasumigaura does not depend on their foods but on water temperature, and the amounts equivalent to their biomass were consumed by metazoans within one day.

References

- Utermöhl, H. (1958): Zur Vervollkommnung der quantitativen, Phytoplankton - Methodik. Internationale Vereinigung für theoretische und angewandte Limnologie, Mitteilungen, 9: 1-38.
- Takamura, N., Ishikawa, Y., Mikami, H., Mikami, H., Fuzita, Y., Higuchi, S., Murase, H., Yamanaka, S., Nanjyo, Y., Igari, T. and Fukushima, T. (1996): Abundance of bacteria, picophytoplankton, nanoflagellates and ciliates in relation to chlorophyll a and nutrient concentrations in 34 Japanese waters. Jpn. J. Limnol., 57: 245-259.
- Sun, L., Takamura, N., Kim, B., Fukushima, M., Nakagawa, M. and Otsuki, A. (1999): The role of heterotrophic nanoflagellates and ciliates and their different fate in fishless and fish-stocked ecosystems. Verh. Internat. Verein. Limnol., 27: 2853-2860.

10. Phytoplankton (by Noriko Takamura)

10-1. Phytoplankton (including picophytoplankton)

1. Introduction

Phytoplankton grow by carbon fixation and absorption of nitrogen, phosphorus and trace elements such as iron. The biomass of phytoplankton in the water is well correlated with the amounts of phosphorus and nitrogen in the water. The dominant species in the lake influence largely the lake ecosystem, because of their diverse properties.

During the past two decades, picophytoplankton (between 0.2 and 2 µm) have been recognized as

being widespread and productive, and playing an important role in the pelagic food webs of freshwaters. We have counted picocyanobacteria and eucaryotic picoplankton (autotrophic picoplankton) in Lake Kasumigaura since 1996 with an epifluorescence microscope.

2. Method

Water samples were taken from the surface to 2.0 m depth with an acrylic column sampler at Sts. 3 and 9. The water sample (100 ml) for counting picocyanobacteria and eucaryotic picoplankton was fixed with glutaraldehyde (final concentration, 1%) and then it was kept cool (4-6°C) until it was counted (up to 2 weeks). The water sample (approx. 1-3 ml) was filtered on nuclepore filters (pore size; 0.2µm), previously dyed with Sudan black B. The filter was placed onto a clean slide, a small drop of the immersion oil added, and a coverslip was mounted on the top of the filter.

400 cells of picocyanobacteria were counted for each sample with an epifluorescence (G-filter) microscope. 100 cells of eucaryotic picoplankton were counted for each sample with an epifluorescence (BV-filter) microscope. The number per one ml was converted as follows:

$$\text{Cells*ml}^{-1} = \frac{\text{Counted number (cells)} \times \text{area of filtration (mm}^2\text{)}}{\text{total counted areas (mm}^2\text{)/volume of filtration (ml)}}$$

Counting procedures were done within two weeks.

The water sample (100ml) for counting phytoplankton was fixed with Lugol's iodine solution (final concentrations; 0.2-0.4%). The Lugol's iodine solution was composed of I₂ (g):KI(g):acetic anhydride (ml):distilled water (ml) as 1:2:2:20.

The sample was put in a sedimentation chamber (Utermöhl 1958), and was kept for 24 hours. The number of each species was counted for each sample with an inverted microscope. The number per one ml was converted as follows:

$$\text{Cells*ml}^{-1} = \frac{\text{Counted number (cells)} \times \text{area of sedimentation chamber (mm}^2\text{)}}{\text{total counted areas (mm}^2\text{)/volume of sedimentation (ml)}}$$

Counting procedures were done within three months.

The phytoplankton species were expressed as µm³*ml⁻¹, because the size of phytoplankton species largely differed among species. The volume of each phytoplankton species occurred in Lake Kasumigaura was measured separately according to the method of Wetzel and Likens (1991).

3. Summary of results

The densities of picocyanobacteria irregularly changed from 1.5×10⁴-5.9×10⁵ cells*ml⁻¹ during the 3 years, and peaked in the spring. The densities of eucaryotic picoplankton changed from 0-1.6×10⁴ cells*ml⁻¹, and peaked from February to April and from March to June at Sts. 3 and 9, respectively. The density peak of picocyanobacteria tended to follow that of eucaryotic picoplankton.

The seasonal changes in the dominant species of phytoplankton in 1978-1989 were reported in Takamura et al. (1987) and Takamura and Aizaki (1991). The dominant phytoplankton in the summer changed drastically in 1987 from *Microcystis aeruginosa* to *Oscillatoria agardhii*. The change concurrently occurred with the increase of TN/TP ratios in the water. The optimum N/P ratio of *Microcystis aeruginosa* is reported to be 4.1 (weight/weight), and that of *Oscillatoria agardhii* is reported to be 12.0 (weight/weight) (Tilman 1982). The zooplankton community rarely changed before 1986 and after 1987. Therefore, Takamura et al. (1992) suggested that the drastic changes from *Microcystis* to *Oscillatoria* was caused by the increase of N/P ratio.

Fujimoto et al. (1997) conducted some continuous culture experiments using *Microcystis aeruginosa* (the optimum N/P ratio for growth is low) and *Phormidium tenue* (the optimum N/P ratio for growth is high) in the laboratory. They showed that *M. aeruginosa* was superior under conditions of low N:P supply ratio and high temperature, whereas *P. tenue* was superior under conditions of high N:P supply ratio, which corresponded to previous field observations of the algal community in Lake Kasumigaura.

However, the TN/TP ratios have decreased again since the middle of the 90's in Lake Kasumigaura, however the dominant phytoplankton remained to be filamentous cyanobacteria.

The filamentous cyanobacteria have occurred in the winter as well as in the summer since 1995, and *Oscillatoria* have dominated all through the year during 1996-1998. Diatoms usually bloomed in April to June. Among the diatom blooming, *Cyclotella* firstly appeared followed *Fragilaria* and *Aulacoseira*.

References

- FUJIMOTO, N., SUDO, R., SUGIURA, N. and INAMORI, Y. (1997): Nutrient-limited growth of *Microcystis aeruginosa* and *Phormidium tenue* and competition under various N:P supply ratios and temperature. *Limnol. Oceanogr.*, **42**: 250-256.
- TAKAMURA, N., IWAKUMA, T. and YASUNO, M. (1987): Primary production in Lake Kasumigaura, 1981-1985. *Jpn. J. Limnol.* S13-S38.
- TAKAMURA, N. and AIZAKI, M. (1991): Changes in primary production in Lake Kasumigaura (1986-1989) accompanied by transition of dominant species. *Jpn.J.Limnol.*52: 173-187.
- TAKAMURA, N., ISHIKAWA, Y., MIKAMI, H., MIKAMI, H., FUJITA, Y., HIGUCHI, S., MURASE, H., YAMANAKA, S., NANJYO, Y., IGARI, T. and FUKUSHIMA, T. (1996) : Abundance of bacteria, picophytoplankton, nanoflagellates and ciliates in relation to chlorophyll a and nutrient concentrations in 34 Japanese waters. *Jpn. J. Limnol.*, **57**: 245-259.
- TILMAN, D. (1982): Resource competition and community structure. *Monographs in population biology* 17. Princeton Univ. Press.
- UTERMÖHL H. (1958): Zur Vervollkommnung der quantitativen Phytoplankton-Methodik.

Internationale Vereinigung für theoretische und angewandte Limnologie, Mitteilungen, 9: 1-38.

WETZEL, R. G. and G. E. LIKENS (1991) *Limnological Analyses*, 2nd ed. SpringerVerlag, New York, NY.

10-2. Primary Production

1. Introduction

Heterotrophs in lakes such as bacteria, zooplankton, invertebrates and fish get energy and nutrient from phytoplankton, directly or indirectly. The primary production is an important parameter of the trophic levels of lakes.

2. Method

Water samples were taken from the surface to 2.0m depth with an acrylic column sampler at Sts. 3, 7, 9 and 12. The method of analysis used since 1981 will be described briefly. The details are shown in Takamura et al. (1987).

$\text{NaH}^{13}\text{CO}_3$ (99 atom%) solution was added to the water sample (final concentration, about 10%) into each of the 100 ml BOD bottles, all of which were incubated for one hour at 6 light intensity levels (0, 20, 50, 100, 300, 1000 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$) in a water tank keeping the *in situ* water temperature. The light sources used were four 300W tungsten lamps. Opaque acrylic boards were used to regulate the light intensity. After incubation, the phytoplankton were filtered with a precombusted Whatman GF/F filter (Whatman GF/C filter were used before 1989).

The concentration of organic carbon was measured by a CHN analyzer (Yanagimoto MT-3). The isotope ratios of ^{13}C and ^{12}C in the samples were determined by a quadrupole mass-spectrometer (Anelba TE-150) facilitated with a combustion furnace (Yanagimoto MT-1) during 1981 to 1995 and by a mass-spectrometer (Finigan Delta plus) facilitated with a combustion furnace (Amco EA1110) since 1996.

The concentrations of inorganic carbon were measured with a total organic carbon analyzer (Beckman Model 915-B) during 1981-1985, with an analyzer (O. I. Corporation Model 700) during 1986-1994 and with an analyzer (Shimazu TOC-5000A) since 1995.

The photosynthetic rate (P_v , $\text{gC m}^{-3} \text{h}^{-1}$) was calculated as:

$$P_v = B (a_2 - a_0) / t (a_1 - a_0) \text{-----(1)},$$

where t is the duration of incubation (hour), B the particulate organic carbon (POC, gC m^{-3}) at the end of the incubation, a_2 the atom % of ^{13}C in the particulate organic carbon of the incubated sample, a_1 the atom % of ^{13}C in the total inorganic carbon at the start of the incubation, and a_0 the atom % of ^{13}C in the particulate organic carbon of natural sample.

The photosynthesis-light curve (P-I curve) was well fitted (Iwakuma and Yasuno 1983) as follows:

$$Pg = P_{\max} I/I_k (1 + (I/I_k)^2)^{-0.5} \text{-----}(2)$$

Two parameters, the maximum rate of photosynthesis (P_{\max} : $\text{gC gC}^{-1} \text{h}^{-1}$) and the initial slope of the photosynthesis-light curve (ϕ : $(\text{gC gC}^{-1} \text{h}^{-1})(\mu\text{mol photon m}^{-2} \text{s}^{-1})^{-1}$) were determined by the nonlinear least square method. I_k is the light intensity ($\mu\text{mol photon m}^{-2} \text{s}^{-1}$) at the junction of initial slope.

Phytoplankton were assumed to be distributed homogeneously. The photosynthetic rate per unit area and per unit time ($\text{gC m}^{-2} \text{h}^{-1}$) was obtained by integrating equation (2) from 0 m to the bottom depth (m), and by multiplying POC (gC m^{-3}). The daily production per unit area was obtained by integrating from sunrise to sunset. Details are shown in Takamura et al. (1986). The extinction coefficient was measured monthly at 4 stations in Lake Kasumigaura, and the hourly incident solar radiation was obtained from the Tateno Meteorological Station.

3. Summary of results

The primary production in Lake Kasumigaura has been reported in Takamura et al. (1987), Takamura and Aizaki (1991) and Takamura (1998). Results of stepwise regression analysis indicate that the variation of photosynthetic rates ($\text{gC m}^{-3} \text{h}^{-1}$) in the warmer seasons ($>20^\circ\text{C}$) is well explained by variations of both water temperature and total nitrogen during 1981-1986 in Takahamairi Bay, when *Microcystis* dominated. However, the deterministic parameter in Takahamairi Bay changed from total nitrogen to total phosphorus during 1989-95, after which filamentous cyanobacteria became dominated. The photosynthetic rates in the main basin were explained by total phosphorus throughout the studied period, although the dominant species have changed similarly from *Microcystis* to filamentous cyanobacteria since 1987 in the main basin.

References

- IWAKUMA, T. and YASUNO, M. (1983): A comparison of several mathematical equations describing photosynthesis-light curve for natural phytoplankton populations. Arch.Hydrobiol. 97: 208-226.
- TAKAMURA, N., IWAKUMA, T. and YASUNO, M. (1986): Photosynthesis of size fractionated phytoplankton population in hypertrophic Lake Kasumigaura, Japan. Arch.Hydrobiol.108: 235-237.
- TAKAMURA, N., IWAKUMA, T. and YASUNO, M. (1987): Primary production in Lake Kasumigaura, 1981-1985. Jpn.J.Limnol. S13-S38.
- TAKAMURA, N. and AIZAKI, M. (1991): Changes in primary production in Lake Kasumigaura (1986-1989) accompanied by transition of dominant species. Jpn.J.Limnol.52: 173-187.
- TAKAMURA, N., HANAZATO, T., IWAKUMA, T., NOJIRI, Y., OTSUKI, A., AIZAKI, M. and Kasumigaura Research Group of NIES (1998): Long-term monitoring of nutrients, plankton and

benthos in Lake Kasumigaura. Proc. 2nd East Asia-Pacific Regional Conference on Long-Term Ecological Research, pp.155-165. CGER-I03'98.

TAKAMURA, N (1998): The relationship between the occurrence of algal blooms and the water quality in Lake Kasumigaura. Nippon Suisan Gakkaishi, 64, 2, 305-306. (in Japanese)

11. Gross production, Net production, Respiration (by Noriko Takamura)

1. Background

Since use in the field of radioisotopes such as ^{14}C is legally limited in Japan, the primary production in Lake Kasumigaura has been measured using ^{13}C since 1981 (see the primary production section), and it had been measured using the O_2 method from 1976 to 1980. Although the O_2 method is not so sensitive in ^{13}C measurement, it can be sufficiently applicable to eutrophic waters such as Lake Kasumigaura. But since the respiration rate that we can measure means the community respiration rate, which includes bacteria and zooplankton as well as phytoplankton, the gross production and net production measured by the O_2 method will become an overestimate and underestimate, respectively.

Gross production, net production and respiration from 1976-77 were measured by Aizaki (Tsuno et al. 1977, Iwakuma and Aizaki 1979), and those from 1978-79 were measured by Iwakuma (Iwakuma and Aizaki 1979, Iwakuma and Yasuno 1981). The respiration rate of the plankton community was measured until 1985 using the Winkler method. Recently the respiration rate of phytoplankton can be obtained directly with the use of ^{13}C because of the high sensitivity of mass-spectrometer.

2. Methods

Surface water from each station was put in 6 BOD bottles. Two bottles, and two bottles covered with aluminum foil were suspended *in situ* in the lake water for a day. The O_2 concentrations at the initial (V_i : mg m^{-3}), those after one day incubation in the lake water (V_p : mg m^{-3}), and those after one day incubation in the dark (V_d : mg m^{-3}) were measured using the Winkler method (APHA 1998). The daily respiration rate, gross primary production and net production were obtained as follows:

$$\text{Respiration rate (mg m}^{-3}\text{d}^{-1}) = V_d - V_i$$

$$\text{Gross production (mg m}^{-3}\text{d}^{-1}) = V_p - V_i + V_d$$

$$\text{Net production (mg m}^{-3}\text{d}^{-1}) = V_p - V_i$$

The gross production and net production per unit area were obtained by hanging the bottles at 5 depths.

References

- APHA (1998): Standard methods for the examination of water and wastewater. 20th Eds. APHA, AWWA, WPCF, Washington.
- Tsuno, Y., Aizaki, M., Sudo, R. and Goda, K. (1977): Water quality in the summer of Takahamairi Bay. Res. Rep. Natl. Inst. Environ. Stud., 1: 80-93.
- Iwakuma, T. and Aizaki, M. (1979): Primary production at Takahamairi Bay in Lake Kasumigaura: Seasonal and summer diurnal changes. Res. Rep. Natl. Inst. Environ. Stud., 6: 139-154.
- Iwakuma, T. and Yasuno, M. (1981): Primary production in Lake Kasumigaura. Res. Rep. Natl. Inst. Environ. Stud., 22: 99-122.

12. Zooplankton (by Takayuki Hanazato)

1. Method of sampling

(1) From 1977 to March 1981

Water samples were taken at a depth of 0.5 m using a Van-Dorn sampler (6 liters in volume). The sampled water was filtered through a 94- μm mesh plankton net, and the collected zooplankton were fixed with 4 % formalin.

(2) From April 1981 to April 1987

Samples in water column from the surface to 2 m depth were sampled using an acrylic tube sampler (5 cm in diameter and 2 m in length). Zooplankton were collected by filtering 10 liter of the sampled water through a 94 μm mesh plankton net, and were then fixed with 4% formalin (from April 1981 to April 1983) or formalin sucrose (4% formalin with 40 g l⁻¹ sucrose; from May 1983 to April 1987).

(3) From May 1987 to present

Zooplankton were collected as in the period of April 1981 – April 1987 but with a 40- μm mesh plankton net and fixed with formalin sucrose.

2. Results and discussion

Predominant species of zooplankton in Lake Kasumigaura were as follows:

Rotifera: *Polyarthra vulgaris*, *Keratella valga*, *Trichocerca* spp., *Filinia longiseta*

Cladocera: *Bosmina fatalis*, *Diaphanosoma brachyurum*, *Bosmina longirostris*

Copepoda: *Thermocyclops taihokuensis*, *Cyclops vicinus*, *Eodiaptomus japonicus*

Cladocerans attained their highest density in summer, when *Bosmina fatalis* and *Diaphanosoma brachyurum* were predominant. The rotiferan community was dominated by several species, which showed an irregular pattern of seasonal succession. In contrast, copepoda showed a clear pattern of

seasonal succession; *Thermocyclops taihokuensis* and *Eodiaptomus japonicus* appeared abundantly from spring to fall, while *Cyclops vicinus* did in the cold season from fall to spring.

Zooplankton community of Lake Kasumigaura was characterized by the dominance of rotifers and the small cladoceran *Bosmina fatalis*. The dominance of rotifers and small cladocerans is often found in the zooplankton communities of eutrophic lakes. So, it could be said that Lake Kasumigaura has a zooplankton community typically found in eutrophic lakes.

Lake Kasumigaura is inhabited by the mysid *Neomysis intermedia*, which are predators and have exerted a large impact on the lake zooplankton community. The mysid predators showed a clear seasonality in their population dynamics before 1983: they showed two density peaks in spring and fall, when cladocerans disappeared and rotifers and copepods had low densities. However, in 1983 and later, the seasonal variation pattern of the *Neomysis* density has become irregular, and they were scarcely found in some years. This change in occurrence manner of *Neomysis* has induced a change in zooplankton community. Although cladocerans were scarcely found in the cold season from fall to spring before 1983, *Bosmina longirostris* often developed large populations (>100 individuals l^{-1}) in the cold season when *Neomysis* disappeared in 1983 and thereafter. To our surprise, the large-sized cladoceran, *Daphnia galeata* appeared for the first time in Lake Kasumigaura in the winter of 1986-1987, and their appearance occurred every winter after November of 1988 (see Fig.16).

This change in the cladoceran community has affected much the phytoplankton community, because cladocerans, especially *Daphnia*, are effective grazers on phytoplankton. A noticeable event occurred in January 1989, when *Daphnia* increased to a density of 277 individuals l^{-1} and the chlorophyll *a* concentration, an indicator of phytoplankton abundance, was reduced to $< 1 \mu g l^{-1}$, which was extremely lower than usual values (20-30 $\mu g l^{-1}$). The reduced phytoplankton abundance resulted in increased water transparency up to 4 m. This was considerably higher in comparison with that in usual years (about 1m). The great reduction in phytoplankton abundance did not occur when small zooplankton such as *Bosmina* and rotifers had elevated densities. Thus, the event occurred in Lake Kasumigaura has indicated that the large cladoceran *Daphnia* have a large impact on phytoplankton abundance. In other words, changes in the zooplankton community structure (changes in species composition of zooplankton community) induce great changes in the phytoplankton community.

The summer zooplankton community of Lake Kasumigaura is characterized by dominance of the small cladoceran *Bosmina fatalis* and *Diaphanosoma brachyurum*, and this has not been altered after the start of the ecosystem survey of Lake Kasumigaura in 1978. In contrast, the summer phytoplankton community changed drastically in 1987, from a dominance of the cyanobacterium *Microcystis*, which forms water blooms, to that of another cyanobacterial species, *Planktothrix*, which does not develop it. The replacement of the dominant phytoplankton species was not followed by the changes in zooplankton community structure, however. Both of the two species of

cyanobacterial form colonies, which are inedible to the small zooplankton species inhabiting Lake Kasumigaura due to their large size. This may be the reason why the zooplankton community structure did not respond to the changes in the dominant phytoplankton species.

13. Higher Plants in the littoral zone of Lake Kasumigaura (by Seiich Nohara)

1. Study site and method

1) Study site

The following four stations were set at the shoreline of Lake Kasumigaura, and the survey was conducted on August 3-4, 1992 (Fig.17)

Furuwatari of Edozaki-iri (St. 1)

Miho (St. 2)

Tsuchiura (St. 3)

Sakihama (St. 4)

In general, large vegetation of *Nymphoides peltata*, one of floating-leaf plants, was found, except at St. 2. Among these stations, natural conditions of the lakeshore are kept near St. 3, except in the vicinity of old shore protection.

We set several observation lines perpendicular to the lakeshore at each station. The number of lines is from 3 to 5 for one station. The line number *m* is counted from the right direction facing the lake, and the lines indicated as Line (*m*). The observation points were set 5 m interval along each line. The positions of these points were determined by digital theodolite (Nikon, DTM-A20CLG). The quadrats for plant coverage were set at each observation point.

2) Method

We set 13 observation lines in total for the four stations. The quadrats of 1 m × 1 m were set at intervals of 5 m, and the most offshore point was set at the water depth of about 1 m. Species of the plants found in each quadrat were recorded, and coverage degree of each species was measured.

The following 7 ranks are used for the coverage degree: r (one plant is found), + (coverage ratio is 1-5%), 1 (6-10%), 2 (11-25%), 3 (26-50%), 4 (51-75%), and 5 (76-100%).

Identification of species and of original growing conditions (aquatic plant, swamp plant or land plant) was made according to the illustrated book of the Japanese flora (Kitamura et al., 1964). Submerged plants were not surveyed, as they cannot be measured by eye.

Water depth and thickness of mud were measured by putting vertically a glass-fiber pole of 5 mm diameter and of 2 m length.

Further, aerial photographs were taken obliquely from a Cessna type plane, by using 4 × 5 camera (Aerotechnica) and color film (KODAK PCNG ISO160⁰) for Edozaki-iri and Tsuchiura-iri on

August 10, and for Takahama-iri and offshore of Asou on August 25.

2. Results and discussions

We found 83 species of higher plants in the 162 quadrats along the 13 observation lines. A list of the species observed is shown in order of the occurrence frequency (from high to low). The ratio of land plants is 51 % in total, and that of naturalized plants is 4.8%.

The aquatic and swamp species, occurrence frequency of which exceeds 50%, are reeds (*Phragmites australis*), *Bidens frondosa*, *Phalaris arundinacea*, *Lycopus lucidus*, Indian rice (*Zizania latifolia*), *Miscanthus sacchariflorus*, *Actinostemma lobatum*, *Persicaria maackiana*, *Typha angustifolia*, *Scirpus yagara*, *Persicaria japonica*, *Persicaria thunbergii*, *Nymphoides peltata*, *Persicaria lapathifolia*. Reeds appear on all observation lines. The number of aquatic and swamp species, which appear on each observation line, ranges between 10 and 17.

Marui (1990) surveyed at 36 stations on the lakeshore of Kasumigaura, and reported about 190 species in total. The number of species in this study (32) is 44% of that reported by Marui. Sakurai (1981) surveyed 80 stations on the lakeshore in 1979, and recognized 44 species of aquatic and swamp plants except submerged plants. Our number is about 77% of them.

As to the differences among stations and lines, the number of species of land plants is smallest at St.1. The number increases in order of St. 1 (1-4 species), St. 4 (4-8 species), St. 2 (10-12 species), and St. 3 (13-16 species). The number of all species increases in the same order, indicating that the variety of species is increased when the land species increases.

Old shore protection works occur only near St. 3, and there is no concrete protection work. Gentle slope extends from lotus cultivation field to the lakeshore. While, at other stations, concrete protection works or high banks separate the lake from land clearly.

The variation of number of aquatic and swamp species among observation lines is largest at St. 2. The growing area is limited as it is separated by a natural sandbank into two portions at St. 2. There are natural outside bank and a little higher concrete protection work exist in parallel, and the level of the land between these is about 50 cm lower than the natural sand bank. Diversity of species appears to be influenced both by the area of vegetation and by the lakeshore structures.

References

- Kitamura, S., G. Murata and T. Koyama (1964): Colored illustrations of herbaceous plants of Japan. I, II, III. Hoikusha Pub., Co., LTD., Osaka.
- Sakurai, Y. (1981): Changes of flora, vegetation area and biomass of aquatic plants in the recent progress of eutrophication in Lake Kasumigaura. Res. Rep. Natl. Environ. Stud. No. 22: 229-279, (in Japanese).
- Marui, H. (1990): Change of the aquatic flora conditions in the Lake of Kasumigaura, and

environmental factors. Bachelor Thesis of Tsukuba University.

14. Zoobenthos (by Toshio Iwakuma and Ryuhei Ueno)

1. Methods

(1) Sample collection

During the period from April 1990 to March 1998, the zoobenthos was sampled at four stations (St. 3 in Takahamairi Bay, 4 m depth; St. 7 in Tsuchiurairi Bay, 2.8 m depth; St. 9 in the main basin, 6 m depth; and St. 12 off Asou Town, 4 m depth) after the routine surveys such as measurement of environmental factors and samplings of lake water and plankton. Three replicate sediment samples were collected with an Ekman-Birge sampler (15 cm × 15 cm) at each sampling station.

(2) Pretreatment

Each sediment sample was washed in situ with a nylon net (NGG54, 0.315 mesh opening) to remove fine mud. Zoobenthos retained on the net was collected in a polyethylene bag with 10% formalin solution, and the bag was tied firmly.

(3) Microscopic observation

Zoobenthos sample was dispersed in a white plastic pan in the laboratory, and the larger chironomids and oligochaetes were picked up. Smaller organisms were picked up under a dissecting microscope of 5× - 40× magnifications for sediment subsamples. Wet weights were measured for chironomids and oligochaetes up to the nearest 0.1 mg. Torn-off bodies of chironomids were all picked up for the measurement of weights but only the head parts were counted for the number of individuals. Similarly, all torn-off bodies of oligochaetes were picked up, but all the parts were included for measurement of weight and for counting of individuals. Dry weights were estimated from the wet weights using a reported dry weight:wet weight ratio of 0.19 (Iwakuma *et al.*, 1984). The densities and biomasses of each chironomid species will be reported elsewhere.

(4) Accuracy control

4.1. Sampling efficiency

The maximum sampling depth in sediment was 10 cm. The burrowing depths of zoobenthos in Lake Kasumigaura are variable among developmental stages and seasons. Larvae of an Orthoclaadiinae species, *Propsilocerus akamusi* (Tokunaga), which was formerly named as *Propsilocerus akamusi* and have recently been revised to the current name by Saether and Wang (1996), burrow about 80 cm in the sediment. Larvae of a Chironominae, *Chironomus plumosus* (L.)

burrow to about 40 cm in the sediment (Iwakuma and Yasuno, 1981, 1983). The sampling efficiency of the Ekman-Birge sampler against an 80-cm tall sediment sampler in early March, when fourth-instar larvae of *P. akamusi* and *C. plumosus* ascend to near the sediment surface, is 55% for *P. akamusi*, 65% for *C. plumosus* and 65% for oligochaetes (Iwakuma *et al.*, 1984). No *P. akamusi* larvae were collected with the Ekman-Birge sampler during April-September since they burrowed deeper than 40 cm in the sediment. Major chironomid species collected with the sampler during the period are *C. plumosus* and Tanypodinae species, *Clinotanypus sugiyamai* Tokunaga and *Procladius culiciformis* (Iwakuma, 1987).

4.2. Retention efficiency during pretreatment

The mean head capsule widths of third-instar larvae of chironomids dominant in Lake Kasumigaura are 0.43 mm ($n=30$, range 0.41-0.47 mm) for *P. akamusi*, 0.44 mm ($n=21$, range 0.40-0.48 mm) for *C. plumosus*, 0.50 mm ($n=58$, range 0.39-0.64) for *C. sugiyamai* and 0.41 mm ($n=59$, range 0.31-0.51 mm) for *P. culiciformis* (Iwakuma 1987). The values of head-capsule width are larger than the mesh opening of the nylon net used for washing sediment in situ. Therefore all the third- and fourth-instar larvae of the four dominant chironomids were considered to be collected on the nylon net during sampling and washing. Chironomids pupate after four larval instars. The average larval weight of each instar of chironomids relative to that of the fourth instar (taken to be 100) is 4.0 (second instar) and 12 (third instar) for *C. sugiyamai*, 24 (third instar) for *P. culiciformis*, 0.09 (first instar), 0.7 (second instar) and 5.1 (third instar) for *P. akamusi* and 1.2 (second instar) and 4.8 (third instar) for *C. plumosus* (calculated from Iwakuma 1987). Since the average weights of the second instar are about or less than 10% of the fourth instar for both *P. akamusi* and *C. plumosus*, and since these two species are much larger than the other two Tanypodinae species, *C. sugiyamai* and *P. culiciformis*, both in terms of density and individual weight, the loss of biomass due to washing of sampled sediments in situ is expected to be less than 10% of the actual value.

Meiobenthos, namely zoobenthos less than 0.3 mm in length, such as rotifers, cladocerans, harpacticoids, ostracods, nematodes, tardigrades and small oligochaetes are distributed in the sediment of Lake Kasumigaura at densities of 10^4 - 10^5 individuals m^{-2} (Iwakuma *et al.*, 1984). Since these meiobenthos would have all passed through the nylon net, they are not included in the present study.

4.3. Other remarks

Since each torn-off body of oligochaete was counted as one individual in the present study, the number of oligochaetes shown in the present report does not indicate the actual density. The number should be treated as an indicator, and we must take biomass value into consideration for understanding the structure of Lake Kasumigaura ecosystem.

2. Results and discussion

The density and biomass of zoobenthos are summarized in Table.3 which includes monthly variation of the density and biomass per square meter (Table.3a) and yearly variation of these values (Table.3b). (Also see Figs.18, 19, 20)

Neglecting the several missing data, chironomid densities averaged for 8 years were 415 individuals m^{-2} (St. 3), 500 individuals m^{-2} (St. 7), 366 individuals m^{-2} (St. 9) and 354 individuals m^{-2} (St. 12), and their biomasses were 3.06 g wet weight m^{-2} (0.59 g dry weight m^{-2} , St. 3), 3.33 g wet weight m^{-2} (0.64 g dry weight m^{-2} , St. 7), 4.42 g wet weight m^{-2} (0.86 g dry weight m^{-2} , St. 9) and 1.82 g wet weight m^{-2} (0.35 g dry weight m^{-2} , St. 12). The oligochaete biomasses averaged for 8 years were 1.09 g wet weight m^{-2} (0.21 g dry weight m^{-2} , St. 3), 0.90 g wet weight m^{-2} (0.17 g dry weight m^{-2} , St. 7), 1.34 g wet weight m^{-2} (0.26 g dry weight m^{-2} , St. 9) and 1.62 g wet weight m^{-2} (0.31 g dry weight m^{-2} , St. 12). The values for 1 year during April 1990-March 1991 are not included for the calculation at St.7 and St.12.

The annual mean (for a period from April to March in the following year) chironomid biomasses averaged for four stations (Sts. 3, 7, 9, 12) were 0.52 (1990), 1.32 (1991), 0.48 (1992), 0.47 (1993), 0.52 (1994), 0.54 (1995), 0.65 (1996), 0.43 (1997) and 0.52 g dry weight m^{-2} (1998) (Table.3c). The biomass was high in 1991 because the biomass of *P. akamusi* was high at all stations during January-March 1992 and the biomass of *C. plumosus* was also high at St. 9 (see Table.3a).

The four chironomid species were collected from all the 10 stations (Sts. 1, 2, 3, 4, 6, 7, 8, 9, 11, and 12) during April 1982-April 1986. Five species belonging to the subfamily Chironominae, i.e., *Dicrotendipes* sp., *Glyptotendipes* sp., *Microchironomus* sp., *Polypedilum* sp. and *Stictochironomus* were occasionally collected at stations in Takahamairi and Tsuchiurairi Bays (Iwakuma, 1987). The chironomids collected in the present study are therefore composed of the dominant four species, i.e., *C. sugiyamai*, *P. culiciformis*, *C. plumosus* and *P. akamusi*.

The annual mean (for a period from April to March in the following year) chironomid biomasses averaged for four stations (Sts. 3, 7, 9, 12) during 1982-1989 were 2.55 (1982), 1.09 (1983), 1.25 (1984), 1.30 (1985), 1.48 (1986), 1.14 (1987), 1.04 (1988) and 0.60 g dry weight m^{-2} (1989) (Iwakuma, 1990). Combining the reported values and the values in the present study, between-year variation of zoobenthos biomass during 17 years is shown in Table.3d. Excepting a high value in 1991, chironomid biomass in Lake Kasumigaura changed little up to now since 1989 at a value of ca. 0.50 g dry weight m^{-2} , which is about half the biomass during 1982-1988 (Fig.21). The chironomid biomass in 1991 was as high as that during 1982-1988.

The annual mean (for a period from April to March in the following year) oligochaete biomasses averaged for four stations (Sts. 3, 7, 9, and 12) were 0.02 (1990), 0.10 (1991), 0.25 (1992), 0.07 (1993), 0.28 (1994), 0.29 (1995), 0.38 (1996), 0.33 (1997) and 0.29 g dry weight m^{-2} (1998). The

biomass tended to increase during 1990-1996 with some fluctuations (Fig.22). The oligochaete biomass in the surface 0-10 cm layer of sediment averaged for 50 locations arranged in grids was 1.6 g dry weight m⁻² in March 1982 (Iwakuma *et al.*, 1984).

The oligochaete biomasses during 1990-1998 in the present study were much lower than that obtained at the survey in 1982, although the sampling methods differed between these two, which made the comparison difficult.

References

- Iwakuma, T. (1987): Density, biomass, and production of Chironomidae (Diptera) in Lake Kasumigaura during 1982-1986. *Jpn. J. Limnol.*, 48: S59-S75.
- Iwakuma, T. (1990): Change in densities and biomasses of chironomid larvae in the pelagic zones of Lake Kasumigaura during 1982-1990. *Miscell. Rep. Natl. Inst. Environ. Stud.*, F25: 53-79 (in Japanese).
- Iwakuma, T. and M. Yasuno (1981): Chironomid populations in highly eutrophic Lake Kasumigaura. *Verh. Int. Ver. Limnol.*, 21: 632-642.
- Iwakuma, T. and M. Yasuno (1983): Fate of the univoltine chironomid, *Prosilocerus akamusi* (Diptera: Chironomidae), at emergence in Lake Kasumigaura, Japan. *Arch. Hydrobiol.*, 99: 37-59.
- Iwakuma, T., M. Yasuno and Y. Sugaya (1984): The distribution and production of zoobenthos, and the role of chironomids in the matter flow, in Lake Kasumigaura. *Res. Rep. Natl. Inst. Environ. Stud.*, 51: 103-140 (in Japanese with English summary).
- Saether, O. A. and X. Wang (1996): Revision of the orthoclad genus *Prosilocerus* Kieffer (= *Prosilocerus* Sasa) (Diptera: Chironomidae). *Ent. Scand.* 27: 441-479.

15. Fish (by Shin-ichiro Matsuzaki and Seiichi Nohara)

1. Importance of fish monitoring

Fish species play a significant role as top predators of lake food webs as well as important resources for inland fisheries. In recent years, fish fauna in lakes has been modified due to human activities, which led to a decrease of the number of native fish and an increase of invasive fish. However, few quantitative monitoring has been implemented in Japanese lakes including Lake Kasumigaura. A long-term monitoring that enriches understanding of a change in fish species is indispensable for conservation of native fish species and ecosystem management. We have started monitoring of fish species (including shrimp) at Lake Kasumigaura since 2005, and the survey is conducted 5 to 6 times a year.

2. Methods

Fish and shrimp samples were taken from the southeast shore of Lake Kasumigaura (near the Dosakibana in Inashiki city). In cooperation with a local professional fisherman, we captured fish and shrimp using a large stationary net, which consists of three trap nets (70 cm in diameter, 6 m in length, 3 mm mesh size) and a leader net (80 m in length, 11 mm mesh size). The stationary net was washed out before sampling and was set for 24 h in a similar manner. The samples were identified to the lowest possible taxonomic unit and the number of individuals of each species was counted. The wet mass of each species was also measured.

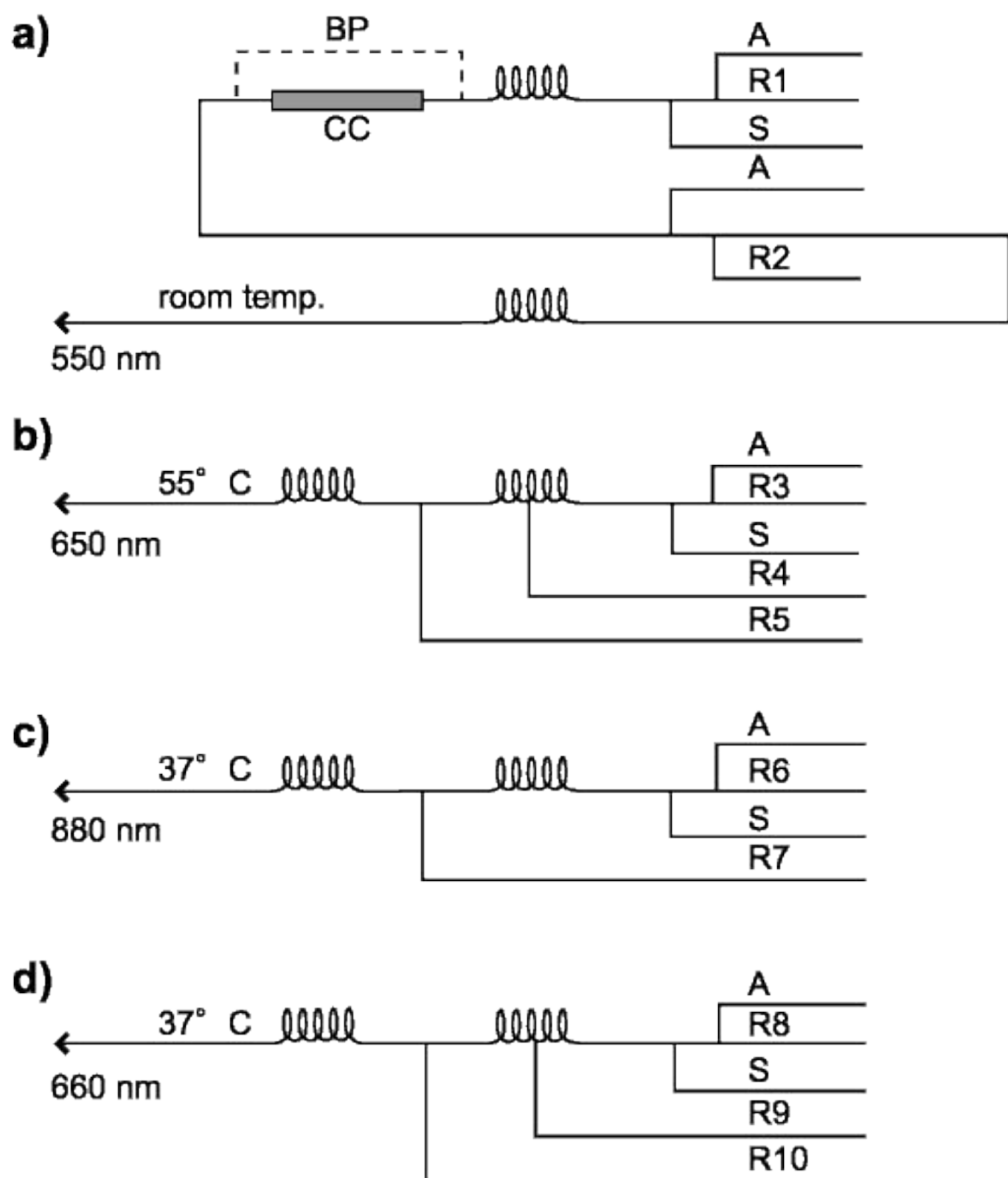


Fig.1 Schemes of analysis of nutrients using auto-analyzer

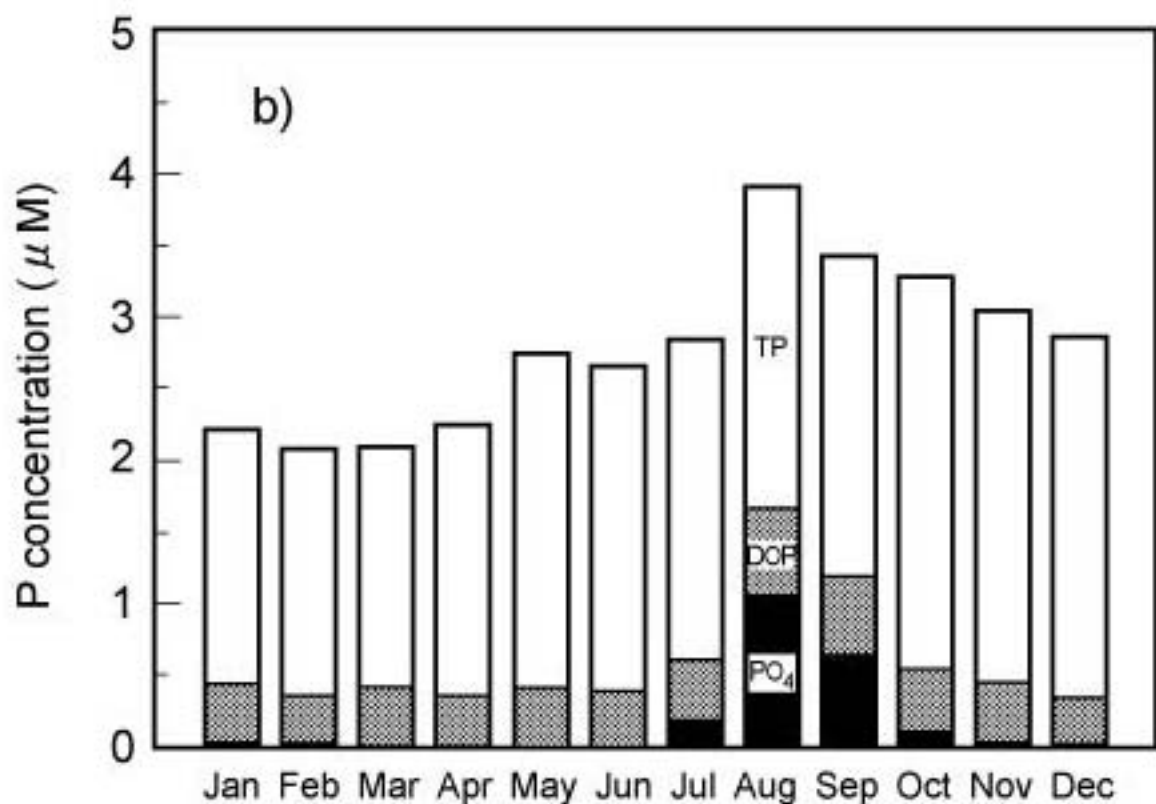
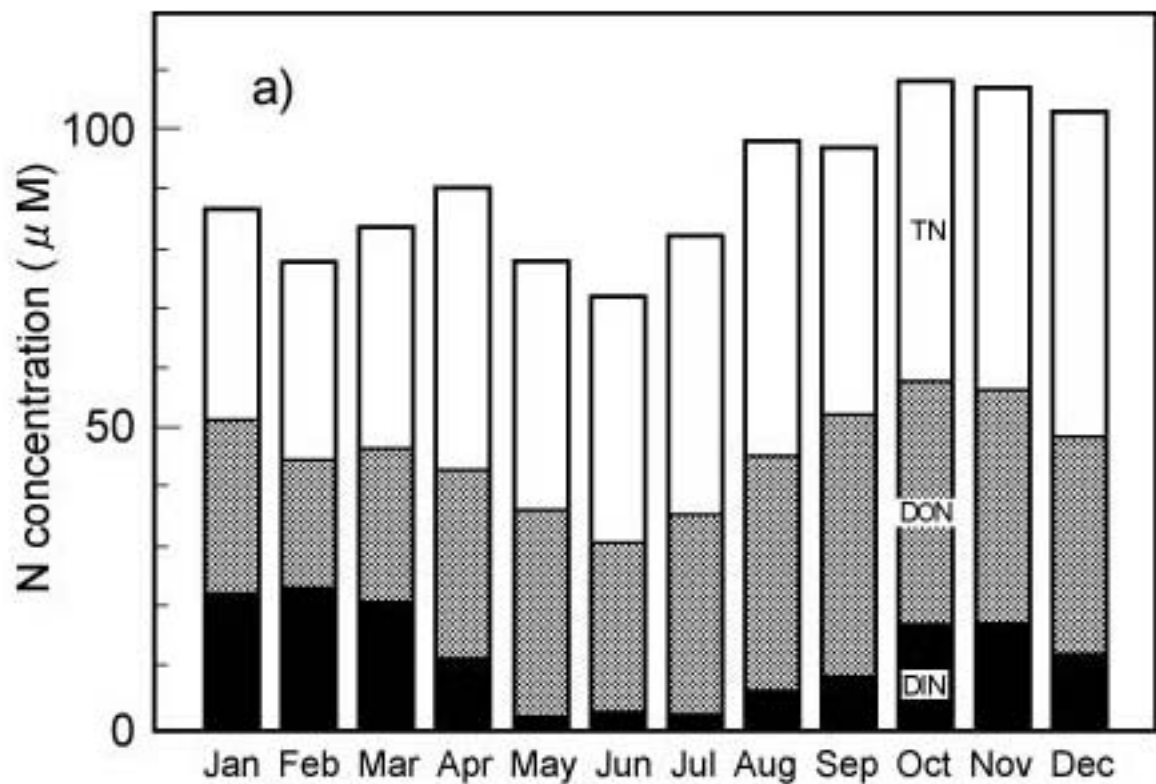


Fig.2 Seasonal variation of concentrations of various forms of nitrogen (top) and of phosphorus (bottom) in μM at St. 9. Monthly averaged over 6 years period from April 1990 to March 1996 are shown.

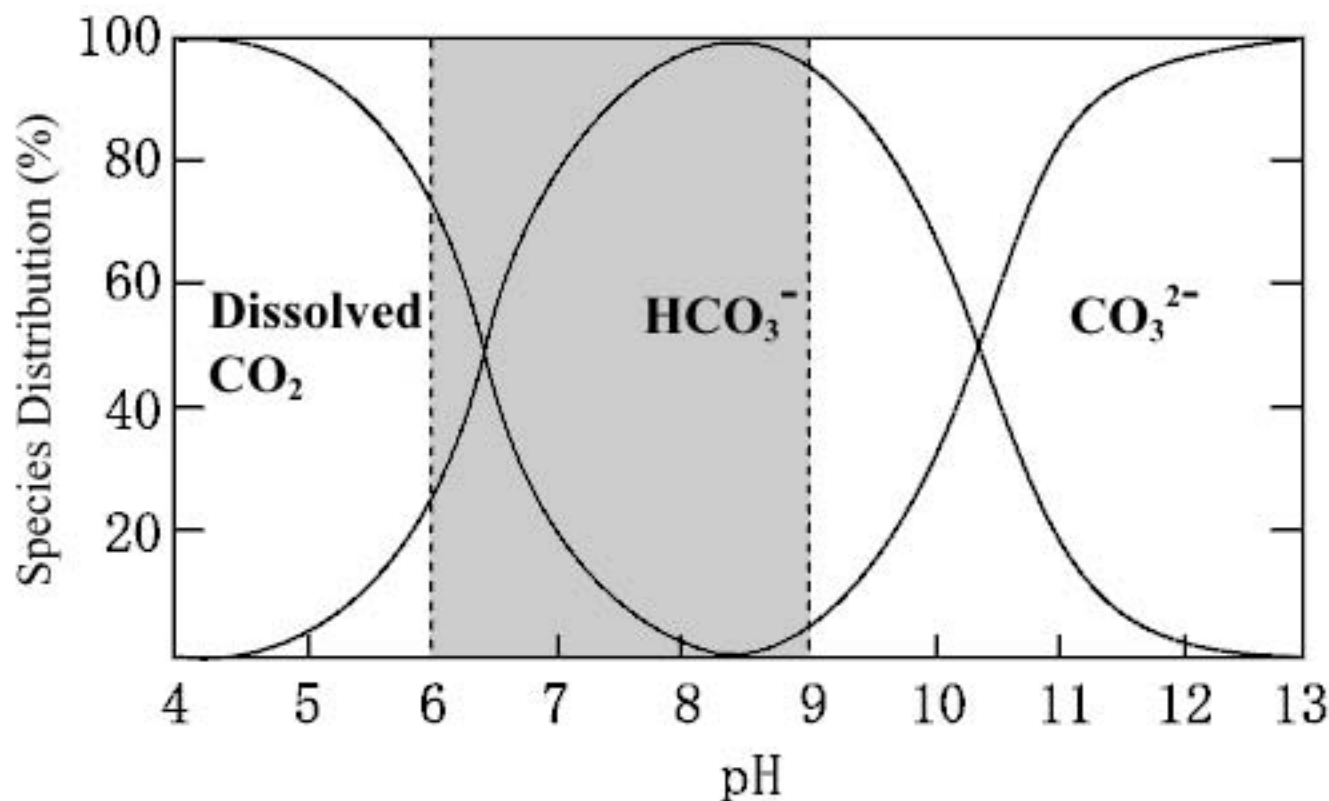
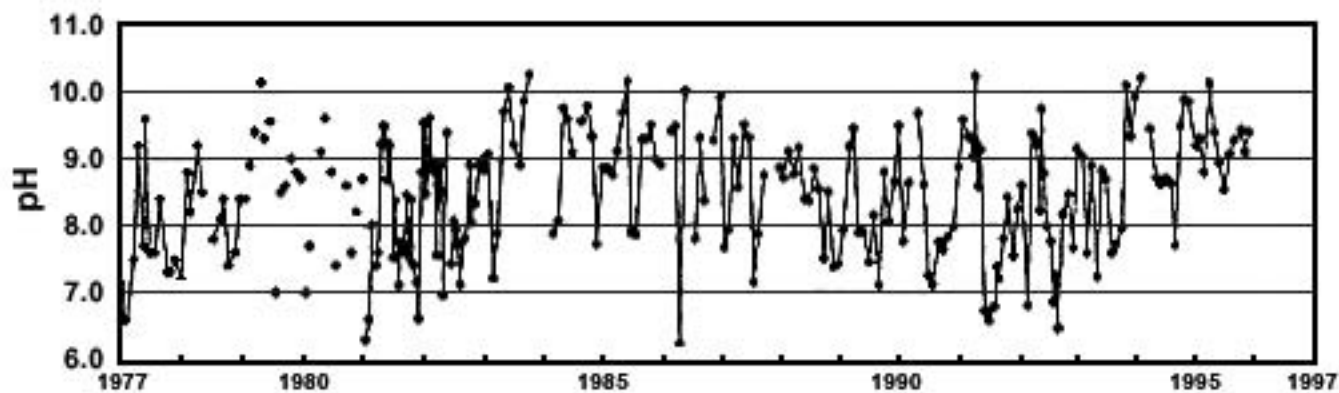
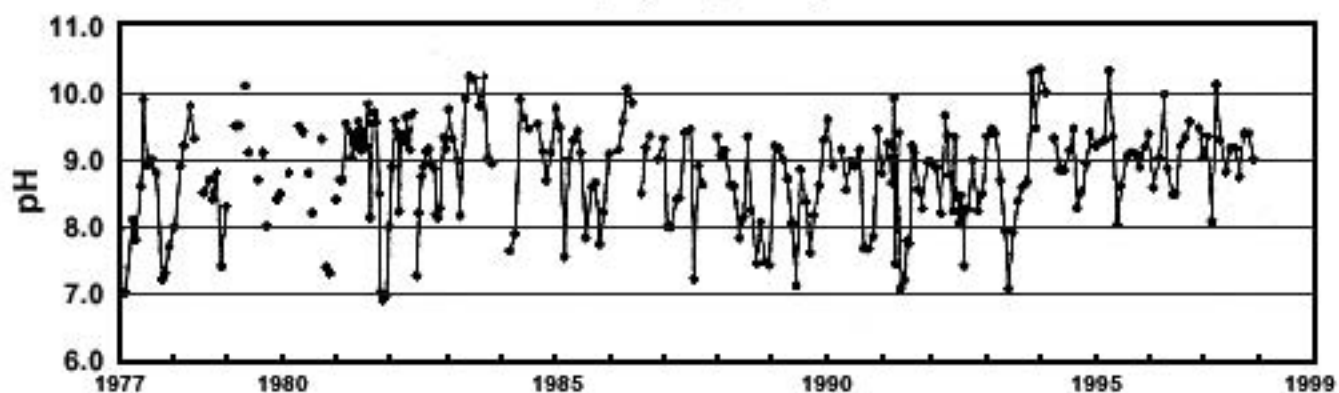


Fig.3 Distribution of carbonic acid species due to variation of pH. The range of pH of lake water is shown as gray zone in figure. (Cited from "Survey Method of Lakes and Marshes" by Y. Saijo and O. Mitamura.)

pH(St.1, 0.5m)



pH(St.3, 0.5m)



pH(St.9, 0.5m)

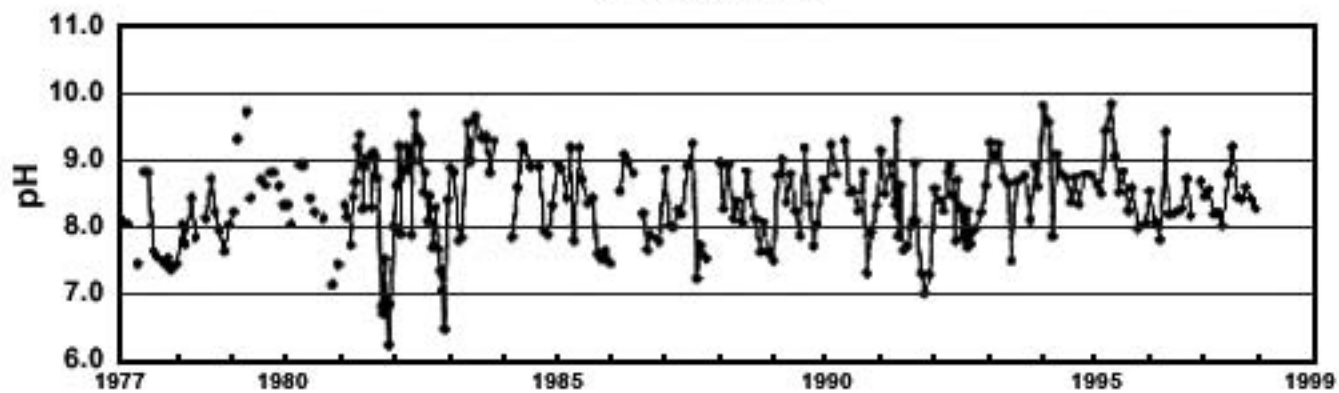


Fig.4 Interannual variation of pH in the surface layer water at each observation point in Lake Kasumigaura.

pH(St.9, 4m)

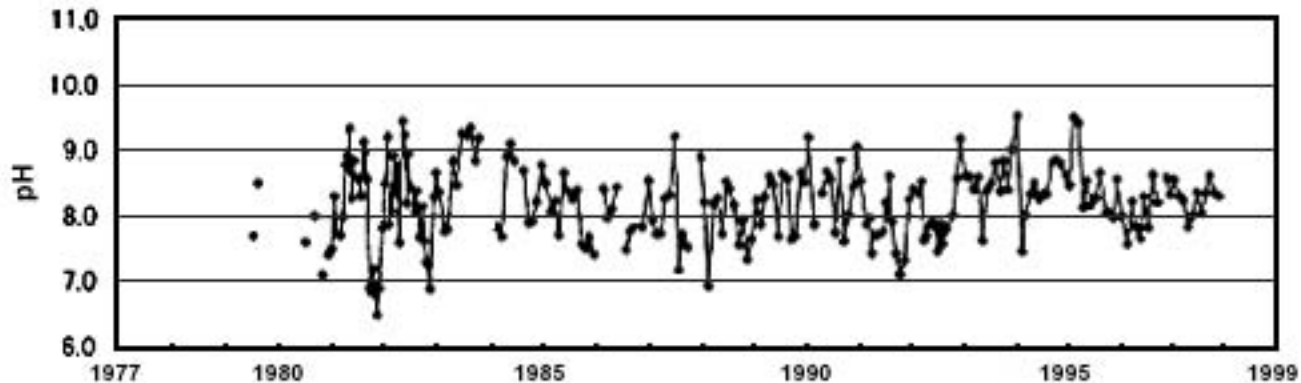


Fig.5 Interannual variation of pH at 4 m depth at St. 9.

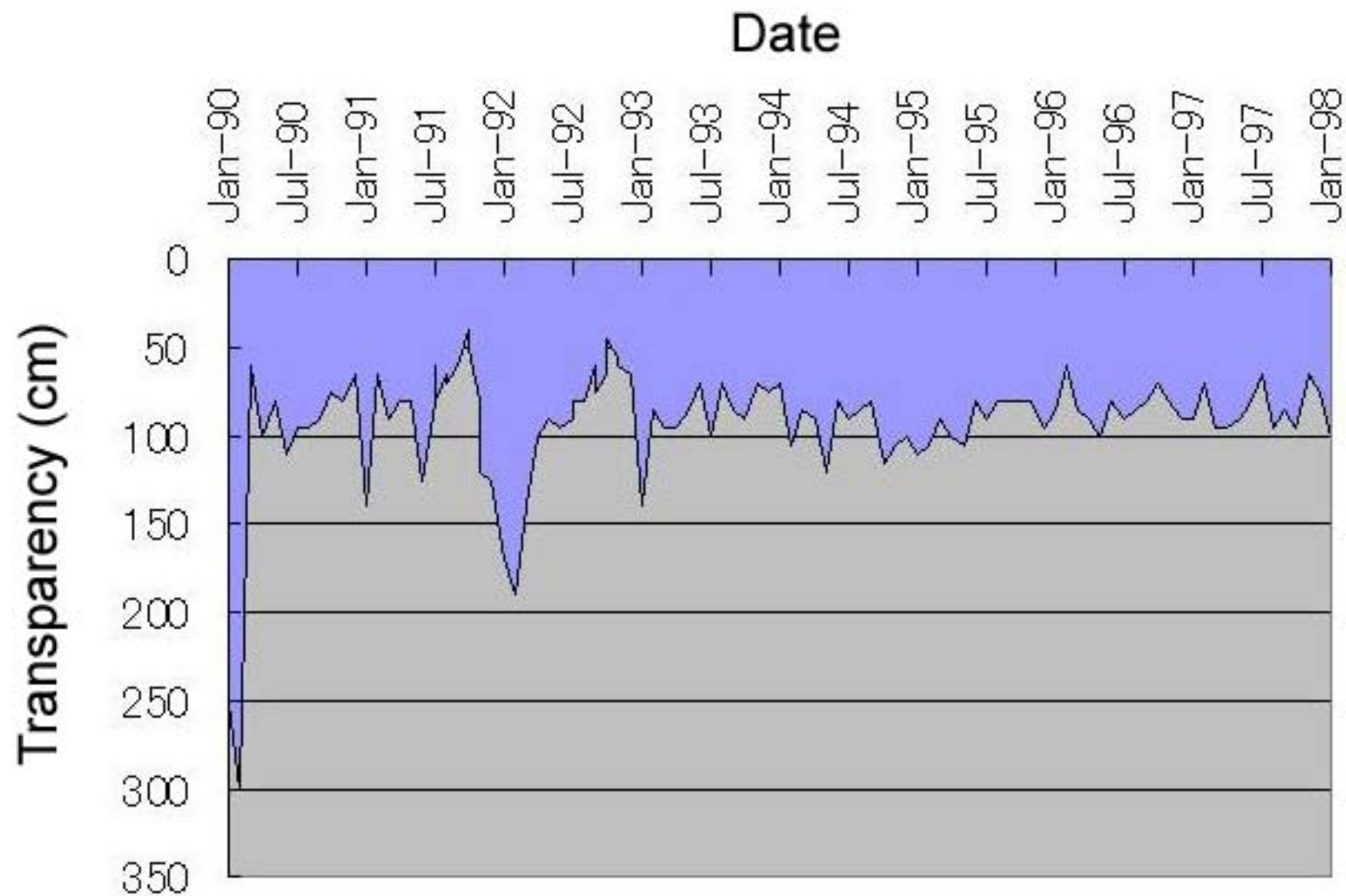


Fig.6 Variation of transparency in 1990-1998

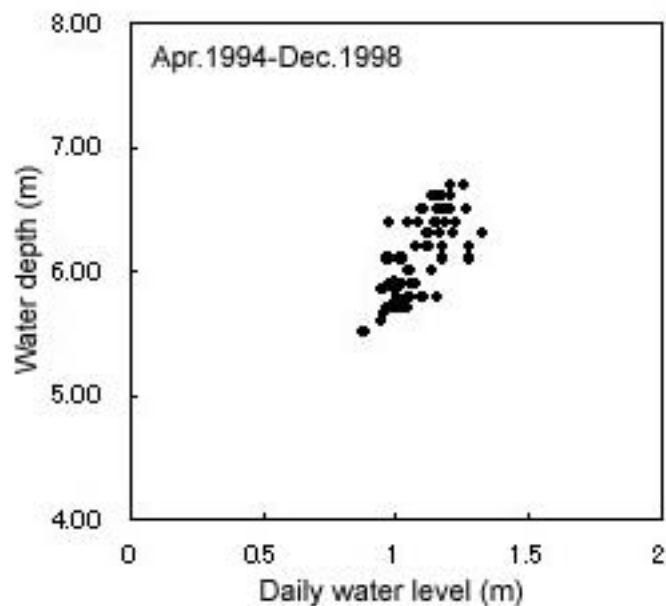
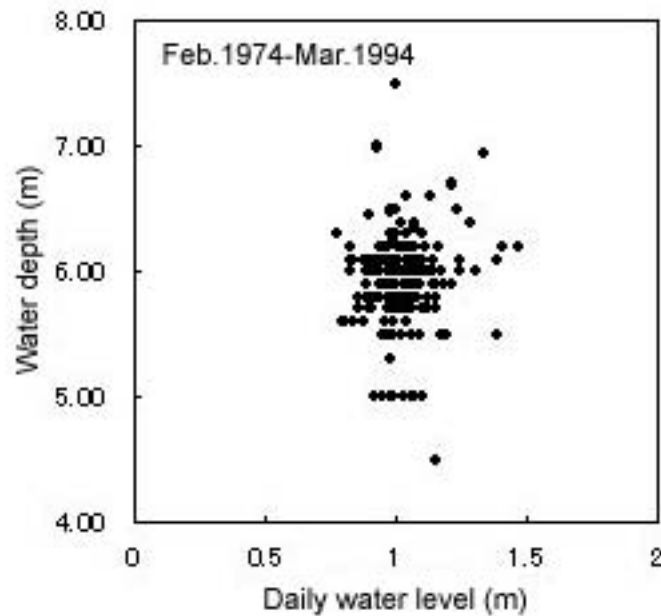


Fig.7 Relationships between the water level and the water depth at St. 9: the figure on the left showed data for the period before GPS was introduced, and the figure on the right for the period after GPS introduced.

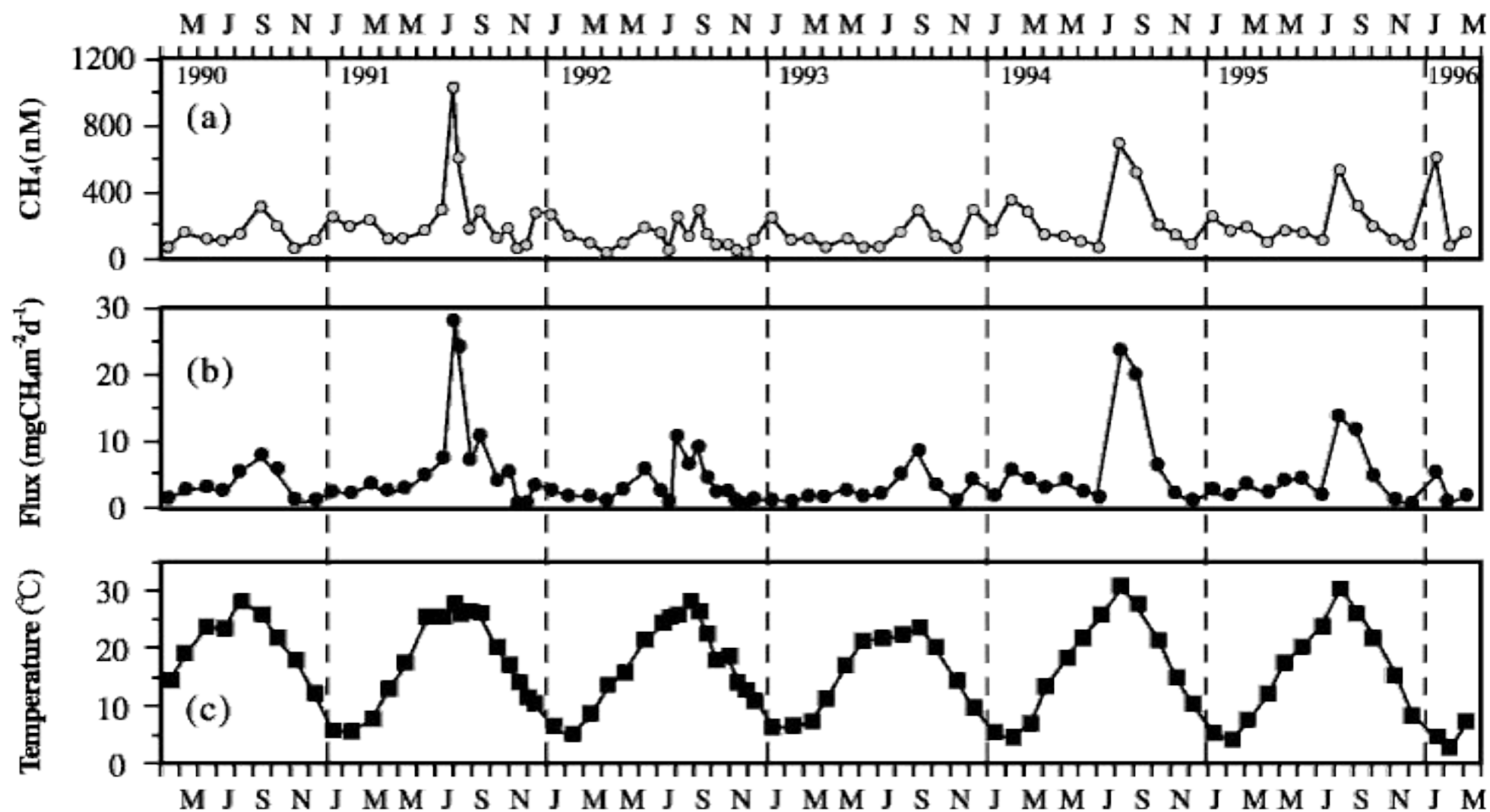


Fig.8 Variations of the concentration of dissolved methane, the flux of methane through lake surface, and the water temperature of Lake Kasumigaura. The values averaged over whole area of the lake are shown for the period from April 1990 to March 1996: (a) the concentration of dissolved methane (nM), (b) the emission of methane through lake surface due to gas exchange per unit area (mgCH₄/m²/day) (emission due to bubble generation is not included), and (c) the water temperature (°C).

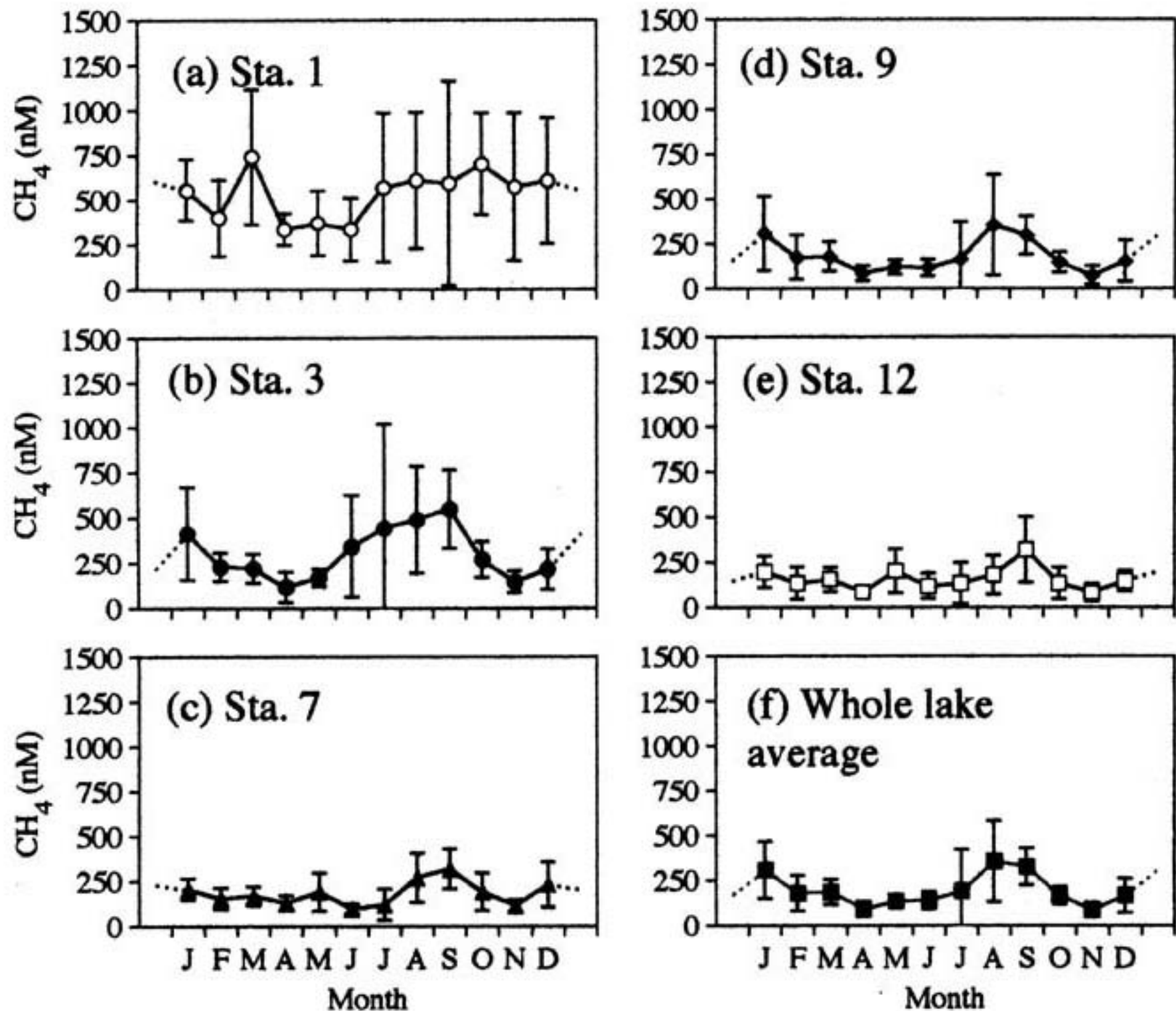


Fig.9 Monthly variation of the concentration of dissolved methane: the averaged value over water column (nM) is shown.

(a) is for St. 1 at the bay head of Takahama Inlet, (b) St. 3 in Takahama Inlet, (c) St. 7 in Tsuchiura Inlet, (d) St. 9 at the center of the lake, (e) St. 12 near the lake outlet, and mean value for whole area. Bars attached to data points indicate standard deviation (1σ) calculated from monthly observations during the 6 years period from April 1990 to March 1996.

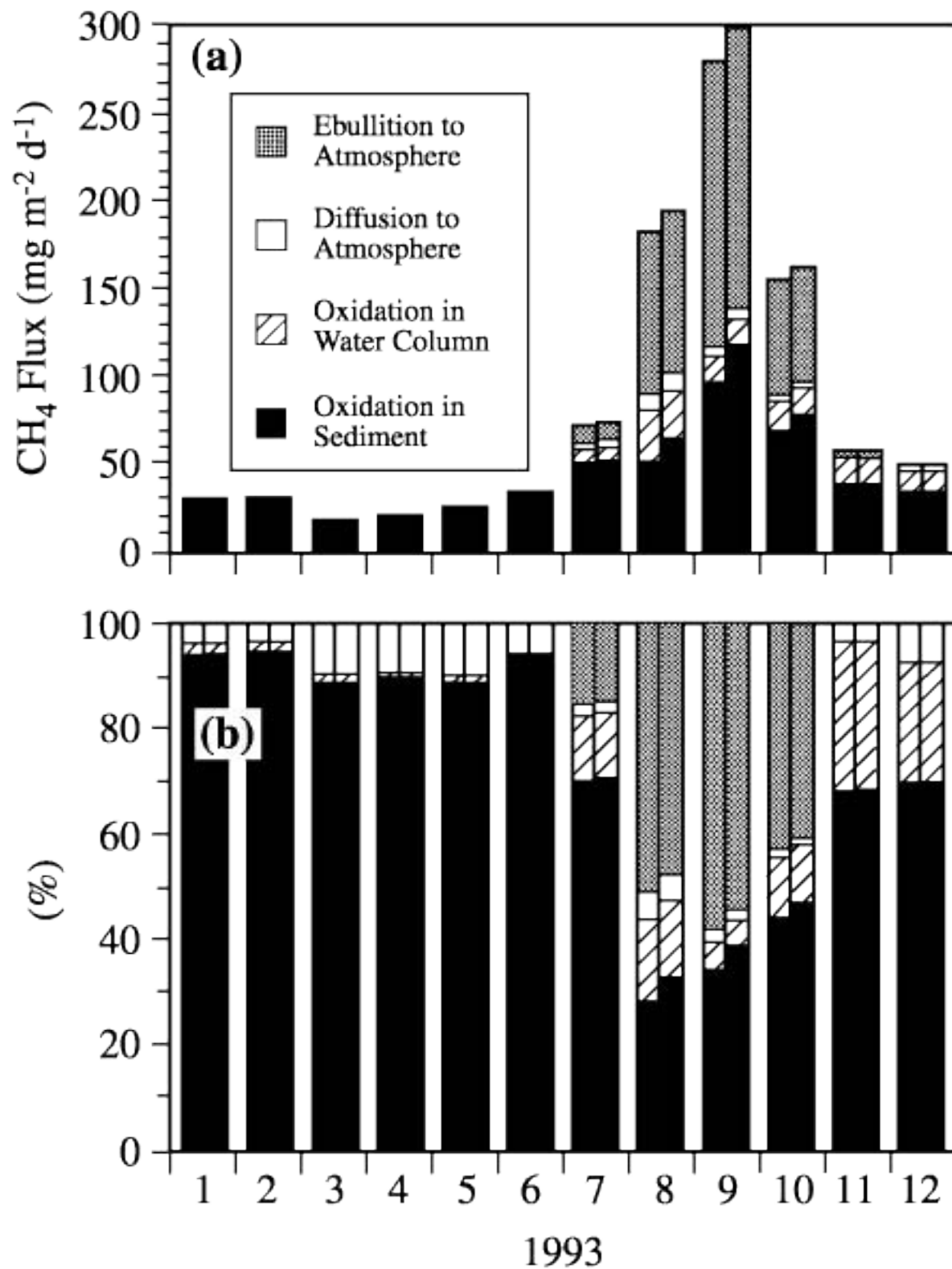


Fig.10 Estimated monthly values of generation, consumption, emission of methane of Lake Kasumigaura based on observed values in 1993: (a) the generation rate of methane ($\text{mgCH}_4/\text{m}^2/\text{day}$) in bottom sediment, which is obtained as a sum of oxidation at sediment surface, oxidation in water column, diffusion to atmosphere, and ebullition to atmosphere. As to the vertical bars shown for each month in the histograms, the left bar indicate the value obtained assuming that bubbles of methane generated at the bottom surface are not dissolved in water as they are coming up through the water column, and the right bar indicates that assuming that 12 % of the methane is dissolved into water column. The 12 % is the maximum dissolving rate estimated for Kasumigaura Lake. So, these two bars indicate two extreme estimations. (b) the ratio of dissipation of methane in the processes above mentioned.

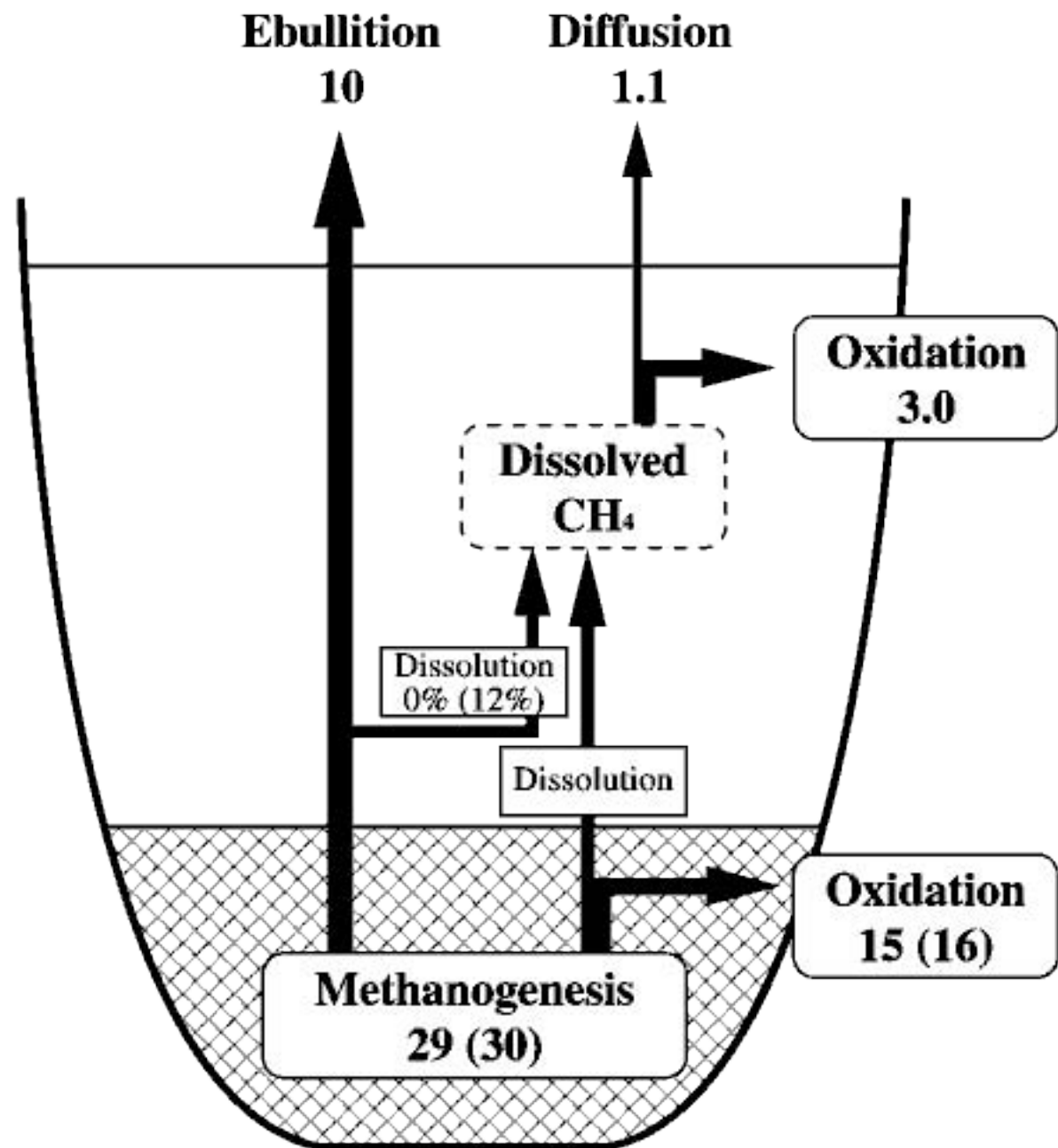


Fig.11 Schematic diagram of fate of methane in Lake Kasumigaura estimated from observations in 1993. The annual average is given in gCH₄/m²/year. Two extreme values are shown as same as in Fig. 3.5.3: for the case that no methane is dissolved in water column, and for the case 12% of methane is dissolved. The latter is shown in parenthesis. The total balance of methane for annual means is almost the same between for two cases.

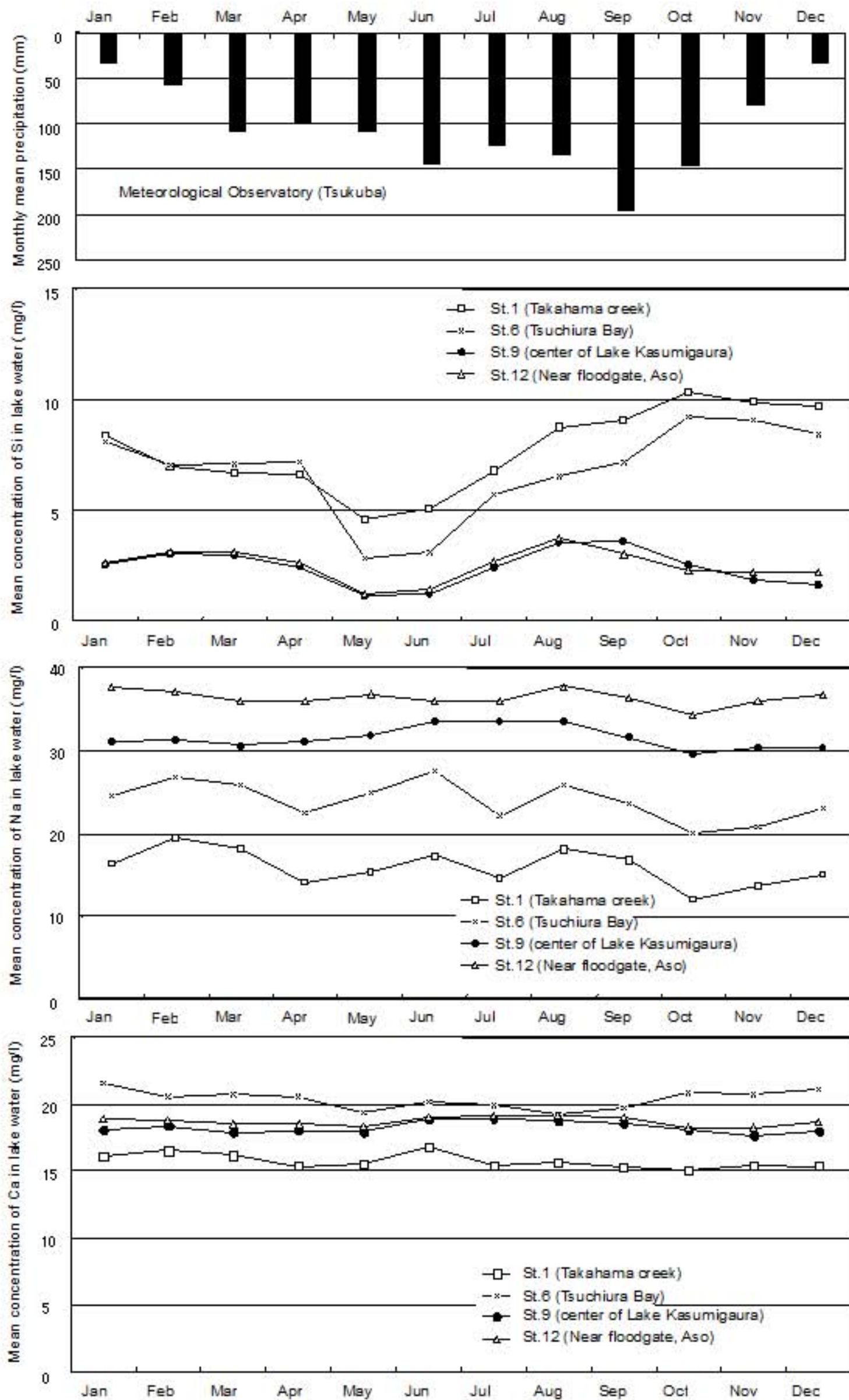


Fig.12 Seasonal variations of precipitation and concentration of Si, Na, and Ca at several monitoring points at Lake Kasumigaura for 17 years (April 1980 - March 1996).

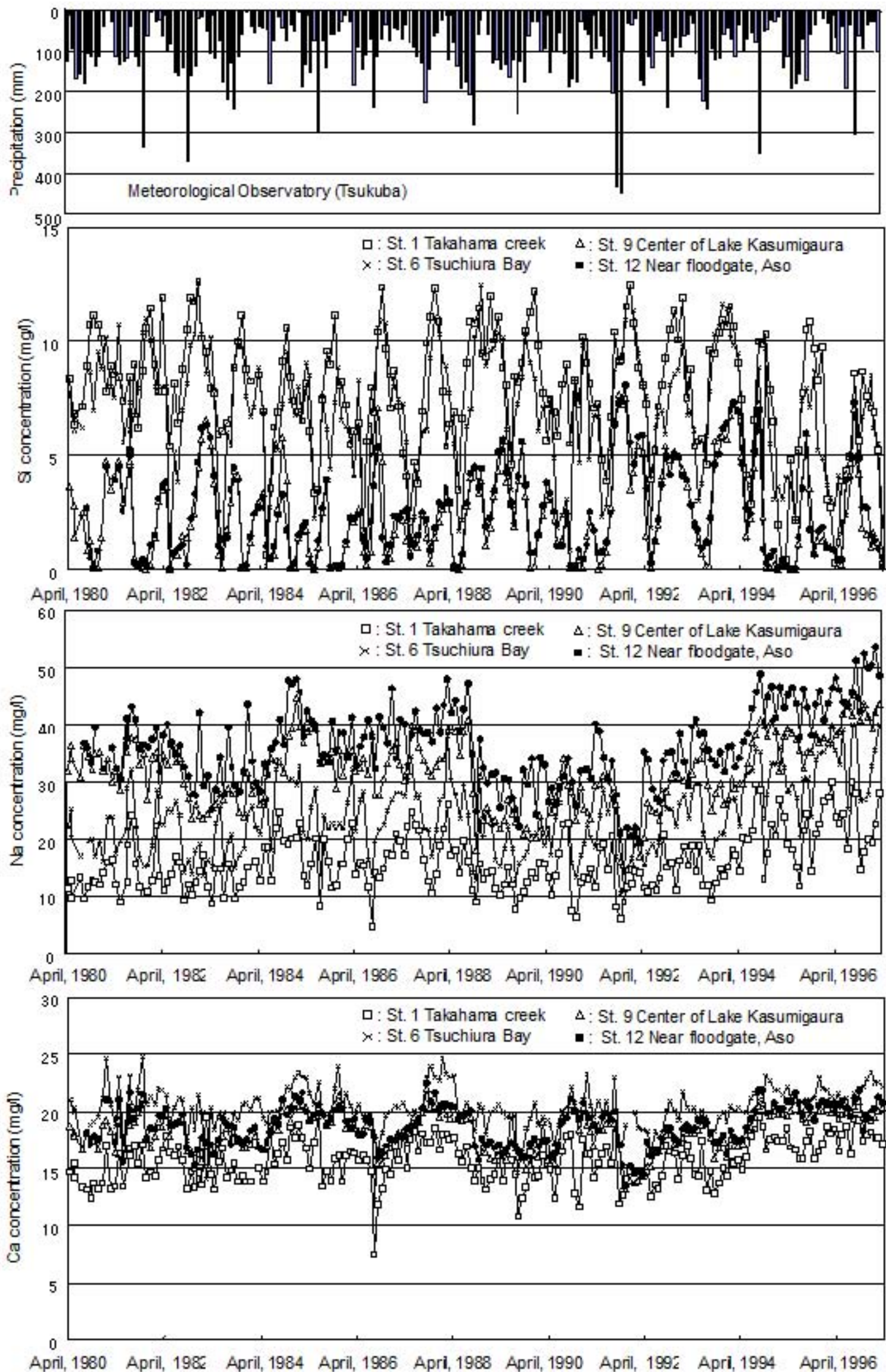
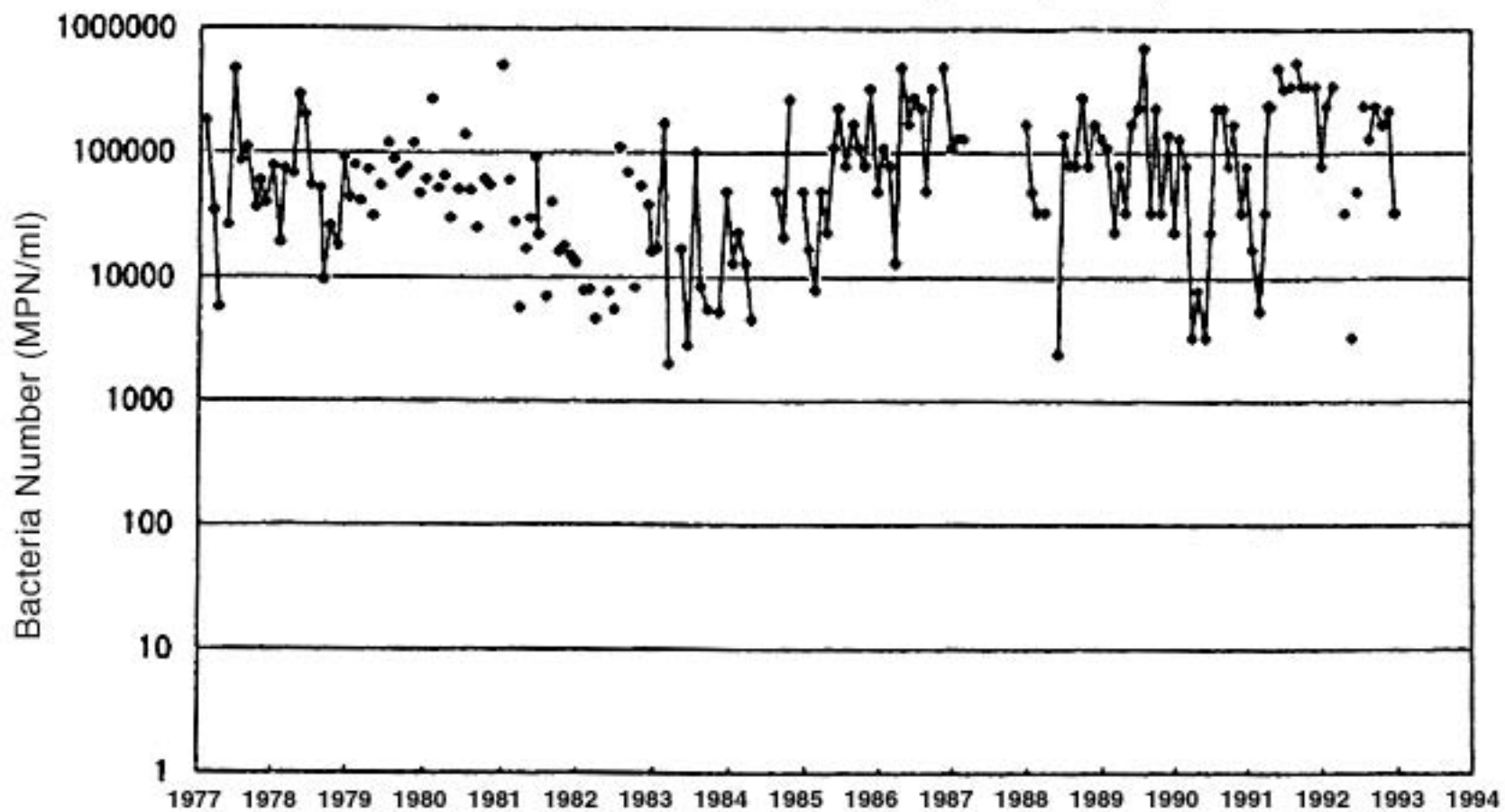


Fig.13 Temporal variations of precipitation and concentration of Si, Na, and Ca at several monitoring points at Lake Kasumigaura from April 1980 to March 1997.

Live Bacteria Number (St. 1, 0.5m)



Live Bacteria Number (St. 9, 0.5m)

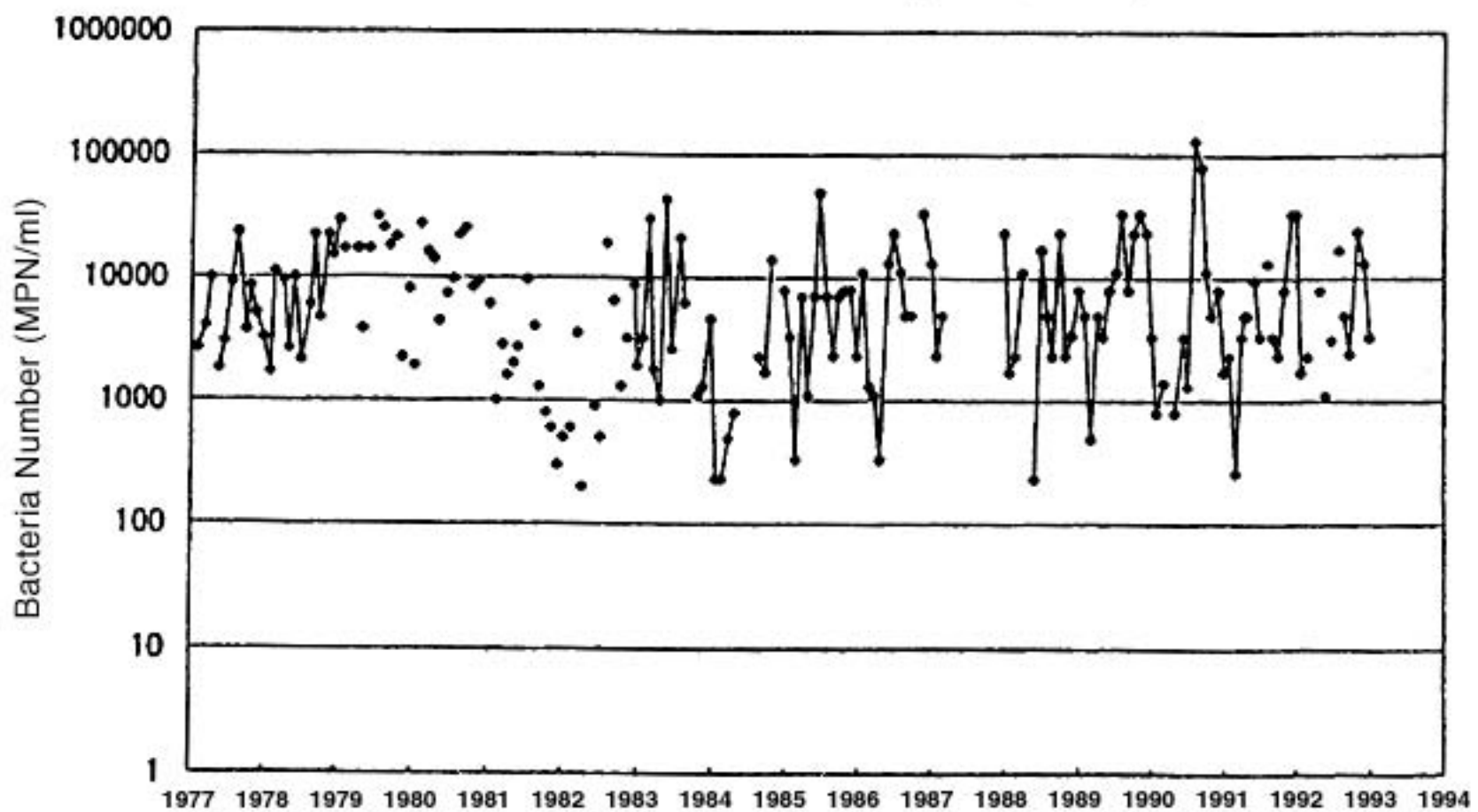


Fig.15 Yearly variation of total number of live bacteria in surface layer water at St.1 and St.9

Seasonal variation in community density of *Daphnia galeata* at Takahamairi Bay (St. 3)

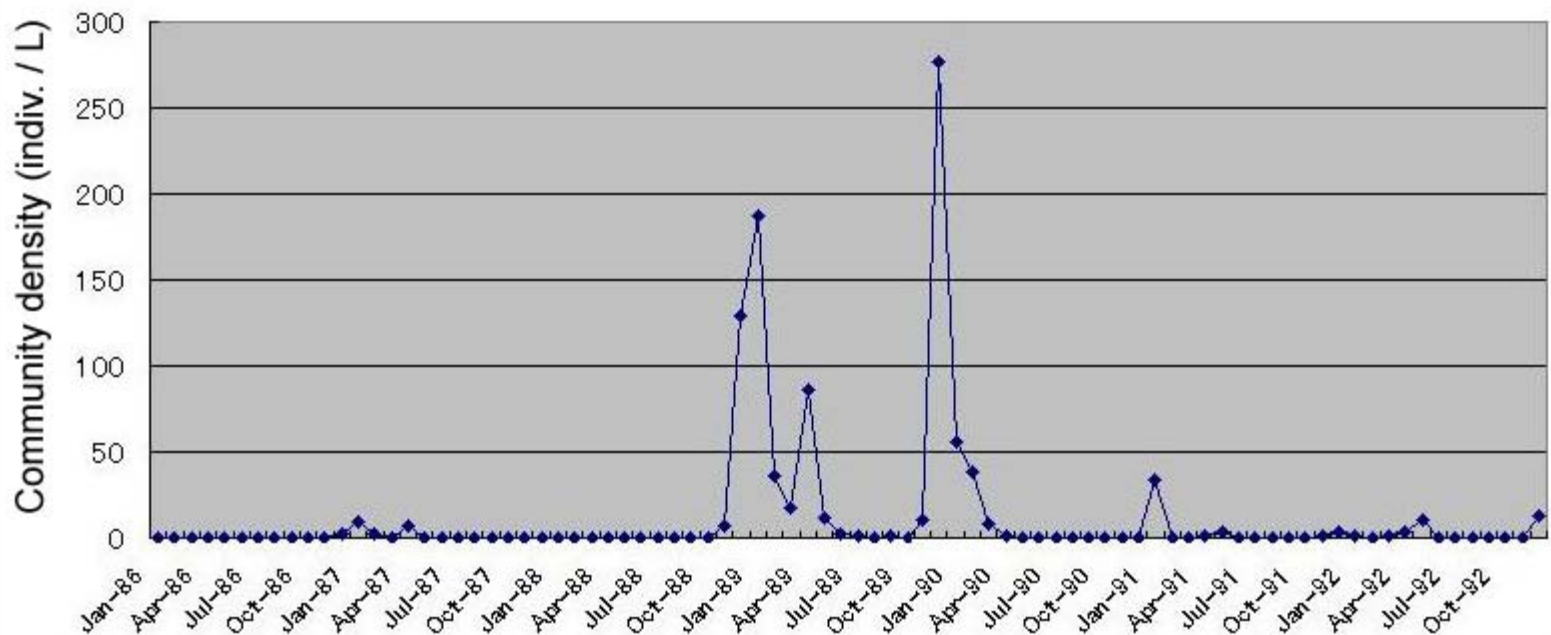


Fig 16 Seasonal variation in Community density of *Daphnia galeata* (St.3)

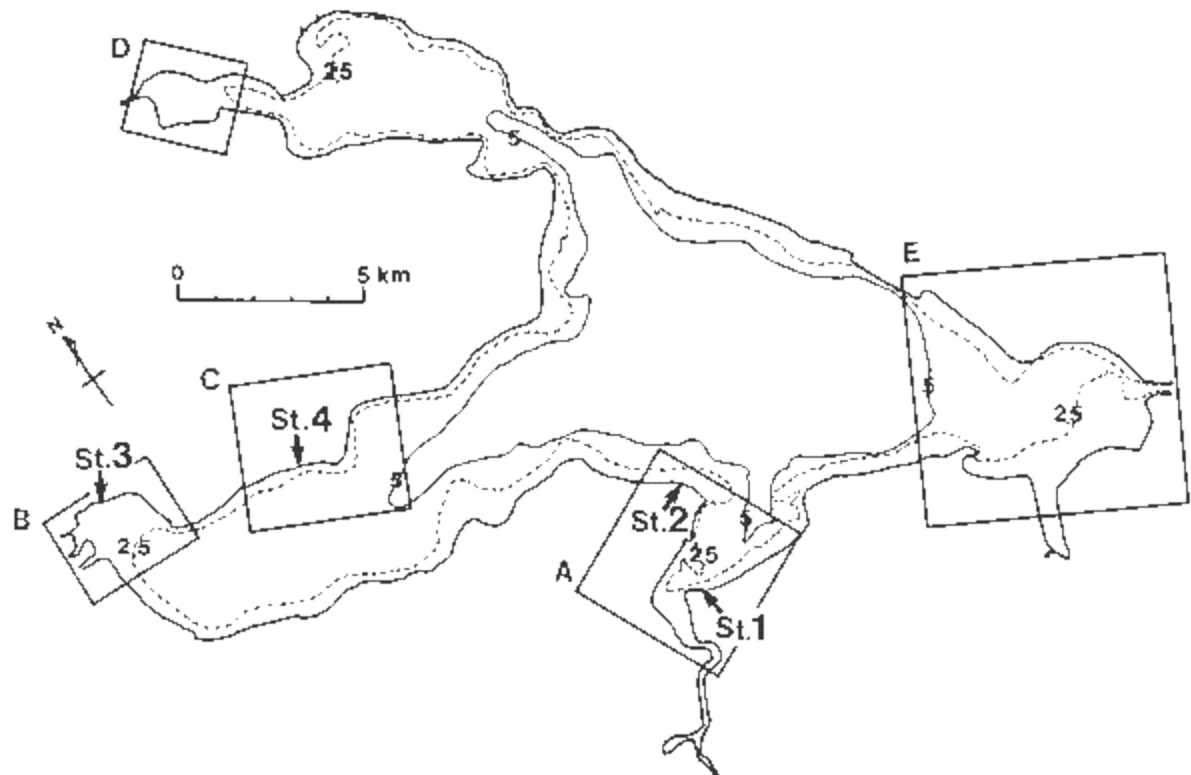


Fig.17 Location of study sites for lakeshore plants

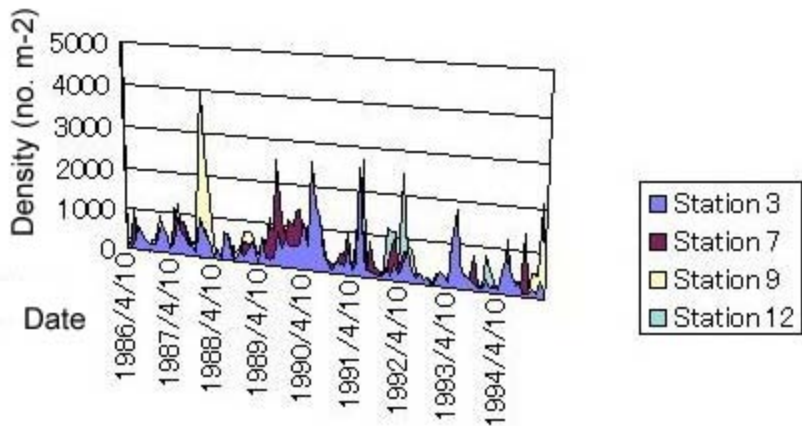


Fig. 18 Monthly variation of density of Chironomids

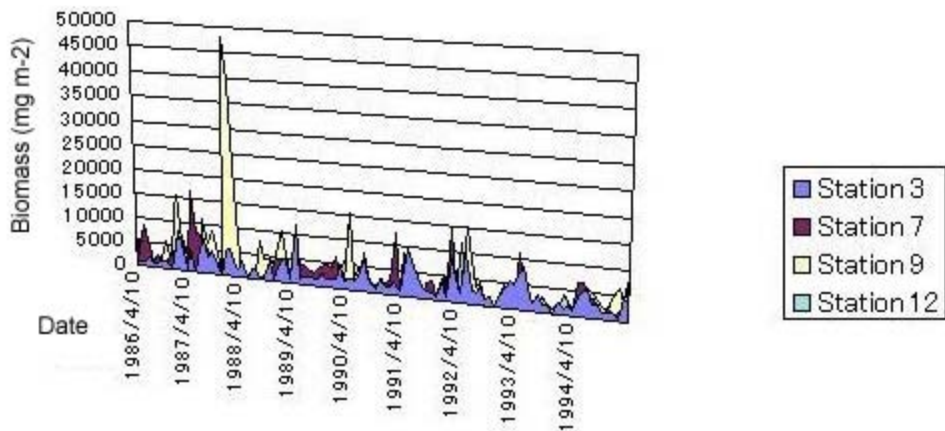


Fig.19 Monthly variation of biomass of Chironomids

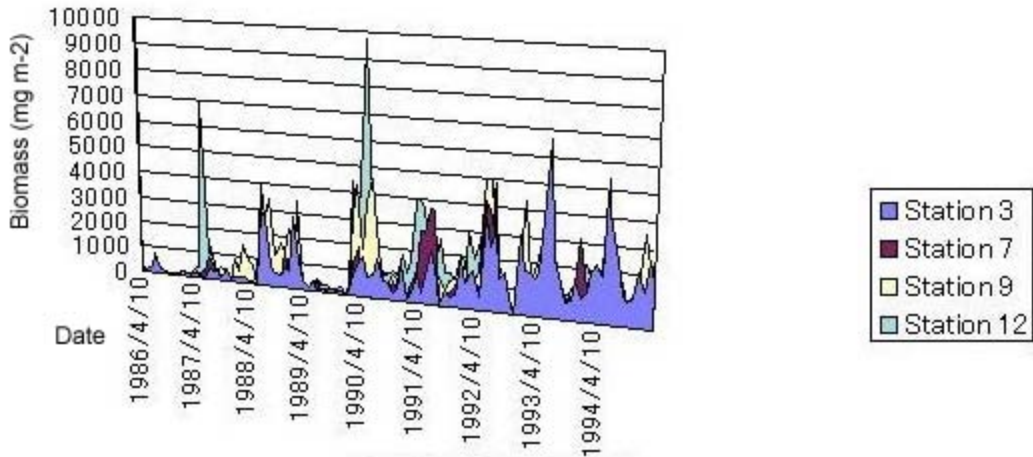


Fig.20 Monthly variation of biomass of Oligochaete

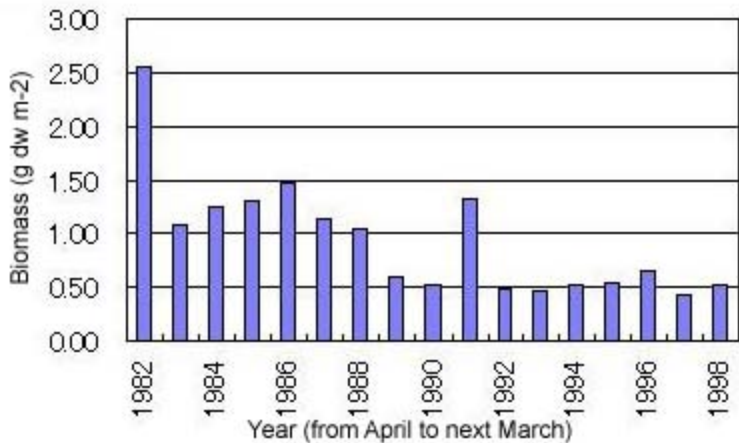


Fig.21 Variation of annual mean of biomass of Chironomids

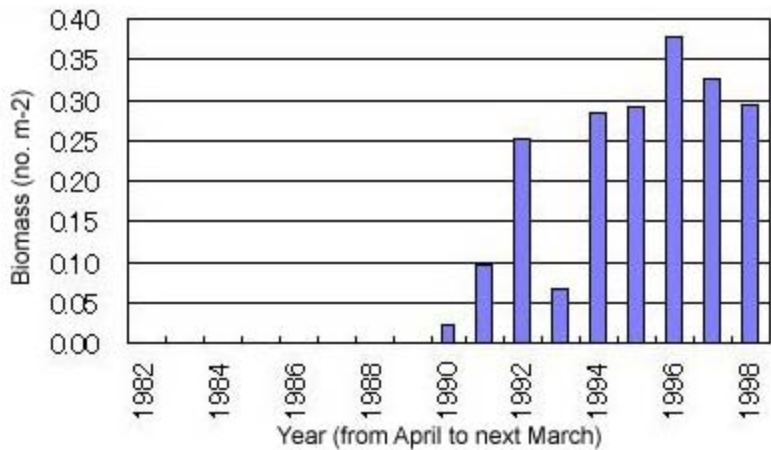


Fig.22 Variation of annual mean of biomass of Oligochaete

Table.1 Detection limits of each type of ICP-AES for various elements under routine analysis conditions.
 (μg/l) (Masataka Nishikawa)

	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Mg
Atomcomp 975	100	190	20	20	15	70	15	20	30	25	30	800	15
JY-48P	25	90	10	8	5	35	10	10	20	18	10	800	5
ICAP-750	70	150	15	10	10	50	10	18	20	20	20	700	10
	Mn	Mo	Na	Ni	P	Pb	Se	Si	Sr	Ti	V	Zn	
Atomcomp 975	20	50	150	50	700	100	200	100	10	15	25	25	
JY-48P	10	30	200	30	400	80	150	60	10	10	20	20	
ICAP-750	15	30	150	40	500	80	150	70	10	10	25	20	

Table.2 Results of repeated measurements of the standard solutions (0 and 10 mg/l) for various elements. (Masataka Nishikawa)

Measurement term	(mg/l)	Al		B		Ba		Ca		Fe		K	
		0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l
1980, Apr.- 1992, Oct.	Av.	0.0062	9.98	0.0003	10.1	0.0009	10.0	0.0164	10.0	0.0008	10.0	0.0231	10.1
	S.D.	0.0133	0.214	0.0031	0.224	0.0012	0.200	0.0359	0.209	0.0037	0.215	0.0867	0.272
	3×S.D.	0.0398	0.642	0.0093	0.671	0.0035	0.601	0.108	0.626	0.0112	0.646	0.260	0.816
	R.S.D.%		2.14		2.22		2.00		2.08		2.15		2.71
1992, Nov.- 1994, Dec.	Av.	0.0003	10.1	0.0001	9.91	-0.0003	9.97	0.0062	10.0	0.0001	9.95	0.0012	9.98
	S.D.	0.0008	0.161	0.0023	0.179	0.0007	0.131	0.0112	0.158	0.0010	0.121	0.0725	0.192
	3×S.D.	0.0024	0.484	0.0070	0.538	0.0022	0.394	0.0335	0.475	0.0031	0.364	0.217	0.577
	R.S.D.%		1.60		1.81	0.0108	1.32		1.58		1.22		1.92
1995, Jan.- 1997, Mar.	Av.	0.0002	10.0	-0.0002	9.92	0.0001	9.96	0.0028	9.98	-0.0007	9.98	0.0169	10.0
	S.D.	0.0049	0.217	0.0018	0.165	0.0014	0.135	0.0097	0.0915	0.0020	0.0831	0.0725	0.162
	3×S.D.	0.0148	0.652	0.0054	0.495	0.0042	0.405	0.0291	0.274	0.0061	0.249	0.217	0.487
	R.S.D.%		2.17		1.66		1.36		0.917		0.832		1.62
	(mg/l)	Mg		Mn		Na		Si		Sr			
		0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l	0-Base	10mg/l		
1980, Apr.- 1992, Oct.	Av.	0.0034	9.99	0.0003	10.0	0.0176	9.98	0.0116	10.1	0.0003	10.0		
	S.D.	0.0089	0.232	0.0028	0.227	0.0271	0.242	0.0348	0.230	0.0016	0.158		
	3×S.D.	0.0267	0.695	0.0083	0.680	0.0813	0.727	0.104	0.690	0.0048	0.473		
	R.S.D.%		2.32		2.27		2.43		2.29		1.57		
1992, Nov.- 1994, Dec.	Av.	0.0012	10.0	0.0001	9.98	0.0130	10.0	-0.0004	9.90	0.00004	10.0		
	S.D.	0.0015	0.138	0.0003	0.129	0.0145	0.160	0.0042	0.203	0.0002	0.199		
	3×S.D.	0.0046	0.413	0.0009	0.388	0.0436	0.480	0.0125	0.608	0.0006	0.596		
	R.S.D.%		1.37		1.30		1.60		2.29		1.98		
1995, Jan.- 1997, Mar.	Av.	0.0010	10.0	0.0002	9.98	0.0051	9.95	0.0023	9.93	0.0004	9.94		
	S.D.	0.0018	0.125	0.0019	0.116	0.0108	0.128	0.0059	0.115	0.0008	0.139		
	3×S.D.	0.0054	0.375	0.0056	0.349	0.0324	0.385	0.0178	0.345	0.0024	0.417		
	R.S.D.%		1.25		1.16		1.29		1.16		1.40		

*The period is divided into three according to the type of ICP-AES used: Plasma Atomcomp 975 (Apr. 1980 - Oct. 1992), JY-48P (Nov. 1992 - Dec. 1994) and ICAP-750 (Jan. 1995 - Mar. 1997).

*Av. indicates the average, S.D. the standard deviation, and R.S.D. the relative standard deviation (=S.D./Av.). The results show the stability of the measurements in each period.

b) Variation of annual mean of biomass and density of benthos for 8 years from April 1990 to March 1998

	Year (April - March)	Density of Chironomids (no m ⁻²)								Biomass of Chironomids (mg m ⁻²)								Biomass of Oligochaete (mg m ⁻²)							
		Station 3		Station 7		Station 9		Station 12		Station 3		Station 7		Station 9		Station 12		Station 3		Station 7		Station 9		Station 12	
		mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw	mg ww	mg dw
<i>annual mean</i>	1990	344		289		283		65		2080	395	3325	632	4861	924	706	134	133	25			91	17		
<i>annual mean</i>	1991	478		506		1065		742		4071	774	5310	1009	13549	2574	4947	940	233	44	301	57	588	112	922	175
<i>annual mean</i>	1992	308		329		382		151		2384	453	1920	365	5191	986	603	115	1179	224	698	133	2070	393	1367	260
<i>annual mean</i>	1993	462		1040		151		341		2778	528	3910	743	1738	330	1540	293	212	40	239	45	359	68	579	110
<i>annual mean</i>	1994	762		711		165		356		2417	459	4033	766	2741	521	1669	317	838	159	645	123	1757	334	2751	523
<i>annual mean</i>	1995	402		614		96		600		3903	742	4128	784	1695	322	1663	316	1000	190	1765	335	1168	222	2188	416
<i>annual mean</i>	1996	264		279		315		390		3749	712	2574	489	4656	885	2628	499	1932	367	1562	297	2360	448	2103	400
<i>annual mean</i>	1997	420		355		185		256		3345	636	2230	424	2151	409	1405	267	2072	394	1204	229	1769	336	1815	345
<i>annual mean</i>	1998	298		382		498		281		2993	569	2659	505	4009	762	1352	257	2178	414	744	141	2014	383	1272	242

c) Annual mean of density and biomass of benthos. Mean value is calculated for each year from April to next March.

Dry weight is 0.19 times of wet weight.

Year (April - March)	Density of Chironomids (no m ⁻²)					Biomass of Chironomids (mg dry weight m ⁻²)					Biomass of Oligochaete (mg dry weight m ⁻²)				
	3	7	9	12	Lake	3	7	9	12	Lake	3	7	9	12	Lake
1990	344	289	283	65	245	0.40	0.63	0.92	0.13	0.52	0.03		0.02		0.02
1991	478	506	1065	742	698	0.77	1.01	2.57	0.94	1.32	0.04	0.06	0.11	0.18	0.10
1992	308	329	382	151	293	0.45	0.36	0.99	0.11	0.48	0.22	0.13	0.39	0.26	0.25
1993	462	1040	151	341	498	0.53	0.74	0.33	0.29	0.47	0.04	0.05	0.07	0.11	0.07
1994	762	711	165	356	498	0.46	0.77	0.52	0.32	0.52	0.16	0.12	0.33	0.52	0.28
1995	402	614	315	600	483	0.74	0.78	0.32	0.32	0.54	0.19	0.34	0.22	0.42	0.29
1996	264	279	245	390	295	0.71	0.49	0.88	0.50	0.65	0.37	0.30	0.45	0.40	0.38
1997	420	355	185	256	304	0.64	0.42	0.41	0.27	0.43	0.39	0.23	0.34	0.34	0.33
1998	298	382	498	281	365	0.57	0.51	0.76	0.26	0.52	0.41	0.14	0.38	0.24	0.29
<i>9years mean</i>	<i>415</i>	<i>500</i>	<i>366</i>	<i>354</i>	<i>409</i>	<i>0.59</i>	<i>0.64</i>	<i>0.86</i>	<i>0.35</i>	<i>0.61</i>	<i>0.21</i>	<i>0.17</i>	<i>0.26</i>	<i>0.31</i>	<i>0.22</i>
<i>Mean wet weight(mg ww/m2)</i>						<i>3061</i>	<i>3332</i>	<i>4416</i>	<i>1817</i>	<i>3157</i>	<i>1086</i>	<i>895</i>	<i>1344</i>	<i>1622</i>	<i>1237</i>

d) Variation of annual mean of biomass of benthos in Lake Kasumigaura.

For each year, mean value is calculated using data from April to next March.

Data is sited from Iwakuma (1990)

	Annual mean (g dw m ⁻²)	
	Chironomids	Oligochaete
1982	2.55	
1983	1.09	
1984	1.25	
1985	1.30	
1986	1.48	
1987	1.14	
1988	1.04	
1989	0.60	
1990	0.52	0.02
1991	1.32	0.10
1992	0.48	0.25
1993	0.47	0.07
1994	0.52	0.28
1995	0.54	0.29
1996	0.65	0.38
1997	0.43	0.33
1998	0.52	0.29