Long-Term Monitoring of Nutrients, Plankton and Benthos in Lake Kasumigaura

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INTRODUCTION

Lake Kasumigaura is the second largest lake (171 km^2) in Japan, and is shallow and eutrophic. As the lake is situated close to the metropolitan area, the water resources of the lake have been used for various kinds of human activities, and as a result, the lake has suffered from a lot of human impacts. No plankton research and monitoring were conducted in the lake in the 1960s when the eutrophication process was rapid and intense water blooms began to occur every summer in the 1970s.

The National Institute for Environmental Studies (NIES, including 178 research scientists in 1995) is the only institute which belongs to Japan Environment Agency and was established in 1974 in Tsukuba to study all kinds of pollution and the environmental impacts. Since the control of eutrophication of Japanese lakes was one of the most important environmental research subjects to be solved then, the NIES had conducted research programs on lake environments for 10 years entitled 'Comprehensive studies on the eutrophication of freshwater areas' from 1978 to 1979; 'Comprehensive studies on the eutrophication control of freshwaters' from 1980 to 1982 and 'Comprehensive studies on effective use of natural ecosystems for water quality management' from 1983 to 1986. More than 35 NIES scientists with various backgrounds studied in these projects, and approximately 10 scientists who studied on the nutrient dynamics and functioning of the ecosystem of Lake Kasumigaura, began monthly or biweekly monitoring of water quality, plankton and zoobenthos in Lake Kasumigaura in 1976 as a part of these large research projects. The monitoring has been continued through the personal efforts of each researcher although without enough

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a part of the Global Environment Monitoring System Program (GEMS/Water) by Center for Global Environment Research (CGER) of NIES.

In the present paper, we summarize results of approximately 20 years of monitoring as well as geography, history and human impacts of this field, and future perspectives, including several problems that will continue to be monitored.

GEOGRAPHICAL DESCRIPTION OF LAKE KASUMIGAURA WITH CLIMATE INFORMATION

Lake Kasumigaura (= Lake Nishiura) is located in the eastern Kanto plain (35°52'N–36°9'N, 140°13'E–140°38'E). Fig. 1 shows a contour map of Lake Kasumigaura with 10 sampling stations. The lake lies only 16 cm above sea level. The maximum depth is 7.0 m and the mean depth is 3.9 m. The volume is 662 million m^3. The catchment area (including lake surface area) is 1597 km^2. The lake has 29 inflows of varying sizes and one major outflow. Annual mean air temperature at Tateno Meteorological Station (approx. 20 km from Tsuchiura Harbor) these 20 years varied from 12.2 to 14.5°C.

Annual mean water temperature at 0.5 m depth at the center of main basin (near Sta. 9) from 1977 to 1995 varied from 15.2 to 17.1°C (Ministry of Construction). Annual maximum and minimum values of water temperature during 1977 to 1995 varied from 26.0 (1980) to 31.1°C (1994) and from 1.7 (1984) to 5.7°C (1989), respectively (Ministry of Construction). Annual precipitation at Tateno Meteorological Station these 20 years varied from 772.5 to 1,839.5 mm $year^{-1}$. The maximum daily global solar radiation at Tateno Meteorological Station from 1981 to 1995 was 33.64 MJ m^{-2} recorded in June 1987 and the minimum was 0.80 MJ m^{-2} recorded in February 1983.

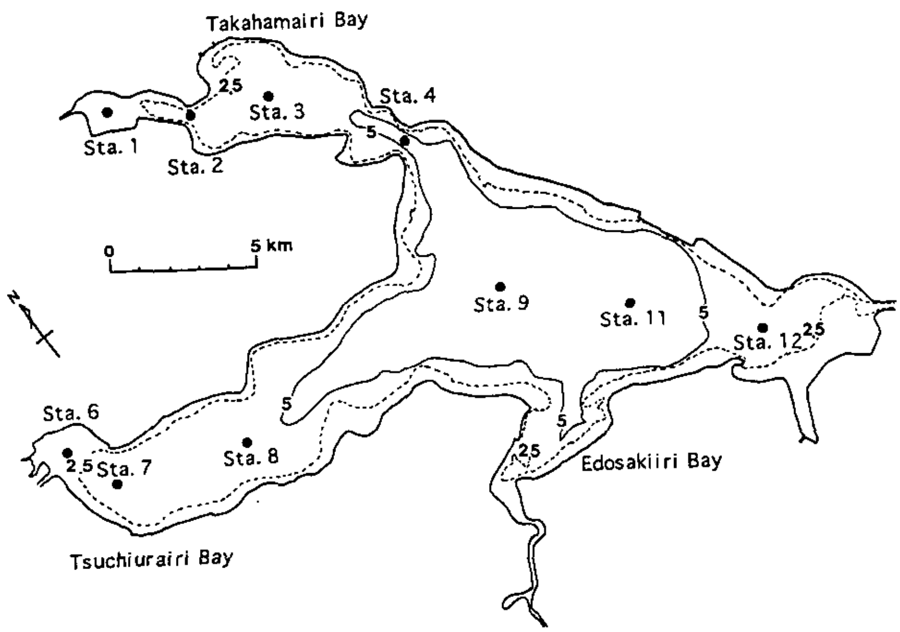

Fig. 1. Map of Lake Kasumigaura showing depth contours in meters and sampling sites.

Annual maximum values of monthly average global solar radiation were recorded during April to August varying from 1695 (1986) to 2,036 (1982) MJ m^{-2} and annual minimum values were recorded during the period November to January, varying from 722 (1982) to 1,027 (1994) MJ m^{-2}.

HISTORY OF LAKE KASUMIGAURA: MANAGEMENT AND HUMAN IMPACTS

The 'Kasumigaura' area was part of a large coastal inlet open to the Pacific Ocean about 6,000 years ago. The inlet was blocked by shifts in the height of a sill due to sediments deposited by the rivers in the middle of the Edo era (17th Century). According to Aizaki (1991), the social environment of Lake Kasumigaura over the past 100 years is divided into 3 periods. During the first period (~1945), the fishery was prosperous with steady annual catch of pond smelt and Japanese whitebait. A unique sail trawling called 'Hobikiami' was used to catch fish. Transportation by waterway was active, and famous towns were developed around the lake. Reclamation project were started in 1921, and created 524 ha of new paddy fields in this period. Several big floods also occurred in this period.

The fisheries and reclamation projects remained active during the second period (1945–1963), however water transportation almost disappeared as land transportation systems were developed. Water quality became more brackish during this period due to the dredging of the outflowing Hitachigawa River for flood control in 1948. As a result, the use of salty water for irrigation damaged agricultural land in many places. Construction of the Hitachigawa Water Gate was started in 1959, 0.5 km upstream of the confluence of the Hitachigawa and Tone Rivers, both to control floods and to prevent damage to agricultural lands from the intrusion of brackish water. The Water Supply Work for domestic use was started in 1961 in Lake Kasumigaura, but the filtration plant has been affected by sedimentation, filter clogging and odor tastes of tap water.

In 1963, the Hitachigawa Water Gate was completed and the gate was closed completely in 1973. The chlorine concentrations of lake water were 100–400 mg l^{-1} before 1976, but has decreased below 70 mg l^{-1} since 1976 (unpublished data, Ibaraki Prefecture Government). The fishery in the lake also changed; the pen culture of carp was started in 1963, and the trawling changed from using natural winds to using gasoline motors in 1965. The fish catch increased to reach 18,000 tons in 1978, but has continued to decline since then. Production of carp in pens was 3,000 tons in 1973, increased to 8,500 tons in 1982, decreased to 5,000 tons in 1986 and as maintained at 6,000 tons from 1987 to 1994. Reclamation was suspended in 1975. Total reclaimed area amounted to 1884 ha, equivalent to 11% of the present surface area. The comprehensive development project of Lake Kasumigaura was started in 1968 for flood control and water resource development, and dike construction of Y.P.+3.00 m (Y.P.; Yedogawa Peil, and Y.P. 0 m = -0.84 m of mean tide level of Tokyo Bay) had been completed all around the lake by 1995. Ministry of construction has controlled the water level of the lake at Y.P. +1.30 m since 1996, but has decided to keep lake levels 20 cm lower than usual from April to October for conservation of remaining emergent macrophytes. Littoral zones of the lake have been destroyed because of the reclamation and the dike construction. The water conveyance project (1976–2000) is ongoing for further water resource supply to Ibaraki, Chiba, Saitama and Tokyo Prefectures, and ministry of construction are now constructing 2 long raceways (4.0 to 4.5 m in diameter) which connect Lake Kasumigaura with the Tone River (2.6 km long) and the Naka River (42.9 km long), respectively.

The eutrophication process had proceeded rapidly in the late 1960s and the early 1970s. Ibaraki Prefecture Government recorded that heavy waterblooms had been observed since 1968, and that 1,349 tons of carp in pens were killed by O_2 shortage in 1973. The population in the catchment area was about 60 million until 1968, and increased linearly to reach 95.7 million in 1995. Sanitary facilities and sewerage have operated since 1978. At present (1995) 31.5 million people use the sewerage, 10.5 million people use the conventional domestic wastewater treatment system (Johkaso), 22.1 million people use the old type Johkaso which treats only night soil and 28.9 million people use the classic treatment of raw sewage. Percentage distribution of phosphorus loadings to the lake in 1995 was 46.1% of domestic sewege, 19.3% of pen culture, 7.7% of factories, 4.9% of livestock industry, and 22.1% of non-point sources. Percentage distribution of land use in the catchment area in 1995 was 10.3% of lake, 40.5% of forests, 13.3% of towns, 20.2% of paddy fields and 15.7% of plowed fields and orchard. The percentage of towns has increased from 4.4% (1980) to 13.3% (1995) in these 16 years.

For countermeasures to prevent pollution and eutrophication of Japanese waters, Japanese government established Law for Water Pollution Control in 1970 and determined some environmental criteria. The chemical oxygen demand (COD) value of Lake Kasumigaura was determined to be less than 3 mg l^{-1} in 1972, since the lake water was used for drinking. The government also determined criteria of waste waters from point sources, but these criteria did not contain the nitrogen and phosphorus. Law to control nitrogen and phosphorus loadings to Lake Kasumigaura was established in 1981 by Ibaraki Prefecture Government. Lake Kasumigaura was designated as one of special lakes in Japan by Japan environment agency in 1985, and various kinds of countermeasures to improve water quality have been proceeded since then. The 6th International Lake Environment Committee (ILEC) meeting was held by Ibaraki Prefecture Government in 1995. For a countermeasure for lake restoration, 0.78 million m^3 and 2.1 million m^3 of sediments, mainly in Tsuchiurairi Bay were dredged during 1975 to 1991 and during 1992 to 1995, respectively, and 5.12 million m^3 of sediments is planned to dredge during 1996 to 2000 for water restoration (Ibaraki Prefecture Government).

OUTLINE OF THE RESEARCH

Sampling sites and sampling methods changed slightly during the 20 years monitoring (1976–1996), but mostly we surveyed as follows. The water samples from 1976 to 1980 were collected at 0.5 m depth with a Van-Dorn sampler, and those since 1981 have been collected with a column sampler from 0 to 2 m depth. The variables measured on ship are vertical profiles of water temperature, dissolved oxygen, pH, underwater irradiance (at all stations during 1976–1986 and at Stas. 3, 7, 9 and 12 from 1987) and Secchi disc transparency. Concentrations of NH_4-N, NO_2-N, NO_3-N, PO_4-P, dissolved total nitrogen (1981–), dissolved total phosphorus, total nitrogen (1981–), total phosphorus, Si (1980–), chlorophyll *a* (chl*a*), suspended solid (SS), particulate organic carbon (POC), particulate organic nitrogen (PON), total COD and dissolved COD of the water are also measured. The above data and density of heterotrophic bacteria, total bacteria and primary production from 1976–1992 were published by NIES (Goda, 1979; Aizaki *et al.*, 1981, 1984, 1988, 1990; Ebise *et al.*, 1994). Characteristics of nutrients, chlorophyll *a* and particulate organic matter and some related subjects were reported in Aizaki and Otsuki (1987), Aizaki and Takamura (1991), Ebise (1987), Fukushima *et al.* (1987, 1991), Hashimoto *et al.* (1993), Hosomi and Sudo (1987, 1992), Otsuki and Takamura (1988) and Otsuki *et al.* (1981, 1987, 1993, 1994). Heterotrophic bacteria (Aizaki, 1987) was counted at all stations during 1976–1986 and at Stas. 1, 3, 7, 9 and 12 during 1987–1992. Total bacteria was counted at all stations during 1976–1982 and at Stas. 1, 3, 7, 9 and 12 in 1983 and 1987. Total bacteria, picocyanobacteria, heterotrophic nanoflagellates and ciliates has been counted at Stas.3 and 9 since 1996.

Abundance and/or biomass of phytoplankton species has been studied at Stas. 3 and 9 since 1978 (Takamura *et al.*, 1987; Takamura and Watanabe, 1987; Takamura and Aizaki, 1991). Primary production was measured with light-dark bottle O_2 techniques at Stas. 1, 2, 3, 4, 7, 9 and 12 during 1976–1979, and has been measured with ^{13}C at Stas. 3, 7, 9 and 12 since 1981 (Takamura *et al.*, 1987b; Takamura and Aizaki, 1991; Takamura *et al.*, 1992). Various ecological studies have been made for *Microcystis* spp.: blooming (Imamura, 1981), diel vertical distribution in water column (Takamura and Yasuno, 1984), sedimentation (Takamura *et al.*, 1988), overwintering in sediment (Takamura *et al.*, 1984), photosynthesis (Takamura *et al.*, 1985, 1986) and nitrogen uptake (Takamura *et al.*, 1987a).

Abundance and biomass of zooplankton especially cladoceran species have been studied at Stas. 3 and 9 (Hanazato and Yasuno, 1985a,b, 1987c; Hanazato, 1991a; Hanazato and Aizaki, 1991). Impact of a predatory mysids, *Neomysis intermedia*, on zooplankton community was prominent in years with high mysid density (Hanazato and Yasuno, 1988). Population dynamics of this mysid has been studied by Toda (1982) and Toda *et al.* (1983). Factors affecting zooplankton communities have been tested for food (*Microcystis* spp.) quality (Hanazato and Yasuno 1987a; Hanazato, 1991b), *Microcystis* abundance (Hanazato *et al.*, 1984, 1991) and competition (Hanazato and Yasuno, 1987b).

Density and biomass of zoobenthos have been studied at Stas. 2 and 9 since 1978 (Iwakuma and Yasuno, 1981; Iwakuma *et al.*, 1984). Zoobenthos data hade been obtained at all the 10 stations during 1982–1985 (Iwakuma, 1987) and has.been taken at Stas. 3, 7, 9 and 12 since 1986 (Iwakuma, 1990). Chironomids are dominant in zoobenthos community. Chironomid fauna and emergence (Iwakuma *et al.*, 1987; Iwakuma, 1992; Ueno *et al.*, 1993) and production in relation to phytoplankton production (Iwakuma *et al.*, 1984; Iwakuma and Yasuno, 1987) has been investigated and their role in nutrient cycling has been evaluated (Iwakuma and Otsuki, 1991). Factors affecting chironomid populations have been studied in relation to redox potential in bottom mud (Takamura and Iwakuma, 1990) and predation by fish and crustaceans (Iwakuma and Yasuno, 1983).

MAJOR IMPORTANT RESULTS OBTAINED BY THE LONG-TERM STUDY

Heavy waterblooms of *Microcystis* were observed from 1969 in Lake Kasumigaura by Sugiura and Iijima (1978). During our 20 years monitoring, the dominant phytoplankton has drastically changed since 1987 from *Microcystis* to filamentous cyanobacteria, including *Raphidiopsis*, *Oscillatoria*, *Phormidium* and *Lyngbya* (Fig. 2). The change was concurrent with the increase of TN:TP ratios of the lake water during the summer、and the light-saturated photosynthesis of phytoplankton in the summer from 1982 to 1986 was nitrogen-limited, but tended to become phosphorus-limited

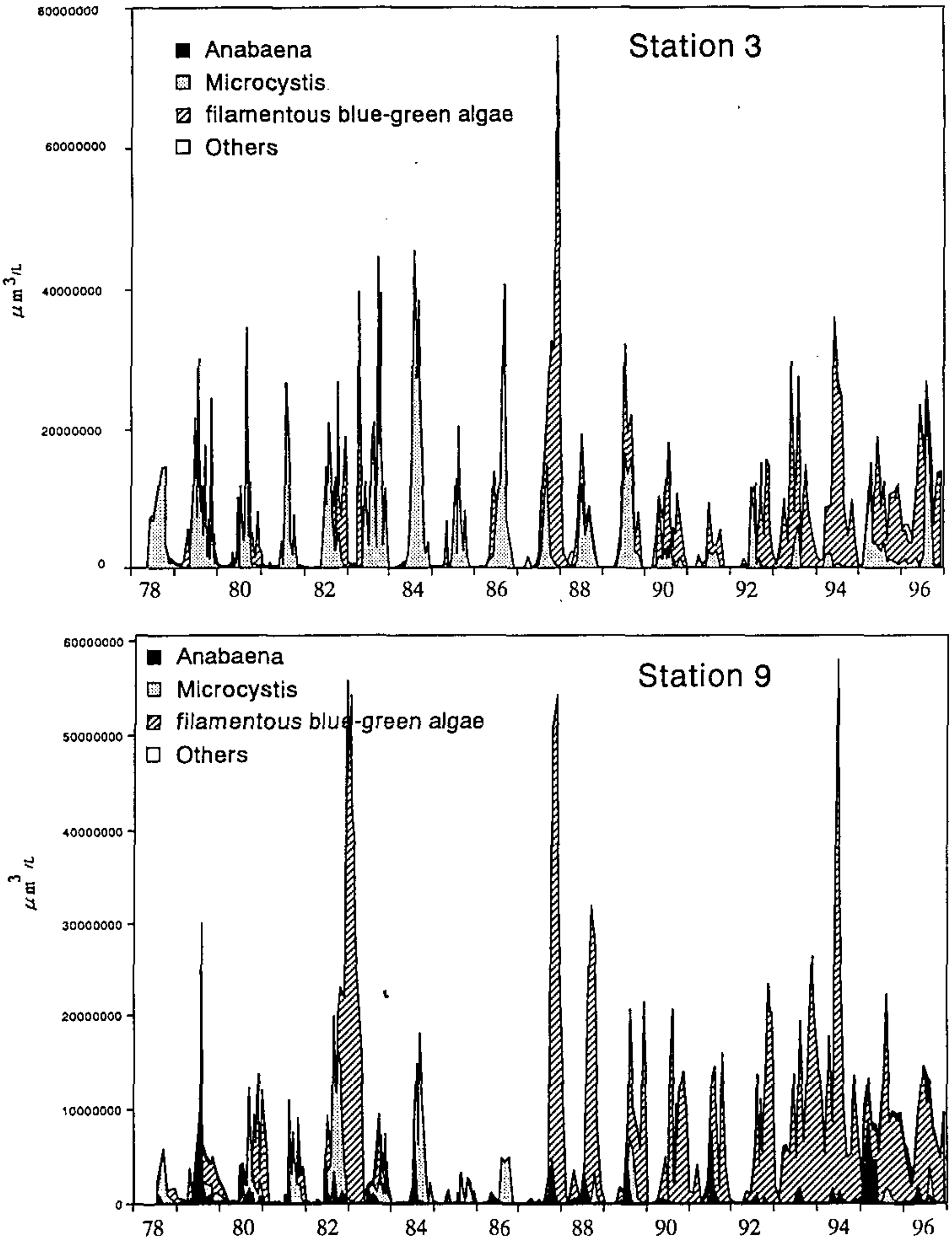

Fig. 2. Changes in volume of each group of Cyanophyceae at Stas. 3 and 9.

from 1987 to 1989 (Takamura *et al.*, 1992). Since the optimum N:P ratio of *Oscillatoria* is higher than that of *Microcystis* (Tilman, 1982), we assumed that the change of the dominant phytoplankton was due to the change of nitrogen and phosphorus ion balance in the lake. However, although the TN:TP ratios in the summer have become low since 1991 again, with an increase of TP in the water, the filamentous cyanobacteria have remained unchanged. The cyanobacteria did not occur in winters and springs from 1978 to 1992, but has continued to occur all year round since 1993. Only recently the chl.*a* concentrations have not decline in the winter.

The density of rotifers has increased since 1987 accompanied with the change of the dominant cyanobacteria. While the density of Cladocera tended to decrease from 1987 at Sta. 9. The reason is unknown. The annual means of transparency from 1977 to 1995 varied from 64–127 cm and 83–145 cm at Stas. 3 and 9, respectively. High transparency of above 2 m, occasionally observed in the lake in the winter was concurrent with the appearance of *Daphnia* and may be the result of grazing.

The annual means of chl*a* concentrations tended to decrease at Sta. 3, because the summer peaks that appeared until 1986, dropped to half since 1987 (Fig. 3). The change was consistent with the change from *Microcystis* to filamentous cyanobacteria. The tendency was not observed at Sta. 9, however, because the chl*a* concentrations in winters have been increasing these 4 years at Sta. 9. The monthly photosynthetic rates varied depending on the water temperature, but the summer peaks were lower in 1994 and 1995 than the other years, and therefore the production rate in both years remained low, although the chl*a* amounts were high at Sta. 9. The variation of annual means of gross primary production (GP) was explained by that of chl*a* concentration (GP = 20.95 + 0.26 chl*a*, F=6.721, P=0.024, R^2=0.359, df1=1, df2=12) and not by the

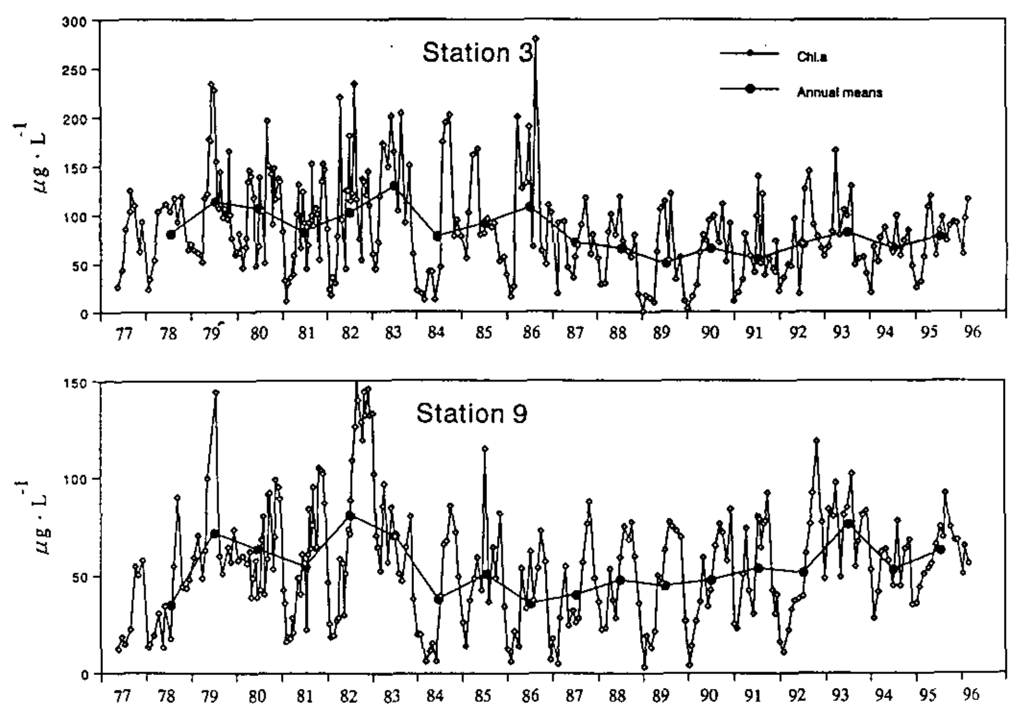

Fig. 3. Changes in chlorophyll *a* concentrations at Stas. 3 and 9.

variation of water temperature, irradiance, total nitrogen (TN) and total phosphorus (TP) at Sta. 3. The variation of GP at Sta. 9 was explained by that of TN (GP = -19.87 + 0.054 TN, F=6.911, P=0.022, R^2=0.365, dfl=1, df2=12) and not by the variation of the other variables.

FUTURE STUDY

We have some difficulty continuing the long-term study in the lake. No new researchers are starting programs after researchers who have been studying the lake have moved to other projects. We do not have research programs which study the lake ecosystem structure, function, biodiversity, interrelations between organisms, etc., in the lake. We need further experimental studies to analyze and understand long-term results of monitoring in the lake. To continue only monitoring without doing simultaneously ongoing research efforts in the lake is not meaningful. We lack long-term data set of fish biomass and nutrient loadings which are closely related to the long-term changes of nutrients and plankton in the lake.

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