International Hydrological Programme

Limnology

— The Textbook for the Ninth IHP Training Course in 1999 —

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United Nations Educational Scientific and Cultural Organization

Prepared for the 9th IHP Training Course on Limnology, 26 July-8 August 1999, Nagoya, Nagano and Shiga, Japan

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Published in November 1999
by the Institute for Hydrospheric-Atmospheric Sciences,
Nagoya University and United Nations Educational Scientific
and Cultural Organization

Sponsored by
Nagoya University

Printed by
Nagoya University COOP

ISBN: 4-9980619-1-7

Cover: A summer view of Lake Suwa (by H. Terai)
Back cover: Photomicrograph of *Bosmina fatalis* (by T. Hanazato)

Preface

This training course, as one of the activities of the International Hydrological Programme (IHP), has been supported by a large number of university professors and institute researchers who are devoted to the hydrological education for young scientists and engineers from the Asia-Pacific region. Substantial efforts have been also made by those who are involved in some committees; Japan National Commission for UNESCO, Sub-committee for IHP, and Working Group for IHP Training Course. In addition, contributions from governmental organizations and institutions have been essential for the training course to be successful. Since last year, a new trial had been planned for the schedule of the training course. Firstly, we put a clearly defined study target every year for the training students, Snow Hydrology in March 1998, Remote Sensing in March 1999 and Limnology in July-August 1999. Secondly, we established an experimental programme to allow the students to better understand the target.

For this purpose we need to edit a textbook. The textbook of this year is titled Limnology and is composed of selected contents from which students can obtain introductory and up-to-date knowledge of Limnology in a short period. We express our gratitude to the authors for the dedication to prepare this textbook.

7th July, 1999

Takao Takeda
Chairman of Working Group of IHP Training Course
Director of Institute for Hydrospheric-Atmospheric Sciences, Nagoya University

Acknowledgements

I would like to express my thanks to all the authors for their many contributions to this textbook. Without their efforts, this textbook would never have been published. The editing work was done with great helps from Dr. David A Short and Ms. Junko Banno and members of the Secretary office of IHAS. Thanks are extended to Prof. T. Takeda, the Chairperson of the Working Group of the IHP Training Course and the Director of the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University and Prof. M. Nakawo, the Secretary of the Working Group of the IHP Training Course. The IHP Training Course is under continuous support from the Ministry of Education, Science, Sports and Culture in Japan and special thanks will go to Mr. T. Noda, Programming Officer in the Ministry.

July 1999
Hisayoshi Terai
Editor

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Part I

Textbook

Chapter 1

Material cycling in deep and shallow water ecosystems

Hisayoshi Terai

1. 1 Introduction

Limnology has been developed in the early 20th century through comparative studies between deep and shallow lakes by August Thienemann. He started to study several Eifel maar lakes with Prof. W. Voigt from August 1910 and discovered that the bottom fauna of the deep maar lakes was characterized by the occurrence of *Tanytarusus* larvae, while *Chironomus* larvae were typical for shallow maar lakes. From his earlier studies on the distribution of two kinds of chironomid, he suspected a different oxygen demand between them. So he studied oxygen content in several Eifel maar lakes from April 1913, when nearly identical oxygen concentrations were observed through the entire depth of the shallow and deep maar lakes. At the beginning of August, oxygen concentration of the shallow maars decreased markedly near the bottom, whereas it hardly decreased in the deep maar lakes. He concluded that the difference of oxygen concentration in the hypolimnion of the two types of lakes was caused largely by the differences in plankton abundance. The deep maar lake was poor and the shallow maar lake was rich in plankton. Thienemann developed a "Lake Type" idea from this Eifel maar study. Lake morphology and dissolved nutrients, which is affected by the former, affect the amount of littoral vegetation and plankton. Lake morphology and plankton abundance affect water color, transparency, and hypolimnetic oxygen concentration, which regulate species of benthic fauna and presence of coregonoid. He designated deep maar lakes as *Tanytarusus*-lakes or Subalpine-lakes and shallow maar lakes as *Chironomus*-lakes or Baltic-lakes. Later, in accordance with E. Naumann, the former type of lake was called "Oligotrophic" and the later one was named "Eutrophic", with addition of another type of lake called "Distrophic".

Thus Thienemann and Naumann established the basis of limnology and they also founded the International Society of Theoretical and Applied Limnology (SIL) in 1921.

1. 2 Microbialy mediated nitrogen, sulfur and carbon cycling in aquatic ecosystems

In an usual pelagic aquatic ecosystem, organic carbon is produced by phytoplankton in the epilimnion, cycled through the food chain and finally decomposed by aerobic heterotrophic bacteria with consumption of dissolved oxygen in the hypolimnion. In the presence of oxygen, NH_4^+ which is released from bottom sediments during decomposition of organic matter, is oxidized to NO_2^- and NO_3^- by the nitrifying bacteria. Thus NO_3^- is accumulated in the circumstance of oxygen depleted hypolimnion, where organic carbon is decomposed by denitrifying bacteria. They reduce NO_3^- to NO_2^-, N_2O and N_2. Redox potential (E_h) of the reaction called denitrification ($NO_3^- + 6H^+ + 5e = 1/2\ N_2 + 3H_2O$) is 750mV/e, which is not so much lower than that of oxygen reduction by aerobic respiration ($1/2\ O_2 + 2H^+ + 2e = H_2O$, $E_h = 810$ mV/e). After nitrate is consumed by denitrification, although organic carbon is partly consumed during manganese reduction ($MnO_2 + HCO_3^- + 3H^+ + 2e = MnCO_3 + H_2O$, $E_h = 525$mV/e) and iron reduction ($FeOOH + HCO_3^- + 2H^+ + e = FeCO_3 + H_2O$, $E_h = -50$ mV/e) by some kind of heterotrophic bacteria, it is largely decomposed by sulfate reducing bacteria and methanogenic bacteria. Sulfate reduction and methanogenesis proceed under completely anaerobic conditions as indicated by the greatly reduced redox potential as followings.

$SO_4^{2-} + 9H^+ + 8e = HS^- + 4\ H_2O$, $E_h = -220$ mV/e

$CO_2 + 8\ H^+ + 8e = CH_4 + 2H_2O$, $E_h = -240$ mV/e

$CH_3COOH = CH_4 + CO_2$ ($E_h = -290$ mV/e, intramolecular redox reaction)

Hydrogen and some organic compounds such as acetate are used for electron donors both in methanogenesis and sulfate reduction, so that the two anaerobic carbon degradation processes compete especially in freshwater aquatic sediments depending on sulfate concentration.

Sulfide reduced from sulfate is oxidized by photosynthetic sulfur bacteria (i.e. *Chlorobium, Chromatium*) in anoxic low light environments or by chemotrophic sulfur oxidizing bacteria (i.e. *Thiobacillus*) in oxic conditions to sulfur and sulfate. Thus sulfur is also cycling in the aquatic ecosystem coupled with carbon cycling.

1. 3 Nitrogen metabolism in deep and shallow lakes

1. 3. 1 Nitrification and denitrification in a deep lake: a case of Lake Kizaki

Studies on the nitrogen metabolism in a lake such as nitrogen fixation, nitrogen uptake by phytoplankton, nitrogen turnover in the epilimnion, nitrification, denitrification and nitrous oxide production in the hypolimnion, have been accumulated on Lake Kizaki, a mesotrophic lake with a maximum depth of 29 m and surface area of 1.4 km^2. Here I would like to show elucidated processes of nitrification and denitrification during a stratification period in the water column of Lake Kizaki to compare to those in shallow lakes.

In early April, Lake Kizaki is under a vernal circulation where dissolved oxygen and inorganic nitrogen species (NO_3^-, NO_2^-, and NH_4^+) are homogeneously distributed throughout the water column. As the thermal stratification proceeds, accumulation of NH_4^+ in the hypolimnion becomes clear whereas this accumulated NH_4^+ decreases rapidly with the increase of NO_3^- as shown in Fig.1. It is especially evident in middle to late June. Increased NO_3^- and decreased NH_4^+ during the observation period are stoichiometrically consistent as shown in Table 1. This phenomenon is thought to be nitrification and incubation experiments using ^{15}N-NH_4^+ and ^{15}N-NO_2^- confirmed this idea as shown in Table 2 (Takahashi et al. 1982). It was observed that nitrification activities were higher in deeper layers during middle June to early July and they lasted at a lower rate in rather shallower layers of the hypolimnion during summer season. Occurrences of such active nitrification in early summer are reported also in Lake Mendota (Brezonik and Lee, 1968) and in Hamilton harbor of Lake Ontario (Harris et al. 1980). So that it is not a characteristic phenomenon in Lake Kizaki but a general feature of a lacustrine environment. Why does active nitification occur in middle June to early July in Lakes?

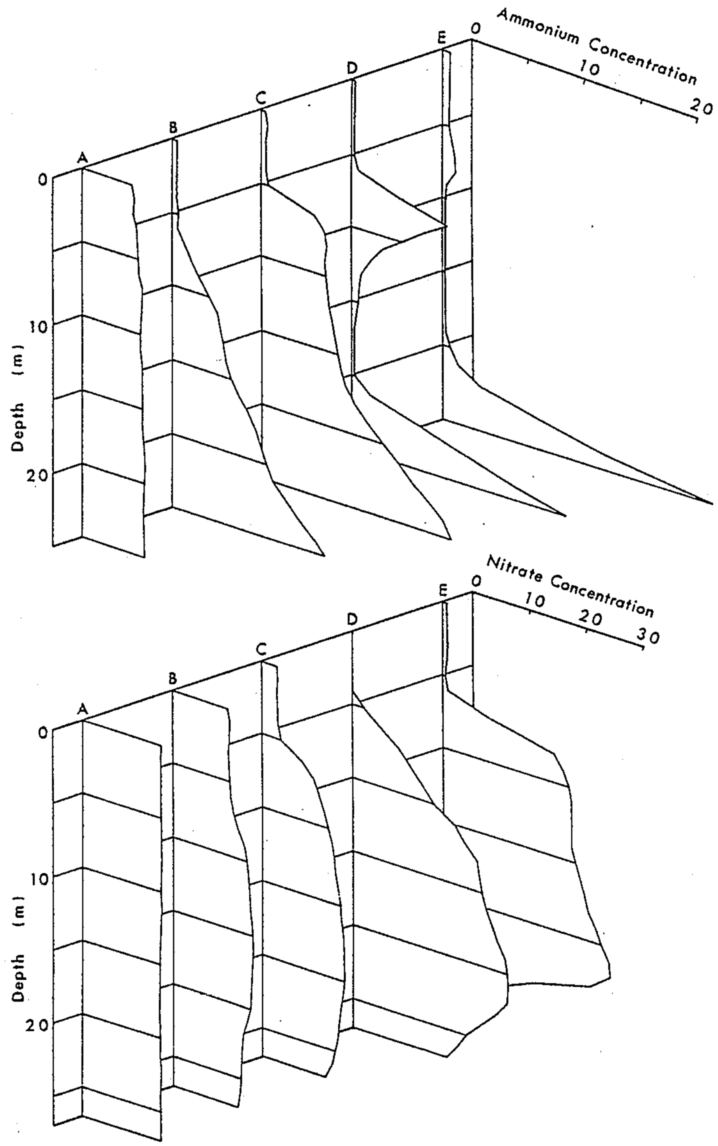

Fig. 1 Vertical distributions of ammonium (upper part) and nitrate (lower part) in Lake Kizaki from April to September in 1977. Sampling date; A: 5 April, B: 16 May, C: 14 June, D:29 June, E: 21 September. Units are μ g-atom l^{-1} (Takahashi et al. 1982, reprinted with permission by E. Schweizerbart'sche Verbuchhandlung).

Table 1 Relationship between increase in nitrate-N and decrease in ammonium-N during the active nitrification period in 1979. Units are μ g-atom l^{-1} (Takahashi et al. 1982, reprinted with permission by E. Schweizerbart'sche Verbuchhandlung).

Depth	nitrate concentration			ammonium concentration		
m	(A)	(B)	(B)−(A)	(A)	(B)	(B)−(A)
12	8.73	15.8	+7.1	6.89	0.26	−6.6
14	8.90	16.8	+7.9	7.62	0.22	−7.4
16	8.88	17.7	+8.8	8.60	0.42	−8.2
18	8.92	19.9	+11.0	10.9	0.31	−10.6
20	9.21	22.0	+12.8	12.4	0.39	−12.0

Column A: data on 15 June. Column B: data at a time when ammonium concentration attained to the low level. Date as follows; 12 m: 15 July, 14 m: 6 July, 16, 18 and 20 m: 4 July.

Table 2 Potential rate of ammonium and nitrite oxidation in Lake Kizaki. Units are μ g-atom l^{-1} day^{-1} (Takahashi et al. 1982, reprinted with permission by E. Schweizerbart'sche Verbuchhandlung).

Depth	1977	ammonium oxidation rate						
m	30 May	14 June	1 July	13 July	27 July	10 Aug.	24 Aug.	21 Sept.
8	n. d.	n. d.	0.028	0.067	0.036	0.031	0.067	0.003
10	n. d.	n. d.	0.17	0.092	0.030	0.033	0.035	0.013
15	0.006	0.004	0.33	0.031	0.031	0.025	0.029	0.023
20	0.006	0.050	0.24	0.032	0.017	0.032	0.022	0.009
Depth	**1979**	**ammonium oxidation**			**1979**	**nitrite oxidation**		
m	**30 May**	**30 June**	**10 July**	**2 Aug.**	**30 May**	**30 June**	**10 July**	**2 Aug.**
7	—	0.007	0.028	0.008	—	0.032	0.040	0.043
10	0.003	0.050	0.21	0.043	0.019	0.72	0.31	0.50
15	0.004	0.21	0.22	0.071	0.018	2.0	0.35	0.38
20	0.004	0.27	0.14	0.064	0.029	3.9	0.27	0.35

n. d.: less than 0.003 μg-atom · $liter^{-1}$ · day^{-1}.

The mechanism of nitrification commencement was analyzed by the idea of light inhibition on the nitrifying bacteria (Olson 1981). Yoshioka and Saijo (1985) confirmed this idea by an incubation experiment of lake water under light and dark condition. Fig. 2 shows that lake water sampled from 5 and 20m depth at the vernal circulation period (late March) exhibited a NH_4^+ decrease with NO_3^- increase after 50-60 days of incubation under dark, while no NO_3^- increase was observed under light conditions (5 μ E/m²/sec, 14L:10D). Nitrification activities of lake water were measured with the nitrapyrin inhibition method during 2 days-incubation both under dark and light conditions (30 μ E/m²/sec, 14L:10D). Fig. 3 shows that nitrification activities become maximum on 24 June, although a certain amount but significantly lower activities than the dark condition are measured under the light one.

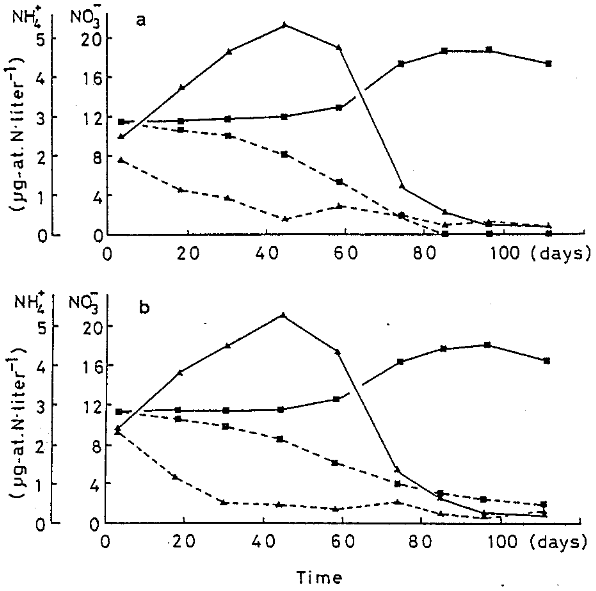

Fig. 2 The changes in ammonium (▲) and nitrate (■) concentrations in the samples collected on 27 March at 5m (a) and 20m (b) depths, during the incubation under the dark (solid line) and the light (dashed line) conditions (Yoshioka and Saijo 1985, reprinted with permission by E. Schweizerbart'sche Verbuchhandlung).

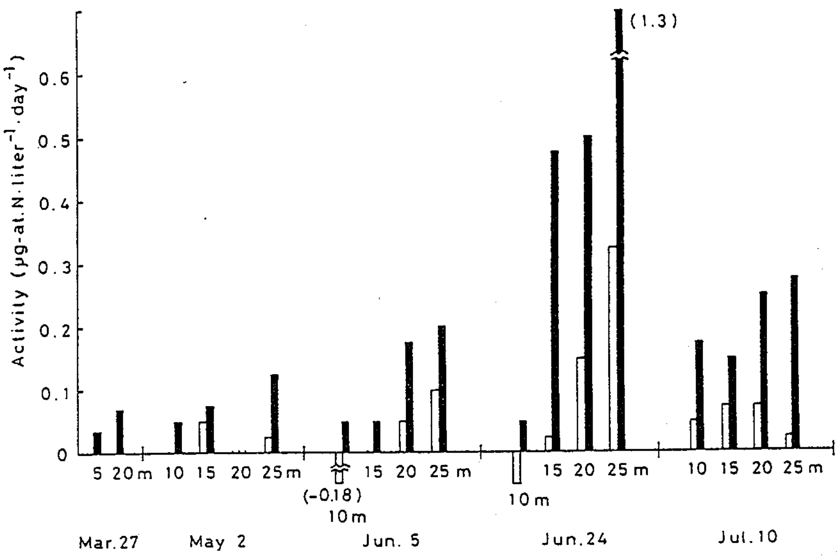

Fig. 3 Nitrifying activities of lake water measured with nitrapyrin under the dark (solid bar) and the light (open bar) conditions (Yoshioka and Saijo 1985, reprinted with permission by E. Schweizerbart'sche Verbuchhandlung).

Yoshioka and Saijo (1984) also reported experimental results on the recovery from photoinhibition of nitrifying bacteria isolated from Lake Kizaki under dark conditions. Thus, during the vernal circulation period, the nitrifying bacteria distributed throughout the whole water column suffer light inhibition by exposure to light. With the progress of stratification, they recover from this inhibition under dark conditions prevailing in the hypolimnion of the lake. This is a possible mechanism triggering the occurrence of active nitrification in the hypolimnion of lakes during early summer.

Thus accumulated nitrate in the hypolimnion is then reduced to dinitrogen gas via nitrous oxide by denitrifying bacteria under the oxygen-depleted environment. This phenomenon, so called denitrification, begins from the bottom layer of the water column in late summer and moves upward concomitant with the progress of anoxic conditions until the autumnal water circulation reaches this layer (Fig. 4) (Terai et al. 1987a, Terai 1987).

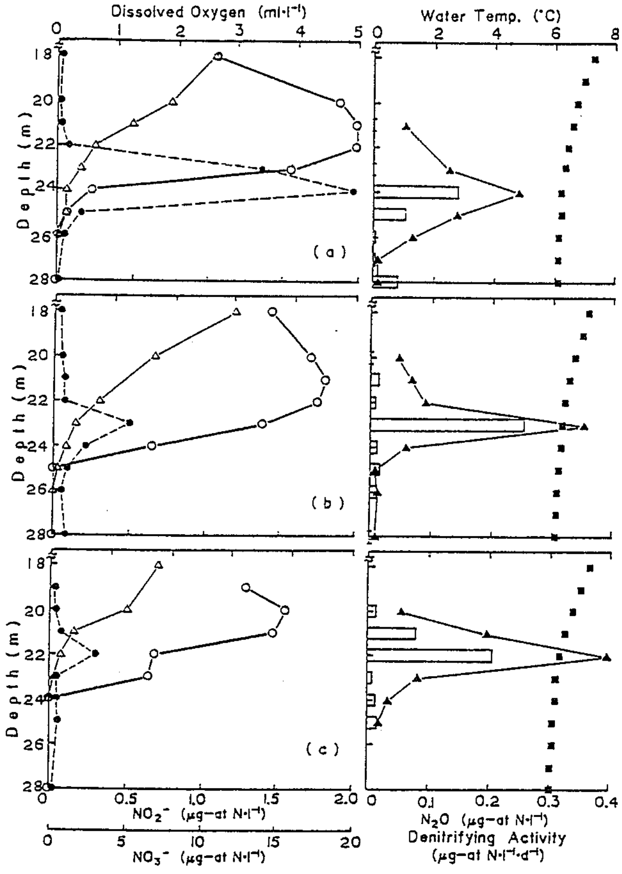

Fig. 4 Vertical profiles of water temperature, dissolved oxygen, nitrate, nitrite, nitrous oxide and denitrifying activity in the hypolimnion of Lake Kizaki on (a) 6-7 October, (b) 4-6 November and (c) 29 November - 2 December 1986. ■, water temperature; △, dissolved oxygen; ○, NO_3^-; ●, NO_2^-; ▲, N_2O; and open column, denitrifying activity (Terai 1987, reprinted with permission by Japanese Society of Limnology)

Denitrified nitrogen calculated from denitrifying bacterial activity, which was measured by the acetylene blockage method (Yoshinari et al. 1977, Sorensen 1978), was compared with loss of nitrate in the hypolimnetic water column below 21m depth (Terai and Yoh, 1996). Between 15 September to 2 December, the former value was calculate as 43 kg-at N, which is almost equal to the sum of disappeared nitrate (37.4 kg-at N) and dissolved nitrogen in the water column as N_2O (4.2 kg-at N). And an extrapolated denitrifying activity until full overturn of the lake water (assumed to occur in the middle of December) showed all nitrate remaining in lower hypolimnion are to be denitrified (Terai and Yoh, 1996). And also all of the nitrous oxide accumulated in the hypolimnion are to be degassed at the full overturn of lake water. Thus in the deeper lake, denitrification in the hypolimnetic water column is driven mostly by nitrate produced and accumulated in the hypolimnion.

1. 3. 2 Denitrification process in a shallow stagnant lake: a case of Lake Fukami-ike

Lake Fukami-ike is a small lake in central Japan with an area of 2.2 ha and a maximum depth of 8 m. As it is located at the bottom of a basin and well protected from the wind, lake water is well stagnated between late March and late September. Although it is unclear whether nitrification occurs or not after stagnation, denitrification proceeds just after the beginning of stratification (late March) as shown in Fig.5 (Terai 1988) and both denitrifying activities and the population of denitrifying bacteria increase with time (Fig. 6) (Terai et al., 1987b).

These processes, however, are different in the drought year. Fig 7 shows that denitrifying activity dropped down after the drought period (late May), but that it increased with time until middle June when an incubation experiment was performed with the addition of enough nitrate. This indicates that denitrification activities in this lake are regulated by nitrate which is supplied through surface runoff by precipitation. This idea is supported by a good relationship between the maximum dentrifying activity in the lake and the amount of precipitation during 20 days preceding the observation and experiment (Fig. 7).

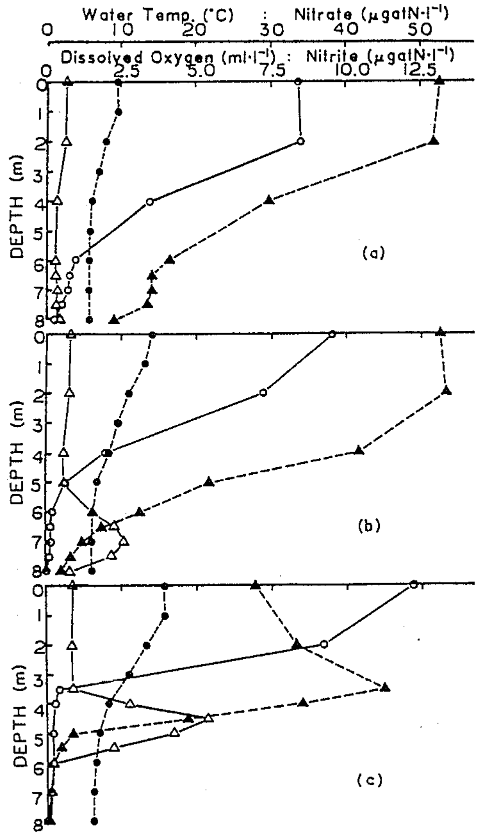

Fig.5 Vertical profiles of water temperature (●), dissolved oxygen (○), nitrate (▲), and nitrite (△) concentration in Lake Fukami-ike on 21 March (a), 5 April (b) and 22 April (c) 1985 (Terai et al. 1987, reprinted with permission by Japanese Society of Limnology).

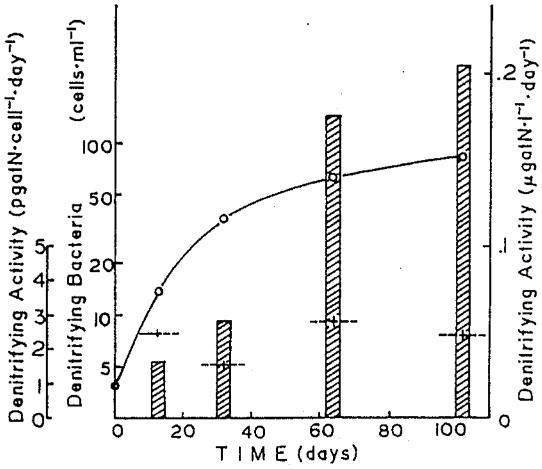

Fig.6 Time course of development of denitrifying activity and denitrifying bacterial population in Lake Fukami-ike. Initial time was set on 22 March with no denitrifying activity detected. Both denitrifying bacterial population (open circle) with solid line) and denitrifying activity (hatched column) were averaged in actively denitrifying layers. --+--: calculated value of denitrifying activity per cell. (Terai et al. 1987, reprinted with permission by Japanese Society of Limnology).

Figure 8 shows a good relationship between the nitrate concentration of the lake in Mid-March, when a vernal circulation occurred, and the amount of precipitation from 21 Feb. to 10 Mar. of the observed year. This indicates that nitrate in this lake is mainly supplied by precipitation during early spring rather than by nitrification.

1. 3. 3 Nitrification and denitrification in a shallow lake sediment: a case of Lake Suwa

In the eutrophic shallow lakes, the sediment surface is a very active site for microbial degradation of organic carbon. Lake Suwa is a freshwater lake having an area of 13.3 km^2 and a maximum depth of 6.3 m

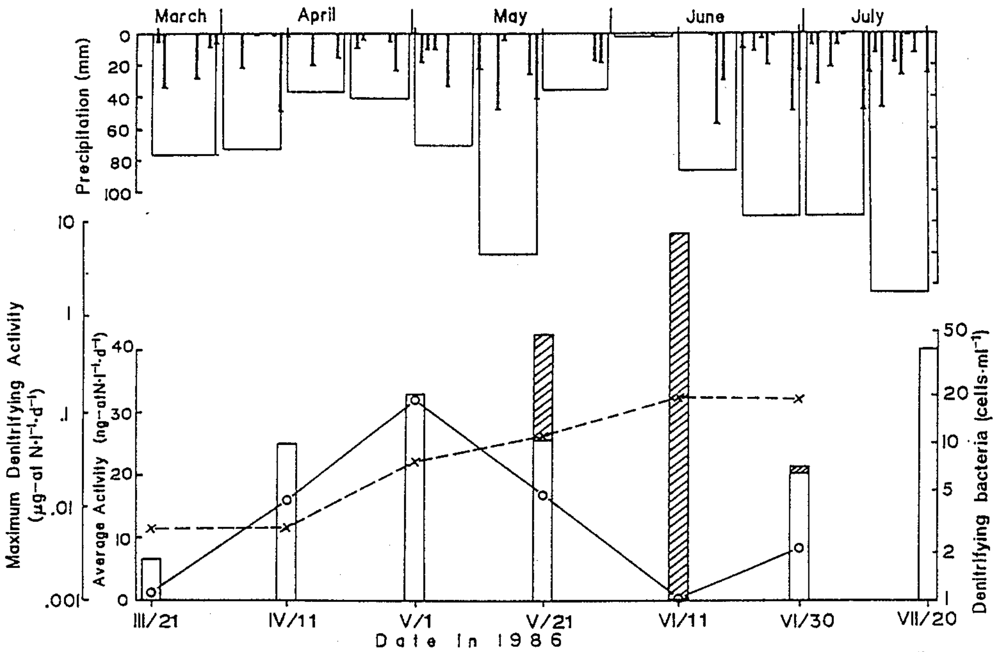

Fig. 7 Trace of denitrifying activity in Lake Fukami-ike, contrasted with precipitation, during March to July 1986. (lower side) open and hatched column, maximum denitrifying activity without and with added NO_3^-, respectively ; O: average denitrifying activity ; ×: numbers of denitrifying bacteria. (upper side) vertical bar, daily precipitation ; broad column, ten days integrated precipitation. (Terai 1988, reprinted with permission by Japanese Society of Limnology)

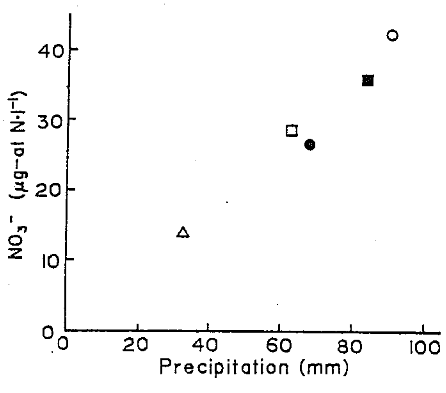

Fig. 8. Relationship between the NO_3^- concentration of Lake Fukami-ike in mid-March and the amount of precipitation from 21 February to 10 March.

1979 (○), 1980 (●), 1981 (□), 1985 (■) and 1986 (△). (Terai 1988, reprinted with permission by Japanese Society of Limnology)

and is located at 759 m above sea level along the Fossa Magna (Itoigawa-Shizuoka techtonic line) in central Japan. Its watershed area is 531 km^2, 22 % of which are utilized for urban and agricultural use. Nutrient release from these areas extremely eutrophicated the lake since the 1960's and occurrence of microcystis bloom, so called "Aoko", were often observed.

In Lake Suwa, nitrification and denitrification in the sediment were examined from December 1991 to October 1992 in order to elucidate the source of nitrate for denitrification (Zhao, 1995). Ambient denitrification activities were calculated from the Michaelis-Menten kinetic parameter (Ks and Vm) measured by the acetylene blockage method of surface sediment slurry and nitrate concentration in the lake bottom water. Nitrification activities were calculated by the difference of NH_4^+ concentration in the overlying water of sediment-water cores between the presence and absence of N-serve during incubation. Nitrate fluxes between sediment and surface waters were measured from the nitrate concentration change in the overlying water during incubation of the core system.

From the experimental results on Lake Suwa sediments, both nitrification and denitrification activities showed clear seasonal changes with maximum activity in early July. Denitrification activities, however, exceeded nitrification activities except for March. Nitrate fluxes were usually downward (overlying water to sediment) except for the case of March, when the flux was inverse (sediment to water). This nitrate flux almost coincided with the difference of the activities between nitrification and denitrification. Thus denitrification in Lake Suwa sediments is supported by mainly nitrate supplied from nitrification in the sediment and additionally supplied by diffusion from overlying lake water, except for March, when nitrification exceeds denitrification and excess nitrate is fluxed upward from sediment to the water column.

1. 3. 4 Nitrification and denitrification in a shallow brackish lake: a case of Lake Nakaumi

Finally one more interesting case of coupling between nitrification and denitrification in a shallow lake is to be shown. Lake Nakaumi is a shallow brackish lake located in the northwestern part of Honshu island, having an area of 86.2 km^2 and a maximum depth of 8.4 m.

Seike et al. (1997) showed that NH_4^+ accumulated in the bottom layer in July were oxidized and that NO_3^- and especially NO_2^- were accumulated in August, when dissolved oxygen was supplied in the bottom layer by marine tides. Thus accumulated nitrate and nitrite decreased in September (Fig. 9).

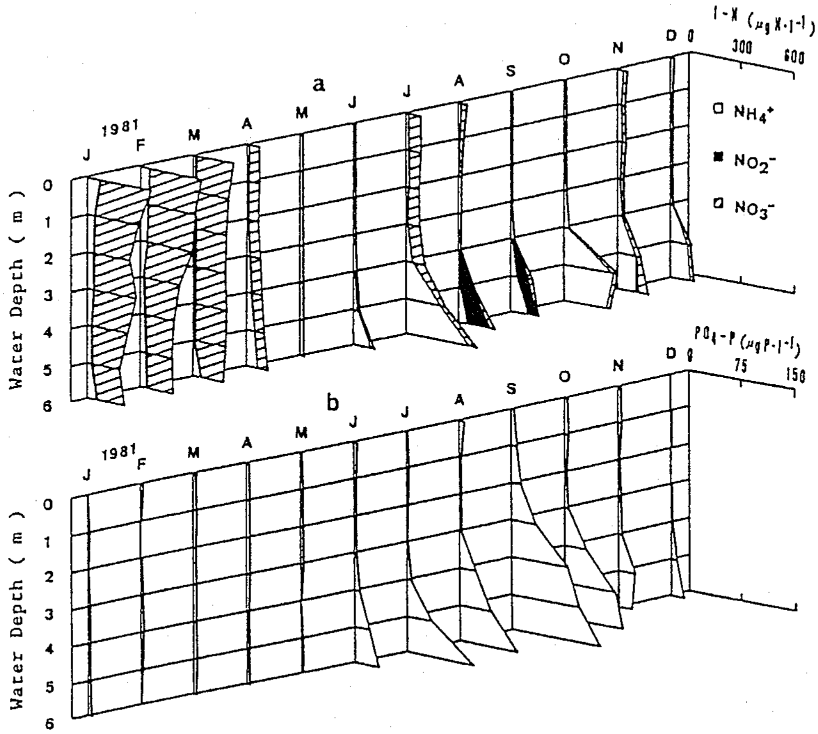

Fig. 9 The depth-time distributions of NH_4^+, NO_2^-, NO_3^- (a) and PO_4^{3-} (b) at the central part of Lake Nakaumi (Sta. 4) in 1981. (Seike et al. 1997, reprinted with permission by Japanese Society of Oceanography)

By the experimental examination of the effect of light on the nitrification, they showed that all of DIN were changed to nitrate in the dark but nitrite was accumulated in the light condition (Fig. 10). From these results, nitrite is accumulated by differential inhibition by light between ammonium oxidation and nitrite oxidation in Lake Nakaumi. Nitrification was confirmed to occur in the hypolimnetic water column in Lake Nakaumi, however, denitrification was considered to occur in the sediments.

1. 4 Manganese and iron distribution in lakes

Oxidation and reduction of manganese and iron take place under very limited redox conditions in aquatic environments. As mentioned earlier (1.2), the redox potential of manganese and iron are 525mV/e and -50mV/e, respectively. The following situation is observed in the hypolimnion of an oxygen depleted deep lake (i.e. Lake Kizaki) or redox interface of a shallow stagnant lake (i.e. Lake Fukami-ike). As oxidated manganese (Mn^{+4}) and iron (Fe^{+3}) are found in the particulate form (collected on the GF/F filter) in the water, while reduced manganese (Mn^{+2}) and iron (Fe^{+2}) are in the soluble form, their distributions in the water column show a very clear indication of a redox state of the environment. During studies on nitrification and denitrification, we observed that nitrification and denitrification occurred simultaneously under very low concentrations of oxygen (below 0.1ml/l), where dissolved Mn was observed but there was no dissolved Fe (Yoh et al., 1990).

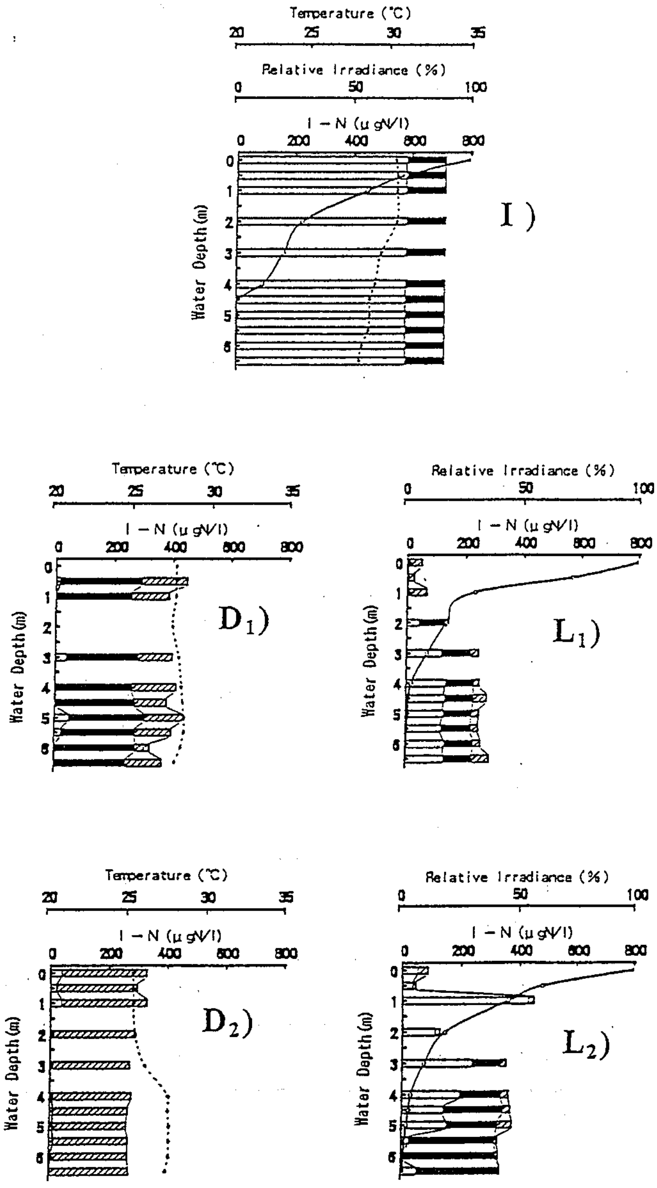

Fig. 10 Effect of light intensity on nitrification activity by *in situ* incubation experiment. Vertical distributions of NH_4^+(□), NO_2^- (■), NO_3^- (▨), relative irradiance (○) and water temperature (●) in the dark (D) and light (L). I: Initial data; D_1 and L_1: after incubation for 6 days; D_2 and L_2 after incubation for 13 days. (Seike et al. 1997, reprinted with permission by Japanese Society of Oceanography)

1. 5 Dissimilatory sulfate reduction in lake

Sulfate is reduced under completely anaerobic environments such as lake sediments by dissimilatory sulfate reducing bacteria to sulfide, which is partly precipitated and buried in the sediment as metal sulfide. Hydrogen sulfide diffused into the water column is oxidized either by phototrophic sulfur bacteria in anoxic low light conditions or by chemolithotrophic sulfur oxidizing bacteria such as *thiobacillus* in the oxic environments, where chemical oxidation also occurs. As a result sulfur is not easily removed from an aquatic ecosystem but recycled and accumulated gradually in the system. It is different from denitrification, which removes nitrogen from aquatic ecosystems.

In freshwater lakes, sulfate concentrations are usually lower compared with marine or estuarine environments, while organic matters which serve as electron donors for sulfate reduction are sufficient. So that dissimilatory sulfate reduction rates (SRR) are expected to be limited by sulfate concentrations. Comparative studies were carried out on SRR in deep and shallow lake sediments of different trophic levels; Lakes Kizaki, Suwa and Fukami-ike. SRR were measured by incubating slurries of sliced sediment cores (2cm intervals from surface to 10cm depth) with $^{35}SO_4^{2-}$ under a helium atmosphere and radio-activities of acid labile $^{35}S^{2-}$, which was trapped by zinc acetate, were measured. The results are shown in Table 3.

Table 3 Comparison of dissimilatory sulfate reduction rates in lake sediments between Lakes Kizaki, Suwa and Fukami-ike (He and Terai, unpublished data).

Lakes	**Bottom water SO_4^{2-} conc. (μ mol l^{-1})**	**SRR (m mol SO_4^{2-} m^{-2} d^{-1})**	**Pore water DOC conc. (mg l^{-1})**
L.Kizaki (profundal:29m depth)	0.4-25	0.07 (0.02-0.18)	4 -14
L.Kizaki (littoral: 5m depth)	22-27	2.2 (0.5-5)	1 - 5
L.Suwa	180-280	5.1 (2-13)	3 - 9
L.Fukami-ike	280-880	15.4 (11-22)	4 -22

SRR of lake sediments depended clearly on bottom water sulfate concentrations, which reflected the trophic status of lakes; lowest in mesotrophic L. Kizaki and highest in hypereutrophic L.Fukami-ike. SRR in deep or well- stratified lake sediments (profundal area of L. Kizaki and L. Fukami-ike) sharply decreased from spring to autumn according to the decrease of sulfate concentration in the bottom water. While in shallow lake sediments (L. Suwa and littoral area of L. Kizaki), SRR showed a summer or autumn peak and sulfate concentrations in the bottom water did not show a simple decrease. It means that sulfate reduced in the sediment are easily oxidized by the supply of enough light or oxygen in shallow lakes. SRR in shallow water sediments might be not limited by sulfate concentrations but by other factors such as temperature or quantity and quality of organic substances. DOC concentrations of sediment pore water in shallow waters were lower than those in deep or well stratified lakes (Table 3). It is noticeable that SRR in the littoral sediment of L. Kizaki is one order or more higher than that in the profundal sediment and that it shows nearly half the rate compared with L. Suwa sediment in spite of lower sulfate concentrations.

1. 6 Methanogenesis in lake sediments and methane fluxes

The final microbial degradation of organic matter in freshwater ecosystems is methanogenesis, which occurs at -240mV or lower redox potentials. Methanogenic activities in L. Kizaki sediment and methane fluxes by diffusion and ebullition in Lakes Kizaki, Suwa and Fukami-ike were studied. Methanogenic activities were measured by methane concentration increase using a FID gas chromatograph during incubation of slurries, which were prepared from sliced sediment cores, under a helium atmosphere. Methane fluxes by ebullition were estimated by methane concentrations and the total volume of collected gas in bubbled gas collectors, which were set on each lake surface. Diffusive methane fluxes from the lake surface was calculated using the equation of Sebacher et al. (1983) from dissolved methane concentrations of the surface water and prevailing average wind speed by the lake-side observatory. The results are shown in Table 4.

It is very similar to the case of SRR that methanogenic activities in the littoral sediment of L. Kizaki are also higher than those in the profundal one and reach to almost half the rate of those in L. Suwa sediment. Diffusive fluxes of methane were not so much different between lakes. No methane ebullition was observed in the profundal area of L. Kizaki, where over saturated methane was accumulated and oxidized during diffusion to the upper oxic water column. As a result methane flux to the atmosphere in the pelagic area of deep lakes is usually negligible except for the case of full turnover of lake water. Methane ebullitions from L. Suwa and L. Fukami-ike, especially in summer are so high that they are supposed to contribute to organic carbon mineralization. Then contribution for mineralization of organic carbon between denitrification, sulfate reduction and methano-genesis during summer period are compared in the case of L. Suwa sediments using the following equation of organic carbon oxidation by nitrate and sulfate;

$$NO_3^- + 5/4\ C(H_2O) \Rightarrow 1/2\ N_2 + 5/4\ CO_2 + 3/4\ H_2O + OH^-$$

$$SO_4^{2-} + 2C(H_2O) \Rightarrow S^{2-} + 2CO_2 + 2H_2O$$

Table 4 Comparison of methanogenic activities and methane fluxes between Lakes Kizaki, Suwa and Fukami-ike (a: unpublished data by Takeshima, b:unpublished data by Takita, c: Takita and Sakamoto, 1993, d: no data).

Lakes	**Methanogenic Activities ($mgC\ m^{-2}\ d^{-1}$)**	**Methane ebullition ($mgC\ m^{-2}\ d^{-1}$)**	**Methane diffusive flux ($mgC\ m^{-2}\ d^{-1}$)**
L.Kizaki (Profundal:29m depth)	19 – 30 [a)]	0 [b)]	1 – 7 [b)]
L.Kizaki (Littoral: 5m depth)	38 – 211 [a)]	0.1 – 1 [a)]	N. D. [d)]
L. Suwa	(200 – 360) [b)]	53.2 [b)] (0 – 150) [c)]	1.3 [b)] (0.1 – 6.5) [c)]
L. Fukami-ike	N. D. [d)]	100 – 1000 [b)]	0.1 – 7 [b)]

Table 5 shows that dissimilatory sulfate reduction plays a more important role for anaerobic degradation of organic carbon in eutrophicated shallow water ecosystem than denitrification or methanogenesis, which have been recognized as more important in freshwater ecosystems.

Table 5 Comparison of mineralization activities of organic carbon in L. Suwa sediments between denitrification, Sulfate reduction and methanogenesis.

	Denitrification (Zhao, 1993)	**SRR (He, 1995)**	**Methanogenesis (Takita, 1993)**
Measured rate	(m mol NO_3^- m^{-2} d^{-1}) 3.36 (1.7-5.8)	(m mol SO_4^{2-} m^{-2} d^{-1}) 5.0 (2.0 - 12.8)	(mgC m^{-2} d^{-1}) 54.4 (1 - 150)
Carbon mineralization rate	(mgC m^{-2} d^{-1}) 50.4 (25.5- 87)	(mgC m^{-2} d^{-1}) 121 (48 - 307)	(mgC m^{-2} d^{-1}) 54.4 (1 - 150)

1. 7 Conclusion

Recently shallow water ecosystems have been seriously affected by human activities. Nitrogen cycling of shallow lakes is closely coupled between the water column and sediment system as shown in the case of Lake Suwa and Lake Nakaumi. Therefore, human impact on the surface water such as nutrient loading should affect sediment metabolism through acceleration of primary production, sedimentation flux and oxygen consumption in the bottom layer. Extreme blooms of cyanobacteria should bring oxygen depleted surface sediments, where nitrification is inhibited and denitrification does not proceed. In such a case completely anaerobic metabolisms such as dissimilatory sulfate reduction and methanogenesis remains in the sediment except for occurrence of water turbulence by wind or inflowing currents rich in oxygen. Sulfate tends to accumulate in lake ecosystems as eutrophication proceeds, and might play a major role for the anaerobic carbon degradation process in freshwater sediments compared with methanogenesis.

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Chapter 2

Low-cost water treatment systems using constructed wetlands

Kazuo Ichino

2.1 Constructed wetlands

Usually, in natural fresh water ecosystems, aquatic plants dominate in shallow regions, and they contribute to improve water quality. Their abilities to improve water quality are supposed to be based on their absorption activities of nutrients from roots and holding capacities of microorganisms on their surfaces of stems, leaves and roots. The microorganisms adhering to plant surfaces decompose organic polluted substances in water.

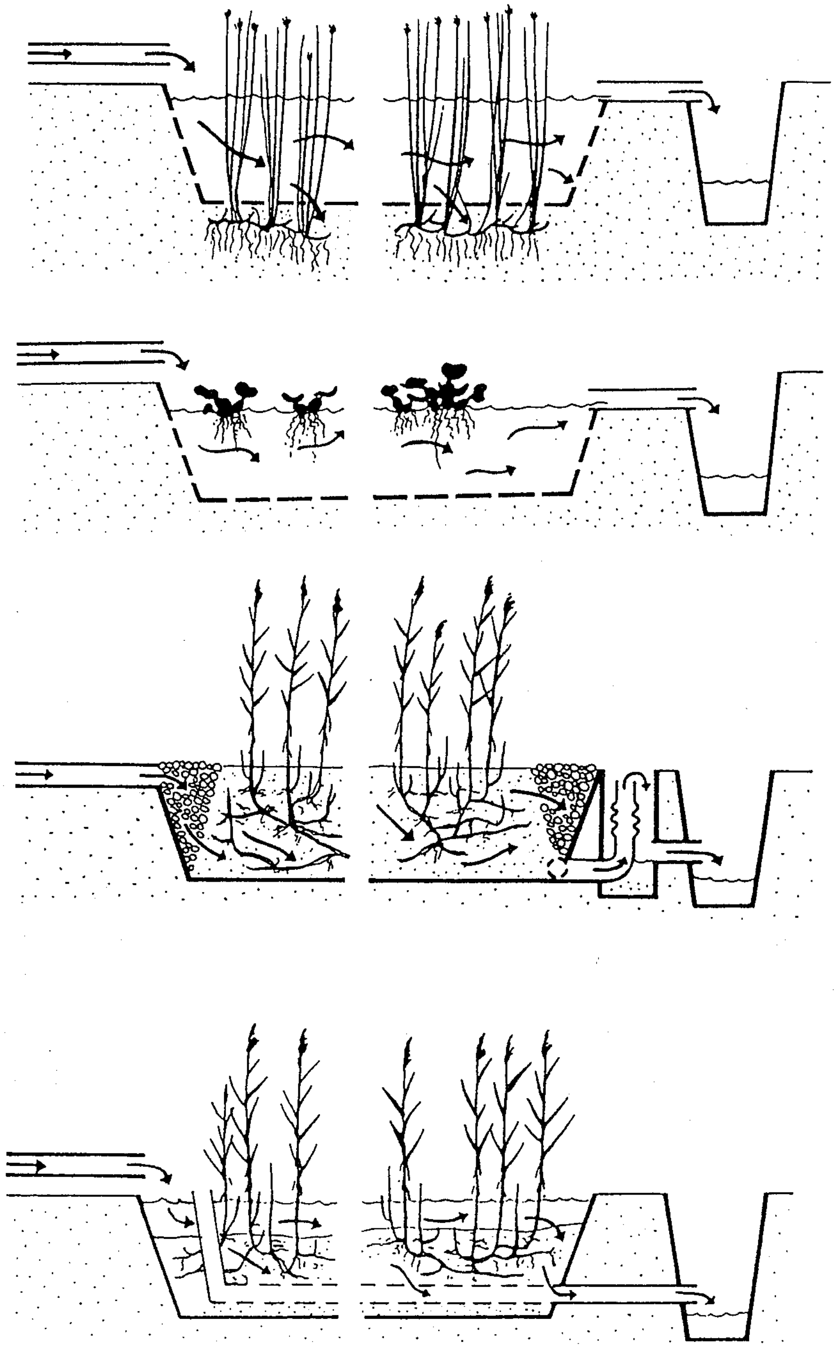
Aquatic plants are distinguished by four life forms as following: as emergent aquatic plants, floating-leaved aquatic plants, submerged aquatic plants and free-floating aquatic plants.

Constructed wetlands are designed to use various aquatic plants and classified into several types by the life forms in them as shown in Figure 1 (Brix, 1993, Brix and Schierup, 1989).

2.1.1 Types of Constructed wetlands

Free-floating aquatic plant systems: Water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), some species of duckweeds (*Lemna* spp., *Spirodella* spp.), floating moss (*Salvinia* spp.) and fairy moss (*Azolla* spp.) are often used to treat wastewater. Submerged aquatic plant systems: *Elodea canadensis* and other species are examined.

Emergent aquatic plant systems: *Scirpus* is often used in horizontal surface flow systems. In horizontal infiltration systems and in vertical ones, reeds (*Phragmites australis*) are usually planted in treatment beds.



A

B

C

D

Fig. 1 Various types of constructed wetlands. (Brix & Schierup, 1989, reprinted with permission by AMBIO).

A: Surface-flow system planted with *Scirpus* spp., an emergent aquatic plant.

B: Free-floating type system with water-hiacinth.

C: Horizontal subsurface-flow type planted with reeds (*Phragmites australis*).

D: Vertical flow type with reed beds.

2.1.2 Performance of wastewater treatment using horizontal reed beds

Judging from experiences in Denmark (Schierup et. al., 1990) and in the Netherlands (Verhoeven and Meuleman, 1999), horizontal infiltration reed beds have shown good performance for secondary treatments, though nutrient removal (the tertiary treatments) is not so good.

Bacteriological and virological pollution are removed by rates more than 99.9%. Effluent qualities for suspended solids satisfy mostly the official demands. Removal efficiencies of BOD are mostly in the range of 80 to 95%. On the other hand, removal rates of total-nitrogen and total-phosphorus are in the range of 25 to 35%.

2.1.3 Vertical reed beds

Vertical infiltration types of reed beds are used to aerate the matrix of reed beds by intermittent wastewater supply. Oxidation and nitrification are accelerated in the vertical system. Therefore, if a horizontal system combines properly with a vertical one, nitrogen removal would increase largely through joint processes of nitrification and denitrification (Brix, 1994-a, -b, Brix and Schierup, 1993, 1990).

2.2 Experiences for improving water quality using paddies in Japan [1]

Mikawa Bay is located in Aichi Prefecture on the Pacific-side of central Japan. The bay has been highly eutrophied because of its closed nature and of the increased nutrient loadings from the water catchment of the bay during the '60s and '70s, when rapid economic growth occurred (Hibino, 1995). In the '70s and '80s, wide areas of shallow foreshore of the bay were lost by reclamation for developing industries. Shallow foreshore has a high potency of improving polluted water (Sasaki, 1997). Therefore, reclamation of the shallow foreshore was another big causal factor of eutrophication.

Fertilizers, manure, and discharge of wastewater lead to elevated concentrations of nitrate in surface and groundwater. In the countryside, centralized wastewater treatment systems are not appropriate because of centralized wastewater treatment systems are not appropriate because of the high costs of piping and because the wastewaters generally are rather dilute. On-site low-technological or natural systems are preferred. Irrigation systems for paddy fields are well developed in East and Southeast Asia, and it is a well-known fact that paddy fields have good denitrifying abilities (Yanagida, 1984; Ogawa and Sakai, 1985; Kasuya and Kotake, 1997). Ichino et. al. (1995) found a distinct seasonal decrease of nitrate concentrations at the downstream end of a tributary during irrigation periods. In this area, irrigation water is repeatedly introduced to paddy fields from the stream and allowed to flow out again on the downstream end of the field. Furthermore, it was reported that the groundwater under paddy fields had distinct low concentrations of nitrate-nitrogen (Kasuya et. al., 1994).

Nowadays, large amounts of irrigation water are obtained from upstream of the Toyo River and introduced to the main area of paddy fields through an extensive canal and piping system, the Toyogawa Yousui, which was constructed in 1968 by the government. Furthermore, in many cases, agricultural uses of water from small streams have been restricted because their concentrations of nitrogen are higher than the State standard of agricultural irrigation water in Japan (lower than 1 mgL^{-1} of total nitrogen). Therefore, the modern irrigation system has suppressed the potential use of paddy fields for improving water quality of rivers (Ichino and Hatano, 1994).

(1): Present contents have mostly been reported in the reference of Ichino and Kasuya, 1998.

2.2.1 Location of the experimental fields and methods

We selected a paddy field located on the floodplain of the river Toyo flowing into Mikawa Bay. The paddy field was irrigated from a tributary of the Toyo. The irrigation water was nutrient rich because of wastewater discharges to the tributary. Surface water was collected at six points on the small rectangular paddy field, and electric conductivity and water temperature were measured on site. The samplings that were done on the selected five days seemed to be in steady state conditions for water flow during the growing season of rice plants in 1993. Influx of irrigation water to the field was measured, and the water flow rate was estimated based on water influx, water depth and width of the paddy field.

Analyses of solutes in water were performed using the following analytical procedures: ammonium: indophenol method (Sagi, 1966); nitrite: sulfanilic acid and N-1-naphthyl-ethylenediamine method (Bendschneider and Robinson, 1952); nitrate: salicylic acid absorption photometry (Editing committee for Applied Inorganic Colourimetric Analysis (ed.), 1974); and phosphate: ammonium-molybdate absorption photometry (Murphy and Riley, 1962).

2.2.2 Nitrate-nitrogen

The concentrations of nitrate and total inorganic soluble nitrogen at the inlet were 1.91 ± 0.11 and 2.30 ± 0.34mg L^{-1} (n=5), respectively. Nitrate-nitrogen accounted for 83 percent of the total soluble inorganic nitrogen. Twenty-six meters from the inlet the concentrations had decreased to ca. 0.80 and 1.1 mg L^{-1}, respectively. At a 52m distance, they had decreased further to ca. 0.26 and ca. 0.51 mg L^{-1}, respectively. Results are shown in Table 1. The water flow rate was about 1mm sec^{-1} (0.7 to 1.3mm sec^{-1}) and water temperature was about 28℃ (26 to 30℃).

Distance from the inlet (m)	0.1	26.0	27.2	52.0	52.6
NO_3-N (mg L^{-1})	1.91 ±0.11 (5)	0.96 ±0.51 (5)	0.75 ±0.61 (5)	0.19 ±0.17 (5)	0.33 ±0.24 (5)
TIN (mgL^{-1})	2.30 ±0.34 (5)	1.10 ±0.58 (5)	1.07 ±0.76 (5)	0.46 ±0.31 (5)	0.56 ±0.30 (5)
PO_4-P (mgL^{-1})	0.229 ±0.161 (5)	0.123 ±0.107 (5)	0.116 ±0.116 (5)	0.081 ±0.073 (5)	0.082 ±0.089 (5)

Table 1 Nitrate-nitrogen (NO_3-N), total inorganic nitrogen (TIN) and phosphate phosphorus concentrations at the various points on a paddy field. Numerals are averages ± standard deviations. Parentheses mean measuring times.

In Figure 2 the data for total inorganic soluble nitrogen plotted along with the best fit to an exponential decreasing function are shown:

$$Y = 2.383\, e^{-0.0293\, x} \qquad (R^2 = 0.9832),$$

where x is the distance (m) from the inlet.

The nitrogen removal seems to be a first-order reaction, which can be described by the general formula:

$$Y = A\, e^{-b\, x},$$

where Y is the concentration of total inorganic nitrogen (mg L^{-1}) at a distance of x meters from the inlet, A is the inlet concentration (mg L^{-1}) and b is a removal rate constant (m^{-1}).

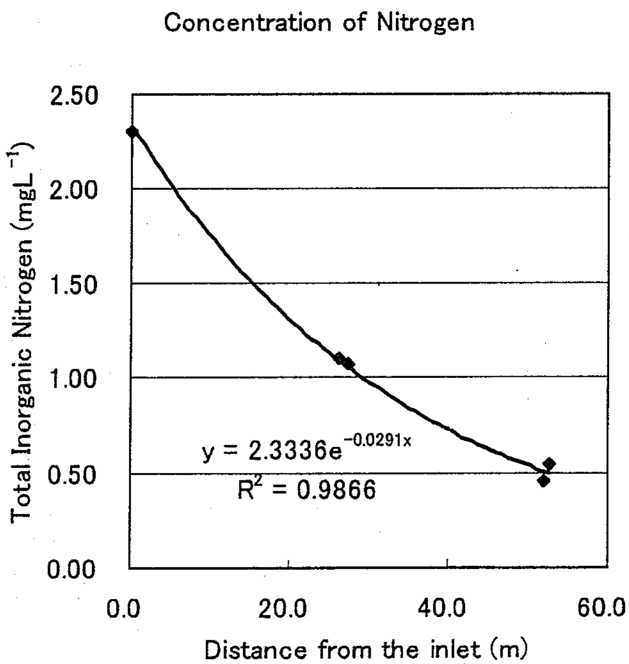


Fig. 2 Decrease of TIN along the distance from the irrigation inlet. (Ichino, K. & Kasuya, M. 1998)

2.2.3 Modeling a paddy field system to decrease nitrogen in river water

In the Mikawa Bay area the nutrient loadings should decrease to half of the present level in order to improve the conditions of the bay (Matsukawa, 1997). The above equation can be used to design a model for improving water quality in the countryside of the catchment by solving for x as follows:

$$Y = A\, e^{-bx}$$

$$1/b\ (\ln A - \ln Y) = x$$

$$x_{1/2} = 1/b \ln 2,$$

where $x_{1/2}$ means a half value distance.

On the basis of this relation, the length of the paddy fields necessary to reduce the nitrogen levels by 50% can be calculated. The estimated value of the removal rate constant b is $0.0292 m^{-1}$, which corresponds to a half value distance of 23.7m.

Besides the Toyo River, which has comparatively low nutrient concentrations, there are twelve small streams having higher concentrations of nitrogen in the water catchment area of Atsumi Bay. The sum of the annual average flow rates for them is about $10 m^3\ sec^{-1}$, and the annual average inflow of total nitrogen loading is about $62 g\ sec^{-1}$ (the Department of Environmental Management, Toyohashi C., 1992). Based on the above findings, it should be possible to remove half of the nitrogen loading by using 240ha of 24m long paddy field systems with a water depth of 10cm and a flow rate of $1 mm\ sec^{-1}$. The needed area constitutes only 5% of the total paddy field area (5000ha) in this region. It is only a small part of the area compared to paddies that are non-cultivating for political reasons.

2.2.4 Phosphate phosphorus

It seems we may be able to adapt the general equation, $Y=A\ e^{-bx}$ gotten for nitrogen to phosphorus. According to an approximate equation in Figure 3, we can get a value of 36m as a half value distance for phosphate-phosphorus.

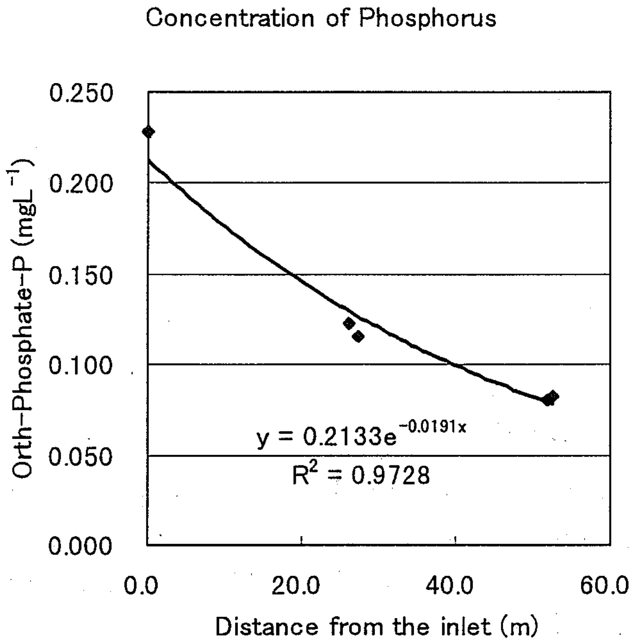


Fig. 3 Decrease of Phosphate-P along the distance from the irrigation inlet.

2.2.5 Discussions

Ozaki and Kondo (1995) also studied the spatial distribution of total soluble nitrogen (main component was nitrate) in surface waters in a paddy field in the Kanto district in Japan. In this case, the average concentration of total soluble nitrogen in the irrigation water was 5.42mg L^{-1}. From their data based on successive (every two hours) measurements of three days we estimated the water flow rate to ca. 0.2mm sec^{-1} and we obtained the following relationship:

$$Y = 5.5019\, e^{-0.0303\,x} \qquad (R^2 = 0.9986)$$

The removal rate constant b is 0.0303m^{-1} and the half value is 22.9m, respectively in this case. In spite of being under different conditions such as different input concentrations of nitrogen and different flow rates, the removal rate constant is similar to our case.

2.3 Conclusion

The constructed wetlands using reed beds show good performances to the secondary treatment. And the paddy system is preferable to the tertiary treatment, namely nutrient removals. Therefore we will be able to construct low-cost wastewater treatment systems by combining the reed beds system and the paddies system in warm-temperate, sub-tropical and tropical regions, where rice paddies and irrigation canal systems exist.

A principle of the combined wastewater treatment system is shown in Fig. 4.

Municipal wastewater

Sedimentation tank

BOD, Organic-N,P, Bacteria

Infiltration: horizontal reed bed

NH_4-N, PO_4-P

Controlling siphon tank system

Intermittent infiltration: small vertical reed bed

NO_3-N, PO_4-P

Dilution in irrigation water

Paddy treatment system

River stream

Fig. 4 A flow chart of a combined wastewater treatment system.

Acknowledgements

I thank Prof. Hans Brix in Aarhus University for an introduction to Danish reed beds.

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Chapter 3

Current technology in limnology (1) Stable isotope ecology

Takahito Yoshioka

3.1 Stable isotopes

Many biophilic elements have two or more stable isotopes (Table 1). In general, the lightest isotope of each element, except for Fe and Sr in the table, is the most abundant one. The isotopic compositions of organic and inorganic materials in ecosystems have been recognized as useful markers of biogeochemical process studies (e.g., Peterson and Fry 1987, Rundel *et al.* 1989, Coleman and Fry 1991). In this chapter, the applications of stable isotope analyses for freshwater environments are briefly reviewed.

3.2 Expression of isotope abundance

Stable isotopic composition fluctuates in physical, chemical and biological processes. Since the variation in isotopic composition is very small, its value is usually expressed as the isotope ratio δ value (‰; per mil deviation from the isotope ratio of standard material). The definition of δ is as follows:

$$\delta X = (R_{sample}/R_{standard} - 1) \times 1000,$$

where, δX is the isotope ratio in ‰ relation to a standard, and R_{sample} and $R_{standard}$ are the absolute isotope ratios of the sample and standard, respectively. Isotopic composition of standards for hydrogen, carbon, nitrogen and oxygen are listed in Table 2 (Ehleringer and Rundel 1989).Using the δ value, we can easily refer to the difference in isotopic composition between samples (Table 3).

Table 1 Average terrestrial abundance of the stable isotopes. (modified from Ehleringer and Rundel, 1989).

Element	atomic weight	Abundance (%)
Hydrogen	1	99.985
	2	0.015
Carbon	12	98.89
	13	1.11
Nitrogen	14	99.63
	15	0.37
Oxygen	16	99.759
	17	0.037
	18	0.204
Magnesium	24	78.70
	25	10.13
	26	11.17
Silicon	28	92.21
	29	4.70
	30	3.09
Sulfur	32	95.00
	33	0.76
	34	4.22
	36	0.014
Chlorine	35	75.53
	37	24.47
Potassium	39	93.10
	40	0.0118
	41	6.88

Element	atomic weight	Abundance (%)
Calcium	40	96.97
	42	0.64
	43	0.145
	44	2.06
	46	0.0033
	48	0.18
Iron	54	5.82
	56	91.66
	57	2.19
	58	0.33
Copper	63	69.09
	65	30.91
Zinc	64	48.89
	66	27.81
	67	4.11
	68	18.57
	70	0.62
Strontium	84	0.56
	86	9.86
	87	7.02
	88	82.56

(modified from Ehleringer and Rundel 1989)

Table 2 Isotopic composition of standards (modified from Ehleronger and Rundel 1989).

Standard	Isotope ratio	Accepted value (10^{-6}) (with 95% confidence interval)
Standard mean ocean water (SMOW)	$^{2}H/^{1}H$	155.76 ± 0.10
	$^{18}O/^{16}O$	2005.20 ± 0.43
	$^{17}O/^{16}O$	373 ± 15
PeeDee belemnite (PDB)	$^{13}C/^{12}C$	11237.2 ± 9.0
	$^{18}O/^{16}O$	2067.1 ± 2.1
	$^{17}O/^{16}O$	379 ± 15
Atmospheric N_2	$^{15}N/^{14}N$	3676.5 ± 8.1

Table 3 Comparison between absolute Isotope ratio (AIR) and δ value.

Example	AIR $^{13}C/^{12}C$	δ
C_3 plant	0.010933	-27.07
C_4 plant	0.011102	-12.03
marine carbonate	0.011249	1.05

3. 3 Analytical methods

In the field of stable isotope ecology, carbon and nitrogen isotopes have been widely used. Analytical methods for measuring carbon and nitrogen isotope ratios are briefly described below.

Carbon and nitrogen isotope ratios are measured by an isotope ratio mass spectrometer (IRMS, Fig. 1). Samples must be treated by various methods to produce CO_2 and N_2 gases (Table 4), since the IRMS measures the isotope ratio of a gas sample. CO_2 and N_2 gases were cryogenically purified before introduction into the IRMS, using the preparation lines (Fig. 2).

Recently, a sophisticated technique has been developed, which is called EA-IRMS. EA-IRMS is the IRMS system equipped with an elemental analyzer for combustion of organic samples and gas-chromatographic separation of CO_2 and N_2 gases, and an interface for sample and standard gases introduction into the IRMS.

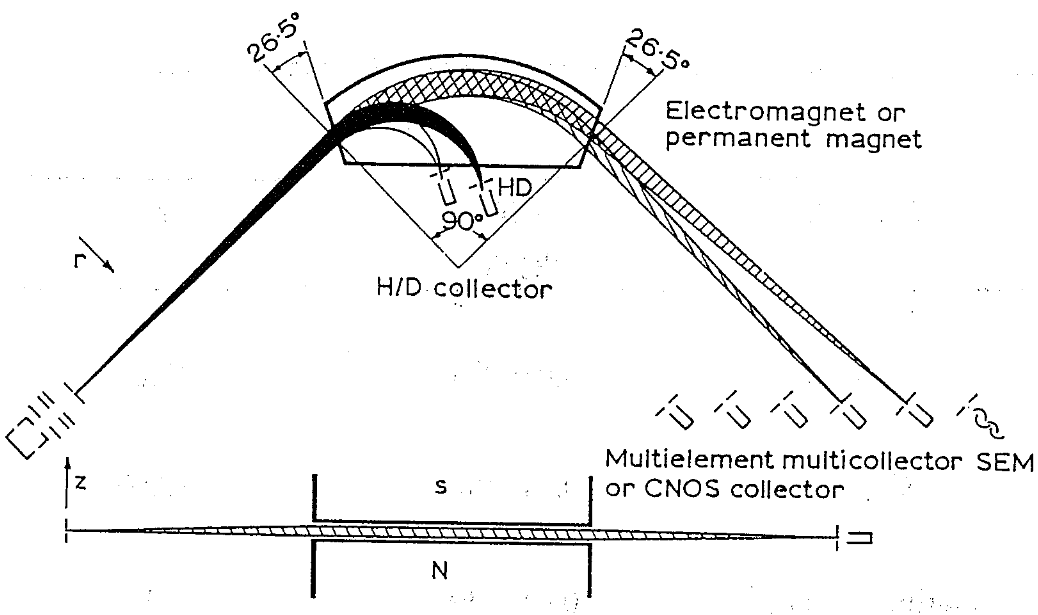

Figure 1 Ion optical system of IRMS (Bowen 1988, reprinted with permission by Elsevier Science Limited)

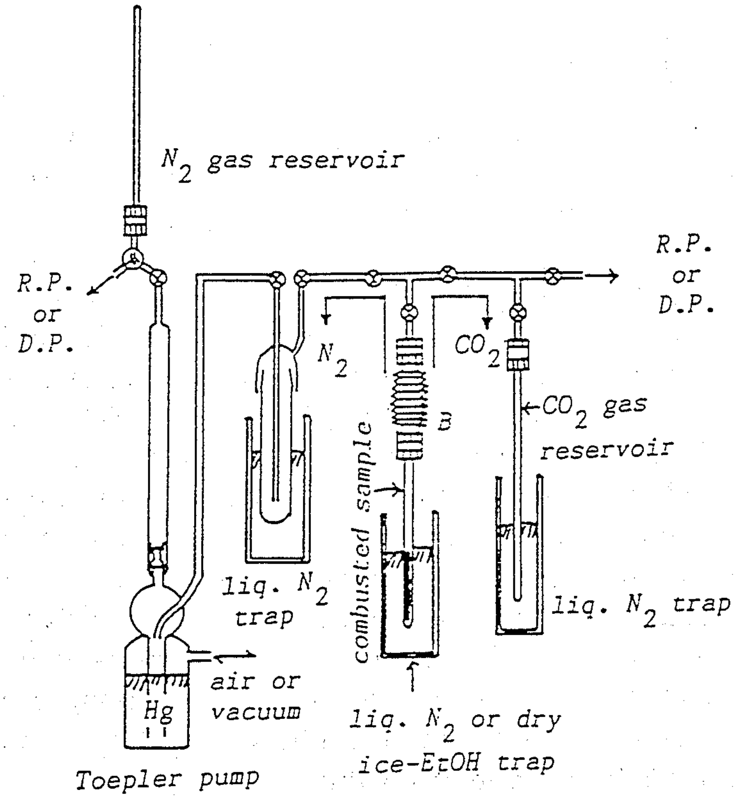

Figure 2 Schematic presentation of the line for gas purification.
R.P.: rotary pump,
D.P.: diffusion pump,
liq. N_2: liquid dinitrogen.

Table 4 Methods for example treatments for Isotope analysis.

Sample	Method
Organic carbon	combustion *in vacuo* [1]
Organic nitrogen	Kjeldahl diggestion and alkaline hypobromite oxidation[2]
Organic cargon and nitrogen	combustion in vaccum-sealed quartz tube[3]
Dissolved inorganic carbon	CO_2 extraction from water sample under acidic condition[4]
Dissolved inorganic nitrogen	steam distillation with/without devalda alloy reduction[5]

[1]Mizutani and Wada 1985
[2]Mizutani *et al* . 1985
[3]Minagawa *et al* . 1984
[4]Kroopnick 1974
[5]Bremner and Edwards 1965 and 1966

3. 4 Source indicator for organic matter

The sources of sedimentary organic matter in estuary and coastal environment can be assessed by the isotope ratios. Terrestrial organic matter shows relatively lower $\delta^{13}C$ and $\delta^{15}N$ values than marine plankton (Table 5). The isotope ratios of sedimentary organic matter are plotted along the mixing line between these two end-members. The relative contribution of terrestrial organic matter to the sediment and its trans-portation in estuary and coastal area have been estimated from $\delta^{13}C$ and $\delta^{15}N$ values (Sweeney *et al.* 1978, Wada *et al.* 1987 and 1990). In the lacustrine (lake) environments, it has been reported that $\delta^{13}C$ and $\delta^{15}N$ values of sedimentary organic matter change with trophic states of Florida lakes (Gu *et al.* 1996). The $\delta^{13}C$ of lake sediments increased with lake trophy (from oligotrophic to hypereutrophic) in Florida lakes. In the hypereutrophic lakes, it was suggested that low $\delta^{15}N$ values of the sediment reflected the N_2-fixation by cyanobacteria (Gu *et al.* 1996). However, such trends were not found clearly among the other lakes (Table 6). Differences in carbon and nitrogen cyclings among the lakes would affect the distribution of δ values.

3. 5 You are what you ate!

As in the case of sedimentary organic matter, we can trace the food source for animals, including us, using carbon and nitrogen isotope ratios. The human body consists of various kinds of biophilic elements. Human being obtains energy and body elements from food. In this sense, we, human beings, are truly heterotrophic organisms. From average isotopic compositions, a person weighing 50 kg has 225g of heavier isotopes in his/her body (Fig. 3, Wada *et al.* 1995). The source of these isotopes are inevitably the foods. We are what we ate!

Our foods are marked by their isotopic compositions, which are determined by the processes including production, transformation, and so on. Since food habits of human populations and available foods are different among the nations, carbon and nitrogen isotope ratios are different among them (Fig. 4).

It was empirically recognized that ^{13}C and ^{15}N stepwisely increased along with the trophic level of animals (Fig. 5, DeNiro and Epstein 1978

Table 5 The $\delta^{13}C$ and $\delta^{15}N$ values of terrestrial and marine end-members.

(units: ‰)

Location	Terrestrial		Marine	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
West coasts of Alaska, California and Mexico[1]	-26	2	~-20	~9
Otsuchi River watershed[2]	-26.5	1.8	-22~-21	4~9
Schelde Estuary[3]	-26	3.5	~-18	~9

[1]Peters et al. 1978; [2]Wada et al. 1987; [3]Middelburg and Nieuwenhuize 1998.

Table 6 Carbon and nitrogen isotope ratios of lacustrine surface sediments.

(units: ‰)

Lake	Trophic status	$\delta^{13}C$	$\delta^{15}N$
Lake Suwa[1]	eutrophic	-24.6 ± 0.5	4.0 ± 0.7
Lake Bled[2]	eutrophic	-33.3 ± 2.4	
Smith Lake[3]	eutrophic	-29.2	0.3
Lake Fukami-ike[4]	eutrophic	-27.2	
Lake Kasumigaura[5]	eutrophic		5.7 ~ 6.9
Lake Erie[6]	meso-eutrophic	-25.9 ~ -24.9	
Lake Kizaki[7]	mesotrophic	-27.8 ~ -23.4	1.7 ~ 4.5
Lake Biwa (north basin)[8]	mesotrophic	-24.7 ~ -23.4	7.0 ~ 7.8
Lake Ontario[9]	mesotrophic	-27.0 ~ -23.8	4.0 ~ 9.4
Lake Superior[10]	oligotrophic	-26.5 ~ -25.5	4.5 ~ 6.0
Findley Lake[11]	subalpine oligo.	-28 ~ -33	
Florida lakes[12]	oligotrophic	-27.1	1.4
	mesotrophic	-26.9	2
	eutrophic	-26.3	2.4
	hypereutrophic	-23.5	1.9

[1]Yoshioka et al. 1988a; [2]Čermelj et al. 1996; [3]Gu et al. 1997; [4]Takahashi et al. 1990; [5]Toda and Wada 1990; [6]Ostrom et al. 1998b; [7]Yoshioka et al. 1988a; [8]Yamada et al. 1996; [9]Hodell and Schelske 1998; [10]Ostrom et al. 1998a; [11]Rau 1980; [12]Gu et al. 1996.

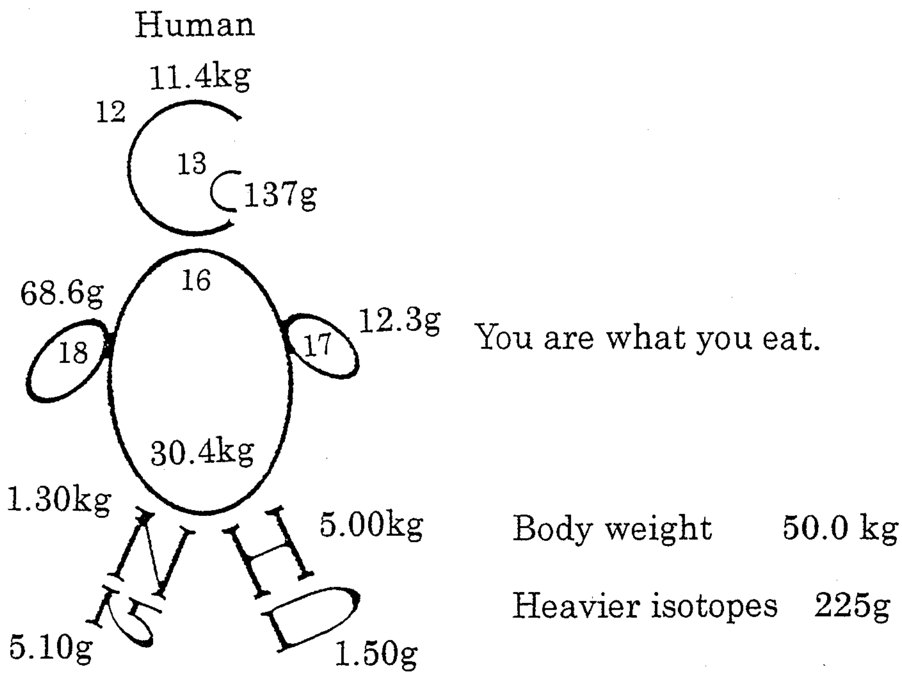

Figure 3 Stable isotope person (Wada *et al.* 1995, reprinted with permission by Kyoto University Academic Press).

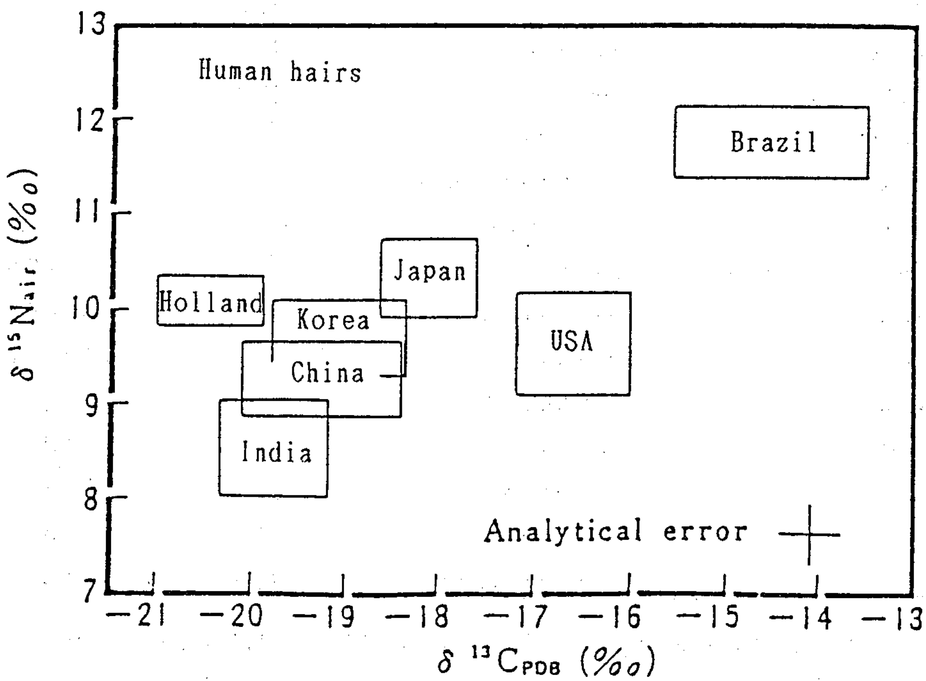

Figure 4 Comparison of carbon and nitrogen isotope ratios of human hair among nations (modified from Minagawa 1987, reprinted with permission by Kagaku to Seibutsu).

and 1981, Minagawa and Wada 1974). In the early study by Rau (1980), the freshwater food chain was clarified by $\delta^{13}C$ measurement (Fig. 6). Many reports have been published on the snap-shot of lacustrine food webs (e.g., Estep and Vigg 1985, Yoshioka *et al.* 1988b, Kling *et al.* 1992, Keough *et al.* 1996). In the lake ecosystem, however, the isotopic analysis of food chains is complicated, because δ values of the primary producer, or phytoplankton, seasonally fluctuate (Yoshioka *et al.* 1989 and 1994, Gu *et al.* 1994, Zohary *et al.* 1994, Gu and Schelske 1996, Yoshioka 1997). Although few studies have discussed the seasonal variation in δ values of lacustrine organisms and in food webs (Toda and Wada 1990, Yoshioka *et al.* 1994), the dynamic features of lacustrine food webs have been elucidated (Fig. 7). As an application of isotopic analysis of food chains, recently, the heavy metal bioaccumulation by lake trout has been modelled (Cabana and Rasmussen 1994). The trophic position of lake trout determined by $\delta^{15}N$ value increased in the presence of intermediate trophic levels (pelagic forage fish and macrozooplankter) and correlated with mercury accumulation in lake trout.

3. 6 Ecophysiology of primary production

Large seasonal changes in $\delta^{13}C$ of phytoplankton is one of the characteristic features of lacustrine environments, compared with marine environments. There are two major reasons for this phenomenon, (1) change in $\delta^{13}C$ of dissolved CO_2 which is the carbon source for phytoplanktonic photosynthesis, and (2) change in kinetic isotope fractionation during photosynthesis.

The $\delta^{13}C$ of dissolved CO_2 is affected by the respired CO_2, of which the $\delta^{13}C$ value is lower than that of atmospheric CO_2. In the deep layer of a lake, hypolimnion,$\delta^{13}C$ of CO_2 becomes low, because of lack of gas exchange with the atmosphere (Quay *et al.* 1986). Because of the thermodynamic difference between isotopes, kinetic isotope fractionation occurs more or less in every physicochemical and biochemical processes, and causes the enrichment of the lighter isotope (^{12}C for carbon) in the product, compared with the substrate. Under a sufficient supply of substrate, isotope fractionation becomes large and the isotope ratio of the product decreases. When the amount of substrate limits the process, isotope fractionation is minimal, then the isotope ratio of the product increases up to that of the substrate.

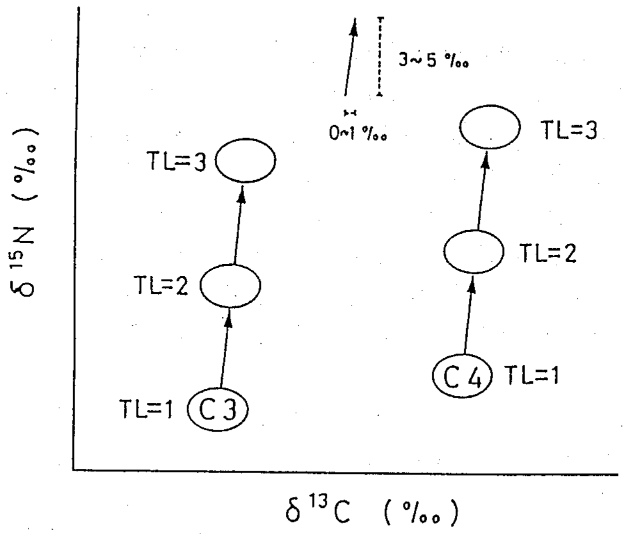

Figure 5 Schematic diagram showing the step-wise enrichment of ^{13}C and ^{15}N along food chain.

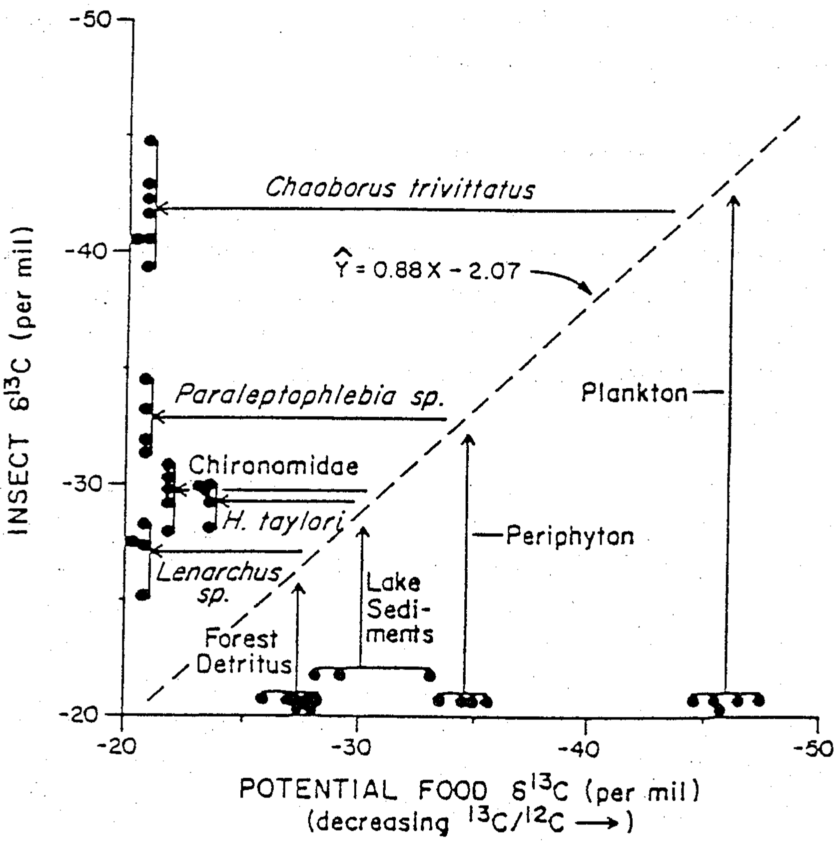

Figure 6 Relationship between insect and potential food $\delta^{13}C$ values in Findley Lake, Washington (Rau 1980 reprinted with permission by NRC, Canada). The broken line represents the linear regression of data reported by DeNiro and Epstein (1978).

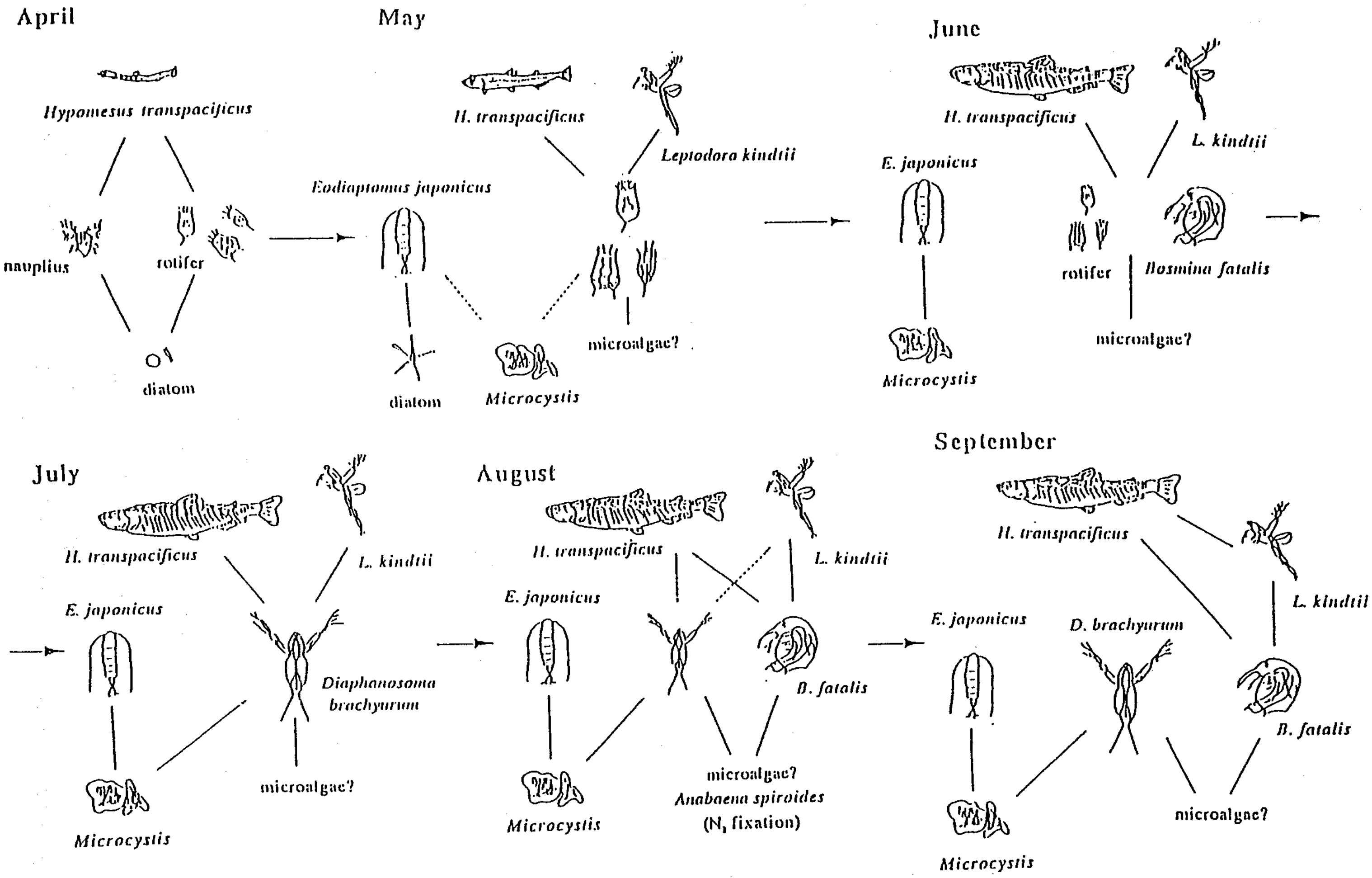

Figure 7 Pelagic food web structure in Lake Suwa during April and September, 1986 (modified from Yoshioka *et al.* 1994).

Phytoplankton $\delta^{13}C$ generally increases in the warm season, or blooming season. Since both photosynthesis and respiration (decomposition of organic matter) become active in the warm season, the increase in $\delta^{13}C$ of phytoplankton suggests that the kinetic isotope fractionation decreases in the warm season, probably because of a decrease in dissolved CO_2 by active photosynthesis. In Lakes Suwa and Kizaki, it was suggested from carbon isotope fractionation that phytoplankton communities were limited by the depletion of dissolved inorganic carbon in the blooming season (Takahashi *et al.* 1990, Yoshioka 1997).

There are many models to interpret photosynthetic carbon isotope fractionation (O'Leary 1981, Berry 1989, Farquhar *et al.* 1989, Rau *et al.* 1992, Fogel *et al.* 1992, Francois *et al.* 1993, Jasper *et al.* 1994, Laws *et al.* 1995). Using the fractionation equation considering a carbon concentrating mechanism (CCM), it was suggested that freshwater phytoplankton might have a high capacity of CCM and adapt to low and/or fluctuating dissolved CO_2 conditions, compared with marine phytoplankton (Yoshioka 1997).

The seasonal change in $\delta^{15}N$ values of freshwater phytoplankton was also reported (Yoshioka *et al.* 1989 and 1994). Dissolved inorganic nitrogen concentration, its $\delta^{15}N$ value and N_2-fixation are the controlling factors for phytoplankton $\delta^{15}N$ values. However, the studies on nitrogen isotope fractionation by phytoplankton have been limited (Wada 1980, Montoya and McCarthy 1995, Waser *et al.* 1998), particularly for freshwater environments. Since denitrification largely affects the $\delta^{15}N$ level of inorganic and, therefore, organic nitrogen, studies on nitrogen cycling in lake environments, as well as isotope fractionation by phytoplankton, are needed to analyze the seasonal variation in $\delta^{15}N$ of phytoplankton. The high $\delta^{15}N$ values of NO_3^- and sediments in Lake Biwa compared with other lakes suggested that massive denitrification might occur in Lake Biwa (Yamada *et al.*, 1996). These studies may be useful also to understand the variation in sedimentary $\delta^{15}N$ values among the lakes shown in Table 6. The isotopic analyses of sedimentary records and the understanding about the mechanisms of lacustrine material cycles would be important in the palaeolimnological studies using sediment core samples (Schelske and Hodell 1991, Teranes *et al.* 1999).

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Chapter 4

A historical review of limnology in Japan and a case study on Lake Suwa

Tokio Okino

4. 1 A historical review of limnology in Japan

Modern limnology in Japan began with the bathymetric survey of Lake Yamanaka, one of the five lakes around Mt Fuji, by Dr. Akamaro Tanaka in 1899. He lived in Europe for 12 years and came back to Japan in 1895. Dr. Tanaka transmitted the modern limnology he learned in Europe to Japanese researchers. After that, he surveyed many lakes in Japan and published numerous monographs for each lake. The Japanese Society of Limnology was organized in 1931 and Dr. A. Tanaka was elected as the 1st president of the Society by unanimous consent.

The important limnological works in Japan are as follows:

1899	Measure of the depth in Lake Yamanakako by Dr. A. Tanaka
1900	The earliest monograph of lake (Lake Biwako) by Suehiro Maeda
1901	The studies on the aquatic plants of Lake Suwa by Haruhusa Nakano
1902	Establishment of Otsu Hydro-Biological Laboratory, Kyoto University
1903	Limnological studies on Lake Suwa (in Japanese) by Akamaro Tanaka (1907-1918) "Freshwater Biology in Japan" by Tamiji Kawamura
1928-40	The studies on aquatic insects in streams and on the ecological types of streams by M. Ueno, K. Imanishi,

	T. Kani and others. The studies on benthic animals of lakes by D. Miyaji
1931	Organization of the Japanese Society of Limnology and publication of The Japanese Journal of Limnology vol.1
1937	Limnology by Shinkiti Yoshimura
1939	The studies on lake metabolism by K. Sugawara (start of the geo-chemical studies on lake)
1941-45	2nd World War
1947	Dr. S. Yoshimura died in the pursuit of his works in Lake Suwa covered by ice.
1949-50	The studies on the bio-production in Lake Suwa by K. Hogetsu, Y. Kitazawa, Y. Shiraishi, H. Kurasawa and S. Ichimura
1950-60	The studies on the primary productivity of lakes by S. Ichimura, Y. Saijo, M. Sakamoto and Y. Aruga
1960-70	Biological studies on polluted waters by M. Tsuda and others
1968-73	IBP (International Biological Program) studies for the productivity of communities of Japanese inland waters
1977-87	Special Program on Environmental Sciences (Studies on the ecosystem of watershed area including lake ecosystem based on material cycles)
1985-90	Experimental studies on the lake ecosystem and the interaction among aquatic organisms Ecological studies on the littoral ecosystem of lakes (Ecotone)
1990- present	applied limnological and ecological studies on mitigation works

4. 2 A case study on Lake Suwa eutrophication and remediation

4.2.1 Changes in the ecosystem of Lake Suwa attendant upon human activities

The ecosystem of Lake Suwa has changed remarkably since the beginning of the 20th century, because of the suffering from various human activities for a long time. At the beginning of the 20th century this lake used to be classified as a mesotrophic lake. Since the 1960s, however, Japans economy has grown remarkably year by year and accordingly the human activities in the watershed area of Lake Suwa, such as intensive agriculture, precision and food industries and tourism, have become considerably augmented. These intensified human activities have brought more and more nutrients into the lake and consequently this lake has changed into a hypertrophic lake. Hypertrophic means a highly eutrophicated lake. As a result, a thick layer of vivid green Microcystis covers the lake surface from late June to October every year.

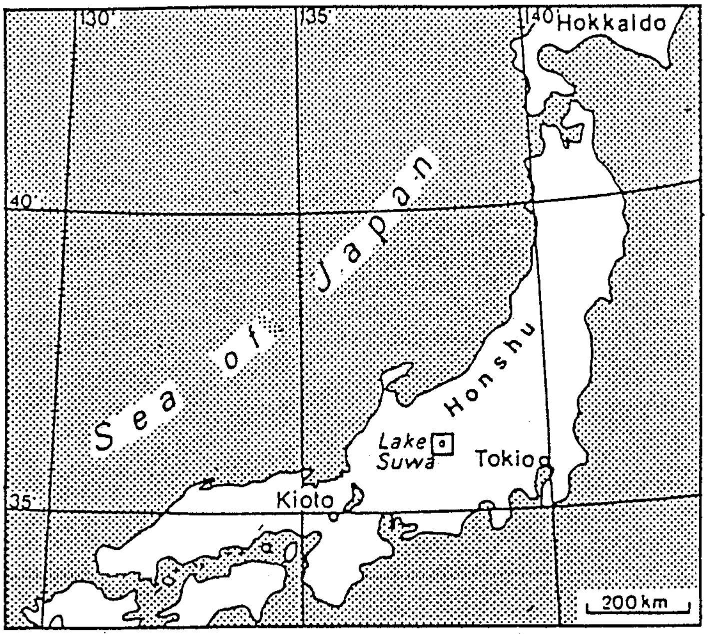
In order to cope with this situation, the local government and the inhabitants around the lake started to inquire into possible ways to clean the lake in 1966. And they worked out a plan of a large-scale wastewater treatment plant, which deals with domestic, industrial and other wastewater, and human feces and urine from the cities around the lake. In October 1979, a part of the sewage plant began to operate.

4. 2. 2 Location and morphometric feature of Lake Suwa

Lake Suwa is located in the central part of Japan proper. Figure 1 shows the morphometric features of Lake Suwa. This Lake is morphometrically characterized as shallow. Its surface area covers 13.3 km^2. However, its maximum depth is only 6.5 meters and the mean depth is about 4 meters. The lake lies in a relatively high altitude of 759 meters above sea level. This region is in the large tectonic belt crossing the Japanese Island, Honshuu, and Lake Suwa is one of the tectonic lakes in this belt. More than 20 rivers and streams flow into the lake from the catchment area, but the outlet is only one, River Tenryu-gawa.

4. 2. 3 Lake Suwa and human activities

About 200,000 people live within the catchment area of the lake. Figure 2 shows the land use of the catchment area of Lake Suwa. The urban areas are located close to the shoreline (Fig. 2). These urban areas contain quite a number of factories of precision and food industries. Moreover, there are lots of hotels and restaurants around the lake, for this area attracts many tourists on account of its beautiful sight and hot springs.



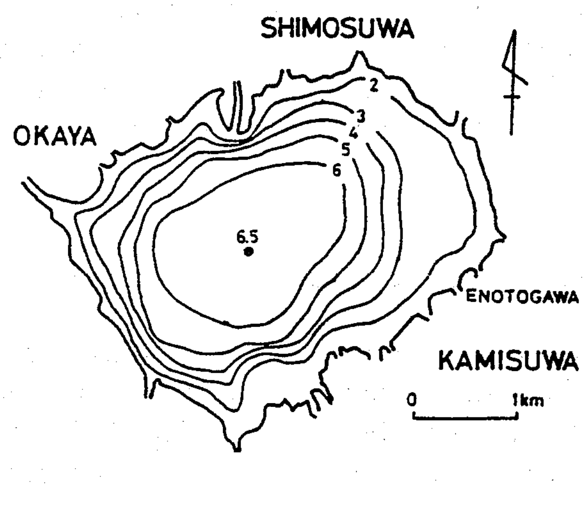


Fig. 1. The contour map of the water depth of Lake Suwa and the location of the cities around the lake.

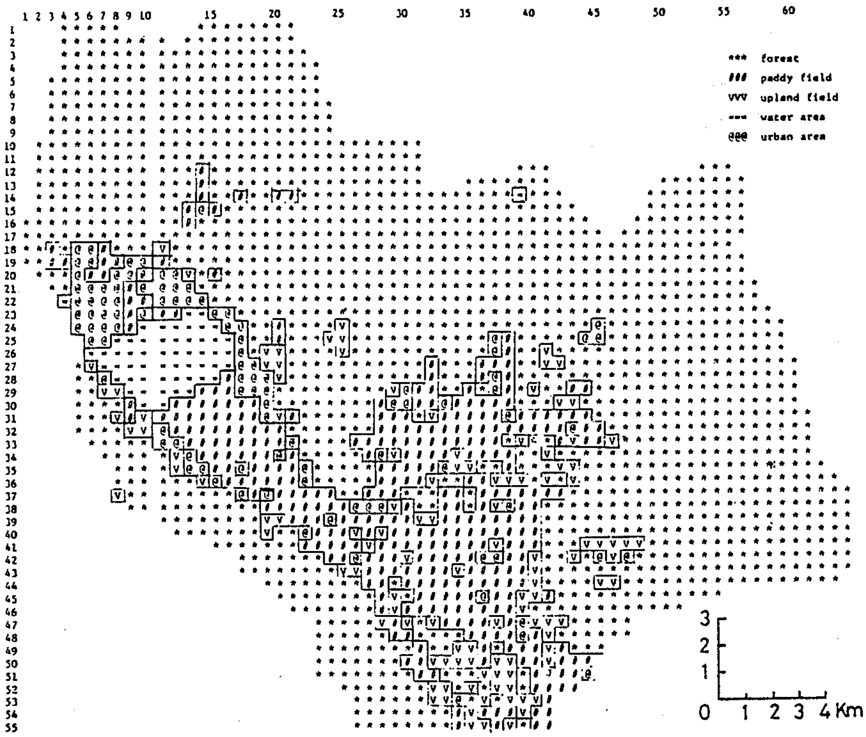


Fig. 2. The map of the urban utilization of the watershed area of Lake Suwa drawn by 0.25km^2 mesh (Quoted from Matsuda, M. and T. Okino, 1982).

Before 1971, no regulations had been adopted for the quality of the water, which flowed into Lake Suwa from factories, hotels, domesticities and so on. Nutrients, particularly nitrogen and phosphorus, contained in the wastewater from factories and hotels as well as domesticities, all of which flowed into the lake finally, had been accelerating the eutrophication. In 1971, the local governments established regulations for the quality of the wastewater from factories, hotels and others. However, the nutrients such as ammonium, nitrate and phosphate were not included in the regulations. Therefore, the regulations for wastewater have scarcely improved the hypertrophic condition of Lake Suwa.

About 65% of the cultivated land are paddy fields and the rest is upland vegetable field (Fig. 2). Especially for the vegetable fields, they use a lot of fertilizers, and consequently the nitrogen compounds from these areas have been another factor which accelerates the eutrophication of the lake.

The bait for cultured carp in floating net cages in the lake is the last artificial source supplying nutrients to the lake ecosystem. They feed carp with artificial bait rich in nitrogen and phosphorus. In 1978, as will be shown in Figure 5, the landing amount of cultured carp increased 13 times as great as that in 1964.

Furthermore, Lake Suwa suffers from civil engineering activities, such as dredging, reclaiming and embanking of the lakeshore all of which have changed the lake morphometrically. In the 1980s, more than 90% of the lakeshore had been embanked artificially and the surface area had decreased 8.3% by the reclamation. Thus, the lake has been suffering from various human activities.

4. 2. 4 Influx of the nutrients into the lake

Table 1 shows a rough estimation of nutrient influx to Lake Suwa from various sources in 1975. Although the data are not the latest ones, it can be seen in this table that the main source of the influx of nutrients is waste from domestic life, that is, the domesticities and the human feces treatment plant. These sources account for some 38 % for nitrogen and 57 % for phosphorus. The bait for cultured carps is the least artificial source of nutrients. The nutrients from the factories and the cultivated fields are some 10 to 20 %.

Table 1. Influx of nitrogen and phosphorus flowing into Lake Suwa from various sources in 1975.

Source	Influx of N		Influx of P	
	$kg \cdot day^{-1}$	%	$kg \cdot day^{-1}$	%
Domesticities	420	12.6	116	35.7
Human feces treatment plant	856	25.7	68	21.0
Factories	364	10.9	53	16.3
Cultivated fields	754	22.7	37	11.4
Forests	247	7.4	4.2	1.3
Bait for carps	100	3.0	8.5	2.6
Miscellaneous	586	17.7	38	11.7
Total	3,327	100	324.7	100

(Modified from the office report of Nagano Prefecture 1975)

In total, about 3 metric tons of nitrogen and 0.3 metric tons of phosphorus flowed into the lake in a day in 1975. And the nitrogen and the phosphorus originated from various human activities amount to 75 % and 87% of the total loading, respectively.

4. 2. 5 Change of transparency in the past 90 years

In the 1910s, Dr. A. Tanaka conducted the first scientific research of Lake Suwa, and afterward a considerable number of scientists have carried out limnological investigations. Figure 3, which is based upon their studies, shows the change in the transparency of the lake water. The upper line indicates the maximum numerical value of each year while the lower line indicates the minimum numerical value of each year.

As shown in this figure, the maximum transparency was about 2.7 meters and the minimum was about 1 meter in the 1910s, but about 1960 they began to decrease drastically and in the summer of the 1970s they often reached about 0 meter.

The 1960s was the period when Japan adopted the high economic growth policy and our economic activities were rapidly accelerated as Figure 4 shows.

4. 2. 6 Economic growth in Japan and Lake Suwa

Figure 4 shows the changes in GNP (Gross National Product) and the production of synthetic detergents for domestic use. The high economic growth policy adopted in the 1960s brought about an exponential increase in Japanese GNP. The similar increase can be seen in the production of synthetic detergent for domestic use, selected as an example of accelerated industrial productions. The reason why we selected the synthetic detergent for domestic use is that it contains 2 to 5% of phosphorus on a weight basis as a builder.

The largest source of phosphorus flowing into Lake Suwa was the wastewater from domesticities. It comprises about 36 % of the total influx. A part of this phosphorus comes from synthetic detergent. This figure suggests a rapid increase in the phosphorus load from synthetic detergent in the hydrosphere including Lake Suwa.

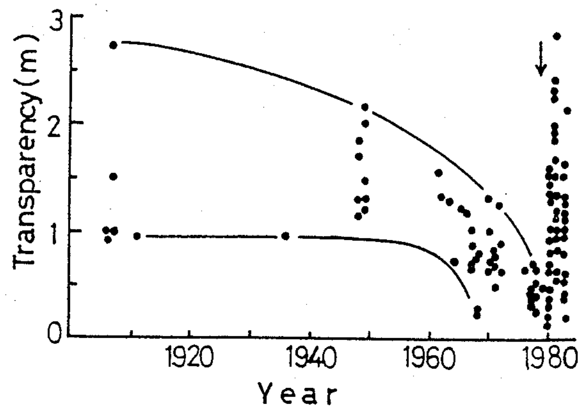


Fig. 3. The process of the change of the transparency in Lake Suwa since the 1900's. The mark of an arrow in this figure shows the opening year of the sewerage system in Lake Suwa area (Modified from Hayashi, H. and T. Okino, 1981).

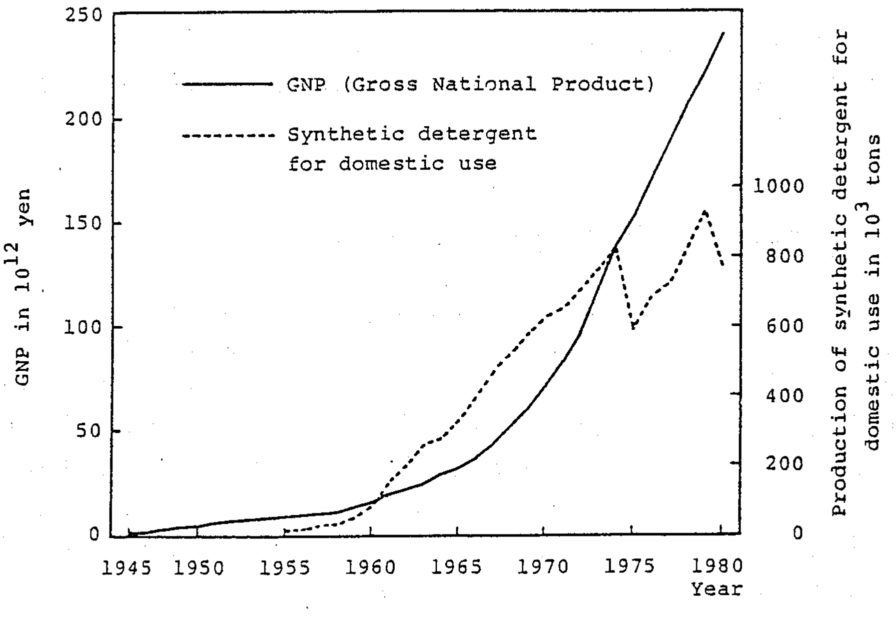


Fig.4. Changes in the Japanese GNP and the annual production of synthetic detergent for domestic use in Japan (Modified from Yomiuri yearbook 1982).

It is worthy to note that the increase in the GNP and the production of synthetic detergent coincided with the decrease in the transparency of the water of Lake Suwa. Generally speaking, the decrease in the transparency of the lake water indicates the acceleration of the eutrophication of lakes. The correlation between the GNP or the production of synthetic detergent and the transparency of the lake water suggests that the eutrophication which has been proceeding in Lake Suwa since 1960s is an artificial one.

4.2.7 Changes in the concentration of nitrogen and phosphorus in Lake Suwa

Lake Suwa has undergone a remarkable change in the standing stock of nitrogen and phosphorus (Table 2). The total amount of nitrogen has increased by about 6 times and the total amount of phosphorus about 15 times as much as 50 years ago. Lake Suwa has been changed into an extraordinarily productive lake, and has been categorized as a hypertrophic lake.

Table 2. Changes in the concentration of nitrogen and phosphorus in the water of Lake Suwa in μg/1.

Date	TN	TIN	TP	RP
1931 Aug.	260	—	20	—
1949 Sept.	490	220	80	14
1958 May.	1160	—	80	14
1966 July.	—	193	30	3
1969 June.	1350	325	—	—
1977 Aug.	1630—2020	2—60	260—340	80—100
1981 Aug.	1220—1500	190—630	160—290	24—40

TN: Total nitrogen TIN: Total inorganic nitrogen TP: Total phosphorus
RP: Reactive phosphorus (Modified from Sakamoto, 1973)

4. 2. 8 Changes in the fish catch in Lake Suwa

Figure 5 shows the changes in the fish catch of Lake Suwa. Lake Suwa is noted for the greatest fish catch per unit area in lakes of Japan. This figure is based upon statistics concerning the yields of aquatic macro-organisms from the lake since 1895.

The yields of aquatic organisms from the lake have been affected by many factors, which is the change in the commercial demand, the composition and standing stock of organisms, the number of fishermen, the technological improvement of fisheries, and the influence of the 2nd World War. Roughly speaking, the total fish catch has been stable at about 400 metric tons a year after the 2nd World War.

When it comes to the component of fish catch, however, there has been a notable change in recent years. Especially, among benthic fishes and shells, Corbicula and shrimps have remarkably decreased. As a result, 70% of the total fish catch is pond smelt (Hypomesus transpacifics) now, and if we add carp and crucian carp to it, more than 90% goes to these three kinds of fishes. Pond smelt is one of the few species that can take good advantage of the eutrophication of the lake, because there are plenty of rotifers in the water, which make good food for the fry of pond smelt, and enable them to grow in large quantities. In addition to that, there are few fishes that eat pond smelt in this lake. In order to promote the landing of pond smelt, the collection of fish eggs, fertilization and stocking are all artificially done here.

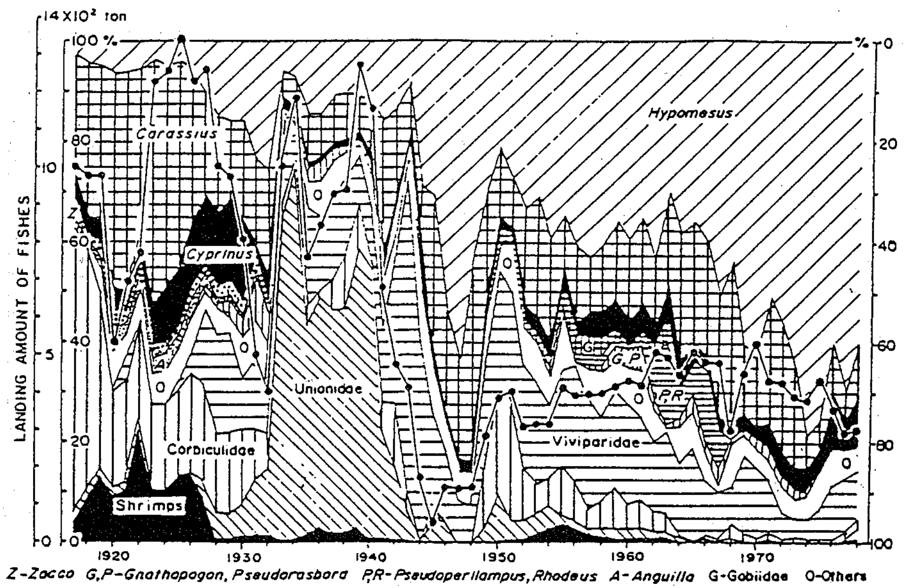


Fig. 5. Transitions in percent abundance of annual landing amounts of commercial fishes, molluscs and shrimps in Lake Suwa. A solid line in this figure shows the total landing amounts of fishery products in Lake Suwa (Quoted from Kurasawa, H. et al., 1983).

●——● Total amount

Figure 5 also indicates a remarkable increase in the yield of carp by aquaculture in the 1970s. The total landing of cultured carps exceeded four times as much as that by fisheries in 1978.

The change in the composition of aquatic organisms caught by fishermen does not always reflect the in situ change. However, these are the only data about the aquatic macro-organisms in Lake Suwa which cover nearly 100 years. Owing to the presence of these records, we have an outline for the change in the composition of aquatic macro-organisms before the scientific researches began.

4. 2. 9 Changes in the rooted aquatic plants

Figure 6 shows the changes in the standing crops of rooted aquatic plants and the changes in the percentages of three different groups divided by life form of aquatic plants in Lake Suwa.

The total standing crop of rooted aquatic plants in the whole lake reached a maximum in 1966. The standing crop at that time was about 1960 metric tons. It decreased by 24 % in 1976. This decrease is attributable mainly to the decrease in their habitats. The area of the emerged plants has been destroyed by embankment work. On the other hand, dredging work has destroyed the area of submerged plants.

As was mentioned previously, the surface area of Lake Suwa in 1978 decreased by 8.3% as compared with that in the 1910s by the embankment works. The embankment works along the shore have been carried out using sediments dredged from the lake. These human activities brought about not only changes in the standing stock of plants but also changes in the occupation percentages of each group of life form of aquatic plants as shown in Figure 6. Submerged plants were dominant in 1949. However, in 1976 floating leaf plants became dominant in their place. Floating leaf plants have suffered least from these engineering works.

On the other hand, the standing crop per unit area for the distribution zone of aquatic plants continued to increase until 1972 after that it decreased. This increase is due to the eutrophication of the lake water, in other words the eutrophication brought about the high production of plants. And the standing crop per unit area decreased in 1972 because the hypertrophic condition of the lake prevented light from reaching the submerged plants.

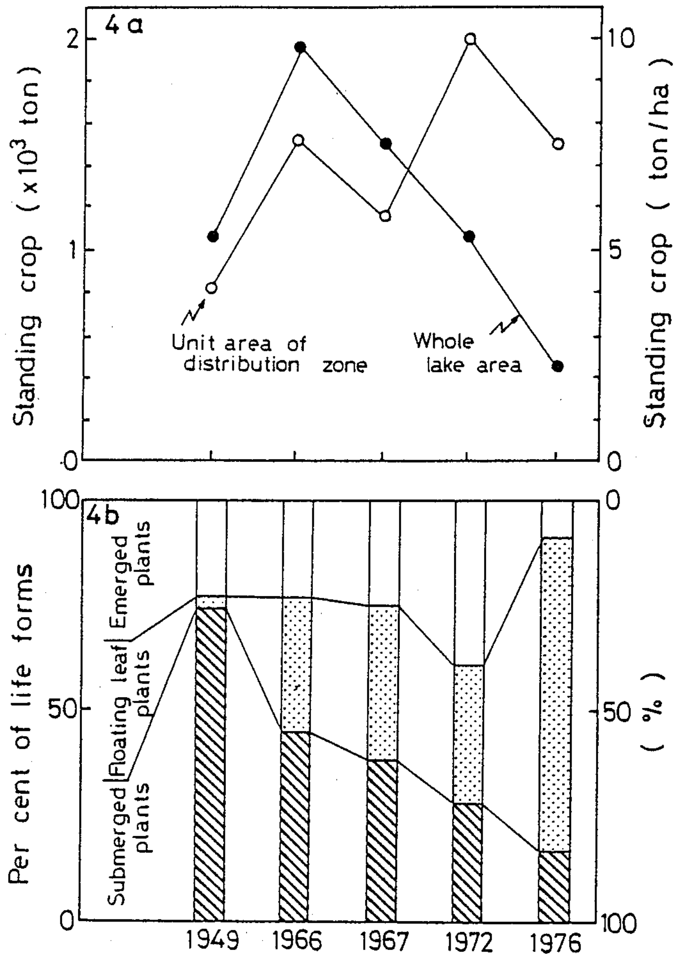


Fig. 6. Upper fig.; Standing crop of rooted aquatic plants in the whole lake area and the unit area of distribution zone of Lake Suwa. Lower fig.; Changes in the percentage of three life forms of aquatic plants (submerged, floating leaf and emerged plants) (Quoted from Kurasawa, H. et al., 1979).

4. 2. 10 Seasonal change in chlorophyll-a amounts

As was mentioned previously, the surface of Lake Suwa is covered with a thick green layer of bloomed *Microcystis* spp. in summer. Figure 7 shows the seasonal change in chlorophyll-a amount in 1977. The summer peak indicates the bloom of *Microcystis* spp. and the vernal peak the bloom for diatoms.

According to the remote sensing data sent from an American Earth Resource Satellite, the lake looks very much like grassland when *Microcystis* blooms. The tourists, who visit there, sometimes mistake it for green paint thrown in by accident. In order to improve this condition a large-scale wastewater treatment plant is being constructed now.

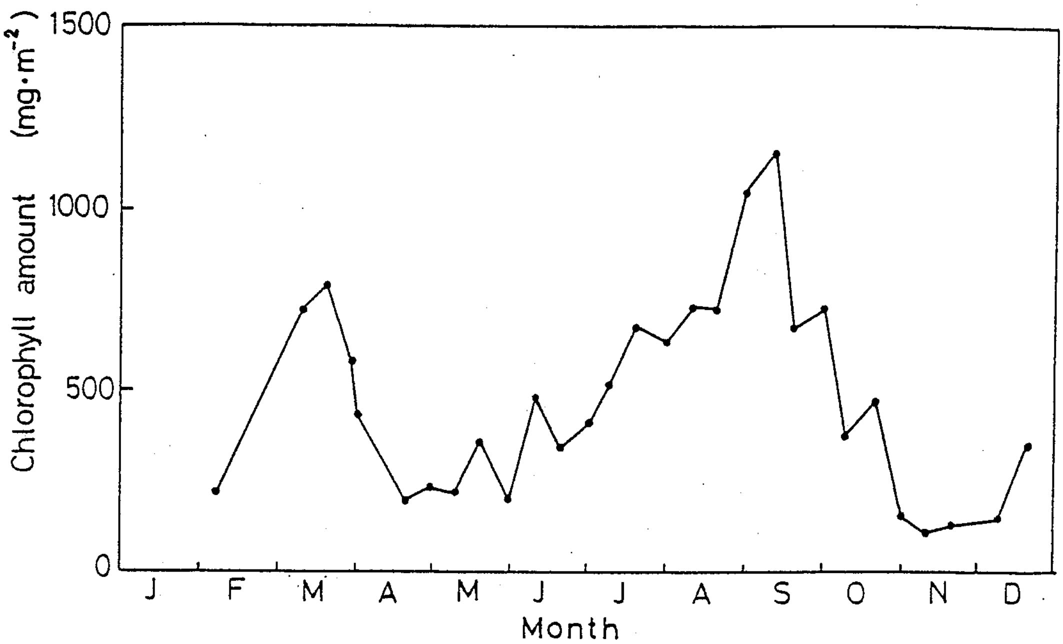


Fig.7. Seasonal change of chlorophyll-a amounts of Lake Suwa in 1997 (after Okino, T. and M. Yamamoto, 1978).

4. 2. 11 Wastewater treatment plant

The project area is shown in Figure 8. This plant deals with domestic, industrial and other wastewater and human feces conveyed from the surrounding areas of Lake Suwa by the main pipelines. In October 1979, a part of this plant started to operate. The mouth of the drainpipe from this plant opens into the Tenryu River, the only outlet of the lake. The nutrients coming from the catchment area of the lake decreased by 30% by the partial operation of this plant in the beginning of the 1980s.

In order to study the effect of the construction of this plant on the hypertrophic condition of Lake Suwa, a project team, research staff and students of the Suwa Hydrobiological Station of Shinshu University, has been carrying out routine observations since 1977. In these observations, more than 30 parameters including ecological, biological, chemical and physical ones have been surveyed in the water column of the lake center every 10 days since 1977, except for the two years of 1978 and 1979.

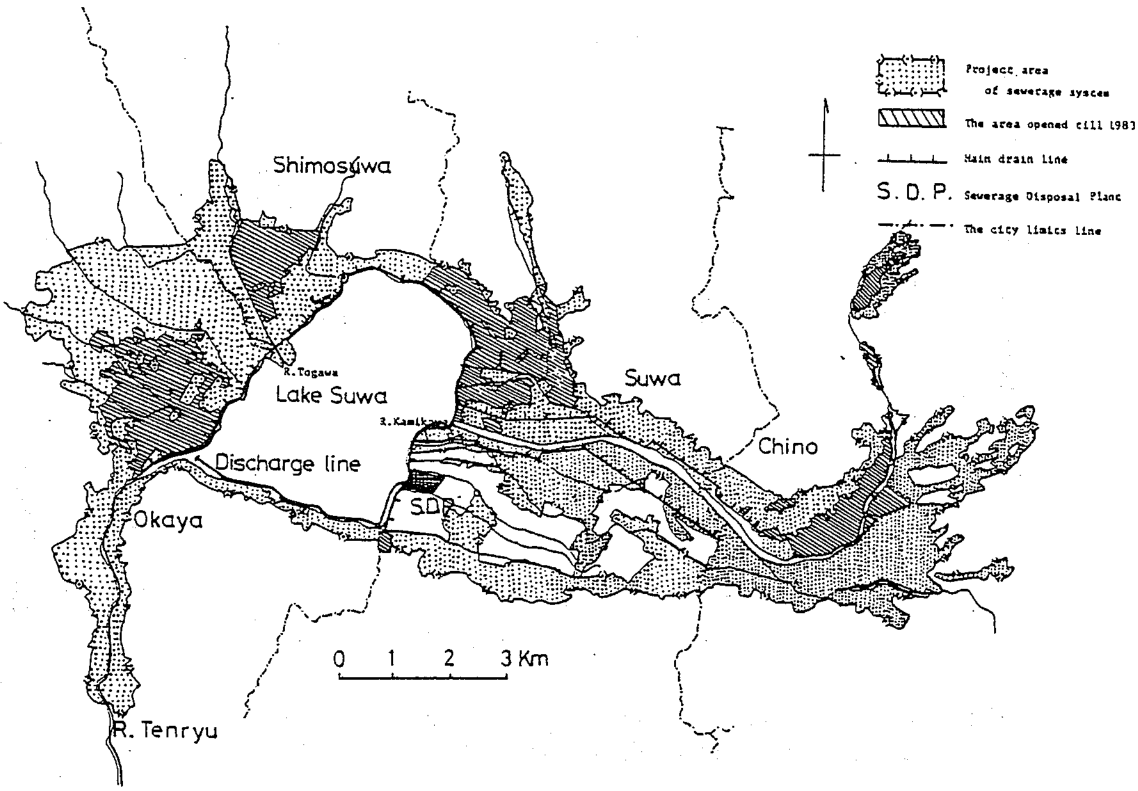


Fig.8. The project area of sewerage system and the opened area among this system till 1983 (by panphlet of the office of local government, Nagano Prefecture, 1983).

The beginnings of a partial recovery from the hypertrophic state of the lake could be seen in 1981 and it became clearer, little by little, in the continued observations at 10 days intervals since 1981 (Table 3). Table 1 shows the sources of nutrients supplied from the watershed area to this lake in 1975. It is apparent that the input from human activities was a critical source for an acceleration of the eutrophication in this lake. In order to cut down these inputs a sewerage system has been under construction, and more than 70 % of the plan has been completed now.

Table 3. Changes in the concentration ($\mu g\ l^{-1}$) of nitrogen and phosphorus in the water of Lake Suwa.

Date	TN	TIN	TP	RP
1931 Aug.	260	-	20	-
1949 Sep.	490	220	80	14
1958 May	1160	-	80	14
1966 Jul.	-	193	30	3
1969 Jun.	1350	325	-	-
1977 Aug.	1630-2020	2- 60	260-340	80-100
1981 Aug.	1220-1500	190- 630	160-290	24- 40
1982 Aug.	1130-2130	570-1730	70-280	20- 54
1983 Aug.	1110-1970	310- 400	100-250	8- 42
1984 Aug.	780-1150	20- 60	140-230	22- 89

TN = total nitrogen, TIN = total inorganic nitrogen, TP = total phosphorus, RP = reactive phosphorus

4. 2. 12 Partial recovery since 1981

In 1984, a 30 % reduction in nutrient loading from the watershed area was achieved by the operation of this plant. The effluent of the plant is diverted into the outlet of the lake through a drainpipe. A change in nutrient concentrations in the lake water is shown in Table 4 by a frequency distribution based on observations taken at 10 day intervals in the lake center for the whole water column.

For total nitrogen (TN), the highest concentration observed was less than 2.0 mg $\cdot$ L^{-1} in 1983 and 1984, while 10.5 % of the total observations in 1977 were in the class of 2.01−2.50 mg $\cdot$ L^{-1}. The annual mean value for total nitrogen was 0.99 mg$\cdot L^{-1}$ in 1984, 63 % of that in 1977. The apparent decrease in inorganic nitrogen, as shown in Table 3, is important in this lake, because the limiting factor for the summer algal growth is presumed to be nitrogen.

For total phosphorus, on the other hand, the highest concentration after the introduction of the sewerage system was 0.25 mg · L^{-1} and the annual mean value was about 0.1 mg·L^{-1}. Concentrations higher than 0.25 mg · L^{-1} were often observed in 1977 (21.4 % of the total observations in a year) when the annual mean value was 0.157 mg · L^{-1}. This latter figure is some 150 % of the values after treatment began. Corresponding to these decreases in the concentration of nitrogen and phosphorus, the algal biomass shown in the concentration of chlorophyll-a reduced significantly (Table 5). In terms of the annual mean values, the chlorophyll-a concentration reduces to half or one-third of that in 1977, in both 1983 and 1984.

Table 4. Frequency distribution of nitrogen and phosphorus concentrations (mg l^{-1}) estimated from sampling at 10-day intervals.

Total N (mg/L)	Frequency (%) 1977	1983	1984	Total-P (mg/L)	Frequency (%) 1977	1983	1984
-0.50	0.0	0.0	0.0	-0.050	0.0	12.8	12.9
0.51-1.00	10.5	16.0	64.5	0.051-0.100	32.1	66.7	51.6
1.01-1.50	47.4	60.0	32.3	0.101-0.150	25.0	12.8	9.7
1.51-2.00	31.6	24.0	3.2	0.151-0.200	7.1	5.1	19.4
2.01-2.50	10.5	0.0	0.0	0.201-0.250	14.3	2.6	6.4
2.51-3.00	0.0	0.0	0.0	0.251-0.300	14.3	0.0	0.0
3.01-	0.0	0.0	0.0	0.301-	7.1	0.0	0.0
Annual mean	1.57	1.31	1.31	Annual mean	0.157	0.080	0.111

Table 5. Frequency distribution (%) of Chl.a (mg m^{-2}) in the lake center.

Chl.a (mg/m^{-2})	1977	1983	1984
- 200	23.3	43.8	48.4
201 - 400	23.3	40.6	35.5
401 - 600	20.0	12.5	9.7
601 - 800	26.7	3.1	6.4
801 - 1000	0.0	0.0	0.0
1001 -	6.7	0.0	0.0
Annual mean	684	353	255

Table 6 shows the changes in gross production and other items. The gross production in the lake was 260 $gC \cdot m^{-2} \cdot yr.^{-1}$ in 1949. It became double in 1969. And then just before the sewerage system began to operate, it became triple. It seems that the gross production in 1982 after the partial operation of the sewerage system decreased to the level of 1969.

In conclusion, we suggest that a partial recovery from a hypertrophic state before 1977 to a eutrophic state in recent years has been achieved. Over this period, no dense algal scum has been observed. The introduction of a sewerage system is probably the main reason for this improvement although it is difficult to evaluate the effect of other controls such as climatic conditions. For instance, typhoons in the summers of 1982 and 1983 might partly contribute to the reduction in chlorophyll-a concentration in summer.

Table 6. Changes in annual gross production, annual mineralization, annual solar radiation and energy transfer efficiency by phytoplankton in Lake Suwa.

Year	Annual gross production $gCm^{-2} \cdot y^{-1}$	Annual mineralization $gCm^{-2} \cdot y^{-1}$	Annual solar radiation $Kcal\ cm^{-2} \cdot y^{-1}$	Energy transfer efficiency %
1949*	260	211	—	0.24
1969	557	615	—	—
1977	756	642	—	—
1978	699	708	114	0.61
1979	777	625	106	0.73
1980	—	—	110	—
1981	576	559	121	0.48
1982	629	541	115	0.55

* from Hogetsu et al. (1952)

4. 2. 13 A new attempt of the mitigation of Lake Suwa

Since 1990, renaturalization works have been under way for the shore of the lake due to the consensus of public opinion based on scientific advice. During this eight years about half of the artificial embankment made in concrete were reconstructed to the natural state with grasses and trees.

In the near future, we expect that the landscape of the lake shore will begin to recover its natural beauty and the littoral zone of lake will get better with aquatic organisms such as many kinds of aquatic plants, benthic animals and fishes. According to our experimental studies for emerged plants, mainly Phragmites, it has been suggested that the water quality of the lake was improved by the existence of aquatic plants and the recovery of the ecosystem as a lake littoral was more important.

Moreover, it is believed that the change in the attitude of local residents to natural environmental conservation has played a significant role in this recovery.

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Chapter 5

Current technology in limnology (2) Microbial ecology

Kenji Kato

5. 1 Bacteria: small but plenty

Introduction of the direct count method of bacteria using epifluorescence microscopy provided the major development in microbial ecology during the last two decades. Studies in various aquatic systems revealed that bacteria including archaea are far more abundant than expected from the knowledge obtained with culture dependent techniques. The abundance of bacteria is $10^{4\text{-}6}$ cells/ml in oligotrophic water and $10^{6\text{-}7}$ cells/ml in eutrophic water.

To characterize bacteria among constituents of aquatic ecosystems, the relation between size and generation time of planktonic organisms is summarized in Fig. 1. Sizes of phytoplankton range from micrometers to some tens of micrometers and their generation time is roughly estimated from a few days to a week. Size and generation time of zooplankton is about one to two orders larger than those of phytoplankton. Bacteria, on the other hand, are small in cell size, but they grow very fast. Thus, bacteria contribute very significantly in the matter flux of the system. By using a technique of direct count and a conversion factor from cell to carbon, the biomass of bacteria on a given day in Lake Suwa was estimated to be ca. 200 mgC/l, where the biomass of phytoplankton was 1000 mgC/1 (Table 1). There was a five-fold difference in the standing stock of these two ecosystem constituents. However, when we consider their doubling time (Fig. 1), i.e., once a day for phytoplankton there and 2 to 8 times per day for bacteria, both of them contributed equally to the carbon flux in the system.

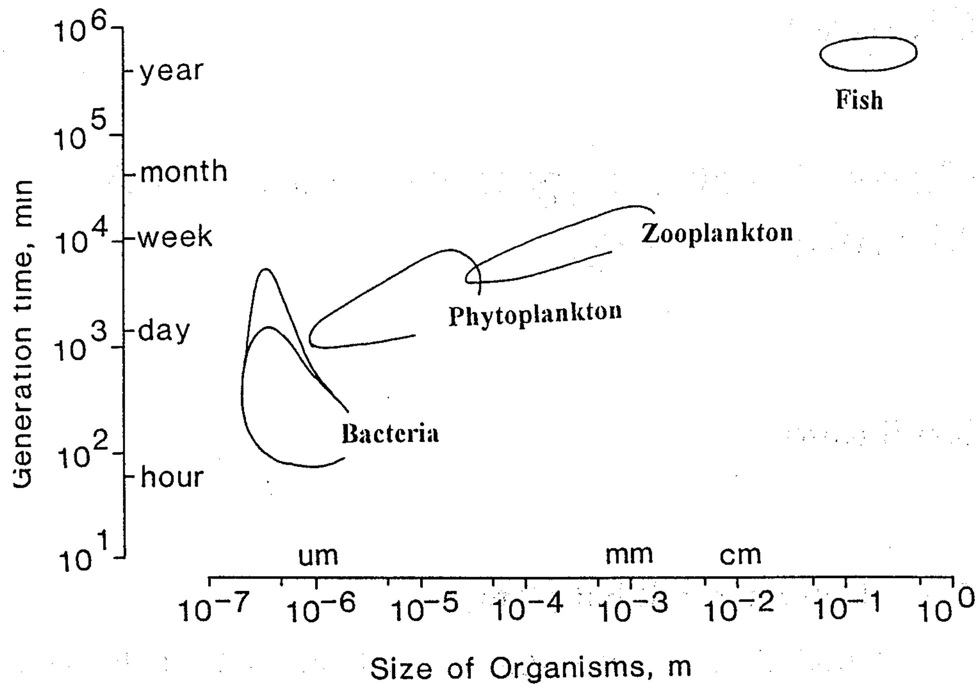


Fig. 1 Size and generation time of major constituents of an aquatic Ecosystem.

Table 1 Biomass of planktonic organisms in a eutrophic lake, L. Suwa. (After Kato, 1996)

	Standing stock (A) (μgC/l)	Turn over (B) (d^{-1})	(A) × (B)
Phytoplankton	1000	1	1000
Bacterioplankton	200	2–8	1000
Zooplankton			
Rotifer	400	0.3–1	240
Copepoda	250	0.03–0.07	12
Cladocera	25	0.03–0.07	1

Recent development of genetic phylogeny separates Archaea from Bacteria (Fig. 2). However, a term of bacteria includes archaea in this chapter.

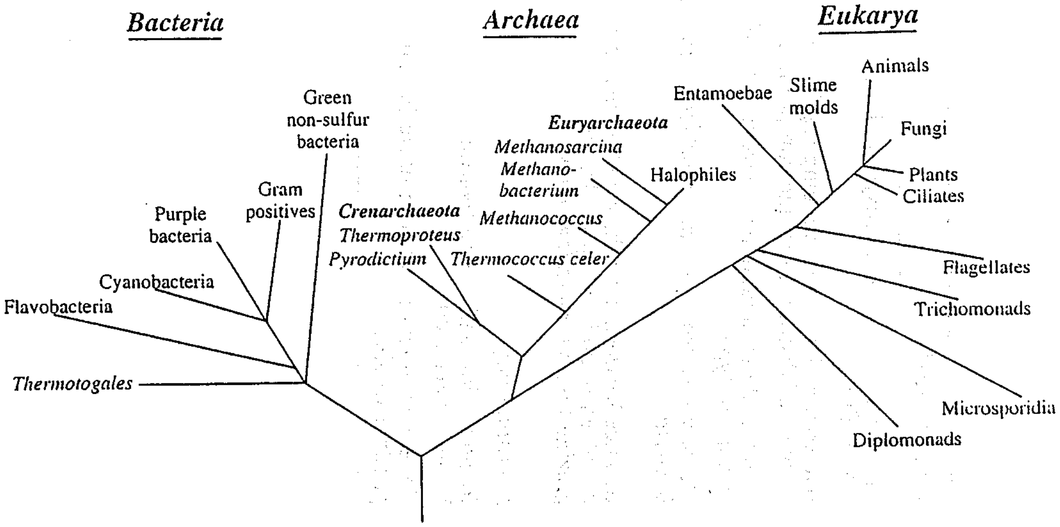


Fig. 2 Universal phylogenetic tree. This tree is derived from comparative sequencing of 16S or 18S ribosomal RNA. (Reprinted from Madigan et al., 1997 with permission by Prentice-Hall, Inc.)

5. 2 A brief history of aquatic microbial ecology

The characteristics of microbial ecology are eventually ascribable to their minute size. Microbial ecology is strongly restricted to the development of the method. Table 2 shows a brief history of major developments in the field of aquatic microbial ecology. The main stream of aquatic ecology began with measuring primary production (photosynthetic fixation of CO_2) using the radioisotope technique after World War II. Primary production rate was measured in various aquatic systems from the Pacific Ocean to small ponds to the degree that radioisotopes could be used in situ. Following the measurement of primary production, a radioisotope method to estimate heterotrophic activity, which could represent microbial activity by uptake of a dissolved organic compound such as ^{14}C-glucose, was proposed in 1965. Thus, the process of organic matter scavenging and flux was first successfully identified as a bacterial function of natural systems. This comprises a part of the function of decomposition of organic matter by bacteria when combined with a method to measure the mineralization rate for the same

Table 2 A brief history of aquatic microbial ecology. (After Kato, 1996)

Era	New techniques	Concept attained
Primary production since the late 1950's	^{14}C-CO_2 tracer experiment (Steeman-Nielsen 1952)	Importance of aquatic ecosystem in global matter flux
Heterotrophic activity since the late 1960's	^{14}C-glucose uptake (Wright and Hobbie 1965)	Bacterial activity in scavenging significant amount of dissolved organic compounds
AODC (Acridine orange direct count) since the late 1970's	Bacterial direct count using epifluorescence (Hobbie et al. 1977)	Great bacterial abundance, particularly of free-living type *Canbon flux from primary production to free-living bacteria*
Thymidine uptake since 1980's	^{3}H-thymidine uptake to estimate bacterial growth from DNA synthesis (Fuhrman and Azam 1980)	Balance between growth, which depends on dissolved organic compounds, and grazing loss by microflagellates *Microbial loop*
16SrRNA	(DeLong et al. 1989)	Identification without cultivation Evolutionary study
Viruses since 1990's	(Bergh et al. 1989)	Genetic interaction between bacteria and viruses; possible studies

substrate.

Throughout the 1970's and 1980's numerous studies were carried out to elucidate the uptake rate of dissolved organic compounds by bacteria size microbes. A method to reveal the aspect of population was established in the late 1970's after several trials. It took ten more years until a method to track bacterial population dynamics directly using gene probes was established.

5. 3 Function of bacteria in aquatic ecosystem: microbial loop

Bacterial function in aquatic systems has long been taken to be a decomposer of organic matter, particularly of particulate form. However, studies carried out in various aquatic systems using radioisotope with the differential filtration technique showed that a majority of heterotrophic activity ascribed to the fraction less than 1 μ m being free-living bacteria (see the next paragraph). Thus, the scavenging of dissolved organic matter by free-living bacteria was highlighted as an activity of planktonic bacteria. Dissolved organic matter is indeed a major pool of organic carbon comparing to that of the particulate form (Wetzel, 1983).

Dissolved organic carbon (DOC) is supplied into the water by (1) excretion of photosynthesized organic matter from phytoplankton, (2) release from sloppy feeding, (3) autolysis of plankton or release from decomposition of particulate organic matter, (4) input via river and others. The pass of (1) and (2) are the major contribution to the supply of DOC. The function of free-living bacteria, thus, is to scavenge DOC and convert it into particulate form, mineralizing nearly half of the uptake DOC through their respiration.

Bacteria are minute organisms. Thus, they had been considered to be too small to be captured by a grazer in water, if they were free floating with a single cell. However, it was shown in the middle 1980's that small planktonic *Metazoa* as microflagellates could consume free-living bacteria by their activity of phagocytosis (Fuhrman and McManus, 1984). Thus, bacteria were known to be included in the aquatic food web. Furthermore, if we think of their high activity of mineralization, they should constitute a very significant part of the food web. Azam et al.

(1983) suggested earlier to this that bacteria could construct a way of matter flux in aquatic ecosystems other than the conventional grazing food chain, i.e., microbial loop (Fig. 3).

It is known today that even large zooplankton (*Bosmina longirostris*) can consume free-living bacteria with their fine filtration apparatus (Toth and Kato, 1997).

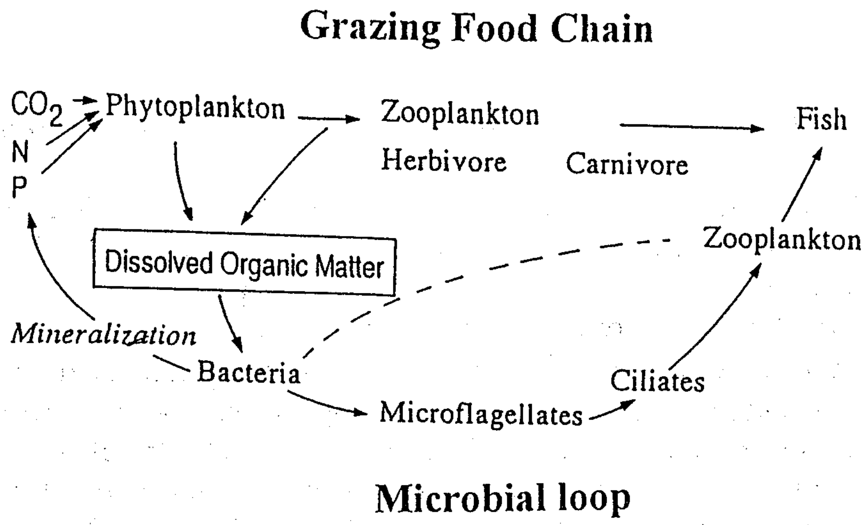
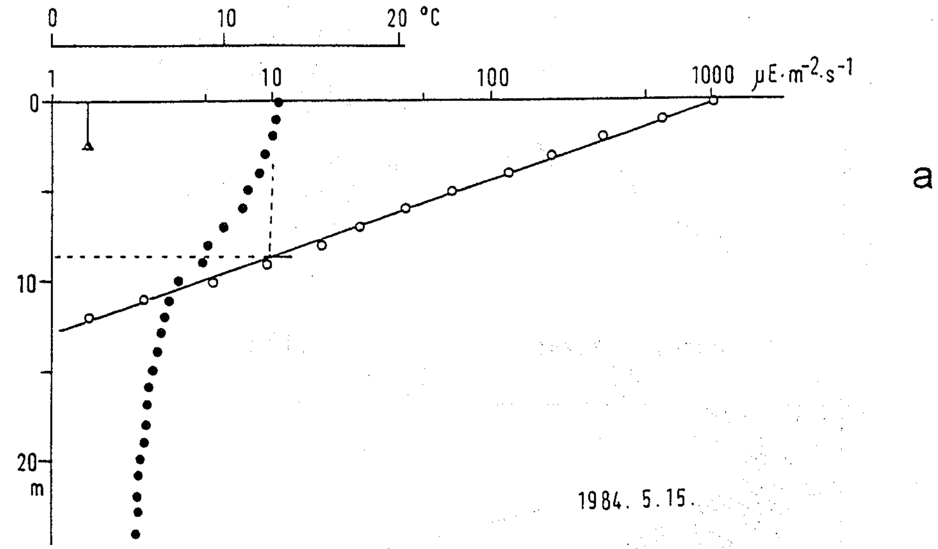


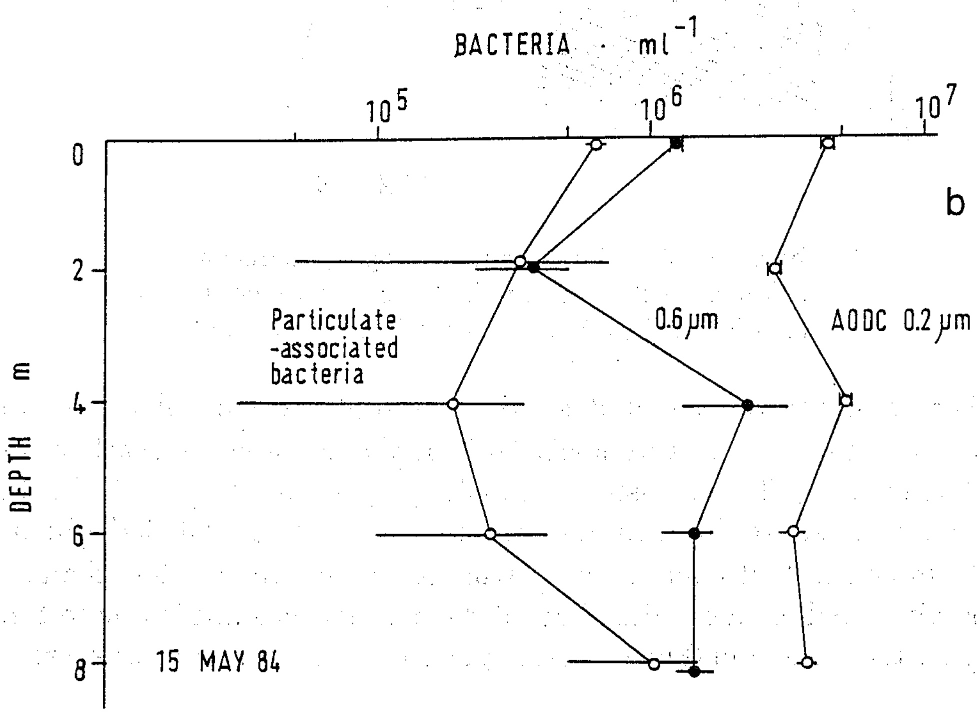
Fig. 3 Grazing food chain and microbial loop (Kato, 1996).

5. 4 Vertical profile of bacteria: abundance and activity

Figure 4a shows vertical profiles of temperature and light penetration measured at the lake center of Lake Kizaki, a mesotrophic lake 29m deep and located in Nagano prefecture. This suggests that the upper 10 m was a layer of light penetration and this was a thermally stable surface layer during spring, summer and autumn.

Figure 4b shows the vertical distribution of bacteria on the same day at the same station. The number of total bacteria counted directly under epifluorescence microscopy (see paragraph 7) amounted to 5×10^6 cells/ml and free-living bacteria constituted nearly 90 % of total bacteria throughout the water column. Vertical differences in number were not apparent. However, when we apply a culture technique to evaluate the vertical distribution of heterotrophic bacteria using some media, differences in number between epilimnion and hypolimnion become larger than this; high number in epilimnion and that of low in hypolimnion, though the absolute number was about two orders smaller than that of the direct count.





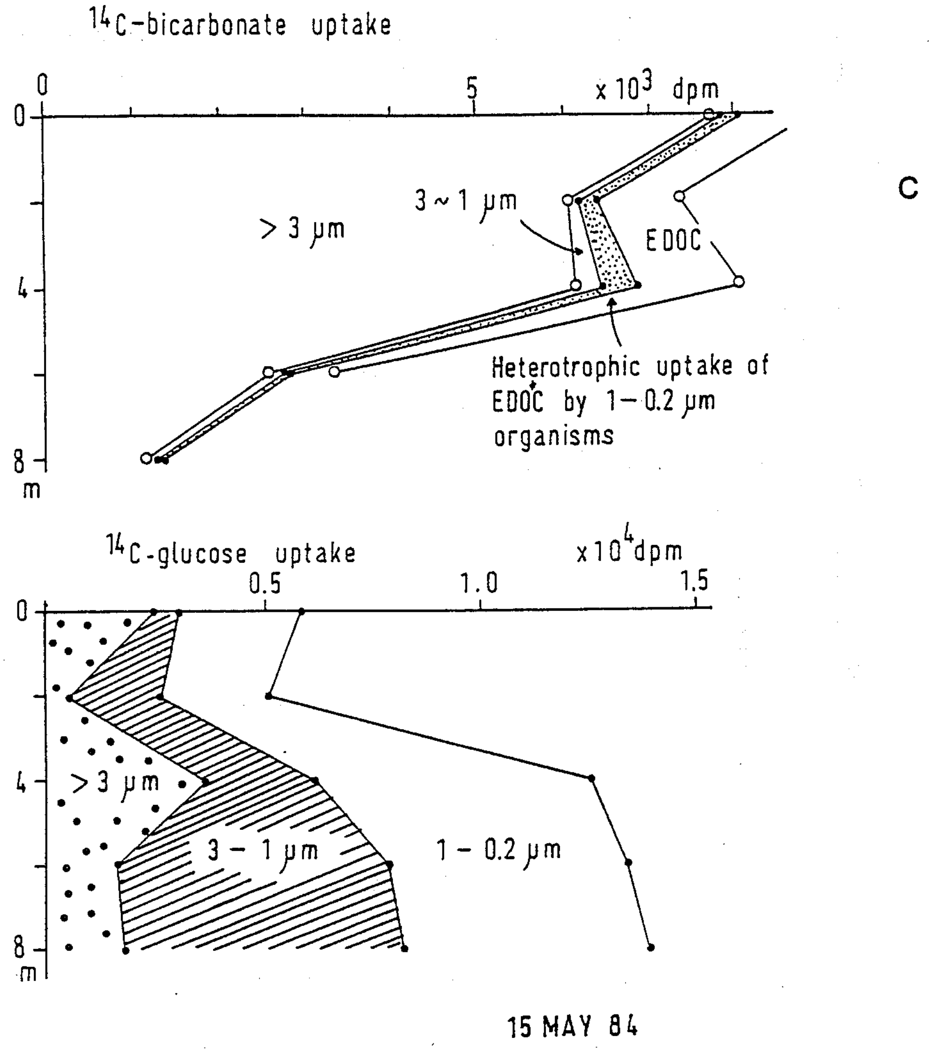


Fig. 4 Vertical profiles of temperature and light penetration **(a)**, vertical distribution of bacteria **(b)** and vertical profile of microbial activity **(c)** in Lake Kizaki on 15 May 1984.

Figure 4c shows that photosynthetic activity was ascribable to the fraction larger than 3 μ m and nearly 10 % of photosynthesized carbon was excreted from algal cells instantaneously (Fig. 4c above panel). On the other side, heterotrophic activity measured by isotope labeled glucose uptake indicated that major activity was due to the fraction less than 3 μ m and about half or more than half of the activity was ascribable to free-living bacterial fraction (Fig. 4c below panel). About one-third of excreted photosynthesized organic carbon was uptaken by bacteria. Vertical analysis suggests that microbial heterotrophic activity is located beneath photosynthetic activity. It is possible to obtain these kind of vertical profiles of bacterial number and activity, if thermal stratification is stable in an aquatic system.

5. 5 Diurnal change in bacteria

Heterotrophic bacteria depend on their substrate mainly for photosynththic activity. Thus, a daily light and dark cycle may control bacterial activity in short time fluctuation. Figure 5 shows a diurnal change in bacterial size class distribution at the surface of L. Soyang, a deep Korean lake (Cho et al., 1999). The smallest size class predominated in the morning (09:00), but the peak became insignificant with time and the middle size class with the size about twice or more became large in contribution until 18:00. After that the small size class once again predominated. Data suggests that size sift occurred once again during mid night as a sequential cell division following that of the evening, or some grazing impact changed the size distribution of bacteria.

5. 6 Geochemical function of bacteria in lakes

Bacterial function in aquatic ecosystems is never limited to the carbon cycle. Nitrogen, phosphate and sulfate are well known elements governed strongly by microbial activity. Among them nitrogen and phosphate are converted rapidly through a microbial loop. In addition to this, planktonic bacteria eliminate nitrogen from water by their denitrification activity, which occurs at the interface between oxic and anoxic layers. Recent study revealed that denitrification initiated from the sediment in summer and the active layer raise up in accordance with the development of an anoxic zone from the sediment (Abe and Kato, 1998). Particulate-associated bacteria were the majority in summer, but free-living bacteria contributed very significantly in parallel with the active layer going up. The finding suggests a possible example of source and adaptation of bacteria in denitrification.

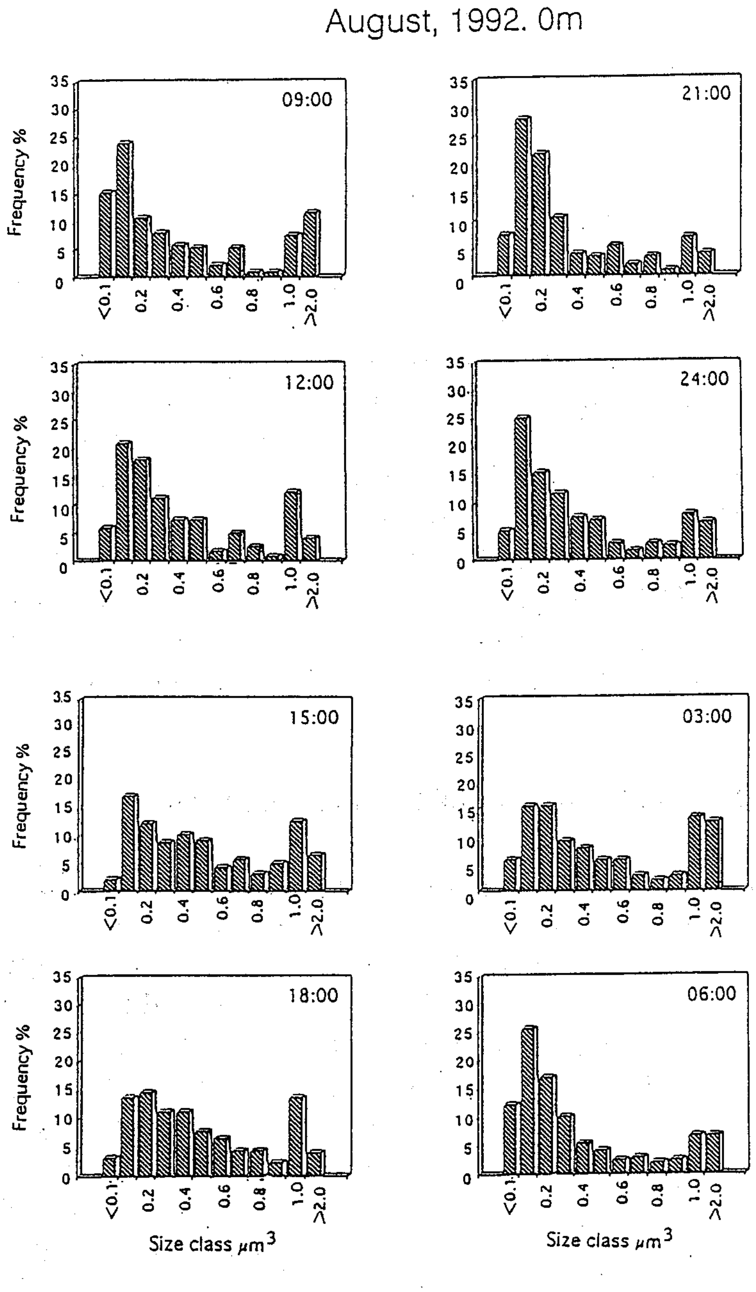


Fig. 5 Diurnal change in frequency of bacterial size classes. Reprinted from Cho et al. (1999) with permission by E. Schweizerbart'sche Verlagsbuchhandlung.

5. 7 How to enumerate bacteria and how to analyze bacteria community

We have two distinct methods to enumerate bacteria; direct count with epifluorescence microscopy with a DNA staining technique using acridine orange (AO) or DAPI and a method that depends on culture. The question is in the difference of enumeration between these two methods. The culture dependant technique provide only one per cent or less of the total bacterial count provided by the direct count method. It is no doubt that one or two different media could not cover the diversity of environments in situ, thus we retrieve a very limited proportion of the natural bacterial assemblage. If bacteria could not grow rapidly, we could not detect their existence in the method that depends on culture. In addition to these technical limits, there might be dead bacteria though they possess some DNA inside. Moreover, it is becoming accepted that there exist bacteria being viable but non-culturable (VBNC or VNC) as a majority in nature. To give a basic knowledge of bacteria in a given sample, direct count is to be first applied. Thus, this technique is described in a chapter on the method.

In addition to the enumeration of total bacteria (direct count with AO or DAPI), recent advancements in microbial ecology provide a direct microscopic method to give a knowledge on (1) how many of the total bacteria are metabolically active, (2) cellular size distribution of bacteria (Kato, 1996), (3) genetic identification of bacteria using gene probes. Information about viability is also given by a culture dependant technique, but the meaning of obtained data is different from those mentioned above. An appropriate technique is to be applied.

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Chapter 6

Global Environment and Lake Ecosystems

Takayuki Hanazato

6. 1 Introduction

Freshwater bodies are intensively utilized by human beings and therefore ecosystems being therein are exposed to environmental stress caused by human activities.

Global environmental problems such as climatic warming, ozone depletion, acid precipitation and contamination with toxic chemicals are becoming big issues. These factors must affect lake ecosystems, and thus the effects should be evaluated.

In this lecture, I discuss the effects of environmental stress on the structure of the zooplankton community and functioning of the lake ecosystem. Zooplankton take the central position in lake ecosystems because they transfer energy from primary producers to top predators. Therefore, an understanding of the effect on the zooplankton community helps us in evaluating the effect on the whole ecosystem.

6. 2 Sensitivity of zooplankton species to environmental stress

Sensitivity of organisms to environmental stress differs among the organic species. Hanazato (1998) applied insecticides with different concentrations to experimental ponds to evaluate the chemical effect on plankton communities, and found that there is a order in sensitivity to the chemicals: the large-sized cladoceran *Daphnia* is the most sensitive, the medium-sized cladocerans the second most sensitive, and the small-sized *Bosmina* the next, and the smaller zooplankters, rotifers, are the most tolerant to the chemicals. That is, larger zooplankton species tend to be more sensitive to the chemicals than the smaller ones (Fig. 1). This trend has been observed also in the sensitivity to the heavy metal copper (Havens, 1994) and acidification (Havens and Hanazato, 1993). Interestingly, *Daphnia* is also very sensitive to high water temperature (Moore and Folt, 1993). So that the trend may be applicable to climatic warming as well.

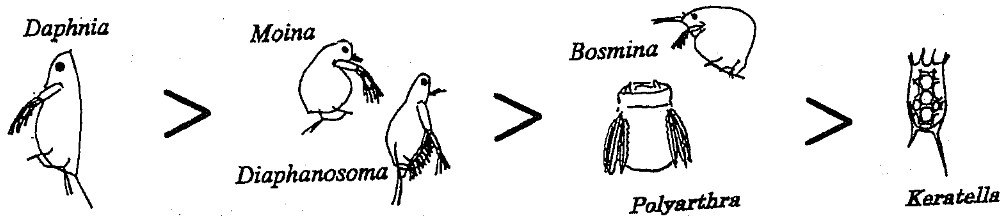

Fig. 1. Presumed order of sensitivity to the insecticide carbaryl among zooplankton species/groups in the experimental ponds (Hanazato, 1998, reprinted with permission by Elsevier Science Limited).

6. 3 Competitive relationship in the zooplankton community

Many zooplankton species compete with each other for food, and there is an order in competitive superiority among them. *Daphnia* are usually the most superior competitors, the medium-sized cladocerans the second most superior and the small-sized cladocerans next, and the smaller rotifers are the most inferior competitors (Gerritsen, 1984; Gilbert, 1988, Hanazato and Yasuno, 1991, Gliwicz, 1990). That is, larger zooplankters tend to be better in competition than small ones (Fig. 2). The superiority of the larger animals is ascribed to the wider spectrum of particle sizes used in feeding, the higher filtering rate, lower metabolic loss and higher tolerance to starvation. Interference competition between cladocerans and rotifers should also be included as a mechanism explaining the competitive order (Gilbert, 1988; Macisaac and Gilbert, 1991).

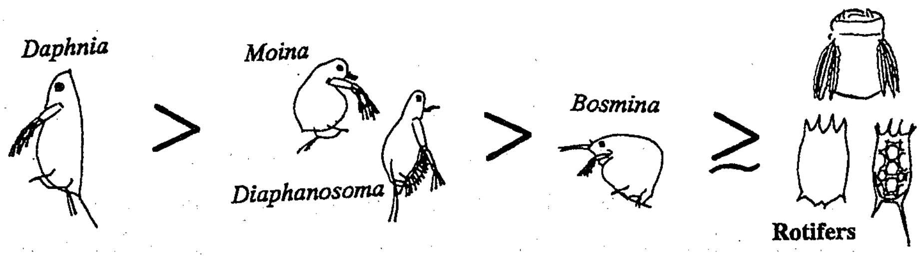

Fig. 2. Presumed order of competitive superiority among zooplankton species/groups in the experimental ponds (Hanazato, 1998, reprinted with permission by Elsevier Science Limited).

It is of interest that the order of sensitivity of the zooplankton species to the environmental stresses (insecticides, heavy metals, high water temperature) is just the same as their order of competitive superiority. For instance, *Daphnia* is the strongest competitor in the zooplankton community, but most sensitive to the environmental stress.This suggests that one effect of the stress in the zooplankton community may be for a relatively low level of stress, which damages only *Daphnia,* to affect the population dynamics of other zooplankton species indirectly through their competitive relationships. In fact, the occurrence of blooms of rotifer species after destruction of the *Daphnia* population by insecticides and acidification has often been observed (Hurlbert *et al.,* 1972; Day *et al.,* 1987; Havens and Hanazato, 1993).

6. 4 Structure of zooplankton communities and functioning of ecosystems in lakes impacted by environmental stress

Daphnia is the most superior competitor in the zooplankton community. Therefore, once *Daphnia* have increased in the community, the densities of other zooplankton species are reduced to very low levels through competition, and the extreme dominance of *Daphnia* is maintained. The *Daphnia*-dominated community is stable and has a low species richness; however, *Daphnia* is sensitive to environmental stress. The *Daphnia*-dominated community is, thus, vulnerable to the stress, and is made unstable by it. Once the *Daphnia* population is destroyed by the stress, many species, such as small cladocerans and rotifers, are released from competition with *Daphnia* and, consequently, the zooplankton species richness increases. However, the high species richness finally settles at a very low level when the stress has been reduced and the *Daphnia* population recovers. The scenario mentioned above is shown in Fig. 3, which was observed in experimental ponds where an insecticide was applied (Hanazato, 1994).

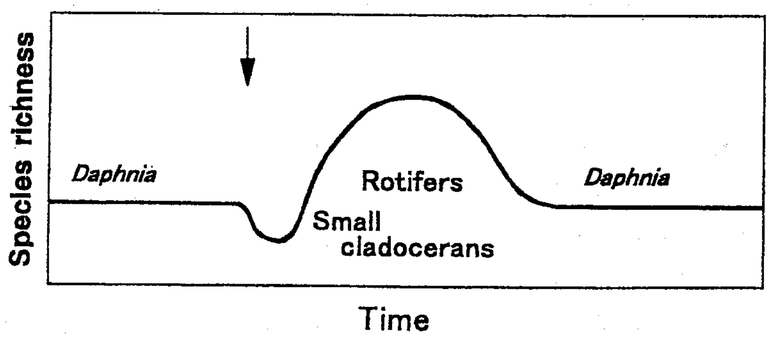

Fig. 3. Changes in species richness after application of the insecticide Carbaryl (arrow). Names of the dominant zooplankton species/groups are shown in the panel (Hanazato, 1994, reprinted with permission by Earth-Human Environmental Forum).

Another example of the stress effect on species richness of zooplankton community has been shown by Hanazato (1997), who applied the insecticide carbaryl of two different concentrations repeatedly to the experimental ponds with or without the predacious midge larva. The high-dose chemical treatment reduced the species richness of the cladoceran community to just one in the ponds without the predator (the Cladocera-dominant ponds) (Fig. 4a): only the small cladoceran *Bosmina* survived. However, the same treatment increased the species richness in the rotifer community in the ponds with predators (the rotifer-dominant ponds) (Fig. 4b): in these ponds, it seemed to suppress, but not eliminate,

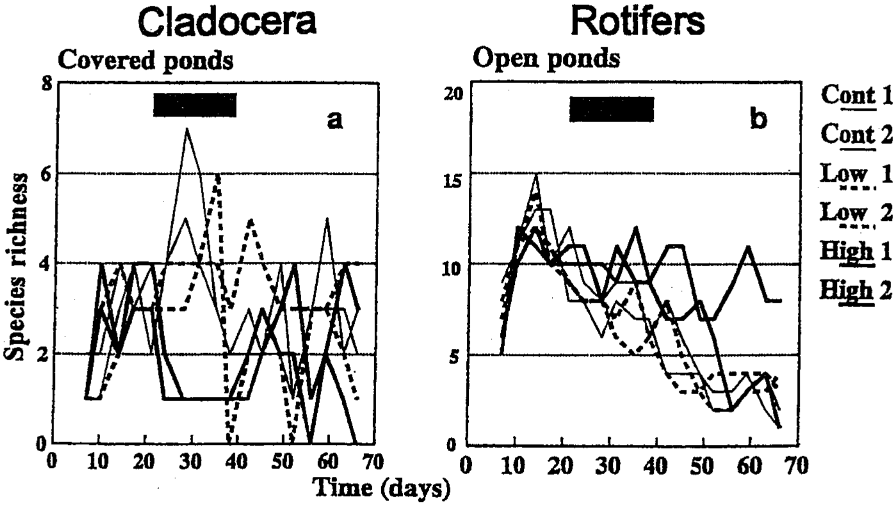

Fig. 4. Changes in species richness of the cladoceran community in the covered ponds (without predacious midge larva) and of the rotifer community in the open ponds (with the predator). The insecticide carbaryl (10 μg liter^{-1} = low dose; 100 μg liter^{-1} = high dose) was applied repeatedly (10 times) during the period shown by shaded bars in the panels. Thin lines: control ponds; broken lines: low-dose ponds; and thick lines: high-dose ponds.(Hanazato, 1997, reprinted with permission by Shinshu University).

the dominant rotifer species, allowing competitively inferior species, but more tolerant to the insecticide, to co-exist with the competitively superior species. This case may indicate that a moderate impact of the insecticide contamination does not always reduce biodiversity in a community, but sometimes increases it. The results support the hypothesis given by Connel (1978) and Menge and Sutherland (1987) that intermediate disturbance increases species richness/diversity, established from studies on tropical rain forests and coral reefs, and from models of community structure.

It has been demonstrated in natural lakes that acidification (a kind of chemical stress) reduces species richness/diversity of the zooplankton community (Confer and Kaaret, 1983; Havens, 1991; Locke, 1992). In that case, the plankton community is under a continuous stress. This is not the case for the Hanazato (1994)'s study, where the plankton community has been exposed to chemical stress for a relatively short period. It may be concluded that short-term or intermittent, but not continuous, perturbation by chemical stress sometimes increases the species richness/diversity of communities.

Because *Daphnia* is most sensitive to various environmental stresses, it is eliminated from the zooplankton community if the water bodies are impacted by the stresses at harmful levels. If so, small zooplankton species are released from competition with *Daphnia* and increase in dominance, as mentioned above. It is suggested that the environmental stress induces dominance of small zooplankton species in lakes and consequently reduces the mean body size of individuals in the zooplankton community (Havens and Hanazato, 1993).

In the case of climatic warming, it also reduces the mean body size of the zooplankton community but by two ways. One way is to reduce the dominance of *Daphnia* and to increase abundance of small zooplankton species as other environmental stresses. Another way is to reduce the mature size of animal species. It is known that increased temperature reduces the mature size of many zooplankton species (Hanazato and Yasuno, 1985; Moore and Folt, 1993: Table 1), decreasing the mean body size of their populations.

Table 1. Mature size (mm) of Cladocera at different temperatures. Mean±SD. Number of observations in parenthesis.

Species	10℃	12℃	15℃	20℃	25℃	30℃
Daphnia						
Longispina	**1.77**	**1.48±0.05**	**1.51±0.06**	**1.37±0.07**	**1.12±0.06**	
	(2)	**(10)**	**(9)**	**(8)**	**(5)**	
Moina						
micrura			**0.78±0.07**	**0.77±0.03**	**0.78±0.03**	**0.70±0.05**
			(10)	**(9)**	**(11)**	**(10)**
Diaphanosoma						
brachyurum			**0.80±0.01**	**0.81±0.02**	**0.74±0.02**	**0.70±0.04**
			(5)	**(4)**	**(8)**	**(9)**

Daphnia is a key member of lake communities because it grazes effectively on algae over a large size range (from picoplankton [<2 μm] to netplankton [>20 μm] and is a preferred food item for fish (Shapiro, 1980; Gerritsen, 1984; Gliwicz, 1990). On the other hand, small zooplankters, such as *Bosmina* and rotifers, feed mostly on nanoplankton (2-20 μm) and are preyed upon by invertebrate predators more intensively than by fish (Dodson, 1974; Bogdan and Gilbert, 1982; Gilbert, 1985). Therefore, the food chain from primary producers (algae) to top predators (fish) may differ between lake ecosystems where the zooplankton community is dominated by *Daphnia* vs small zooplankton (Fig. 5).

In an ecosystem with abundant *Daphnia,* a large part of primary production (due to pico-, nano- and net-plankton) is utilized by the top predator fish through the herbivore *Daphnia,* while in the ecosystem with abundant small zooplankters and few *Daphnia,* a smaller part of primary production (due only to nanoplankton) is brought up to the top predators through the herbivorous small zooplankters and invertebrate predators.

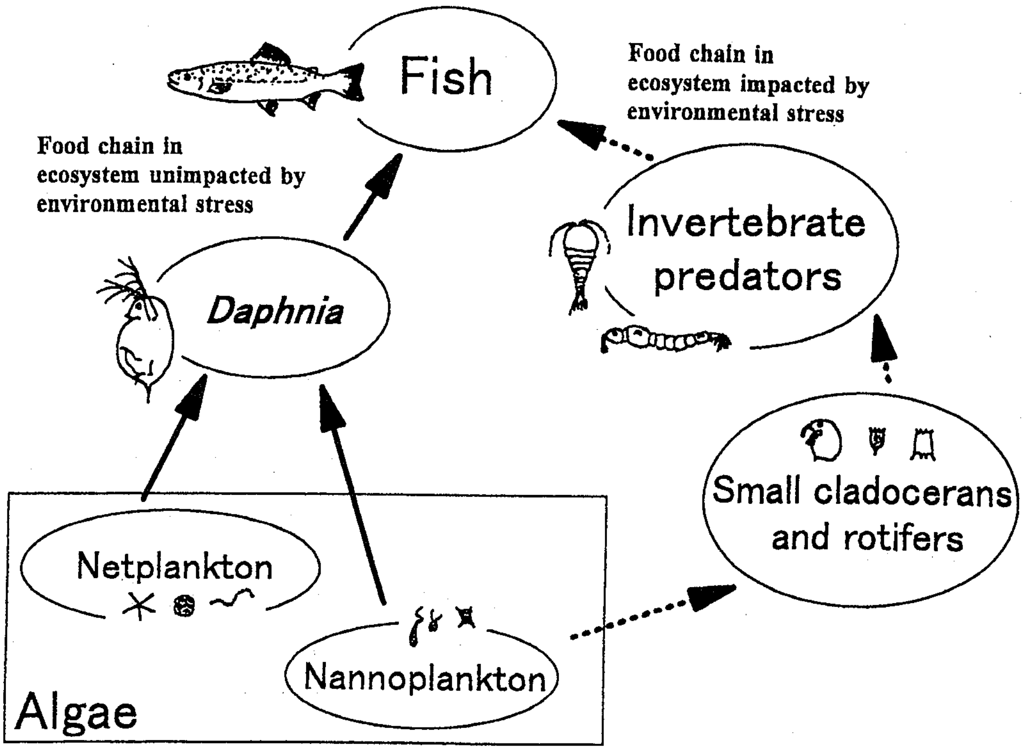

Fig. 5. Main pathways of carbon/energy flow from algae through zooplankton to fish in lake ecosystems impacted and unimpacted by environmental stress.

Thus, the number of steps in the food chain from primary producer to fish (food chain length) is larger in the ecosystem with small zooplankters than that with *Daphnia* (Fig. 5).

It may be assumed that the energy transfer efficiency from primary producer to top predator is higher in the ecosystem dominated by *Daphnia* than the ecosystem with abundant small zooplankters, because the latter ecosystem has more steps in the food chain and energy loss occurs during transfer from one trophic level to another. The latter ecosystem could be induced by various environmental stresses. Hence, one of the effects of the stresses on the functioning of the lake ecosystem may be to reduce energy transfer efficiency through the food chain.

Environmental stress appears to elongate pathways of carbon/energy flow in the food webs in lake ecosystems as mentioned above. The following factor should also be considered as elongating the pathway in a stressed ecosystem. The efficiency of resources use by herbivores is low in the plankton community dominated by small zooplankton species, because the size range of particles that small zooplankters can ingest is narrower than that eaten by large zooplankters. Thus, in the ecosystem with abundant small zooplankton species (which is induced by environmental stress), a larger proportion of the algal material is not utilized by the herbivores directly, but indirectly through the detritus food chain/microbial food web, where bacteria and protozoa play an important role in transferring energy (Porter *et al.,* 1985; Sanders *et al.,* 1989). This certainly increases the number of trophic steps in the food chain.

In conclusion, the hypothesis is confirmed that the following two phenomena characterize the structural and functional responses of ecosystems to various environmental stresses: (1) the average size of organisms is reduced, and (2) energy transfer efficiency from primary producer to top predator is reduced.

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Chapter 7

Water Resources and environmental problems of Lake Biwa, Japan

Hiroji Fushimi

Snow cover plays an important role in the quality and quantity of water resources, such as supplying dissolved oxygen as well as acid materials to Lake Biwa in relation to climatic changes and anthropogenic activities. So, the main topics are A) decrease of snow cover amounts under climate warming and its influences upon the water quality of Lake Biwa and B) microscopic structures of acid materials in snow crystals in relation to acidification processes.

7.1 Decrease of snow cover amounts under climate warming and its influences upon the water quality of Lake Biwa

Abstract

It is reported that the average air temperature will increase by 1.5 to 3.5℃ by the 2030's. If the increase in average air temperature is 1.5℃, the amount of snow cover would not exceed 1 billion tons, which is the average amount of snow cover in the Lake Biwa catchment area, unless the precipitation exceeds the expected amount by more than 20 %. If the average air temperature rises by 3.5℃, the amount of snow cover would significantly decrease to 0.6 billion tons even if the precipitation exceeds by 20 %.

When the amount of snow cover is less than 1 billion tons, the lowest dissolved oxygen concentration in the deep layer of Lake Biwa rapidly decreases. However, the dissolved oxygen concentration increases, when the amount of snow cover is more than 1 billion tons. The climatic warming will significantly decrease the amount of snow cover in Lake Biwa catchment area and the dissolved oxygen concentration in the deep layer of Lake Biwa, leading to further enhancement of eutrophication in Lake Biwa.

7. 1. 1 Introduction

Lake Biwa, the largest lake and the most important freshwater resource in Japan, is located in Shiga Prefecture of the Kinki region nearly in the center of Japan (Fig. 1). Some 13 million people in Osaka, Kyoto and several other municipalities depend on the water supply from Lake Biwa and its outflowing Yodo River.

The areas of Lake Biwa and its catchment are 674 and 3,174 km, respectively. Lake Biwa's catchment area is surrounded by mountain ranges of a little more than 1,000 m above sea level. During the winter season, the northern part of the catchment area gets covered by vast snow cover which is a very important water resource for Lake Biwa.

The water from melted snow has a high concentration of dissolved oxygen. In years when the amount of snow cover is meager, the dissolved oxygen concentration becomes significantly low in the deep layer, hypolimnion, of the lake, indicating that snow cover is expected to play an important role in preserving the dissolved oxygen concentration of Lake Biwa.

It is reported that the annual average air temperature will increase by 1.5 to 3.5℃ by the 2030's (Japan Meteorological Agency, 1989). If so, what will happen to the amount of snow cover in the Lake Biwa catchment area and the dissolved oxygen concentration of Lake Biwa in this coming 21 century?

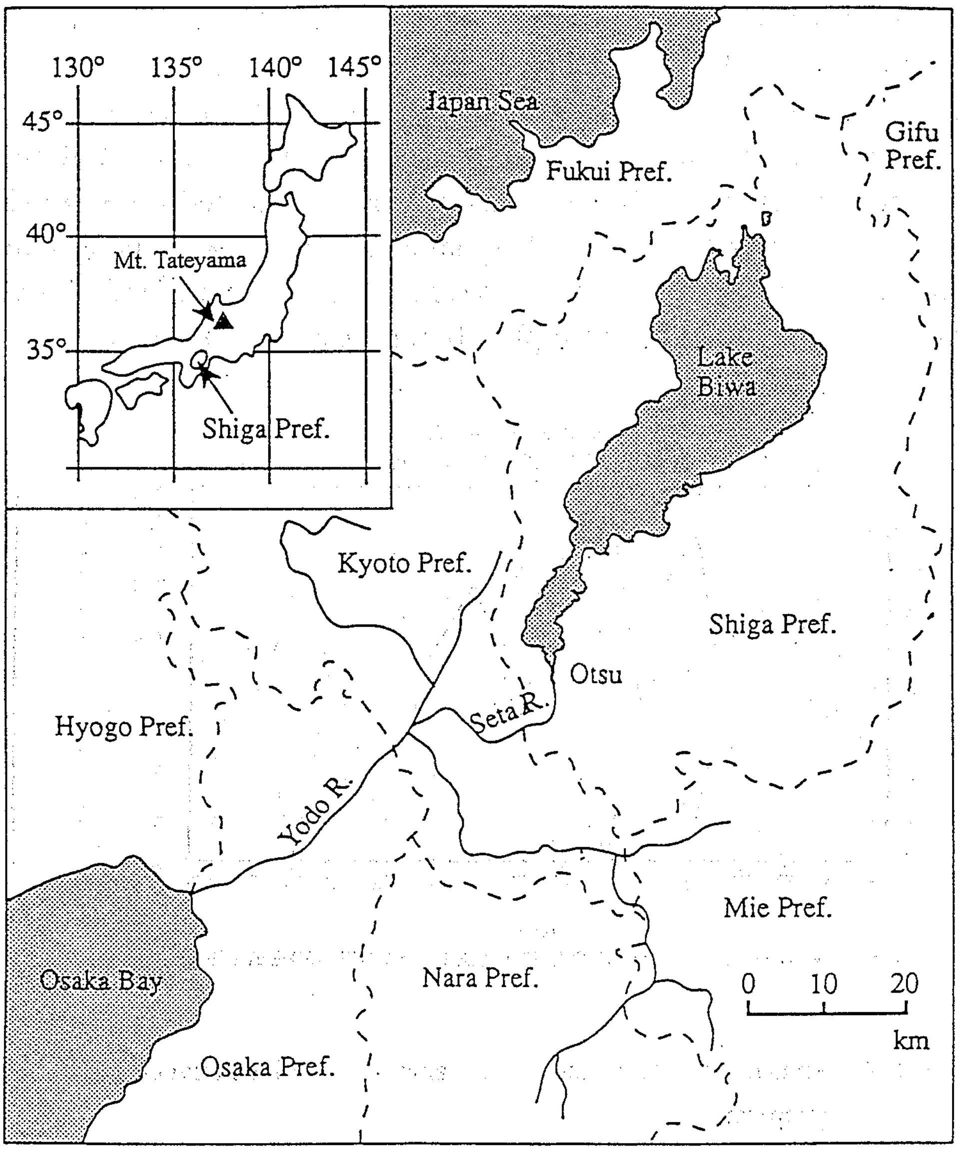


Fig. 1 Lake Biwa and River Yodo catchment areas.

7. 1. 2 Amount of snow cover

Figure 2 indicates annual variations in the amount of snow cover, the lowest dissolved oxygen, percent of saturation, and the water temperature of the deep layer in Lake Biwa from 1968 to 1983 (Fushimi, 1983).

The amount of snow cover in the Lake Biwa catchment area fluctuates from 0.3 to 1.9 billion tons. The mean turned out to be 1.03 billion tons. When the amount of snow cover is above the mean, lower water temperatures and the higher dissolved oxygen concentrations are observed. This is caused by the density current of melted snow subsiding from the river mouth into the deep layer of Lake Biwa. The amount of snow cover affects the dissolved oxygen concentration, and the water temperature as well as the eutrophication process in Lake Biwa.

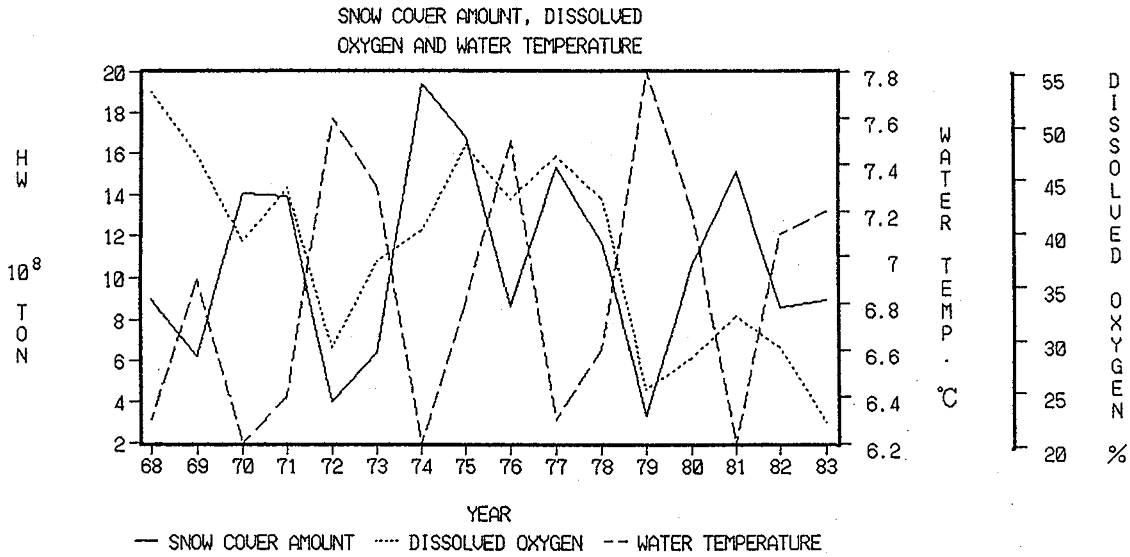


Fig. 2 Annual variation In snow cover amount, dissolved oxygen and water temperature.

Figure 3 shows the relationship between the amount of snow cover and the average winter air temperature from December to March at Hikone in the central part of the Lake Biwa catchment area. The amount of snow cover is less in the warmer winters but more in the colder winters. The amount of snow cover decreases by 480 million tons by an increase of 1℃ in the average winter air temperature. Therefore, there is strong possibility that the climatic warming significantly reduces the amount of snow cover. However, the decrease in the amount of snow cover must be considered in relation to an increase of precipitaion and a rise of the snowline altitude at the time of climatic warming, as a climatic warming of more than 1.5℃ is expected by the 2030's.

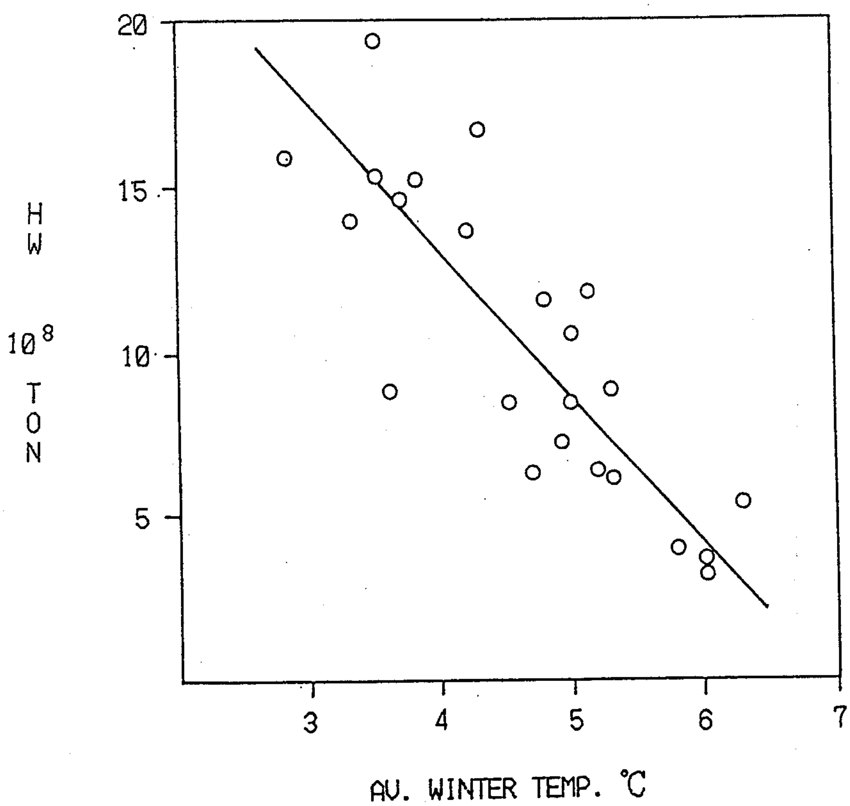


Fig. 3 Relationship between snow cover amount and average winter air temperature.

7.1.3 Concentration of dissolved oxygen

The depletion of dissolved oxygen in the deep layer of Lake Biwa was first reported by Naka (1973). Since then, similar results have been observed by the Shiga Prefectural Institute of Public Health and Environmental Science. Okuda *et al.*(1987) and Kumagai (1988) found that the depletion of dissolved oxygen is caused not only by eutrophication, but also by decrease of snow cover.

Figure 4 shows annual variations in the lowest dissolved oxygen concentration in the deep layer of Lake Biwa from 1958 to 1988.

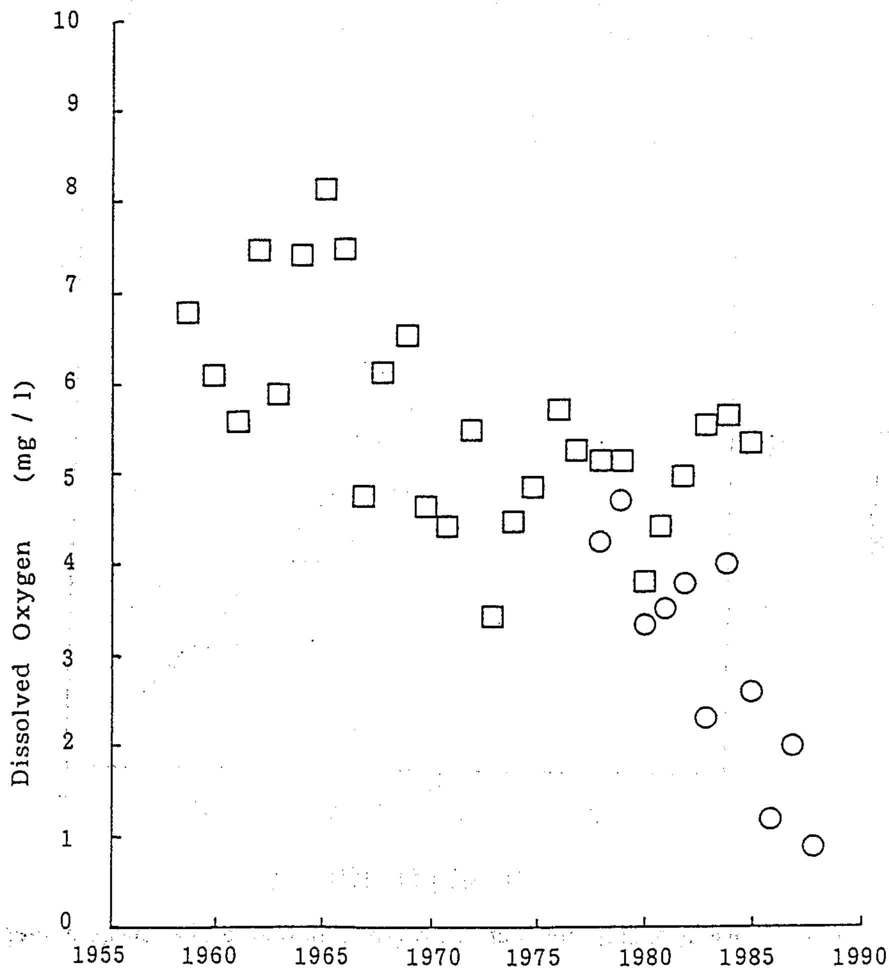


Fig. 4 Annual variation in lowest dissolved oxygen in a hypolimnion.

The dissolved oxygen concentration was measured by the Shiga Prefectural Fisheries Experimental Station and Shiga Prefectural Institute of Public Health and Environmental Science at a depth of about 80 m in October and November just before the overturning period, when the concentration of dissolved oxygen becomes minimum in the deep layer.

Lake Biwa has been suffering from eutrophication since the 1960's and the dissolved oxygen concentration in the deep layer of Lake Biwa has been gradually decreasing. If this decrease of the dissolved oxygen concentration continues, anoxic conditions may prevail by the end of this century, allowing release of ammonia and phosphates from the lake bottom sediments.

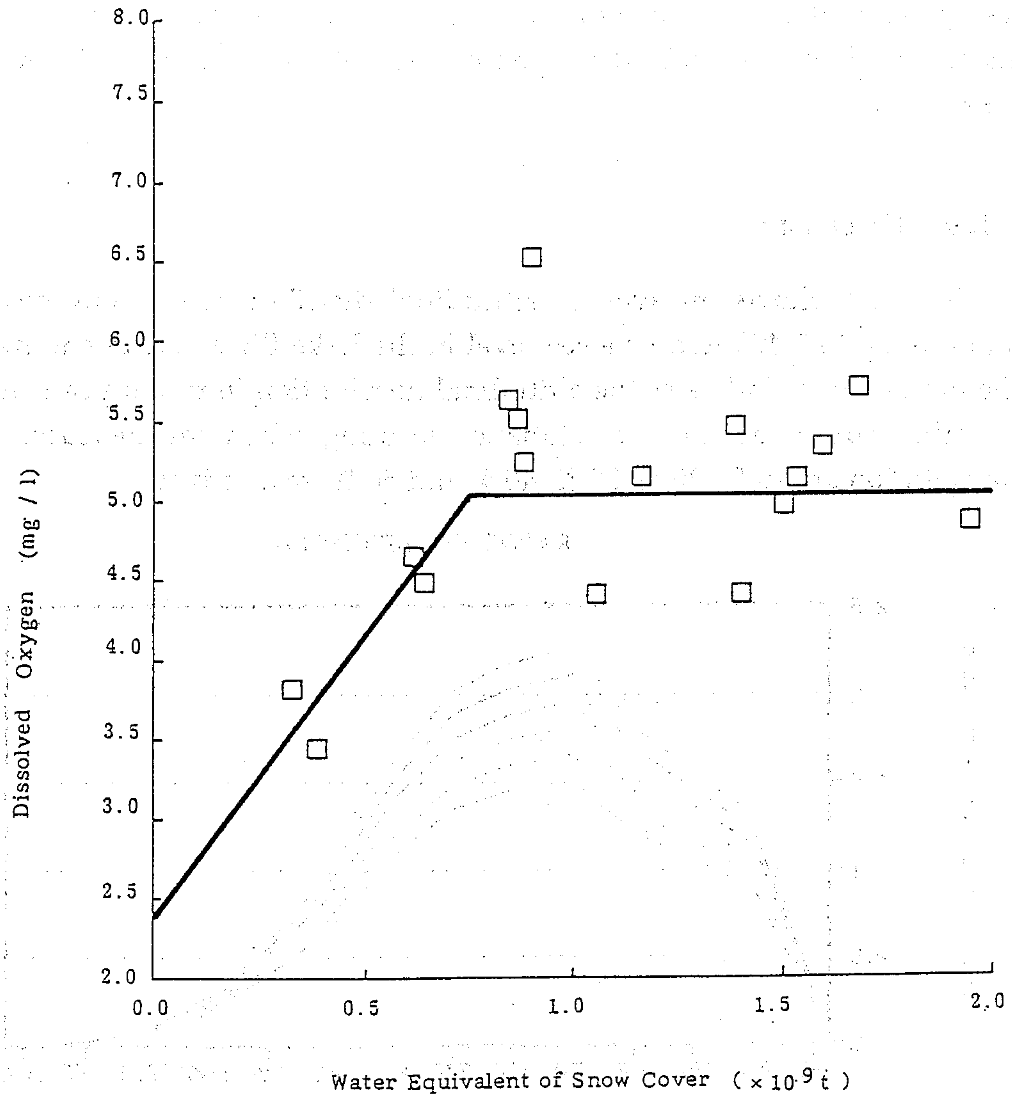


Fig. 5 Relationship between snow cover amount and dissolved oxygen.

Figure 5 shows the relationship between the amounts of snow cover and the lowest dissolved oxygen concentrations. When the amount of snow cover is less than 1 billion tons, the dissolved oxygen concentration in the deep layer of Lake Biwa rapidly decreases. However, when the amount of snow cover is more than 1 billion tons, the dissolved oxygen concentration remains above 4.5 mg/l. It means that there is a critical amount of snow cover of approximately 1 billion tons, which is the average annual amount of snow cover in Lake Biwa's catchment area, to sustain the lowest dissolved oxygen concentration in the deep layer of Lake Biwa.

7. 1. 4 Discussion

Figure 6 shows an average altitudinal distribution of snow cover amounts up to 1,400 m above sea level in the Lake Biwa catchment area. The lowest curve indicates the altitudinal distribution in recent years and the other curves at times of climatic warming when the increases of precipitation are 10 %, 20 %, 30 %, 40 % and 50 %, respectively.

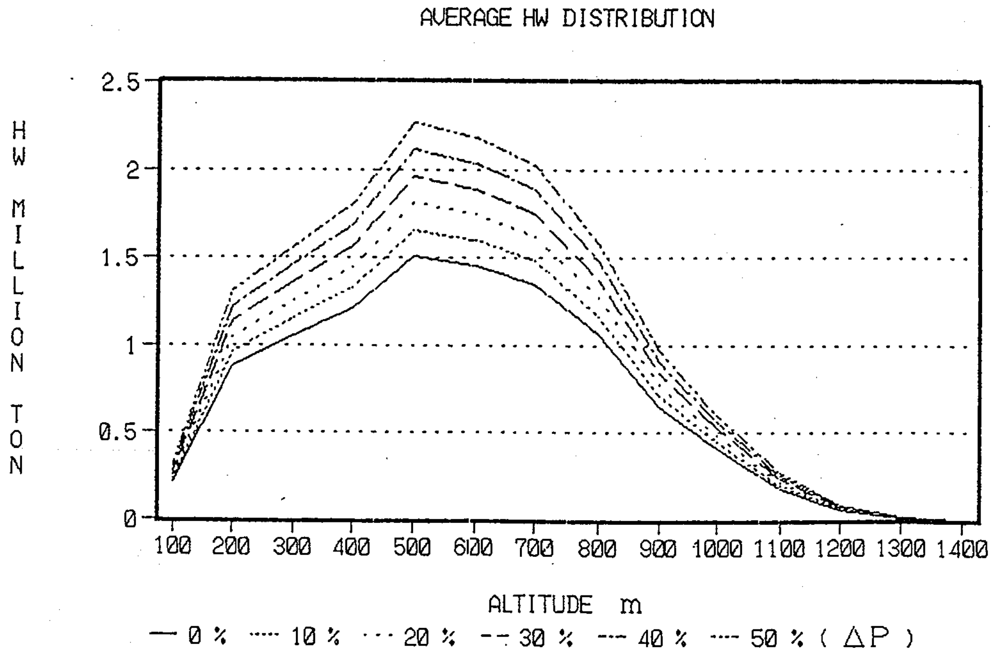


Fig. 6 Altitudinal distribution of snow cover amount.

Due to topographic conditions, greater amounts of snow cover are stored at altitudes between 400 m and 800 m above sea level. When climatic warming takes place, there will be a greater possibility of increase in precipitation and, at the same time, the altitude of the average snowline will rise. That is to say, the boundary altitude between rain and snow will rise by the climatic warming and the rise in snowline altitude will decrease the amount of snow cover. So, the amount of snow cover at the time of climatic warming must be estimated based on the variations in the amount of precipitation and the altitude of the average snowline.

Figure 7 shows the amount of snow cover estimated in relation to the increase in precipitation on the y-axis (%) and that of the average air temperature on the x-axis(℃) under the conditions of climatic warming. The shaded part shows that the amount of snow cover is less than 1 billion tons, an approximate average in recent years, and the unshaded part greater than 1 billion tons.

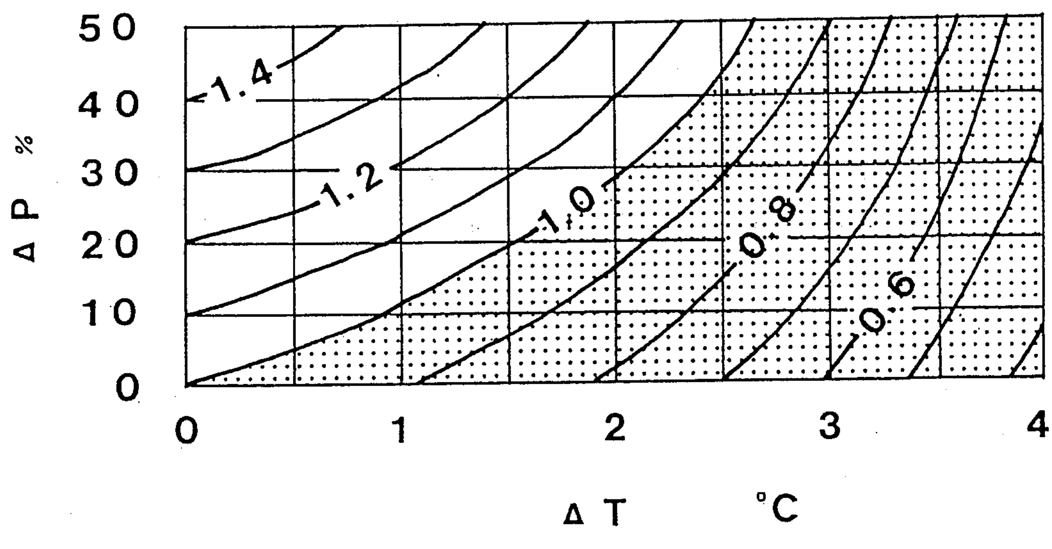


Fig. 7 Variation of snow cover amount (billion ton) estimated from an increase of precipitation (%) and average air temperature (℃).

It is reported that the average air temperature will increase by 1.5 to 3.5℃ by the 2030's. If the average air temperature increases by 1.5℃, the amount of snow cover would not be more than 1 billion tons, unless the amount of precipitation is more than 20 % in excess of the projected mean. If the average air temperature rises by 3.5℃, the amount of snow cover decreases significantly to about 0.6 billion tons, even if the precipitation is 20 % in excess.

The slopes of the snow cover isogram become steeper with lesser amounts of snow cover, and in the air temperature range beyond 2℃. This is due to the topographic conditions in which altitudes between 400 m and 800 m above the sea level, where greater amounts of snow cover in Lake Biwa's catchment area are stored, become lower than the altitude of the average snowline under the conditions of climatic warming.

Consequently, the climatic warming will significantly decrease the amount of snow cover in Lake Biwa catchment area and the dissolved oxygen concentration in the deep layer of Lake Biwa, which may further enhance eutrophication of Lake Biwa. We will face a difficult time from the view points of water quantity as well as water quality of Lake Biwa in the 21st century when the climatic warming is expected to progress.

7. 2 Microscopic structures of acid materials in snow crystals in relation to acidification process

Abstract

It is thought that actual conditions of the acid shock depend on regional characteristics of the melt-refreeze processes forming the internal distribution of acidic materials within snow crystals. Therefore, it is important to clarify the changes in the pH values between the first stage and the last stage of the snow melt process. In a warm climatic region like the southern part of Japan, there are many possibilities to have the complicated concentric distribution patterns of acidic materials within granular snow, since the melt-refreeze processes of snow cover layers take place repeatedly for a long period (even in midwinter). Consequently, the pH value of the melt water does not always increase as the snowmelt progresses, but it does decrease and the melt water turns out to be more

acidic in the case that the acidic materials mainly concentrate in the central part of granular snow. So, it should be noted that the acid shocks occur not only in the first stage but also in the last stage of the snowmelt, that differs from the so called acid shock reported from the northern part of Europe and the eastern part of North America.

It is also important to clarify the microscopic distribution patterns of the acidic materials within snow crystals by using X-ray computed tomography (CT scanner), which shows the distribution patterns of acidic materials by the CT values. The CT value distribution across the center of the granular snow sample showed maximum CT values ranging from 220 to 240. Since the CT value of pure ice is 215, there are domains of higher CT values than that of pure ice distributed from the outer part to the inner part of the granular snow crystal. According to results of artificial samples and chemical analyses, there are possibilities that the domain of the higher CT value corresponds to that of acidic materials. In the three-dimensional as well as cross-sectional profiles of the CT value distributions within a single granular snow, there is clearly seen that domains with the higher CT values exist in the inner parts of the single snow crystal. Consequently, when the acidic materials mainly concentrate in the central part of snow crystals, the melt water turns out to be more acidic in the last stage of the snowmelt and gives influences to hydrological environments that agree with results from field observations of acid snowmelt in Japan.

7. 2. 1 Introduction

Snow crystals in snow cover grow to be granular by the melt-refreeze process and the diameter of the granular snow may reach several millimeters. Along with progress of the crystal growth caused by melt-refreeze processes, the acidic materials tend to be concentrated in the outer part of the granular snow (Suzuki, 1982; Bale et al., 1989). Consequently, the pH value of the melt water at the first stage of melting becomes low, with acidic chemical constituents 2 to 5 times more than the average value of the snow cover (Johannessen and Henriksen, 1978), and the so called "acid shock" results. This indicates that it is possible to estimate the characteristic distribution patterns of acidic materials within granular snow by observing the relative difference between the pH value of the melt water at the first stage and that at the last stage. These acid shocks have been reported in the northern part of Europe (Skartveit and Gjessing, 1979) and in the eastern part of North America (Cadle *et al.*, 1984).

It is thought that actual conditions of the acid shock depend on the regional characteristics of the melt-refreeze processes forming the internal distribution of acidic materials within snow crystals (Fushimi, 1994). Therefore, it is important to clarify the changes in the pH values between the first stage and the last stage of the snow melt process by field observations and the microscopic distribution patterns of acidic materials within snow crystals by using X-ray computed tomography.

7. 2. 2 Field observation

7. 2. 2-1 Method

The field observations were carried out in Lake Biwa's catchment area in Shiga Prefecture and the Mt. Tateyama area (2450 m a.s.l.) in Toyama Prefecture in the central region of Honshu island, Japan (Fig. 1).

In order to predict acidification of meltwater from snow cover, it is important to understand microscopic distribution patterns of acidic materials within snow grains formed by the melt-refreeze process. For this purpose, snow was directly sampled from each snow layer in a snow pit by using a sampling bottle with a volume of 100 ml and a weight of an about 50 g. The samples were melted under room temperature of about 20℃. The pH values were measured both at the first stage and at the last stage of the snowmelt process within a few hours after the sampling. In the first stage, the melting takes place mainly in the outer part of a snow grain and in the last stage, in the inner part.

7. 2. 2-2 Tateyama area

Figure 8 is the profile of the pH values of melt water sampled from compacted snow layers with a snow depth of 500cm at Murodo in the Mt. Tateyama area on 2 April, 1992 when the snow cover was not influenced by the snowmelt process. The pH values ranged from 3.6 to 5.0 in the first stage and from 4.2 to 5.6 in the last stage of the snowmelt. The pH values of the melt water at the last stage were higher than that at the first stage except for a few snow layers in the middle part of the snow cover which showed no considerable changes.

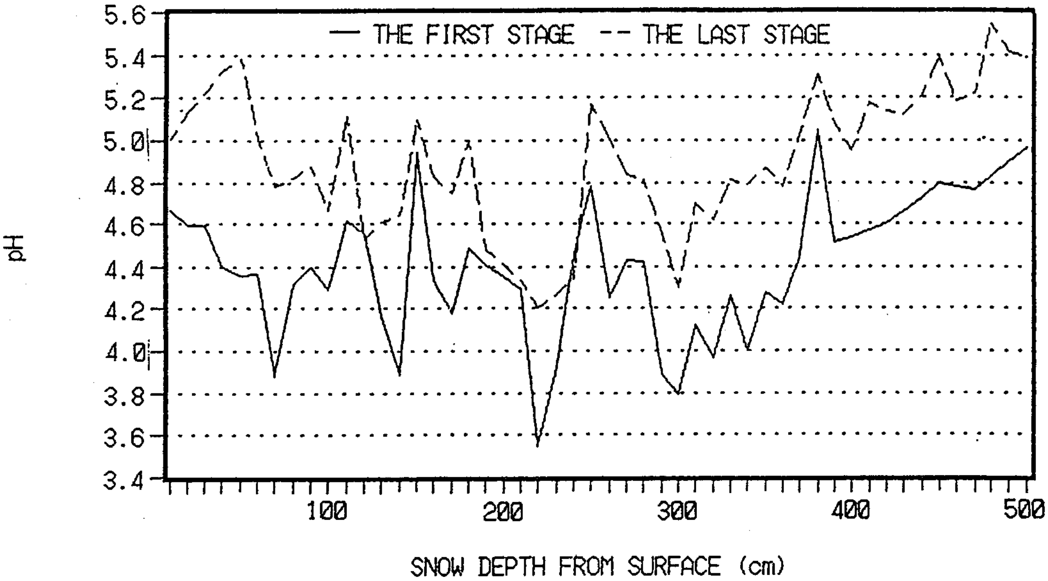


Fig. 8 pH values of the compacted snow in Mt. Tateyama area.

7. 2. 2-3 Lake Biwa catchment area

Figure 9 shows a vertical profile of pH values of the melt water, sampled from the snow cover with completely turned into granular snow grains in the northern part of Lake Biwa's catchment area on 3 April, 1991. The snow depth was 190 cm. The pH values range from 4.2 to 5.6 in the first stage and from 4.4 to 6.0 in the last stage of the snowmelt. There are three different granular snow layers, each with its characteristic pH value changes. (1) The last stage samples exhibit lower pH values in the snow layer from 0 to 30 cm. (2) The pH values of the melt water at the first stage and the last stage samples were nearly identical in the snow layer from 70 to 100 cm. (3) The pH values of the melt water at the last stage samples exhibit higher pH values in the snow layer from 30 to 70 cm and from 100 to 190 cm.

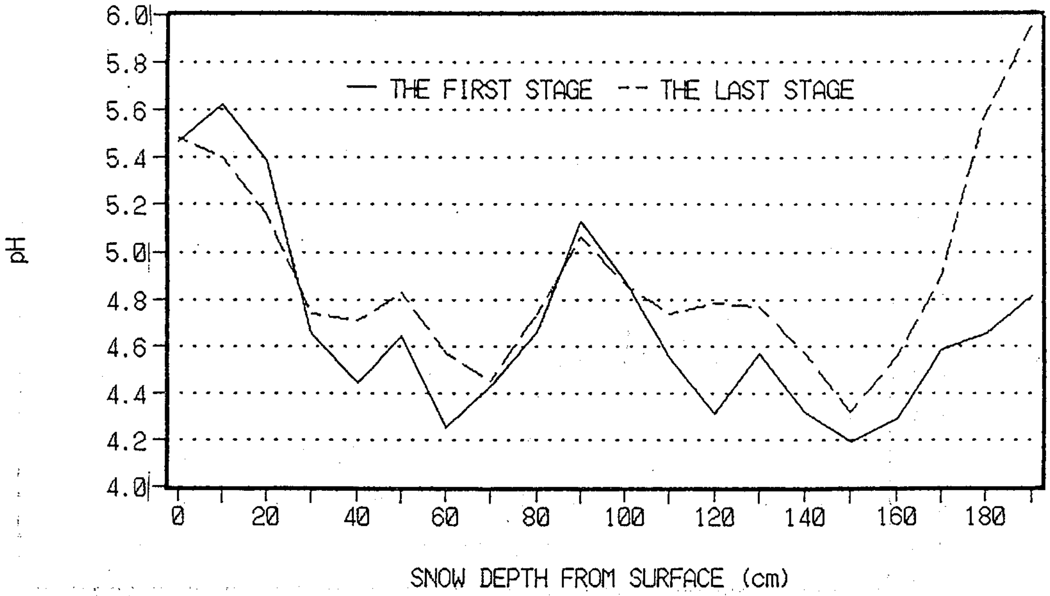


Fig. 9 pH values of the granular snow in Lake Biwa catchment area.

7. 2. 3 Analysis of X-ray computed tomography

7. 2. 3-1 Method

X-ray computed tomography (CT scanner) has led to remarkable achievements in the field of medical science for clinical diagnosis (Hounsield, 1973). The developments of industrial CT scanners have enabled observations of internal structures of metals, ceramics, plastics, or wood (e.g., Hopkins et al.,1981; Onoe et al.,1983; Heidt et al.,1985). The CT scanner has also been applied in a nondestructive manner to measure the distribution of voids in steady state two phase flows (Ikeda et al.,1983;

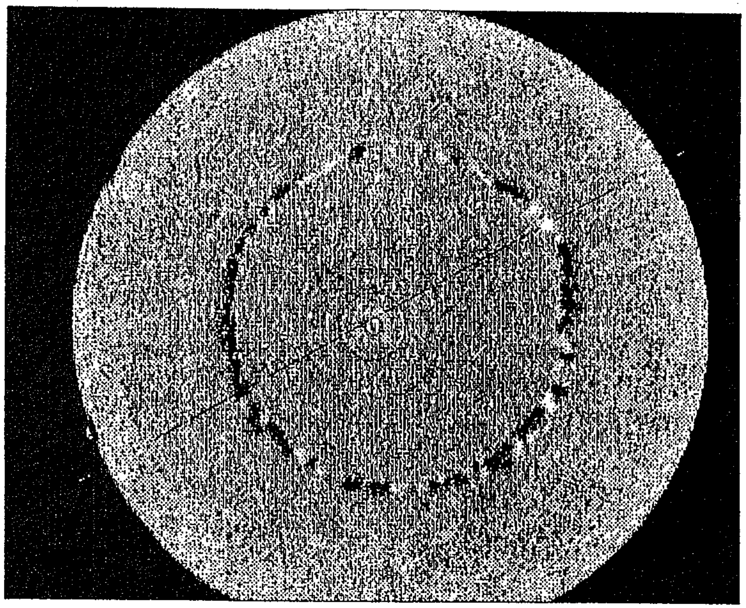
Iizuka et al.,1984). Kawamura (1988 and 1990) has shown that the CT scanner is a useful tool for examining sea ice structure and for measuring core densities of three dimensional ice .

When X-rays were absorbed by samples, the transmitted intensity was detected by a fluorescence plate and a CCD camera in the CT scanner used in this study (SDD Inc.). The distributions of the intensity data were collected by successively rotating the sample through 360 degrees at intervals of 1 degree. The image of the object was then obtained as a map of an attenuation coefficient, designated as the CT value, of pixels for the sample of any desired section (slice). While the horizontal resolution was 100 μm at the selected field of view (FOV) of 50 mm, the vertical one was 300 μm, depending upon the slices. Both CT values of pure water and pure ice samples were measured as standards. If a material is composed of ice and air, the CT value of the pixels corresponds to the air volume. Impurities, e.g. H_2SO_4, have generally higher attenuation coefficients and, therefore, higher CT values than ice. The CT value of ice with only one kind of an impurity is related linearly with the impurity fraction. However, the CT value cannot determine the ratios of three -component-materials such as ice, air and impurities.

7. 2. 3-2 Results of x-ray analysis

7. 2. 3-2-1 Artificial sample

In order to verify the CT values of pure ice and acidic materials, artificial ice samples including H_2SO_4, HCl or NaCl as an acidic impurity were used. Figure 10 shows the CT image of an artificial ice sample with a diameter of 50 mm, including a circular H_2SO_4 layer whose thickness is 1 mm and the CT value distribution across the center of the sample (in this and other figures, pixel size is 100 μm x 100 μm). The CT value of pure ice is shown to be approximately 215. The pixels with the H_2SO_4 layer have higher CT values with a maximum of 270. The lower CT values of about 150 are probably caused by voids trapped during the sample preparation.



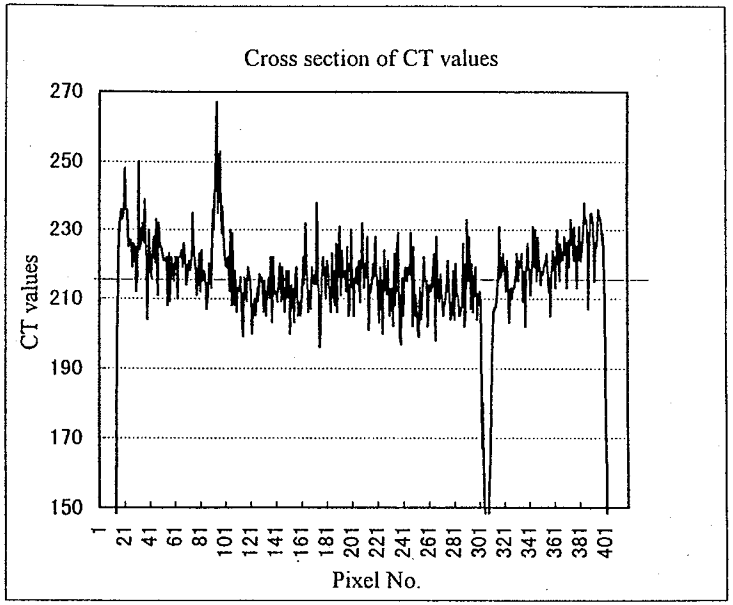


Fig. 10 CT images of an artificial sample with H_2SO_4.

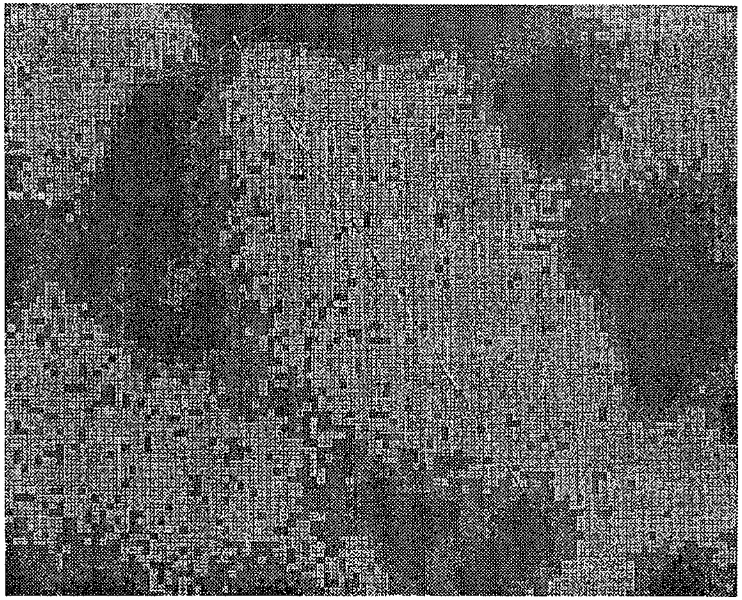
7. 2. 3-2-2 Tateyama area

Granular snow layers with a thickness of 480cm in 1995 and that with 180cm in 1996 were observed. Figure 11 shows the CT value distribution across the center of the sample in which maximum CT values range from 220 to 240. Since the CT value of pure ice is 215, there are impurities with the higher CT values distributed from the outer part to the inner part of the granular snow crystal. According to the results of artificial samples (Fig. 3) and chemical analyses, the concentration of NO_3-N is 0.008 mg/L and SO_4-- 1.78 mg/L, there are possibilities that the domains of the higher CT values correspond to that of acidic materials.

Figure 12 indicate the three-dimensional as well as cross-sectional profiles of the CT value distributions within a single granular snow, with a diameter of 6 mm, sampled from the Kuranosuke perennial snow patch in the Mt. Tateyama area. In the three-dimensional figure, the domains of the higher CT values are shown by the lighter color. Consequently, there are domains with higher CT values in the inner parts of the granular snow crystal indicating that the melt water turns out to be more acidic even in the last stage of the snowmelt.

7. 2. 3-2-3 Lake Biwa catchment area

Observations on granular snow cover were carried out in the northern part of the Lake Biwa catchment area in 1965 and 1996. Figure 13 shows the profile of CT values across the center of the sample where the maximum CT value is 240. Since the maximum CT value is higher than that of pure ice, 215, there are impurities distributed even in the inner part of the granular snow crystal. According to the results of artificial samples (Fig. 10) and chemical analyses, the pH value ranges from 4.6 to 4.9, the concentration of NO_3-N 0.044 - 0.019 mg/L and SO_4-- 0.028 - 0.019 mg/L, there are possibilities that the domain of the high CT value corresponds to that of acidic materials. So, the melt water turns out to be more acidic when the snowmelt comes to the last stage and the inner part of the snow crystals melt away, as the acidic materials concentrate even in the inner part of snow crystals.



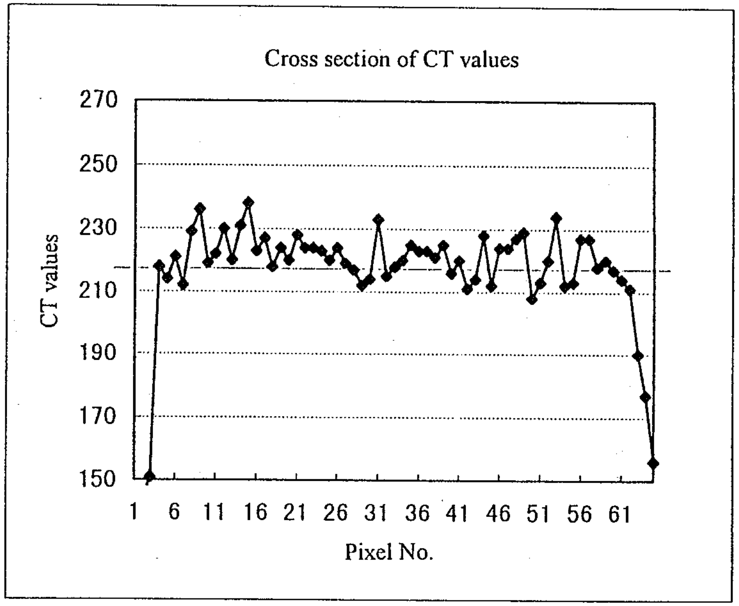


Fig. 11 CT images of an granular snow at Murodo in Mt. Tateyama area.

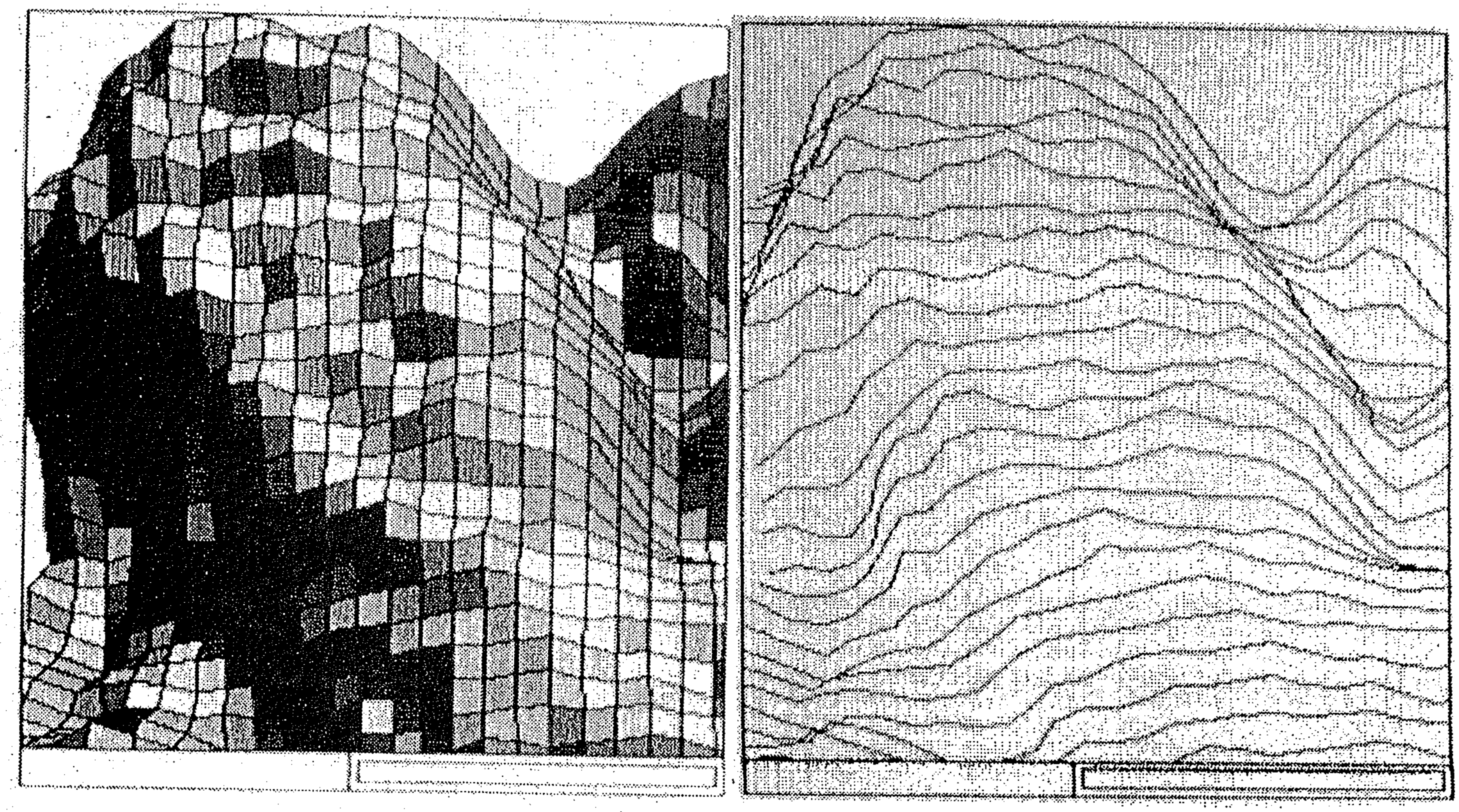


Fig. 12 CT images of an granular snow at Kuranosuke in Mt. Tateyama area.
(Left; three dimensional pattern and right; sectional pattern.)

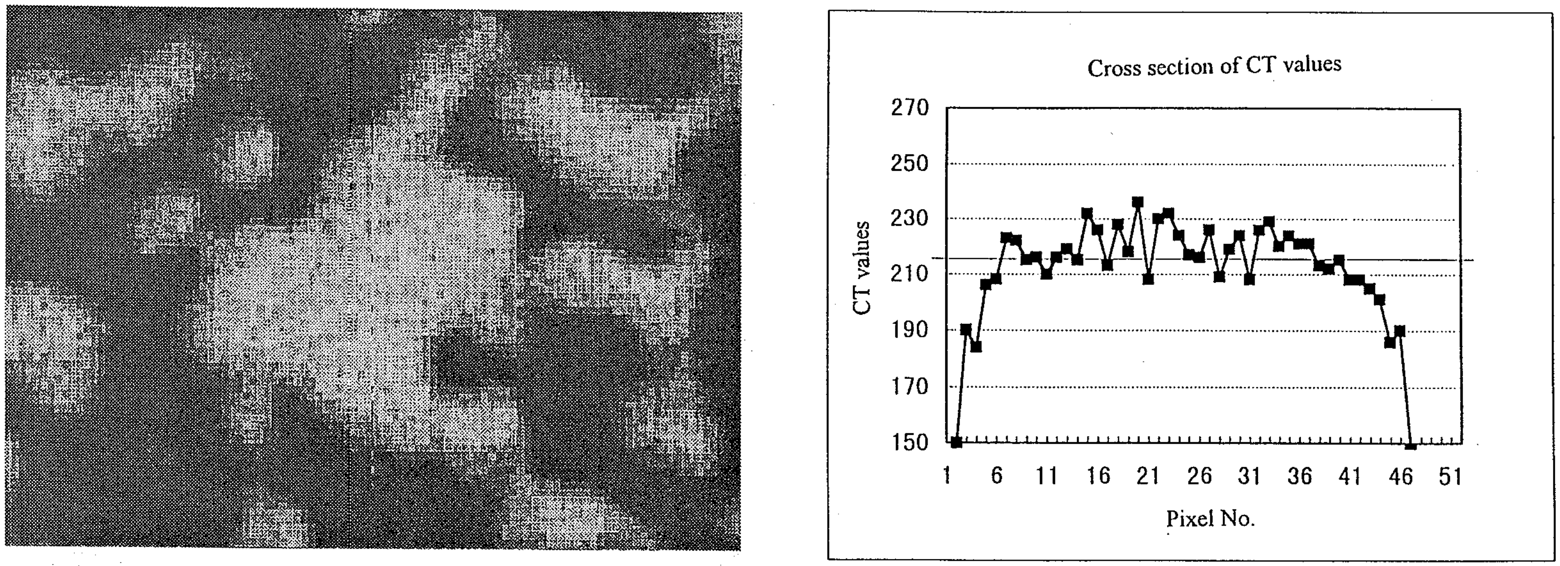


Fig. 13 CT images of an granular snow in the northern part of Lake Biwa catchment area.

7.2.4 Discussions

From the observational results of granular snow layers in Lake Biwa's catchment area and the Mt. Tateyama area, it is shown that the pH value of the melt water does not always increase according to the snowmelt process as it has been reported at the time of the finding of the acid shock (Johannesen and Henriksen, 1978), and it is estimated that there is a certain characteristic in the distribution patterns of acidic materials within granular snow grains since differences are formed between the pH values of the melt water at the first stage and that at the last stage.

In such a warm climate region, there are many possibilities to see the granular snow with complicated concentric distribution patterns of acidic materials within granular snow grains since the melt-refreeze processes of snow cover layers take place repeatedly for a long period (even in midwinter). The pH value of the melt water does not always increase as the snowmelt progresses, but it does occasionally decrease in the last stage of the snowmelt and the melt water turns out to be more acidic in case that acidic materials mainly concentrate in the central part of a granular snow. Therefore, it is important to note that the acid shocks occur not only in the first stage but also even in the last stage of the snowmelt, differing from the so called acid shock phenomena reported from the northern part of Europe and the eastern part of North America.

In order to verify the CT values of pure ice and acidic materials, artificial ice samples including H_2SO_4, HCl or NaCl as an acidic impurity were used and it was found that the CT value of pure ice is approximately 215 and that of the pixels with the H_2SO_4 layer have higher CT values with a maximum of 270.

According to the analyses of granular snow by the X-ray computed tomography, the CT value distribution across the center of the granular snow sample showed maximum CT values ranging from 220 to 240. Since the CT value of pure ice is 215, there are impurities distributed from the outer part to the inner part of the granular snow crystal. According to the results of artificial samples and chemical analyses, there are possibilities that the domains of the higher CT values correspond to that of acidic materials. In the three-dimensional as well as cross-sectional profiles of the CT value distributions within a single granular snow, it is clearly seen that the domains with the higher CT values exist in the inner parts of the single snow crystal. Consequently, when the acidic materials mainly concentrate in the central part of snow crystals, the melt water turns out to be more acidic and gives influences to the hydrological environments even in the last stage of the snowmelt.

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Chapter 8

Eutrophication and management of freshwater environments

Mitsuru Sakamoto

8.1 Introduction

Because of the pressing need of human society for freshwater, sound management of freshwater resources is an inevitable task for sustainable development of our society. Despite such an importance of freshwater resources, the impacts of extending human activities on freshwater bodies during this century have resulted in considerable deterioration of water quality and impairment of water uses in many freshwater bodies. Contamination of natural waters by toxic chemicals and organic matter discharged with waste water from industrial plants and mines have given undesirable effects on human health, human water use and aquatic biotic communities. To remedy the deteriorated aquatic environments, the national government (Environment Agency) and local governments in Japan have made considerable efforts in enacting environment laws and introducing effective technological counter measures to relieve aquatic environments from deterioration. These public actions for relieving natural water environments were very effective in the reduction of harmful substances and the recovery of natural water bodies from deteriorated conditions (Fig.1., Environmental Agency, Japan, 1996). However, little rehabilitation has been accomplished for organic matter pollution of the natural waters as evaluated by COD and BOD values (Fig.1). This is mostly due to increased phytoplankton production caused by the enrichment of natural water bodies by nitrogen and phosphorus supplied from the watershed.

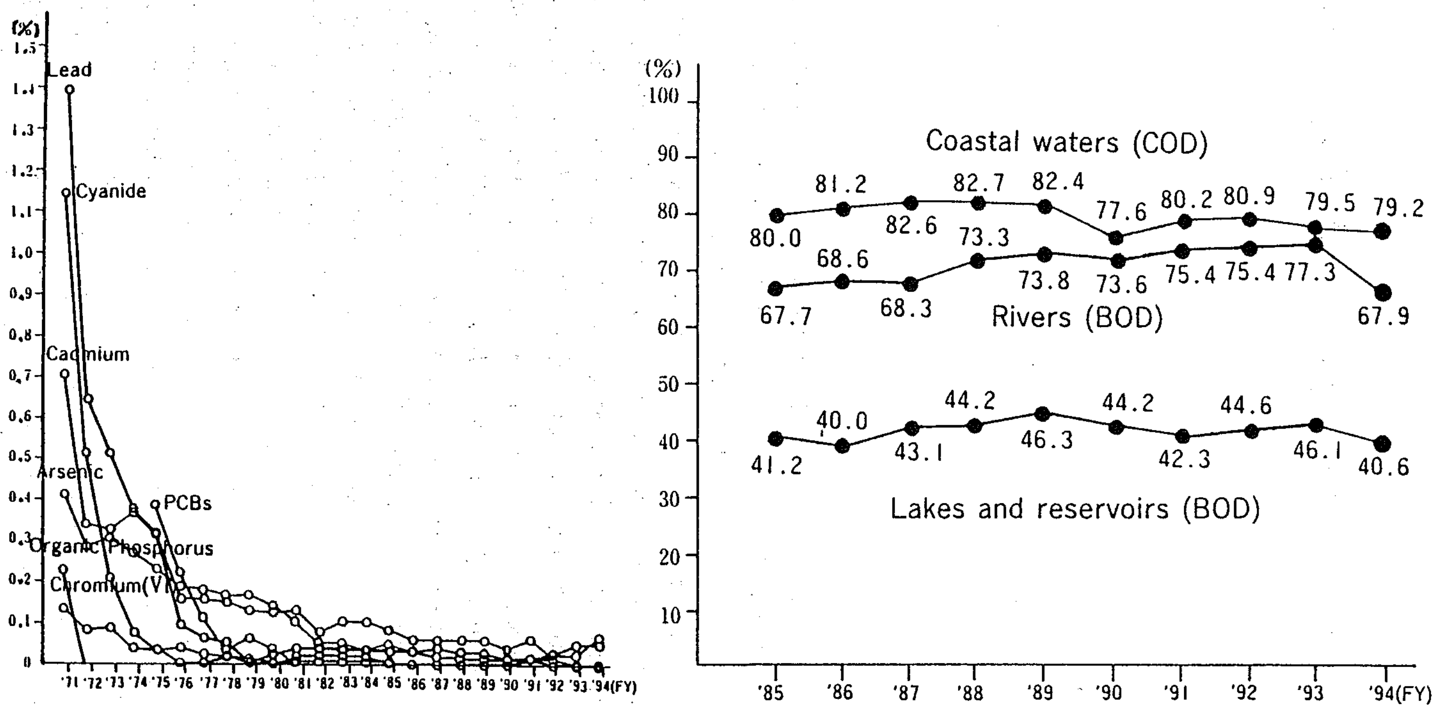


Fig. 1. Changes in water pollution by toxic chemicals (left) and organic matter as evaluated COD or BOD values (right) of natural water bodies in Japan. Ordinate is the percentage of water bodies in compliance with the environmental quality standards. (Environment Agency Japan, 1966)

Resulting increases in the biomass and production of phytoplankton have caused an increased turbidity of lake water, changes in animal community and animal production and decreased dissolved oxygen concentration in deep water layers of lakes. The nutrient enrichment also stimulates the growth of aquatic weeds to affect littoral ecosystems and bother navigation nearby the shore. Such a series of changes of an aquatic ecosystem as induced by the enrichment of natural water bodies is called eutrophication.

Eutrophication is originally a term in limnology to denote the gradual evolution of lake ecosystems from less fertile, less productive, oligotrophic lakes to more fertile, more productive, eutrophic lakes (Table 1) for a long period of time such as thousands of years. Increasing supplies of silt and nutrients into the water bodies from the watershed, caused by weathering of rock and the development of plant communities and soils, are the major causes for eutrophication of natural lakes. However, recent expansion of human activities on the watershed have stimulated the loading of these substances into the water bodies and accelerated the rate of eutrophication. Rapid changes in the turbidity and color of lake water as well as changes in water quality and aquatic organisms have interfered with the daily uses of lake water and lake resources by human society in many countries. Because similar changes of water bodies were observed in not only natural lakes but also reservoirs and coastal bays, the changes of aquatic ecosystems initiated by nutrient enrichment of water bodies by nitrogen and phosphorus are now widely called eutrophication through all kinds of enclosed water bodies.

To protect against such undesirable changes of aquatic environments due to eutrophication, a number of studies have been conducted on the causes and processes of eutrophication and provided effective control measure. In this chapter, the causes and prediction of water quality changes are discussed based on a number of eutrophication studies. Successful and unsuccessful stories on the remediation of eutrophied lakes are described as examples of management of lake environments.

8.2 Environmental factors involved in the control of eutrophication

In general, natural waters contain a limited amount of nitrogen (N) and phosphorus (P) for plant growth. An extreme condition of this situation is observed in deep, oligotrophic lakes located in less weathered, alpine areas. The lake water of the deep oligotrophic lakes in alpine regions contains nitrogen and phosphorus as well as chlorophyll in the least amounts, and maintains a lower level of plankton production. Because of lower biological productivity, the change of water quality due to biological activity is not considerable. On the other hand, lakes located on the fertile lowland are generally shallow and eutrophic, and contain nitrogen, phosphorus and chlorophyll in a larger amount in the lake water. There are curvilinear inverse relations of mean lake depth to total nitrogen (TN), total phosphorus (TP) and chlorophyll (Chl) concentrations in the lake water through many lakes in Japan (Fig.2, Sakamoto, 1966). Similar inverse relations of lake depth to in-lake parameters were observed for the standing crops of plankton, benthos and fishes in Canadian lakes (Rawson, 1939, 1955).

Table 1. Characteristic features of oligotrophic and eutrophic lakes. (modified from Thienemann, 1925; from the citation in Sakamoto, 1997)

	Oligotrophic	Eutrophic
Distribution	Alpine and foothills	Baltic lowlands and Alps
Morphpometry	Deep, narrow littoral	Shallow, broad littoral
Hypolimnion and epilimnion	Large	Small
Water color	Blue-green	Brown-green, Green-yellow
Transparency	Great	Small, or very small
Water chemistry	Poor in N and P; humic material absent; Ca viable	Rich in N and P; humic material slight; Ca usually high
Suspended matter	Minimal	Rich, planktonic
Bottom mud	Nonsaprobic	Saprobic (gyttja)
O_2 in summer	60–70% minimum decrease with depth	0–40% minimum Decrease sharply in metalimnion
Plant production in littoral	Low	Rich
Plankton	Low in quantity, presence at all depths, large diurnal migration, seldom blooms	Large quantity, diurnal migration, often blooms
Benthos	*Tanytarsus* fauna; no *Chaoborus*	*Chironomus* fauna; *Chaoborus* usually present
Succession	To eutrophy	To pond or meadow

*Dystrophic type excluded.

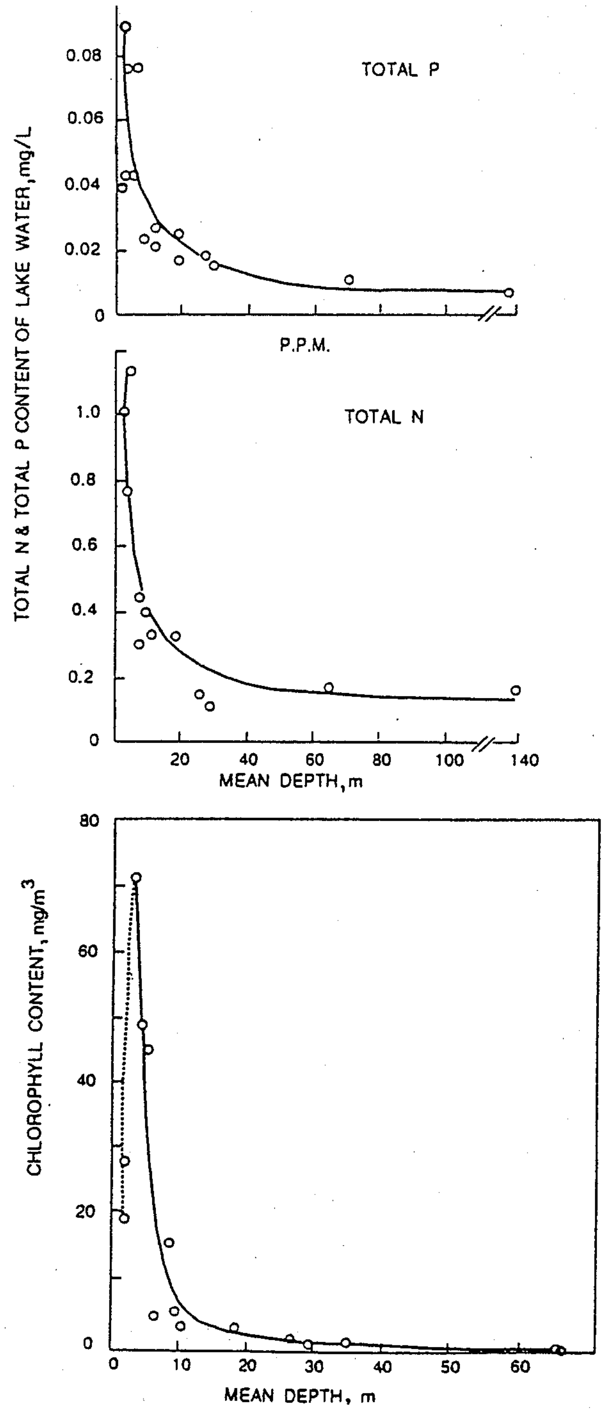


Fig. 2 Total P, total-N and chlorophyll concentrations as a function of mean depth in Japanese freshwater lakes in spring (Sakamoto, 1966; from the figure cited in Sakamoto, 1997).

In Table 2, the range of TN and TP concentrations in the lake water of some Japanese lakes (grouped in three trophic states) and in river water are shown along with the data for other nutritive elements. There is a marked difference in TN and TP concentrations among the lakes of different trophic states, although no large difference is observed in the concentrations of other elements among the three trophic states. To evaluate the significance of these nutrient concentrations in phytoplankton production, the minimum concentrations of major nutritive elements required for optimum growth of phytoplankton in monoalgal culture are presented in Table 3. From comparison of the concentration of nutritive elements in lake water (Table 2) with the minimum requirement (Table 3), it is obvious that the concentrations of nitrogen and phosphorus in less fertile waters, especially in oligotrophic lakes are lower than the minimum requirements, while the other elements are present in far excess of their requirement there. This suggests that if there is an increase of nitrogen and phosphorus concentrations in lake water phytoplankton production could be stimulated to result in the increase of algal biomass.

Actually, a significant increase of phytoplankton biomass was observed in association with increasing TN and TP concentrations in the lake water through many lakes. Figure 3 shows that there is a linear relationship between Chl and TN or TP concentrations in the surface water through some Japanese lakes during the vegetation season from May to September excluding August. Many researchers reported similar linear relationships between summer phytoplankton biomass and TP in epilimnion or surface waters of temperate lakes in spring through a wide range of trophic states (Dillon and Rigler, 1974; Forsberg and Ryding, 1980; OECD, 1982). This suggests that phosphorus could be the dominant factor limiting phytoplankton growth in natural lakes. This idea was confirmed by fertilization experiments in natural lakes of oligotrophic and mesotrophic condition (Schindler et al. 1971).

There are evidences of a shortage of nitrogen supply to phytoplankton in some natural lakes (Goldman, 1981). Based on the analysis of Chl TN and TP data in Japanese lakes, Sakamoto (1966) determined that where the TN/TP ratio (weight) of lake water was smaller than 10 phytoplankton could be limited by a short supply of nitrogen and where the ratio was greater than 17 phosphorus could be the critical factor for phytoplankton growth. Smith (1982), who made detailed analysis of nitrogen and phosphorus limitation for phytoplankton production in

Table 2 Concentrations (mg l^{-1}) of major nutritive elements in natural freshwaters in Japan (Sakamoto, 1966).

	N	P	Fe	Ca
Oligothrophic lakes	0.02—0.2	0.002—0.02	0.02—0.3	1.1—23.4
Mesotrophic lakes	0.1 —0.7	0.01 —0.03	0.1 —1.1	2.3—21.9
Eutrophic lakes	1.3 —0.5	0.01 —0.09	0.5 —0.7	3.4—26.9
Rivers	0.05—1.1	0.002—0.23	0.00—2.2	2.4—28.0
	Mg	Na	SO_4	SiO_2
Oligotrophic lakes	0.8— 4.3	0.0— 5.2	0.6—24.0	1.1—28.1
Mesotrophic lakes	0.1— 2.0	2.1— 6.7	0.8—21.8	3.0—15.4
Eutrophic lakes	2.5—11.3	5.6—28.1	0.6—28.6	1.0—41.7
Rivers	0.4— 8.0	2.1—25.8	1.2—33.9	6.1—54.6

Table 3 Minimum requirement of various planktonic algae for mineral nutritive elements (mg l^{-1}) (Sakamoto, 1966).

Species	investigators	N	P	Fe	Ca	Mg	Na	SiO_2
Pediastrum Boryanum	Chu (1942, 1943)	0.69	0.045	0.02	0.2	2.4	0.04	2.0
Staurastrum paradoxum	„	0.85	0.089	—	0.2	4.0	0.0	0.0
Botryococcus Braunii	„	0.35	0.089	—	0.02	0.0	0.04	0.04
Nitzschia palea	„	1.30	0.018	—	0.9	0.1	—	0.8
Fragilaria crotonensis	„	0.26	0.018	—	0.02	0.1	—	19.6
Asterionella gracillima	„	0.51	—	—	0.18	0.01	—	9.8
Taballaria flocculosa	„	—	0.045	0.3	10.00	1.0	—	2.0
Ankistrodesmus falcatus	Rodhe (1948)	5.0	0.2	0.04	0.0	0.1	—	9.8
Microsystis aeruginosa	Gerloff et al. (1952)	6.8	0.45	0.06	0.25	2.5	—	—

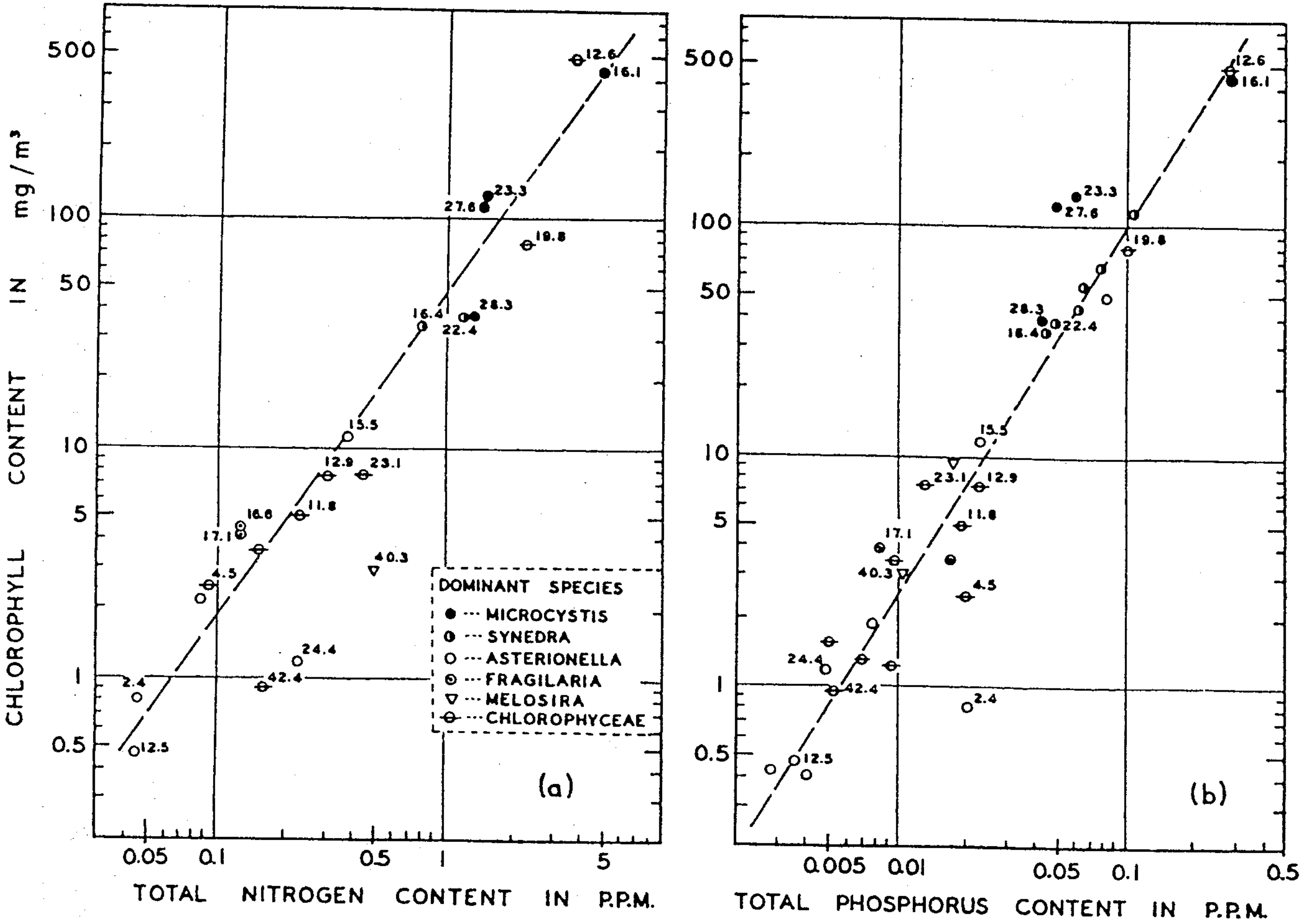
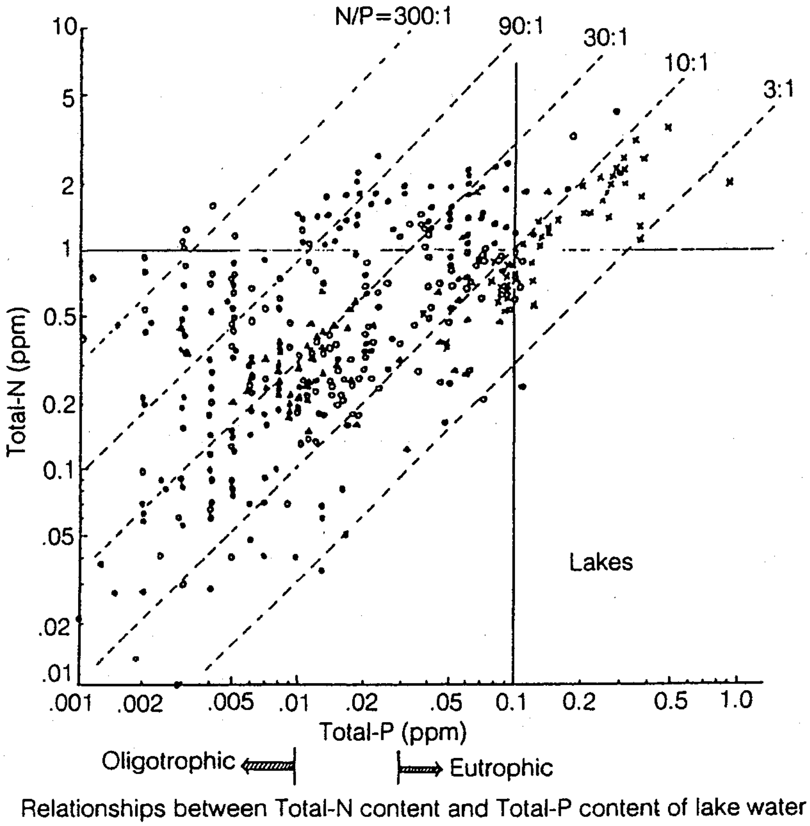


Fig. 3. The relationship between chlorophyll and total nitrogen (left) or total phosphorous (right) in the epilimnetic waters of various lakes and ponds in May, June and September. Numerals in the figure denote the TN/TP ratio (weight) of the water (Sakamoto,1966).

many lakes, found a significant effect of TN on Chl throughout many lakes of different trophic states except the lakes with a TN/TP ratio greater than 35. Forsberg and Ryding (1980) reported that where Chl concentration was higher than 20 mg m^{-3} and the TN/TP ratio was larger than 17 phosphorus was the critical limiting nutrient, but where Chl was higher than 70 and the TN/TP ratio was below 10 the nitrogen could limit algal yield. Based on the data analysis in many lakes ranging from oligotrophic to hypertrophic lakes, Sakamoto (1985) found that the TN/TP ratio of the lake water decreased down to 10 with increasing TP concentrations in the lake water, although the TN/TP ratio of lake water in oligotrophic lakes containing phosphorus at lower concentration was in the range from 10 to 300 (Fig. 4).



Relationships between Total-N content and Total-P content of lake water in some Japanese lakes.
o – oligotrophic, ▲ – mesotrophic, • – eutrophic, × – hypertrophic

Fig. 4 Relationship between total-N and totaol-P concentrations in lake water in some Japanese lakes. Numerals in the figure denote the TN/TP ratio (Sakamoto,1985).

If an N/P ratio of 10 to 17 is required for a balanced growth of phytoplankton, the gradual decrease of the TN/TP ratios of lake water from oligotrophic toward eutrophic lakes suggests that in oligotrophic and mesotrophic conditions phosphorus is critical in limiting phytoplankton production but in eutrophic, especially hypertrophic lakes, nitrogen could limit phytoplankton production.

This does not mean that the reduction of nitrogen in the lake water is effective in the control of eutrophication. In eutrophic environments, phosphorus might be present in far excess above phytoplankton requirements in the lake water and might result in a decreased TN/TP ratio. Development of an anoxic environment in the bottom sediments in eutrophic lakes could stimulate microbial denitrification activity as well as phosphorus release from the sediments, resulting in a decreased TN/TP ratio of the lake water. Thus, the control of phosphorus could be an effective measure to reduce phytoplankton yield and slow down the process of eutrophication. Based on the understanding of phosphorus as a critical nutrient in accelerating eutrophication, a considerable number of field studies have been made to determine the target value of phosphorus reduction in lake water for the control of eutrophication. The next chapter will be devoted to a description of the representative eutrophication model on the basis of these studies.

8. 3 Prediction model of water quality in relation of phosphorus loading

Lake eutrophication is triggered by an increased supply of the limiting nutrient for phytoplankton production from the watershed. Based on the understanding of phosphorus as a critical factor for eutrophication, several models have been developed for predicting in-lake phosphorus concentration. On the assumption of a lake as a biochemical reactor where there are input, output and deposition of phosphorus, Vollenweider (1969) described the mass balance of TP in the lake as

$$\frac{d[\mathrm{P}]}{dt} = \frac{J}{V} - \sigma[\mathrm{P}] - \rho[\mathrm{P}] \qquad (1)$$

where [P] is in-lake phosphorus concentration , J annual phosphorus loading rate, V lake volume, σ sedimentation rate (yr^{-1}) and ρ flushing rate (yr^{-1}), respectively. The flushing rate ρ is equal to the hydraulic load (yr^{-1}) per unit volume of the lake (total hydraulic loading Q (yr^{-1}) /lake volume V). The steady state solution of Eq.1 at d[P]/dt=0 is

$$[P] = \frac{L}{z(\sigma + \rho)} \qquad (2)$$

where L is the areal phosphorus loading rate and z is the mean depth of the lake. Based on the data analysis through many lakes, Vollenweider (1976) approximated σ as

$$\sigma = \frac{10}{z} \qquad (3)$$

From Eq. (2) and a more detailed analysis of field data, Vollenweider (1976) developed a new model to describe the critical loading rate of phosphorus (transitional loading rate between oligotoro-phic and mesotrophic states) as a function of critical in-lake phosphorus concentration $[P_c]$, q_s and z.

$$L_c\,(\mathrm{mg/m^2 \cdot yr}) = [P_c]q_s(1 + (\sqrt{z/q_s})) \qquad (4)$$

where q_s (m/yr) is the annual areal hydraulic loading (=annual hydraulic load Q/ lake surface area A) . Based on the data from many lakes, Vollenweider (1976) proposed 10 mg P m^{-1} and 20 mgP m^{-1} as the critial in-lake phosphorus concentrations between oligotrophic and mesotrophic lakes and between mesotrophic and eutrophic lakes, respectively.

Since z/q_s is water residence time T_w (yr), the annual mean in-lake phosphorus concentration [P] is described as a function of the annual areal phosphorus loading rate L, annual areal hydraulic loading rate (q_s), and lake water residence time (T_w),

$$[P] = \frac{L}{q_s}\left(\frac{1}{1 + \sqrt{T_w}}\right) \qquad (5)$$

Figure 5 is the OECD model developed using Eq.5 and the data from the world wide international monitoring surveys by OECD. Because of the simplicity of the model, the mass balance model described by Eq. (5) and Fig. 5 has been widely applied to many water bodies to predict the in-lake concentration of TP. Especially, the prediction of in-lake water quality using this model has been very useful for the estimation of a target value of phosphorus reduction for rehabilitation of eutrophied lakes and the prediction of in-lake phosphorus concentration after remediation.

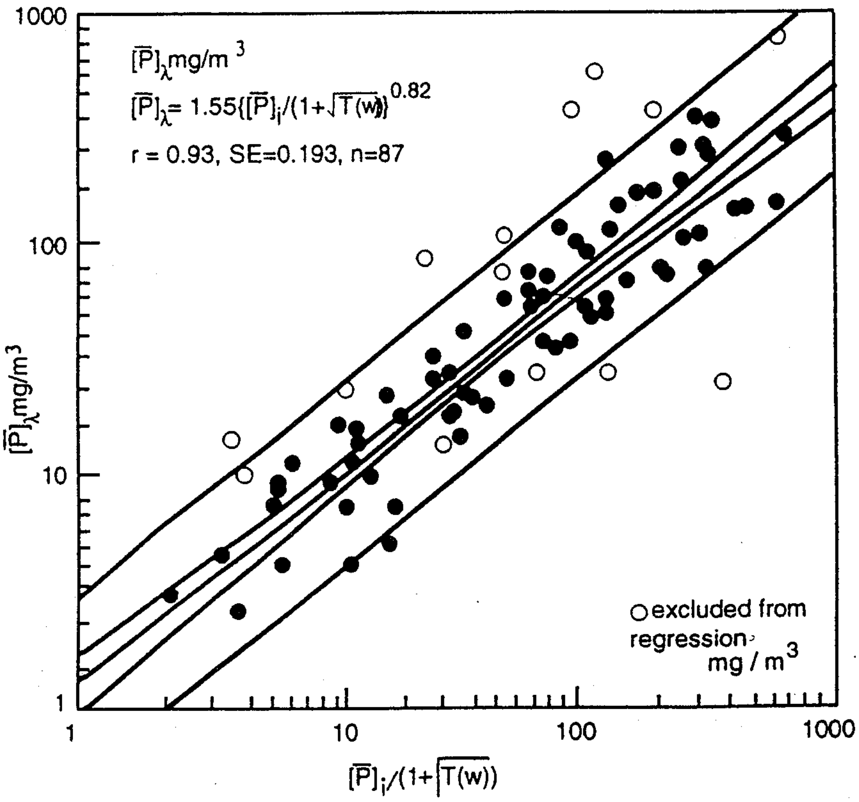


Fig. 5 Annual average in-lake TP concentrations $[P]_\lambda$ as a function of annual average inflow TP concentration $\{ [P]_i/(1+\sqrt{Tw}) \}$ (OECD,1982; from the citation in Sakamoto, 1997).

Although the Vollenweider-OECD model is developed as a global model with a more general applicability, a limitation in this applicability has often been found. In Australian reservoirs (Cullen and Smalls, 1981), the OECD model overestimated the in-lake phosphorus concentration due to a larger contribution of particulate matter to both total phosphorus concentration and phosphorus deposition. Luxuriant growth of rooted aquatic plants in Australian reservoirs might be also responsible for a limited applicability of the OECD model. In follow up studies of the rehabilitation process of eutrophic lakes by the reduction of phosphorus loading, many reports suggested a slower response to phosphorus reduction than the prediction by the OECD model. Continued internal loading of phosphorus from the bottom sediments (Sas, 1990) and from diffused source on the watershed might be responsible for observed slow recovery .

Another important finding related to the limited applicability of the OECD model is that the trophic criteria could be different between temperate lakes and tropical lakes. As described, critical phosphorus concentration at the transition between oligotrophic and mesotrophic states in temperate lakes might be 10 mgP m^{-3}. In tropical and subtropical lakes, the corresponding concentrations are around twofold or threefold larger, probably due to greater metabolic activities and more rapid circulation of nutrients in tropical and subtropical regions (Salas and Martino, 1991).

8. 4 Remediation of eutrophied lakes

Because phosphorus and/or nitrogen are/is the dominant factor in controlling eutrophication, the relevant control measure of eutrophication is to reduce the loading and in-lake concentrations of these two nutritive elements. Several measures have been developed to decrease these nutrient levels in the lake water. Since the sewage discharge from municipalities and the waste water discharge from industrial plants have been identified to largely account for a greater percentage of nitrogen and phosphorus supply into the water bodies (Vollenweider, 1964), a considerable effort has been given to reduce the nutrient supply from these sources. Especially, the introduction of sewer systems to collect sewage and treat it at terminal plants was very effective in the reduction of nutrient loading into the lakes.

However, even when the sewer treatment system was completed, an appreciable amount of nitrogen and phosphorus remained in the effluent water from the treatment plants if the nutrient removal ability at the plants was relatively low for the supply and not enough to remedy eutrophied lakes. Especially, unbalanced increase in human population around the lake often caused the increased loading of nutrients. Two techniques were developed to overcome this problem. The first is the sewage diversion by which the effluent water from the terminal treatment plants is discharged outside of the lake. The second method is an introduction of the technology of a high nutrient removal ability into a terminal treatment system. Because of the effectiveness in the reduction of nutrient loading, sewage diversion has been successfully introduced in some lakes. However, if there are undesirable effects of effluents from the treatment plants on human population and ecosystems at downward areas, the technology to reduce nutrients discharged from the sewage treatment plants must be introduced to remedy the lake. This method is now widely employed in many treatment plants in Japan, because of the increasing importance of water resources with good quality for our society.

A representative successful story of lake recovery by sewage diversion is exemplified by the remediation of Lake Washington, USA (Edmondson, 1972; Edmondson & Lehaman, 1981). A considerable deterioration of water quality and the development of cyanobacterial bloom had been recorded in association with the expansion of the municipality population around the lake during the period of the 1940s through the mid-1960. After 1968 when sewage diversion was completed, TP loading to the lake was remarkably reduced. The lake gradually responded with decreases in the concentration of TP, phytoplankton and the abundance of cyanobacteria in the lake water and was identified to be recovered from eutrophication by 1975.

Sewage diversion is not always effective for the remediation of eutrophied lakes. In the lakes with continued supply of nutrients by their release from the bottom sediments and /or by their loading from diffused sources such as agricultural farms, a small recovery of lake water quality has been often recorded even after the diversion of or nutrient removal from sewage. To reduce the internal loading of nutrients from the sediments, several technologies were employed. Cooke et al. (1993) reviewed various in-lake techniques for the restoration of eutrophication. Dilution and flushing of eutrophied water by introducing appreciable amounts of clear water with nutrients in lower concentration; phosphate inactivation and precipitation by the addition of chemicals such as aluminum sulfate; sediment removal by mechanical means; withdrawal of hypolimnetic water containing phosphate in high concentration;

hypolimnetic aeration to inactivate and precipitate phosphate by complex formation with ferric hydrooxide. For the details of these technologies, see Cook et al.(1993). Restoration of Lake Trummen by sediment removal is well exemplified as a successful remediation story of the lake. For the details of this story, see a series reports on the restoration of Lake Trummen that appeared in Verh. Internat. Ver. Limnol.,*19* (1975).

Continued nutrient supply from diffused sources on the watershed is another cause for a slow recovery of eutrophication in a lake where the construction of a sewer system was implemented to reduce nutrient supply by sewage discharge. One of the representative examples for the slow recovery due to this reason might be observed in Lake Biwa.

Lake Biwa is the largest lake in Japan and increased population on the watershed have adversely affected the lake environments. Increased phytoplankton abundance has interfered with the water purification process at the water work station for drinking water supply and given an unpleasant odor to the tap water. Starting in 1977 and 1978, considerable blooms of *Uroglena americana* in the north basin in June and those of *Microcystis aeruginosa* in littoral small bays during mid-summer have been observed every year. Fish stock has also decreased down to around a half of the original value. To recover the lake, Shiga Prefectural Government enacted several environmental laws for prevention of eutrophication and provided many counter measures. Currently, the control of sewage discharge by construction of sewer systems could cover more than 50% of the population at municipalities on the watershed. Despite such introduction of counter measures, little recovery in in-lake concentrations of TN and TP has been observed in the main basin of Lake Biwa, while even a gradual increase of TN has been observed (Shiga Prefectural Government, 1997). Continued loading of nutrients from diffused sources such as agriculture farms and individual septic tanks on the watershed could be responsible for little recovery of the water quality in the north basin. Thus, national and local governments are now under consideration to introduce new counter measures to reduce nutrient loading from these diffused sources. To set up feasible counter measures for diffused sources, setting up of not only new technological devises but also social counter actions are essential. The discussion of this subject will be given by Dr. M. Nakamura in a later section.

Acknowledgement:

This text was prepared based on the materials in the articles of M. Sakamoto appearing in 1-28p. of *Arch. Hydrobiol. 62,* (1966) and 80-84p. of *Proceedings of Shiga Conference '84 on Conservation and Management of World Lake Environment,* Shiga Prefectural Government (1985), and Chapter 8, Eutrophication in *Water Resources; Environmental Planing, Management, and Development* (Asit K. Biswas, ed.), McCgrow-Hill (1997). I acknowledge the publishers to permit the citation of these material for the present text. I would suggest the students of the Training Course to refer to these articles for a more advanced study of eutrophication.

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Chapter 9

Lake Biwa - Yodo River Water System : Evolving issues on integrated management of water quality

Masahisa Nakamura

9.1 Introduction

Lake Biwa - Yodo River region encompasses the metropolitan districts of Kyoto, Osaka, and Kobe and their suburban municipalities, and the urban, semi-urban and rural areas within the watershed of Lake Biwa. The development of the individual water systems, including water supply, wastewater management, and pollution control have been very much affected by, and have a great deal of impact on, the shaping of the entire Biwa - Yodo water system. The problems facing individual systems have been all quite different, and the ways to resolve such problems have been quite varied. In the process, many different physical systems and managerial approaches have evolved.

As a lake-river system evolves and increases its complexity, conflicting issues may arise as for quantity vs. quality, local vs. region, upstream vs. downstream, resource development vs. resource conservation, etc. These issues may also become more interrelated and interdependent in the process of evolution. As commonly recognized, the incremental approach to deal separately with individual issues became more and more problematic. Interest grows, therefore, toward more holistic approach such as "integrated management".

This paper gives a brief overview of the Lake Biwa - Yodo River water system and how it has evolved, and provide some cursory discussion on the future of this water system, with possible implication toward "integrated management" of water quality.

9.2 The Yodo River - Lake Biwa Water System

9.2.1 Characteristics of the System

Lake Biwa is Japan's largest freshwater lake, both in terms of surface area (674km^2) and volume (27.5 x 10^{9}m^3). It receives water from some 120 rivers (over 400 if small streams are included). It has only one exiting river in the southern end called the Seta River. The Seta River (called as the Uji River in Kyoto Prefecture) is joined by the Katsura and Kizu Rivers some 30km downstream of the lake to become the Yodo River (Figure 1).

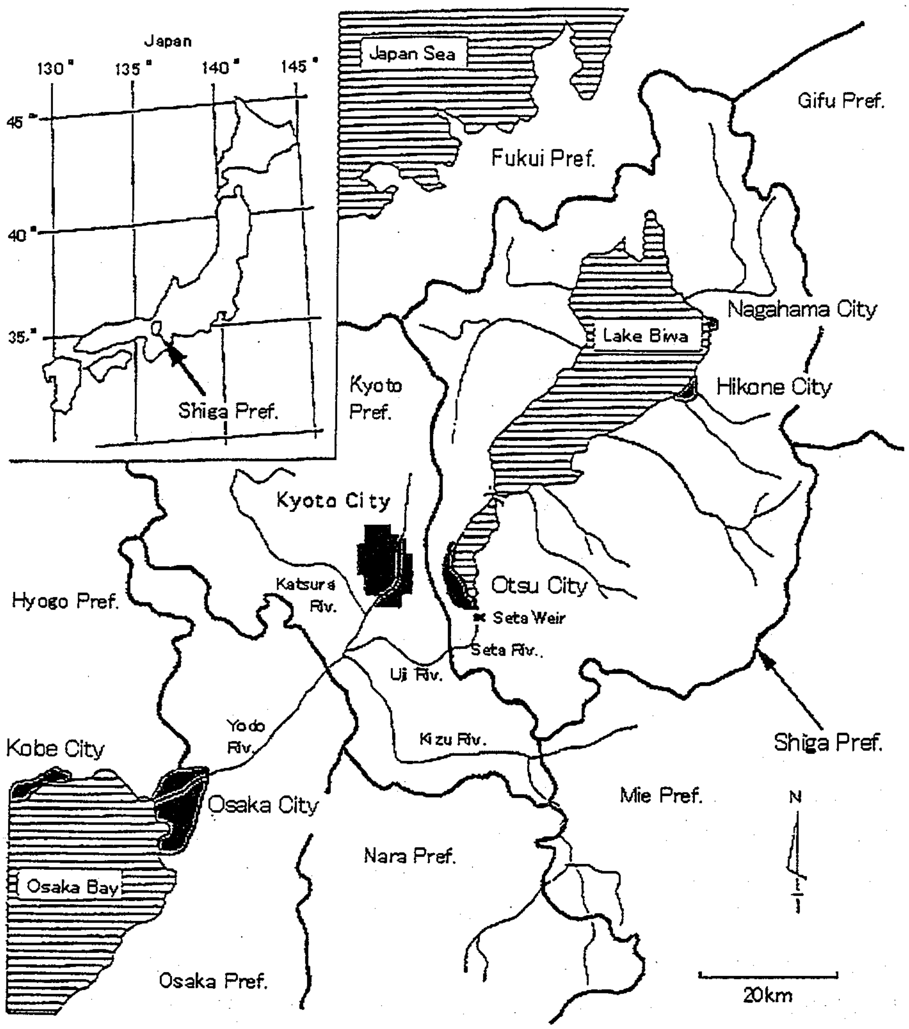

Fig. 1 Lake Biwa – Yodo River Region.

The flow contributions to the Yodo River of the Uji, Kizu and Katsura rivers are, respectively, 64.2 percent, 18.0 percent, and 15.0 percent. The official designation of the whole of the Yodo-Uji and Lake Biwa water bodies is the Yodo River system. Its annual average flow, its high flow, and its low flow are, respectively, 177.6m^3/sec, 226.8m^3/sec and 117.0m^3/sec. The ratio of low to high flows, 0.52, is the lowest among the major river systems in Japan, making Yodo River a very stable source of water.

The Lake Biwa-Yodo River system is one that is of overriding importance in Kansai, the general designation of the western half of Japan. The water from this system is supplied to such large cities as Kyoto, Osaka, and Kobe, to the industries in the Osaka Bay area, besides the urban and semi-urban areas as well as the extensive paddy agriculture fields in the lake catchment area. A complex web of water supply and wastewater networks, which support the region's high level of municipal, industrial and agricultural activities, characterizes the region.

This great metropolitan complex within Kansai, called the Keihanshin region, has been almost totally dependent on the Yodo River for its water resource needs. To meet their growing demands, the water resource capacity had to be gradually increased.

The mountain ranges around Lake Biwa, and the tributaries of the Yodo River are mostly covered with dense forests. They function as a natural reservoir as well as a gigantic filter producing high quality raw water to replenish Lake Biwa and the Yodo River. There are, however, 12 dams (including some under construction, but excluding agricultural irrigation dams) in the watershed for the integrated management of water resources to make up for the fluctuations in precipitation. The Yodo River main watercourse serves most of the downstream needs, as shown (see Figure 2). Wastewater is collected by the sewerage networks, treated, and discharged back into the Biwa-Yodo watercourse or directly into Osaka Bay. The water systems of Lake Biwa, Yodo River, and Osaka Bay are all within a compact geographical area of less than 10,000km^2. The direct distance from the northernmost tip of the Lake Biwa watershed to the southern opening of the Osaka Bay estuary is less than 200km.

The Yodo River system has many features to that make it an excellent water source. These include the beneficial relationship it has with Lake Biwa, which serves as an ideal natural reservoir and regulator of river flow. Other unique characteristics are that the river system gets replenished three times a year by melting snow, by spring rain, and by typhoons. The Yodo River system comprises three river systems with different meteorological features that compensate each other during their individual flow fluctuations. The entire river basin consists of several self-enclosed lowland areas as mentioned earlier. These features allow for the recapture of highland water use within the lower areas, making the lowland area in the upper basin of Yodo River a natural underground reservoir that ultimately contribute greatly to the lower stretch of the Yodo River.

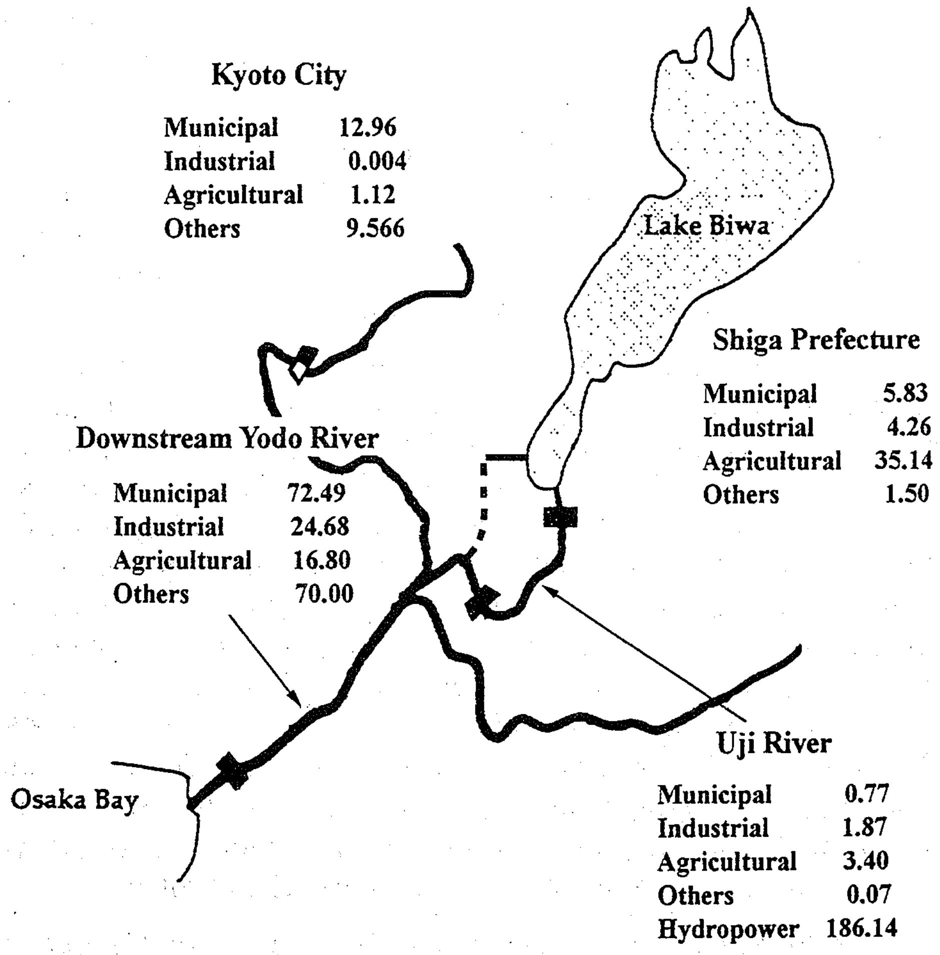

Fig. 2 Water Resource Allocation(m^3/sec) in the Lake Biwa – Yodo River System.

9. 2. 2 Major Demographic and Industrial Features in Downstream Yodo River

The Lake Biwa-Yodo River region has a population of some 18 million. The populations of major metropolitan centers are 2.64 million in Osaka, 1.50 million in Kyoto and 1.41 million in Kobe. Shiga Prefecture, where Lake Biwa occupies one sixth of its jurisdictional territory, has a population of 1.3 million.

Table 1 Population served by Lake Biwa water, 1994

Prefecture	population within jurisdiction	Population served by Lake Biwa	Dependency on Lake Biwa water(%)
Shiga Pref.	1,300,000	1,000,000	79
Kyoto Pref.	2,600,000	1,790,000	69
Osaka Pref.	8,720,000	8,530,000	98
Hyogo Pref.	5,470,000	2,610,000	48

Osaka, a commercial center over many centuries, was heavily destroyed during the Second World War. It made a rapid recovery and achieved remarkable industrialization in post-war decades. The industrial complexes extending south as well as to the west along the Osaka Bay coastline formed what is called the Hanshin Industrial Complex. A large number of small-scale manufacturing industries have sprung up in the mixed residential and commercial districts within the city as well as in the suburban regions, resulting in uncontrolled urban and semi-urban growth into the surrounding regions.

Kyoto, the ancient capital city with many cultural and scenic assets, had been constrained by its water resources, and its industrialization lagged far behind that of downstream Osaka particularly in the 19th century. The water shortage was relieved by the construction in 1891 of a canal liking the city with Lake Biwa. The city gradually regained its strength as it has since never experienced serious water shortage.

Kobe, a port city some 30km or so west of Osaka, has thrived throughout modern history as a port city. With only limited land space available, the city was able to expand by reclaiming land in the hillside and in the coastal shallows. Steel production and shipbuilding dominated the local industry till after the war. Today, however, small and medium size manufacturers support the local industries. Much of the water needs is satisfied with water transported through a main from the Yodo River.

The Lake Biwa-Yodo River system supplies water to these major cities and as well as to the surrounding municipalities. The wastewater effluents, together with urban runoff, find their way into tributary water channels prior to reaching the main watercourse of the Yodo River. In a short stretch of less than 30km between Hirakata where three rivers form the main stream Yodo River, discharge outlets and water intakes competes for their location. We will learn about the situation in more detail in section 4.

One of the outstanding features characterizing Keihanshin Region is that the population density of the region is 2.3 times the national average and is the highest among the three major metropolitan regions in Japan, i.e., Tokyo and Nagoya. The intensity per unit land of water use as well as pollution generation, therefore, is also significantly higher in this region.

The Osaka-Kobe belt zone was the largest industrial complex until the middle of the Second World War. Industrial output from this region, however, began to decline within a few decades after the war because of the decline in heavy industries such as steel mills and ship-building owing to increasing competition from the newly industrializing nations. The economy of the Kansai Region is still heavily dependent on such heavy industry types as iron and steel, chemicals and textiles (33.7%). The size of the light manufacturing industry sector producing household consumption goods such as food, clothing, rubber, plastic and lather items (33.0%) is also quite significant. The relative proportion of the electrical and electronic industries (33.3%) is smaller as compared with other industrial regions. The first two categories of industries are much more water intensive than the third, meaning that the degree of pollution load emitted per unit of production in this region is much greater than the other industrial regions.

9.3 Evolution of Regional Water Metabolism

9.3.1 Lake Biwa Comprehensive Development Project

Among the distinct phases of Lake Biwa management, the earliest and the longest was that of management of flooding and droughts. After the construction of a weir at the lake outlet in 1905, the number of flooding decreased significantly. This phase was followed several decades later by the water resources development phase. The Lake Biwa water, serving downstream needs by way of the Yodo River, had long been more than adequate for the downstream communities. In the 1960's, the Keihanshin area began to experience water shortage due to increasing industrial activities. The water of Lake Biwa immediately became a hot subject of debate. After several years of heated political exchange between the upstream Shiga and the downstream Keihanshin local governments, an agreement was reached in 1972 for the national and local governments to engage in a large-scale water resource development project called the Lake Biwa Comprehensive Development Project (LBCDP).

The basic idea of the Project was to allow the discharge of 40 m^3/sec of additional water at times of drought. The corresponding drawdown of the water level was set at 1.5m below normal. The project comprised water resource development projects, flood control and related water management projects, and compensatory public works projects for the development of catchment land. It was originally a 10-year project. Upon failing to implement the component projects fully by 1982, it was extended by 10 years, and then for another 5 years to become a 25-year national project. The project whose total budget eventually turned out to be 1.9 trillion-yen (or some US$19 billion) when finally completed in March 1997.

As a result of this development project, the lake water can now be released to meet downstream needs at times of droughts. With the much needed investments for infrastructure development having taken place through LBCDP, Shiga Prefecture today is economically much better off as compared to the pre-LBCDP era. The aquatic environment of Lake Biwa, however, has undergone significant change over this period, as will be discussed in section 5.

9. 3. 2 Water Supplies

There are many water supply systems in the Kansai Metropolitan Region (87 fully equipped water treatment systems, 292 partially equipped small treatment systems in rural areas, and 63 special-purpose treatment systems including industrial water supplies). Lake Biwa water is supplied to Osaka Prefecture (58%), Kyoto (20%), Shiga (9%), Hyogo

8%), Mie (1%) and Nara (4%) (Biwako-Yodogawa Mizukankyou kaigi Jimukyoku, 1996, p.28). Municipal water use has increased and continues to increase as a result of changing (life styles demanding greater amounts of water for non-consumption uses such as bathing, showering and car-washing, and because of the proliferation of household appliances requiring large amounts of water such as automatic washing machines and dishwashers. Demand for industrial water use, on the other hand, has been steadily decreasing owing to the change in the nature of industrial activities and to the greater awareness for water conservation.

The Kyoto water supply system consisting of four purification plants is almost totally dependent on Lake Biwa water. The Lake Biwa canals completed in 1890 and the in 1970 provide a total of 23.35m^3/sec of water, much more than the city needs. The Kyoto purification plants suffer in early summer from the problem of musty taste and odor caused by certain phytoplanktons grown in the Lake Biwa water. The Kyoto wastewater drains into the two tributary rivers to the Yodo River.

Osaka City possesses three large water treatment plants supplying to four distribution districts. All the plants depend on the Yodo River as their water source, total water right amounting to 23.49m^3/sec or about 203 million m^3/day. The quality of the water is significantly affected both by the Lake Biwa water as well as by the wastewater drained into Yodo River from its tributaries. The presence of the Kyoto wastewater treatment plants upstream along the Kamo River also makes it necessary for Osaka to resort to treatment technologies that produce water of the highest quality at a very high unit cost of production.

In the suburban Osaka area, the Prefectural Water Supply Utilities supply treated water at wholesale prices to 39 small and medium-sized municipalities. The prefectural government of Osaka operates three major municipal water treatment plants, and two additional water supply systems are currently under construction. A semi-public regional water supply utility called the Hanshin Water Supply Corporation provides water to municipalities in the western part of Osaka Prefecture and to the eastern part of Hyogo Prefecture including the City of Kobe. Several water supply systems in Osaka City and Osaka Prefecture are dedicated to supplying industrial water. In Osaka City four water purification plants supply four service districts with some 271,400m^3/day. In Osaka Prefecture, two water treatment plants provide nearly 344,000m^3/day (as of 1995).

9. 3. 3 Wastewater Management

Osaka, Kyoto, and Kobe have nearly complete sewerage service coverage within their jurisdictions, and each metropolis has its own unique features that reflect specific local requirements.

Most notable among the three is the wastewater system of Osaka City. The sewerage service boasts nearly 100 percent coverage within the city jurisdiction and the cheapest per capita sewer charge in Japan. The current wastewater system developed over a period of more than 100 years. Due to frequent flooding owing to its coastal lowland terrain, Osaka had to place great emphasis on flood control. Almost all of the sewer system, therefore, is the combined system, which allows not only raw sewage but also rainwater to be collected and delivered to treatment plants, thus requiring larger-size pipes. One of the major problems associated with the combined system is that the sewer outflow at times of severe storms gets discharged directly to watercourses, causing serious pollution of receiving water bodies. Currently, the City is working on a plan to improve the system.

As for the city of Kyoto, the sewer service coverage has now reached 97%. The Toba wastewater treatment plant, the third-largest plant in Japan today, was brought into operation in 1936. The city then gradually expanded its coverage. The sewerage system in Kyoto is characterized by a combination of combined and separate sewers, resulting in some 40% of wastewater being released into watercourses after heavy storms. There are four municipal wastewater treatment plants, each meeting specific requirement of the local industries, including typical Kyoto industries such as textile dyeing and *sake* distillation.

In Kobe, nearly 1.2 million m^3 of wastewater is treated by seven plants, four of which are located on the shores of the Seto Inland Sea. The terrain of the city consists of reclaimed coastal land, hillsides, and an upper plateau region, which makes for separate and independent development of individual systems.

Besides those mentioned above, there are some 20 regional wastewater systems in Keihansin Region at various stages of development. In the case of Osaka Prefecture, 12 regional wastewater systems serve some 42 municipalities at various levels of coverage, ranging from nearly 100% for 4 municipalities to less than 50% for 17 (as of 1995). The average service coverage for the whole of the prefecture is 63.7%. In the case of Kyoto Prefecture, two regional treatment plants are being constructed which will contribute to the protection of Yodo River water quality. The overall extent of service coverage was reported to be 73.6% in 1995.

The wastewater system to protect Lake Biwa is another important subject (Figure 3).

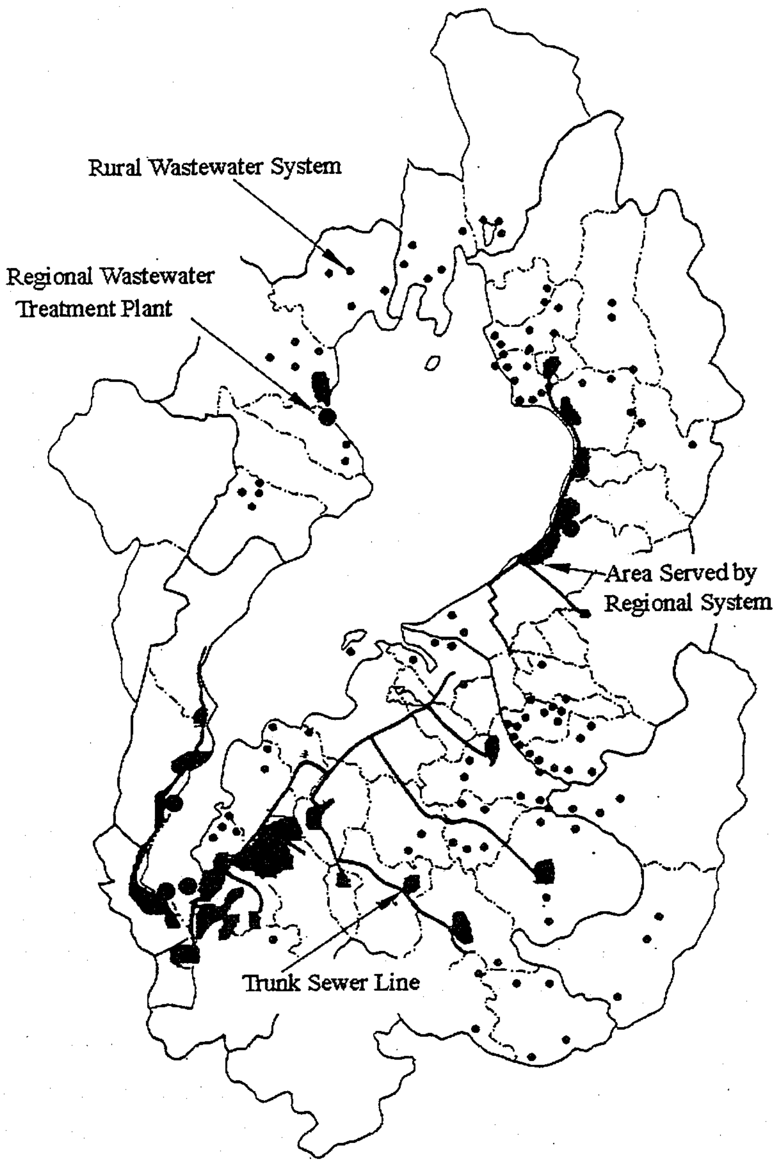

Fig. 3 Wastewater Systems in the Lake Biwa Watershed.

In Shiga Prefecture, household wastewater has been and still is a major polluter of the lake. Although municipal sewerage systems including the regional systems will eventually cover more or less the entire flat part of the watershed, the current coverage by these systems is only 47 percent of the population (50 percent of the population eventually to be served). They are equipped with advanced treatment facilities to remove nutrients in order to protect Lake Biwa from eutrophication.

There are also small-scale sewerage systems for agricultural communities and a variety of on-site sewerage systems collectively called the "Gappei Jokaso" system of which few are equipped with advanced treatment capability. Together, they are serving some 17 percent of the population. That leaves some 36% of population still not served by conventional flush toilet systems. The excreta collected from these households are transported to 12 night-soil treatment systems, which are also all equipped to treat not only organic content but also nutrient.

The regional sewerage systems are to be gradually expanded to integrate in their coverage many of the agricultural community systems and on-site facilities. By around 2010 these regional systems together with a municipal system for the city of Otsu will have served nearly 90 percent of the population. The remaining 10 percent will still remain to be served by the agricultural community systems.

9. 4 Upstream - Downstream Relationships

The water quality profile of the Lake Biwa-Yodo River-Osaka Bay system is quite complicated because there are many different kinds of upstream-downstream relationships. The most obvious relationship is between Lake Biwa, with extensive watershed development, upstream and the great metropolitan region downstream. In the upstream Lake Biwa watershed, infrastructure development through the LBCDP has literally transformed water use practices over recent decades. The new infrastructure for water intake and transmission has made the lake water much more attractive than river water or groundwater because of its abundance, stability, and good quality. Nearly 80 percent of municipal and agricultural water supplies now come from the lake, and nearly all of it is returned to the lake, either with treatment (mostly in the case of municipal supply) or without treatment (mostly in the case of agricultural return flow). There are other more localized upstream-downstream relationships throughout the Lake Biwa-Yodo River system. For example, there are many problematic relationships between upstream wastewater effluent discharge points and downstream water intake points, particularly along the middle and lower stretches of the Yodo River.

This upstream-downstream relationship may be examined in more detail in terms of institutional and political context in two cases, the first involving the Shiga Prefecture and downstream governments as a whole, and the second involving Kyoto and Osaka.

In the first case, the conflict is between the downstream expectations and the upstream mandate. To put it simply, the quality of water the downstream users get is greatly dependent on that of the Lake Biwa water. While the Shiga Prefecture wishes the lake water to be kept clean, it alone cannot pay fully to maintain or restore the quality of the lake water. The financial burden, it claims, has to be shouldered by others as well, including and specially the downstream users.

The second case involves an interesting but difficult issue regarding the Yodo River water quality between Kyoto, upstream, and Osaka, downstream. For the Osaka water suppliers, it is crucial that the quality of Yodo River be kept as high as possible so that the cost of water treatment would not be excessive. Osaka already expends great effort to treat their raw water because the lake water and the river water containing Kyoto wastewater discharges are already significantly problematic. Kyoto, on the other hand, will only attempt to keep the effluent discharges free of residual pollution over and above the level the legal requirements, while making every effort to keep the cost of treatment low.

9.5 Control of Lake Biwa Eutrophication

The first serious sign of deterioration in Lake Biwa water quality came suddenly in the form of a large-scale red tide along the eastern coastline of the northern basin in early 1977. The sighting of this phytoplankton, *Uroglena Americana,* was quite a shock as the northern basin had been, up till then, believed to be nearly pristine. The red tide has since been sighted almost every year. Prompted by the red-tide incident, the Shiga Prefecture enacted the Eutrophication Control Ordinance of 1980 to ban the use and sale of phosphorus-containing synthetic detergents. Further, with the enactment of the Eutrophication Control Act of 1980, the regulatory provisions for industries became even more precise and stringent, with additional controls on nutrient discharges. Wastewater from smaller-scale industries has been progressively brought under control, although very small industries whose discharges are insignificant in comparison with total industrial discharges are yet to be regulated fully. Despite such control measures, typical water quality indices, such as COD, total phosphorus (TP), and total nitrogen (TN) reveal that the improvement in lake water quality has not been very impressive; indeed Figure 4 shows a worsening trend in COD in recent years. In addition, there are other more subtle indicators of what is taking place in the lake ecosystem, such as the change in the dominant species of nuisance-causing phytoplankton in the lake (Figure 5). Putting all the indicators together, it can be noted that the deteriorating trend was accelerated since then up till mid 1980s, and, although the rate since slowed down, the trend itself has not been reversed yet.

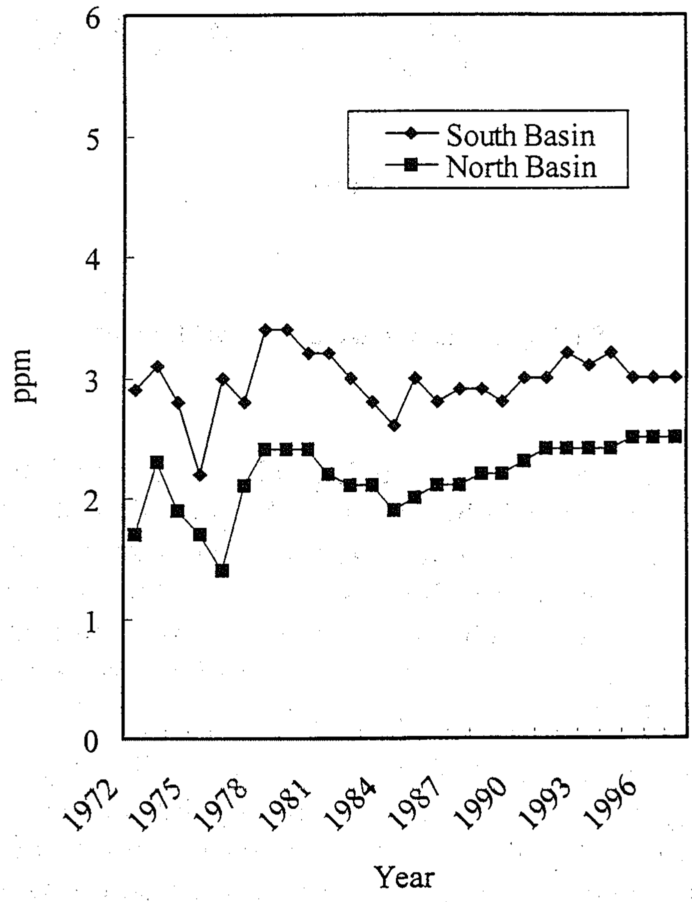

Fig. 4 Lake Biwa COD Trend.

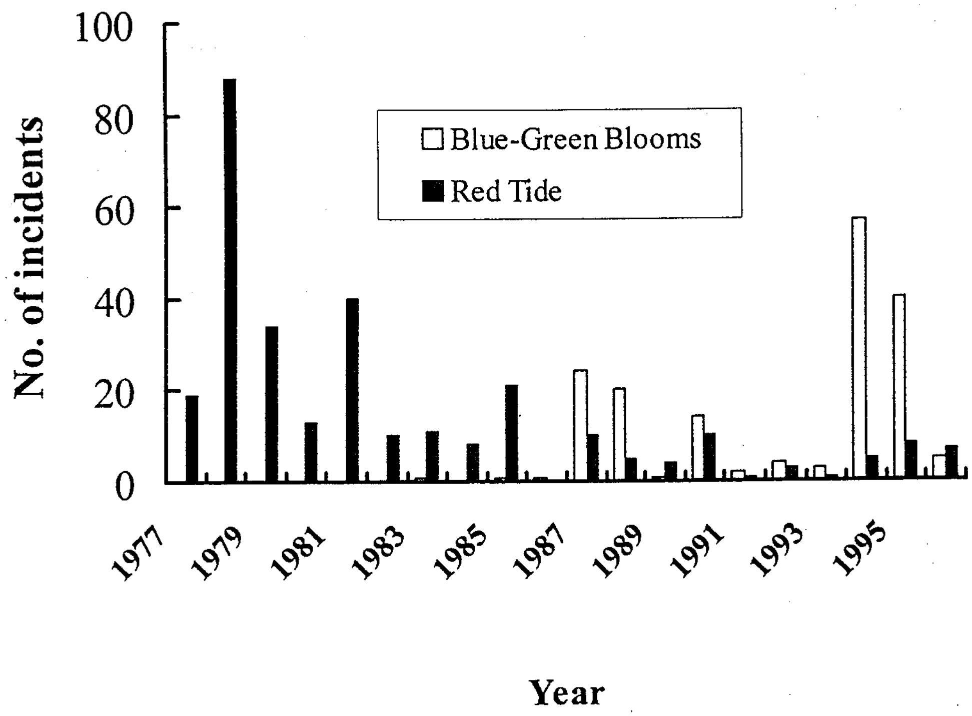

Fig. 5 Shifting Trend of Lake Biwa Algal Blooms

Are there good prospects of reducing polluting inputs into the lake? The regulation of polluting industries and the provision of sewerage to households and commercial establishments are the two main point source management strategies. Time (how soon?) and the mobilization of financial resources (how much?) are the basic considerations affecting progress now that the special budgetary provisions for environmental projects in the LBCDP have been terminated.

Concern about the control of waste load discharge has been gradually shifting in the past decade or so from point sources of pollution to non-point sources of pollution. The four major sources of non-point pollution are (1) rainwater, (2) forest and field runoffs, (3) paddy runoff, and (4) urban runoff. Not only will the development of a comprehensive non-point source control system be expensive, but it will also require legal and institutional measures yet to be elaborated. This is particularly so with wet weather non-point sources of pollution, or storm-water runoff into the lake. Moreover, the financial resources are likely to be tied up in point source control for some time.

Elaboration of control programs for non-point pollution from both urban and agricultural sources has just began. Paddy field runoff under dry weather condition may be managed very effectively by a combination of structural and non-structural means. The current trend in policy is to regard individual paddy fields as point sources rather than non-point sources under dry weather conditions. Proper management of irrigation water and a reduction in the wasteful use of fertilizers and pesticides are the keys to successful control of dry weather runoffs. The promotion of agricultural best management practice and technology developments for the more efficient use of resources will also be necessary.

9. 6 Evolving Issues on Integrated Water Management

The underlying major objective of Lake Biwa-Yodo River management in recent decades, with particular reference to meeting the growing water needs of the Kansai Metropolitan Region, has always been to achieve sustainable water use. In a narrow sense, this seems to have been the mandate of the individual municipal and prefectural governments engaged in water and wastewater management schemes in this region. The major hurdle to achieving sustainable water use, or in having access to enough water, has been overcome in principle through the completion of the LBCDP, except that it pertains only to sustainable water quantity, not quality.

As far as the downstream municipalities are concerned, the sustainable use of Lake Biwa water that meets the quality requirements for their water supplies has a lot to do with the cost of water purification. For example, the City of Osaka has been and will be prepared to pay for the advanced treatment of its drinking water from the Yodo River. It would not, however, be prepared to pay to improve (marginally at best) the quality of Lake Biwa water as a whole because it would simply not be cost effective. The discussion on the sustainable use of water in respect to both quantity and quality, therefore, has to be pursued on the basis of a much broader definition of sustainability, which brings us to the next subject, integrated watershed management.

The management of water quantity in the Lake Biwa-Yodo River system has been integrated in the sense that water rights for extraction from the system have been strictly regulated under the jurisdiction of the Ministry of Construction. The LBCDP was conceived to generate additional water needed at times of predicted water shortage so as to be able to augment the limited water rights. With the completion of the LBCDP, together with the integrated system of reservoir regulation within the watershed, the integrated management of water quantity has been further improved. Unfortunately, the integrated management of water quality has not been fully addressed in the Lake Biwa-Yodo River-Osaka Bay water system.

The management of water quality within a system as extensive and sophisticated as the Lake Biwa-Yodo River-Osaka Bay water system may be pursued in many different ways and at very different levels of integration. The least onerous system for the individual municipalities would be to pursue their own water quality programs independently while keeping track of trends in the overall quality of the Yodo River as a whole, with reference to the established ambient water quality standards. This is the level of integration that the Lake Biwa-Yodo River-Osaka Bay water system has currently reached, and it is working fairly well in that the water quality has been improving steadily in terms of conventional point-source quality parameters, i.e. meeting effluent discharge and ambient water quality standards. The problem is that this level of integration will not be adequate to address issues of growing concern such as human and ecosystem risks involving, for example, non-point sources of pollution and the degradation of ecosystem integrity. An integrated and basin-wide strategy needs to be developed and followed by all members of the water system in a much more coordinated way. Provision for such a system has so far been quite limited.

9.7 Concluding Remarks

The Lake Biwa-Yodo River water system has evolved over the past several decades to meet the growing water needs of the Keihanshin metropolitan region and the Lake Biwa watershed region. In the process, many complex issues had to be resolved, but many new issues have also arisen. These issues generally pertain to conflicts in addressing quantity vs. quality, local vs. region, upstream vs. downstream, resource development vs. resource conservation, etc. The resolution of such issues can be quite problematic because they are inherently interrelated and interdependent, and the piecemeal approach of resolution may prove to be ineffective. In a way, the notion of "integrated management" can be conveniently brought in.

On the other hand, the evolution of a water system is quite generic in nature. What constitute "integrated management" for a particular water system may be quite different from one for another. The fundamental characteristics of the management system evolved should reflect how it could be further enhanced within the context of the evolution having taken place.

Note:

1. *An earlier version of this paper entitled, "Water Quality Management Issues in the Kansai Metropolitan Region", is currently being processed for publication by the United Nations University.*

2. *Figure 1 is a modification of a drawing in a brochure prepared by the Environmental Policy Division, Shiga Prefectural Government. The data used in Figures 2-5 were obtained from various publications of the Environmental Policy Division and Water Policy Division, Shiga Prefectural Government.*

Chapter 10

Ecological inhomogeneity due to dynamic variability in Lake Biwa

Michio Kumagai

10. 1 Introduction

Horizontal distributions of phyto plankton in the surface layers of Lake Biwa have been investigated by the use of newly developed instrument such as a laser fluorescence sensor, and we found that there exists microbial inhomogeneity in Lake Biwa (Kumagai and Tsuda, 1990, Tsuda *et al.* 1995). The spatial inhomogeneity of phytoplankton distribution is often seen in the transient area between inshore and offshore regions in a lake, where physical processes are complicated, and ecological response becomes dominant. That is why we are conducting the field observation to study the relationship between ecological inhomogeneity and dynamic variability in Lake Biwa.

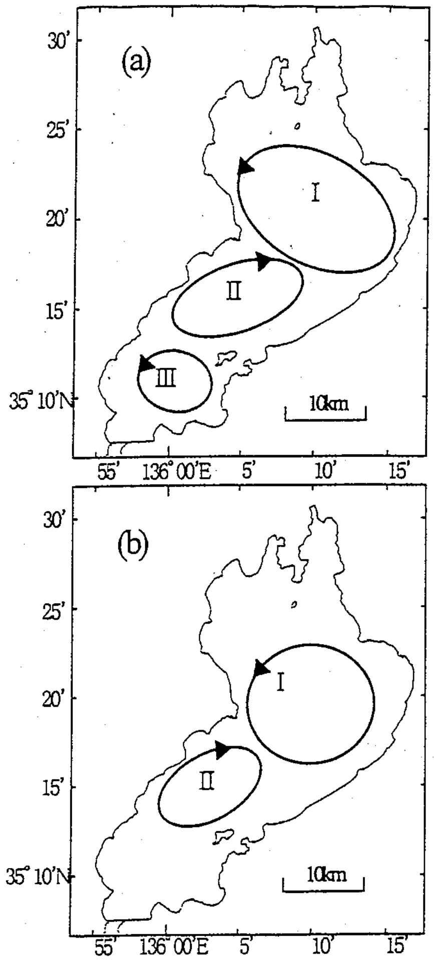

Fig. 1 Gyres in Lake Biwa measurd by
(a) Suda et al. (1926) and
(b) Endoh and Okumura (1993).

The surface water dynamics in Lake Biwa can be characterized by the gyres formed in a stratified period from May to October. The gyres were first found by Suda *et al.* (1926), and certified by Endoh and Okumura (1993) as seen in Figure 1. The annual distributions of gyres have not been clarified until Kumagai *et al.* (1998) measured the current vectors in the surface layer with an ADCP (Acoustic Doppler Current Profiler), and showed that the numbers and distribution of the gyres are changeable according to thermal stratification intensity.

In the present paper, we would like to discuss the distribution of chlorophyll-a, water temperature and horizontal current vectors, and try to explain the ecological inhomogeneity due to dynamic variability.

10. 2 Monitoring methods

ADCP is the instrument to measure currents by the use of the ultra-sonic Doppler shift in water. Different wave frequencies are used for different water depths, and we use the broad band ADCP with 300kH frequency and 2m depth cell size equipped on the R/V Hakken. The average of the ADCP data over 15 seconds allowed us to obtain data at 60m intervals along the ship track, because the vessel speed was kept at 8 knots during measurement.

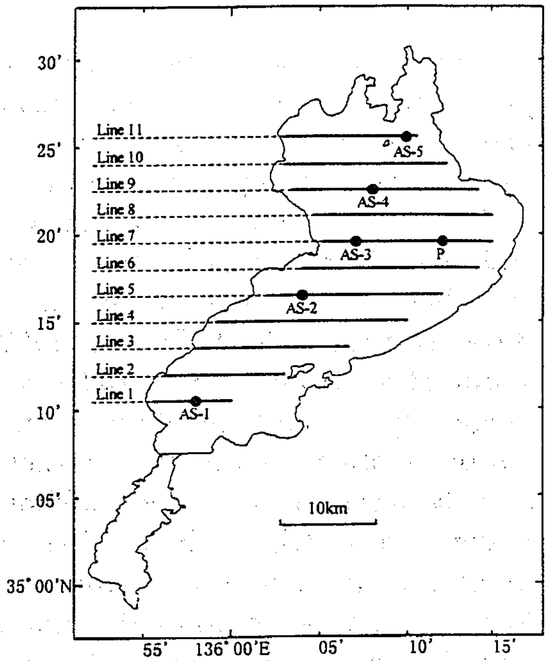

Fig. 2 Observation lines of the ADCP measurements in Lake Biwa.

While the ADCP measurement was carried out, we also continuously measured temperature and fluorescence in surface waters taken up by a pump with an F-probe (Fine Scale Probe) at each second.

Both data are stored in a computer with positioning data obtained by DGPS (Differential Global Positioning System), and we can easily compare fluorescence related to phytoplankton with physical data such as currents and temperature.

10. 3 ADCP measurements

The eleven observation lines of the ADCP measurements are shown in Figure 2. These measurements have been continued once a month since 1994, and we show the results taken from April to August in 1994. The weather condition on each day is summarized in Table 1.

Table 1. Weather conditions during the ADCP measurements. These data were obtained by the Meteorological Station at Hikone

	Apr 19/20	June 22/23	July 26/27	Aug 30/31
Weather	fine/cloudy	fine/rainy	fine/cloudy	fine/fine
Wind speed ($m\ sec^{-1}$)	2.1/1.7	2.1/1.1	2.6/1.6	1.9/2.0
Wind dir.	NW/ESE	NNW/W	SSE/NW	NW/NW
Raifall (mm)	1.5/0.0	0.0/2.5	0.0/0.0	0.0/0.0

Figure 3 shows the current vectors at 8m depth in the North Basin from April to August in 1994. It is obviously found that the gyres were not formed clearly in April, but were gradually getting clear from June to August. Especially, we can see three gyres in August. From North to South, we call the first gyre (counter-clockwise), the second gyre (clockwise) and the third gyre (counter-clockwise).

As the vessel moves at 8 knots for the ADCP measurements, we could not cover the entire area in the North Basin of Lake Biwa within one day. Thus each observation was carried out for two days: the measurements from Line 1 to Line 6 were done on the first day, and the Line 7 to Line 11 were done on the second day. As seen in Figure 3, we could not see any serious discrepancy between the data taken at Line 6 and Line 7, although those were measured in successive days.

The distributions and rotating directions of the gyres in Figure 3 are exactly matched with the results of Suda *et al.* (1926) except for the positions. The first gyre measured by Suda *et al.* (1926) was located at a more northern location than the present position. Kumagai *et al.* (1998) suggested that this discrepancy was caused by the change of stratification intensity. Actually, water temperature in summer of 1926 was cooler than now, and it could be considered that the rotation energy of the first gyre was weaker than the present gyre's. It means that, the first gyre moves south, as the gyre becomes strong, and this fact could be affected by the global climate change. The change of the gyre's position may induce a serious impact on aquatic ecology, because usually the gyre has a huge amount of energy.

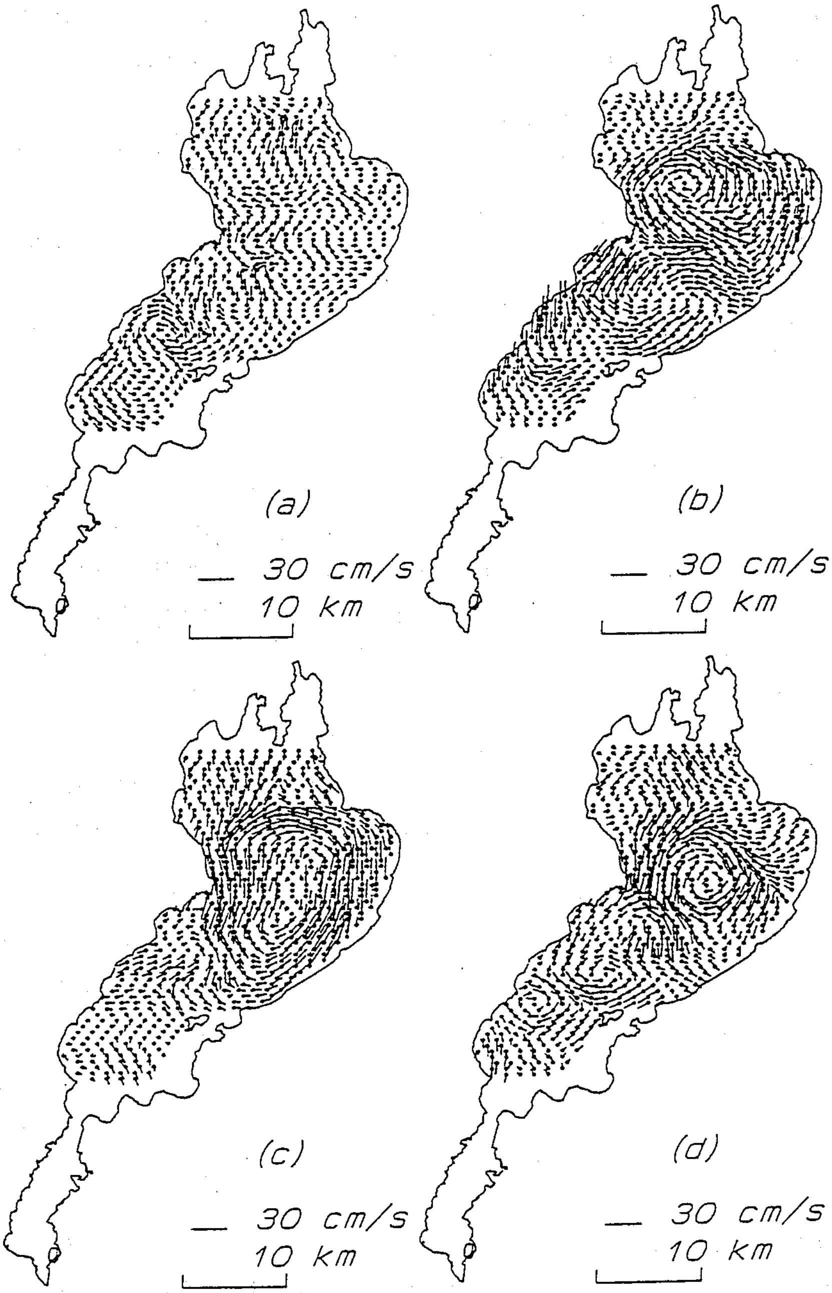

Fig.3 Current vectors, measured by the ADCP in Lake Biwa. Panels correspond to (a) April 19-20, (b) June 22-23, (c) July 26-27 and (d) August 30-31, 1994.

10. 4 Spatial inhomogeneity measured by F-probe

F-probe can measure water temperature, pH, conductivity, dissolved oxygen, turbidity and chlorophyll-a at the same time. To show a spatial inhomogeneity of phytoplankton distribution, we choose Line 8 as seen in Figure 4, which is along the latitude 35° 21′ N.

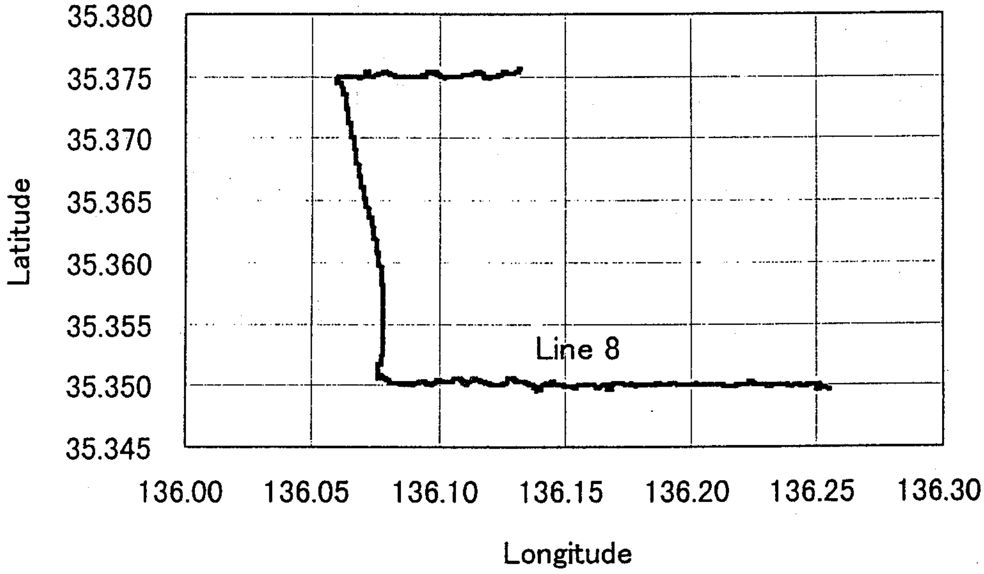

Fig.4 One of trajectories of R/V Hakken a the ADCP measurement on June 23, 1994.

Water temperature and chlorophyll-a on Line 8 are shown in Figure 5, where we can find a slightly strange phenomenon, because chlorophyll-a is higher in the first gyre area than that of the inshore region. This can be explained by the fact which we had small precipitation in 1994. Of course, these data were taken from surface water only, and we cannot discuss total biomass with the data. However, we may say that less discharge of nutrients was flushed into the lake through rivers, and phytoplankton in the inshore region could not grow. Probably, phytoplankton in the first gyre area had a different condition of nutrients, and different type of phytoplankton must have grown. Actually, we found pico-plankton in the offshore region. Thus, physical processes impart a great influence on the phytoplankton distribution in a lake.

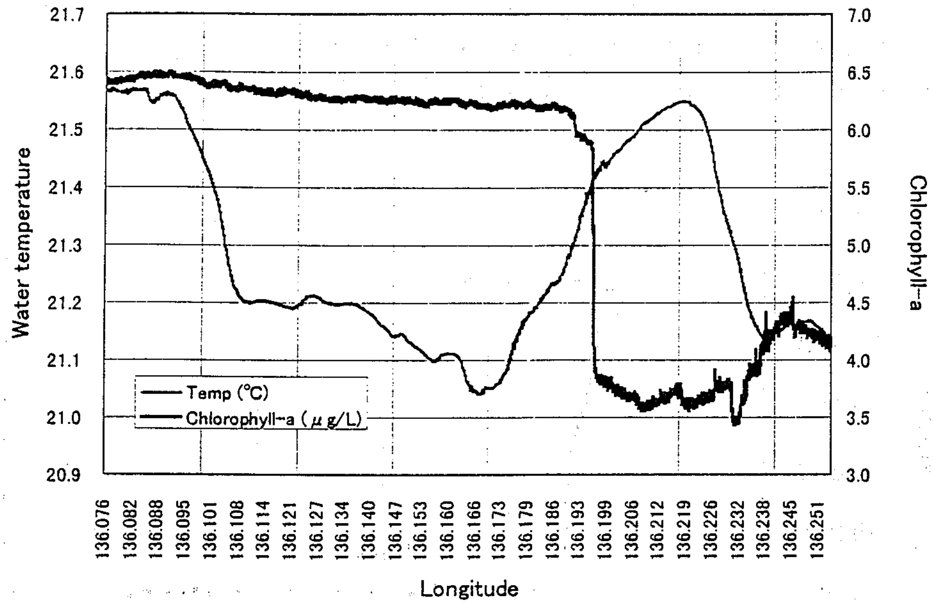

Fig. 5 Spatial change of water temperature and chlorophyll-a along Line 8 on June 23, 1994.

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Chapter 11

Evolution and Distribution of cyprinid fish in East Asia during Neogene, and formation of the cyprinid fauna in Lake Biwa

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11. 1 Introduction

Lake Biwa is an ancient lake originating from one of the lakes formed in the Setouchi Basins, the inland basins formed in Southwest Japan, in the Pliocene. The sediment of Paleo-lake Biwa and its river systems is called the Kobiwako Group from which fossil cyprinids belonging to six subfamilies are collected as fossil pharyngeal teeth. These are the cyprinines, xenocypridines, cultrines, gobionines, leuciscines, and rhodines in decreasing order of abundance (Nakajima, 1986a).

From the lowest part of the Kobiwako Group, the Ueno Formation, abundant fossil pharyngeal teeth of cyprinids were collected. The fossil cyprinid fauna from the Ueno Formation is richest in variety and abundance among the Kobiwako Group. Nearly all taxa are different at the species level from living forms. However, most of them represent living genera, but still unknown extinct genera also occur. The cyprinid fossil assemblage from the Ueno Formation represents the Pliocene cyprinid fauna of Japan and is called the Iga Cyprinid Fauna. It is largely different from that present in Lake Biwa in composition of subfamilies (Nakajima, 1986a). It resembles that of the Pliocene Yushe Fauna in China and of the Miocene Iki Fauna and others in Japan (Nakajima, 1986a).

In this paper, I will state the origin of the Iga Cyprinid Fauna, the geotectonic hystory of Lake Biwa, and the temporal succession of the cyprinid fauna in Paleo-lake Biwa. Then, I will discuss the appearance of the endemic species in present Lake Biwa and the extinction of elements of the Iga Cyprinid Fauna on the basis of fossil data, and the influence of human activities to cyprinid fauna in Lake Biwa.

11. 2 Origin of the Iga Cyprinid Fauna

In the Early Miocene, the cyprinid fauna in Japan, represented by the Iki Fauna and others, was very rich. It consisted of xenocypridines (extinct *Iquius*), cultrines (extant *Hemiculter, Sinibrama, Ancherythroculter* and extinct *Mioculter*), and cyprinines, (extant *Cyprinus* and extinct *Lucyprinus*), danionines (extant *Zacco*) and rhodeines (extinct *Paleorhodeus*) (Tomoda et al., 1977; Nakajima, 1993). Abundance of fossils from many localities suggests that xenocypridines predominated the Miocene fauna (Nakajima, 1991).

On the other hand, the Miocene cyprinid fauna in China, represented by the Shanwang fauna from Shantong Province, contains cyprinines (extant *Cyprinus* and extinct *Lucyprinus, Qicyprinus* and *Platycyprinus*), danionines (extinct *Miheilichthys*), gobionines (extant *Gnathopogon*) and leuciscines (extinct *Plesioleuciscus*) (Zhou, 1990). Only Cyprinus and Lucyprinus among cyprinines were common in both regions. In China, cultrines never occurred, and xenocypridines were very poor during the Miocene. Therefore, the cyprinid fauna was largely different between China and Japan during the Miocene, though the Japanese Islands were part of the continent in the Early Miocene.

The Pliocene cyprinid fauna in China is represented by the Yushe fauna from Shansi. It contains xenocypridines (*Xenocypris*), cultrines (*Culter*, and *Hemiculterella*), cyprinines (*Cyprinus* and *Carassius*), leuciscines (*Leuciscus, Mylopharyngodon,* and *Ctenopharyngodon*), hypophthalmichthyines (*Hypophthalmichthys*), and gobionines (*Gnathopogon*) all of which are extant genera (Liu and Su, 1962). Cultrines appeared first in the Pliocene and xenocypridines were richer in China in the Pliocene than in the Miocene. The cyprinid fauna in China approached to the modern one in the Pliocene from the Miocene one which lacked cutrines. There was a large gap in Chinese cyprinid fauna between the Miocene and the Pliocene.

Fossil genera of three subfamilies, cyprinines, xenocypridines and cultrines from China and Japan listed on Fig. 1 lead me to the following

Fig. 1. Comparison of fossil cyprinines, xenocypridines and cultrines between China and Japan.

	Paleogene	Miocene	Plio-Pleistocene	Holocene
The Sea of Japan area	Lift valley lakes	Formation the sea	The Sea of Japan	
Cyprinines CHINA	Cyprininae, gen. indet.	*C.* (*Cyprinus*) *C.* (*Mesosyprinus*) *Lucyprinus* *Qicyprinus* *Platycyprinus*	*C.* (*Cyprinus*) *C.* (*Mesosyprinus*) *Carassius*	*C.* (*Cyprinus*) *C.* (*Mesosyprinus*) *Carassius* *Carassioides*
Cyprinines JAPAN		Cyprininae, gen. indet. *C.* (*Mesosyprinus*) *C.* (*Cyprinus*) *Lucyprinus*	*C.* (*Cyprinus*) *C.* (*Mesosyprinus*) *Carassius*	*C.* (*Cyprinus*) *Carassius*
Xenocypridines CHINA		Xenocypridine, gen. indet.	*Xenocypris*	*Xenocypris* *Distoechodon* *Pseudobrama* *Xenocyprioides*
Xenocypridines JAPAN		Xenocypridinae, gen. indet. *Iquius*	*Xenocypris* *Pseudobrama* *Distoechodon*	*Xenocypris* *Distoechodon*
Cultrines CHINA			*Culterichthys* *Hemiculterella*	Many genera
Cultrines JAPAN		Cultrinae, gen. indt. *Anchyerythroculter* *Sinibrama* *Mioculter* *Hemiculter*	Cultrinae, gen. indt. *Ishikauia* *Megalobram*	Cultrinae, gen. indt. *Ishikauia*

idea. During the Miocene, the cyprinid fauna in China was constituted by old elements such as Lucyprinus, Platycprinus and Qicyprinus. In the Early Miocene, new elements, xenocypridines and cultrines, characterizing the modern cyprinid fauna of East Asia, originated in the Japanese area which was situated in the marginal part of the Asia Continent at that time. It is probable that the new cyprinid fauna containing cultines and xenocypridines spread from the Japanese area to China by the Pliocene.

The paleomagnetic data suggest that the Japanese Islands formed a part of the east margin of the Asian Continent until the Early Miocene, and that Southwest Japan rotated clockwise and Northeast Japan rotated counterclockwise to reach the present location about 14 million years ago as shown in Fig. 2. During the late Paleogene to the Early Miocene, a large rift valley was formed between the continent and the Japanese Islands (Otofuji and Matsuda, 1984). Wide distribution of freshwater sediments indicates that several large lakes were formed there. Geological activity in such a large scale seems to have generated new environments in the marginal part of the continent, different from those in the inner parts. Such unique environments probably provided the conditions where the new cyprinid fauna originated.

In the Middle Miocene, the Japanese Islands were transgressed by the sea. The rift valley between the continent and the Japanese Islands was expanded by the rotation of the island arc, by which the Sea of Japan was formed. The transgression was on a large scale in Northeast Japan. In Southwest Japan, however, the transgression was comparatively calm (Makiyama, 1956), and the land remained in Southwest Japan with freshwater bodies (Shibata, 1985), where the cyprinid fauna, although poor, could still exist.

In the Late Miocene, the Japanese Islands uplifted. Southwest Japan was connected to Northeast Japan and the Japanese Islands approached their present shape (Minato et al., 1965).

In the Early Pliocene, some sedimentary basins were formed in the Setouchi Geologic Province of Southwest Japan. The sedimentary basin of Paleo-lake Biwa originated as one of the Setouchi Basins (Itihara, 1966). The Miocene cyprinid fauna kept on surviving in Southwest Japan, and the descendant of it became the Iga Cyprinid fauna. That cyprinid fauna seems to have inhabited widely the freshwater bodies in the Setouchi Geologic Province.

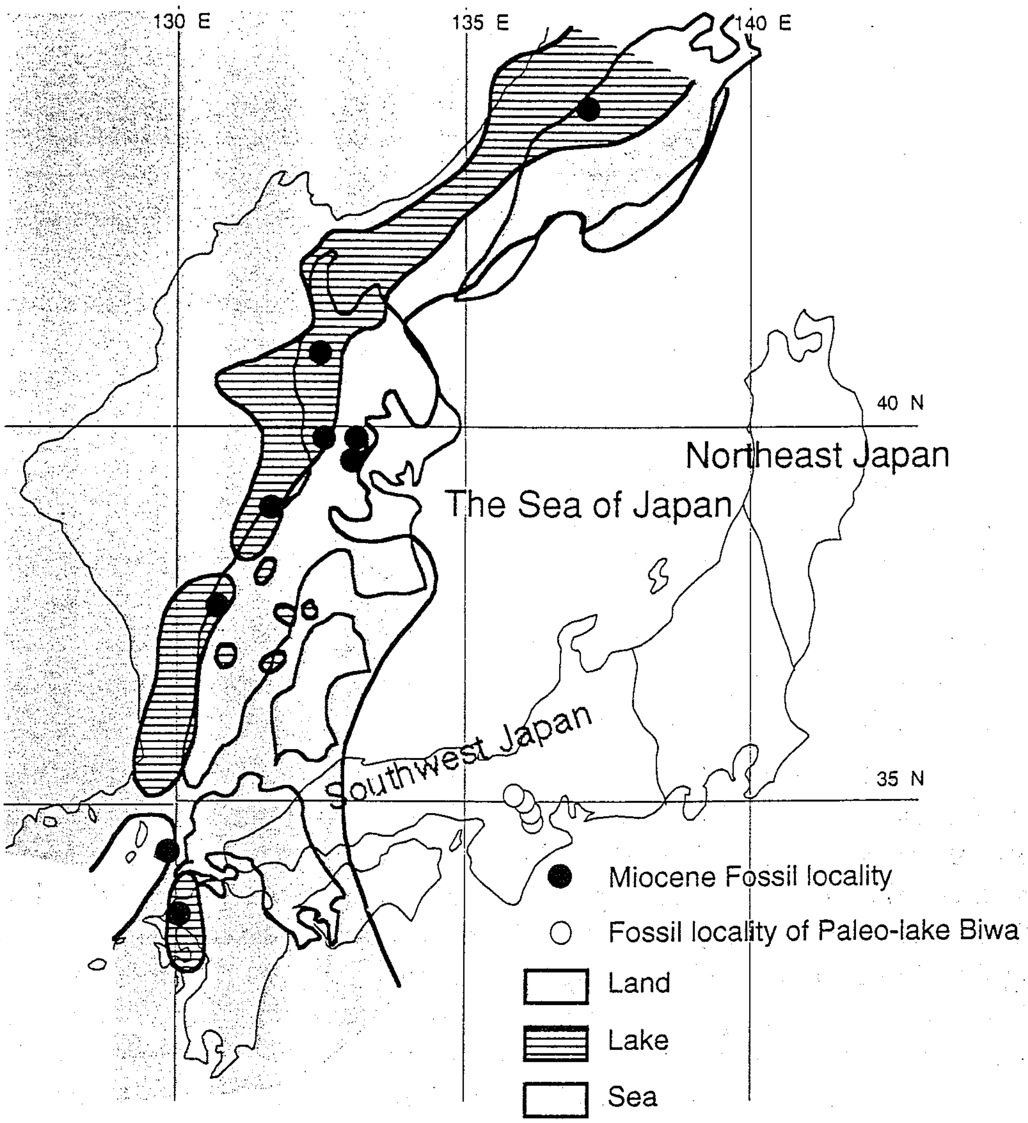

Fig. 2. The lakes in the large rift valley 17Ma (modified from Itoigawa & Shibata, 1993) and cyprinid fossil localities. Fine lines show present coastline. Fossiliferous localities of Miocene sediments are plotted at locations before the rotation of Japanese Islands and those of Paleo-lake Biwa at present locations.

11. 3 Geotectonic history of Lake Biwa

The sedimentary basin where Lake Biwa is presently located originated from one of the Second Setouchi Basins, in the Pliocene epoch. Some of the lakes formed in the basins disappeared later, and others suffered transgression by the sea. Paleo-lake Biwa did not remain a stable lake but was filled up with fluvial sediments twice during its history. However, the sedimentary basin itself has not suffered transgression by the sea and has maintained freshwater conditions until today. The history from the formation of Paleo-lake Biwa to the present Lake Biwa was reviewed by Kawabe (1994) and Yoshikawa and Yamasaki (1998), which I wil summerize below.

The sediments deposited in Paleo-lake Biwa and its river systems are widely distributed in the areas surrounding Lake Biwa at present, viz. the Omi and Ueno Basins. The strata are called the Kobiwako Group and can be lithologically divided into eight formations. They are the Ueno, Iga, Ayama, Koka, Gamo, Kusatsu, Katata and Ikadachi (Biwako) Formations in ascending order (Fig. 3; Yoshikawa and Yamasaki, 1998). Among them, the Iga and Kusatsu Formations are of fluvial sediments.

The lake of the first phase was formed in the Ohyamada area around the Ueno Basin, located about 50 km south-east of the present Lake Biwa, which is called Paleo-lake Ohyamada (3.5-3.1 Ma). It was a shallow lake under a subtropical climate. The deposits of Paleo-lake Ohyamada, forming a part of the Ueno Formation, have abundant and highly diverse land and freshwater remains, such as diatoms, vascular plants, protozoans, sponges, molluscs, fishes, reptiles, and mammals. Composition of the fauna resembles those of the eastern part of the Asian continent, suggesting a geological connection to the continent (Matsuoka, 1987). About 3.1 Ma, a huge volume of gravel and sand was transported from a north-western direction by a river inferred to be about 50 km long. Thereby, Paleo-lake Ohyamada was filled up and disappeared. Thereafter, the fluvial sediment was deposited, constituting the Iga Formation. The river waned, and a shallow lake again appeared in the Ohyamada area, called Paleo-lake Ayama (2.9 Ma). The lake waned in the northern part due to transportation of sand and gravel from the uplifted north-northwest hinterland mountains (2.7 Ma). The fauna of Paleo-lake Ayama became poor, though some of the molluscs and fishes inhabiting Paleo-lake Ohyamada had survived (Matsuoka, 1987; Nakajima, 1986). The

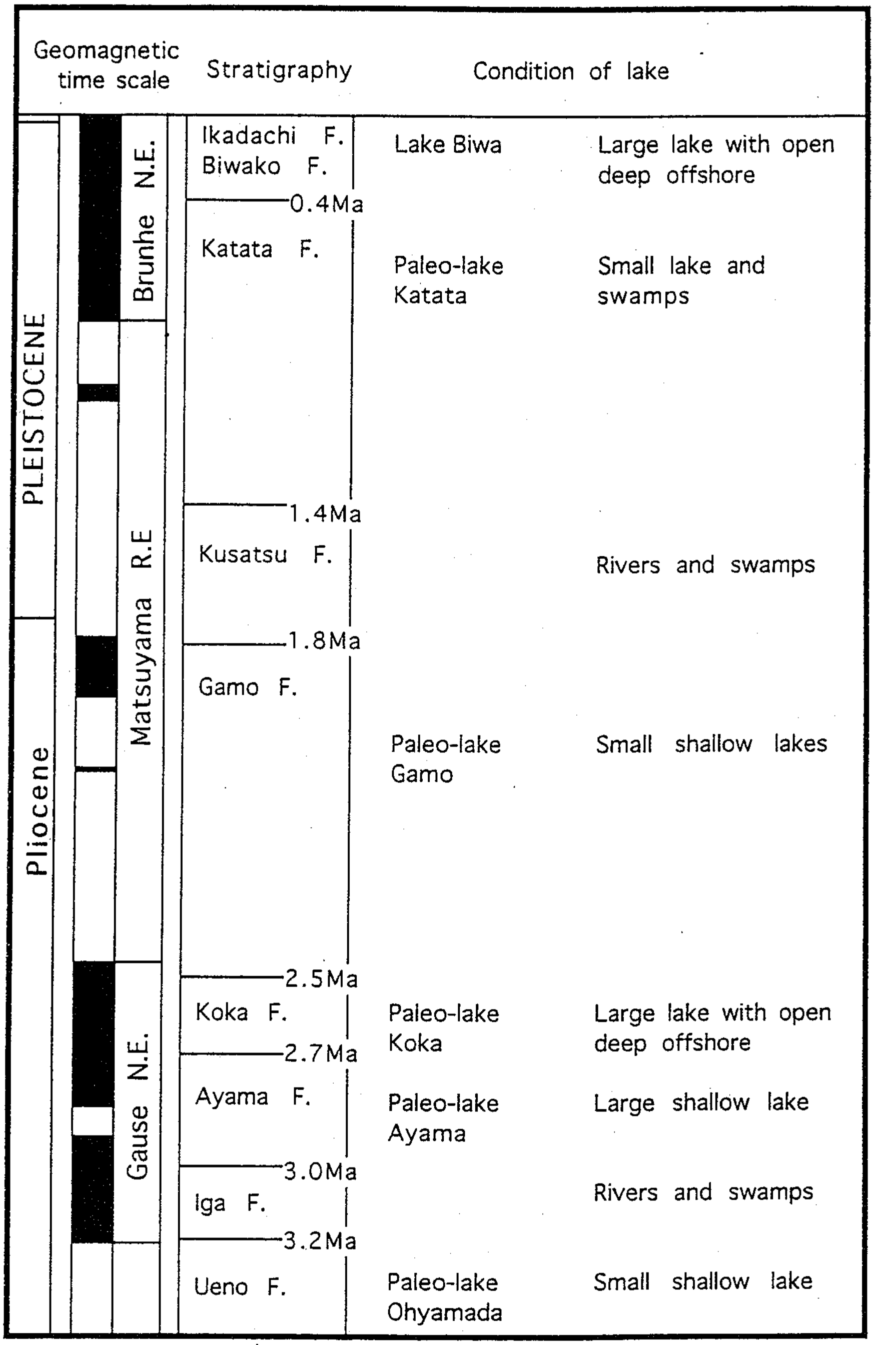

Fig. 3. Stratigraphy of the Kobiwako Group with geomagnetic time scale and condition of Paleo-lake Biwa in each phase (modified from Kawabe, 1994 and Yoshikawa and Yamasaki, 1998).

sediments deposited during the period of Paleo-lake Ayama constitute the Ayama Formation.

The sedimentary basin moved northwards, and the lake became markedly deeper (2.6 Ma). This deep lake is called Paleo-lake Koka which represented one of the stable phases of Paleo-lake Biwa, and its sediments are contained in the Koka Formation. The predominant diatom changed from the species complex of Aulacoseira praeislandica in Paleo-lake Ayama to Aulacoseira solida in Paleo-lake Koka (Tanaka and Matsuoka, 1985), which reflects the drastic change in aquatic environment between the two paleo-lakes. The fauna of Paleo-lake Koka is characterized by the low density of littoral molluscs (Matsuoka, 1987) and the dominance of crucian carp among fishes (Nakajima, 1986).

The area covered with the sediments of Paleo-lake Koka, Ayama and Ohyamada uplifted, and the sedimentary basin migrated further to the north, occupying the southern half of the present Omi Basin (2.2 Ma). This movement made the lake smaller and shallower, and generated many swamps around the lake. This lake, called Paleo-lake Gamo, was very unstable. From two to one million years ago, the Suzuka Mountains uplifted in the east of the lake. High erosion of the moutains supplied a huge volume of gravel and sand into the lake, which made the environments of the basin fluvial again. Paleo-lake Gamo, depositing swampy sediments presently found in the Gamo Formation, thereby disappeared, and fluvial sediments found in the Kusatsu Formation began to deposit.

A small and shallow lake was formed in the Otsu and Katata area on the south and south-west side of the present Lake Biwa (1.4 Ma). This lake, Paleo-lake Katata, was surrounded by swamps, whereas the area to be occupied by the present Lake Biwa had still fluvial environments. Some of the present endemic molluscan species appeared in Paleo-lake Katata (Matsuoka, 1987). Then, the lake gradually became open (0.4 Ma). According to this environmental change, the molluscs increased in number and variety, and many of the present endemic species appeared (Matsuoka, 1987). Upon the strata containing these varieties of fossil molluscs, the sediments with a different lithoface, called the Ryuge sand and gravel of the Ikadachi Formation, was deposited. The lithofacies indicates that elevation of the present Hira and Hiei Mountains became active on the west side of the lake (Hayashi, 1974). During the Middle to

Late Pleistocene, activities of the faults along the lake coast became higher, generating the deep bottom plain of the lake (Itihara, 1982). The open and deep offshore habitat and the littoral rocky habitat were newly formed by such activities. On the appearance of such habitats, the endemic fish species had speciated to utilize and exploit respective habitats. Such series of sediments constitute the Ikadachi (or Biwako) Formation.

11. 4 Succession of cyprinid fauna in Paleo-lake Biwa

Paleo-lake Biwa formed about four million years ago. The history from the formation of Paleo-lake Biwa to the present Lake Biwa is divided into the following stages: Paleo-lake Ohyamada, the first fluvial stage, Paleo-lake Ayama, Paleo-lake Koka, Paleo-lake Gamo, the second fluvial stage, Paleo-lake Katata, and Lake Biwa. There was a change in the cyprinid fauna at each stage.

As mentioned previously, the Iga Cyprinid Fauna found in the Ueno Formation, in the deposits of Paleo-lake Ohyamada, consist of six subfamilies. Cyprinines were dominant, followed by xenocypridines and cultrines. Fossil common carps of the genus *Cyprinus* occupy 65 % of the total fossil teeth of cyprinids, indicating that the common carps flourished in Paleo-lake Ohyamada (Nakajima, 1986b).

The fossil molluscs from the Ueno Formation were dominated by viviparid gastropods, eg. *Igaparludina stricta* and *Bellamya suzukii* (Matsuoka, 1987). Because fossil diatoms are abundant, the diatom productivity of Paleo-lake Ohyamada is inferred to have been fairly high (Tanaka et al., 1984). The diatom flora probably supported the xenocypridines in the lake. Abundance of viviparid gastropods suggests rich littoral flora of submerged plants and benthic and epiphetic diatoms. The rich benthic community may have supported the most dominant fishes, the common carps, which are typically benthivorous.

The fossil molluscans from the Ayama and Koka Formations became poorer. The littoral molluscs, *Igapaludina, Tulotomoides* and *Inversidens,* were low in diversity. The profundal molluscan association containing *Anodonta* (*Plesioanodonta*) *matajiroi* predominated (Matsuoka, 1987). Characteristics of the diatom flora as well as the molluscan fauna of the Ayama and Koka Formations indicate that the lake was oligotrophic to mesotrophic with a wide profundal zone and a narrow littoral zone. Further, the species complex of *Aulacoseira praeislandica* dominate over other species in the Ayama Formation, whereas *Aulacoseira solida* predominates in the Koka Formation. The change in the diatom composition reflects the change in the aquatic environment of the lake from Paleo-lake Ayama to Koka. Probably the lake became remarkably deeper (Tanaka and Matsuoka, 1985). Fossil cyprinids from the Ayama and Koka Formations were also fewer than those from the Ueno Formation. They consist of only three subfamilies, cyprinines, cultrines and xenocypridines (Yasuno, 1983; Nakajima, 1986b). Nearly all fossil teeth from the Koka Formation belong to the crucian carp, *Carassius*, which seems to have dwelled in the upper zone of the offshore waters and to have been a plankton feeder (eg., *C. cuvieri*) adapted for oligotrophic open water in present Lake Biwa.

The cyprinid fauna in Paleo-lake Gamo was slightly richer than that of Paleo-lakes Koka and Ayama. It consisted of three subfamilies, cyprinines, xenocypridines and rhodines. The genus *Carassius* decreased in the composition of the fossil assemblage (Nakajima , 1986b). Among the fossil diatom *Melosira undulata* is the dominant species in the lower part of the Gamo Formation, but no fossil diatoms are found in the upper part of the Gamo Formation (Tanaka & Matsuoka, 1986). The fossil molluscs of the Gamo Formation are quite different from those in the previous formations at the species level. Articulated and thickened bivalves occupy a large part of the fossil molluscans. They inhabited streams rather than lakes (Matsuoka, 1987). Many fossil wood beds are intercalated in the upper part of the Gamo Formation. These findings indicate unstable shallow waters of swamps in the later stage of Paleo-lake Gamo.

In the Katata Formation, the diatom fossils are represented by the *Fragilaria-Gomphonema-Cymbella-Achnanthes* assemblage, whose composition did not change through the formation. The diatom assemblage predominated by these benthic species suggested that Paleo-lake Katata presumably was not a stable lake (Research Group for Natural History of Lake Biwa, 1986). Paleo-lake Katata was a small and shallow lake and located in the Katata area on the southwest coast of present Lake Biwa. Some of the present endemic molluscan species first appeared at the early stage of Paleo-lake Katata. They are *Heterogen longispira* and *Unio* (*Nodularia*) *biwae*. In the upper part of the Katata Formation, the fossil molluscs increased in abundance and variety, and many present endemic species appeared (Matsuoka, 1987). This faunal change may indicate that the lake gradually became an open lake at the later stage of Paleo-lake Katata. The cyprinid fauna of Paleo-lake Katata was richest second to that of Paleo-lake Ohyamada. They consisted of cyprinines, xeno- cypridines, cultrines, leuciscines and gobionines. Most of the teeth are of extinct species, but the teeth which seem to be of ancestral forms of the endemic species, *Ischikauia steenackeri* and *Carassius cuvieri*, are found from the upper part of the Katata Formation (Research Group for Natural History of Lake Biwa, 1986).

11.5 Appearance of the endemic species and extinction of old elements of Iga Cyprinid Fauna

Three taxa of the crusian carps, *Carassius cuvieri, C. auratus grandoculis* and *C. auratus langsdorfii*, inhabit present Lake Biwa. The first two are endemic to Lake Biwa and their food habits and habitats are different from each other. The pharyngeal teeth differ, reflecting respective food habits. The pharyngeal teeth of *C. cuvieri* are remarkably distinctive. Their enameloid layer is thinnest among the three species, and the dentine is composed of two layers, the outer orthodentine and the inner vasodentine. The interglobular dentine is developed in the outer part of dentine. The structure of pharyngeal teeth in *C. cuvieri* is adaptive for phytoplankton feeding (Kodera, 1985).

In the fossil teeth from the most upper part of the Katata Formation, the vasodentine is not seen, but the enameloid layer is very thin and the interglobular dentine widely occupies the central part of the dentine layer (Kodera, 1985). The fossil teeth of the Katata Formation represent a pre-stage of those in *C. cuvieri*. Probably, *C. cuvieri* speciated from this ancestral form in modern Lake Biwa.

The environments of modern Lake Biwa with an open and deep off-shore and rocky shore, are utilized by most of the present endemic fishes (e.g. *Gnathopogon caerulescens, Carassius cuvieri, Carassius auratus grandoculis*, and so on). These species were not in Paleo-lake Katata. In the lowest part of the Ikadachi Formation, the Ryuge sands and gravels, the change of the lithofacies indicates that the elevation of the Hira and Hiei mountains was acutialized (Hayashi, 1974). The faults along the coast of the lake were active, and the deep bottom plain of the lake was formed during the Middle to Late Pleistocene (Itihara, 1982). The lake became deeper and larger, and the northern part of Lake Biwa was formed after sedimentation of the Katata Formation about four hundred thousand years ago. Most of the endemic fishes speciated in the lake when it became large and developed open and deep offshore environments.

Xenocypridines and cultrines were major elements of the cyprinid fauna in Paleo-lake Biwa and are flourishing in China at present. However, they are extinct in the Japanese Islands except for *Ischikauia steenackeri*. Why have they become extinct?

Xenocypridines are bottom dwellers in large calm rivers, and shallow large lakes, and feed mainly on attached algae with horny lips and specialized pharyngeal teeth (Yang, 1964). The Japanese osmerid "ayu fish", *Plecoglossus altivelis,* is amphidromus and adapted to torrential rivers in the Japanese Islands where they also feed on attached algae. The ayu fish, of which an ancestral form was found from the Miocene sediment (Tomoda, 1985), seem to have evolved during the Pliocene to the Pleistocene in the Japanese Islands. Thus, the ayu fish or its ancestral form coexisted with xenocypridines from the Miocene to the Pleistocene.

In the Pleistocene, the mountains were rapidly uplifted and the basins were subsided in the Pleistocene by the Island Arc Movement (Fujita, 1973). Thereby, rivers became torrential, and large lakes disappeared except for Lake Biwa. Consequently, the freshwater bodies in the Japanese Islands became unsuitable for the xenocypridines. Moreover, Lake Biwa became deep in the Middle to Late Pleistocene (Itihara, 1982), and the landlocked population of the ayu fish flourished in Lake Biwa (Kawanabe, 1976). They competed with the xenocypridines for food. Furthermore, attached algae decreased in production during the glacial age (Kawanabe, 1976). The xenocypridines in Japan seem to have become extinct due to disappearance of shallow and large lakes, birth of torrential rivers and decrease in algal production in the Middle to Late Pleistocene. Most cultrines fishes are also adapted to large calm rivers and large shallow lakes. Extinction of the cultrines also seems to be closely related to the tectonic movements in the Japanese Islands during the Pleistocene. The environments of Lake Biwa with an open and deep offshore and rocky shore, utilized by most of the endemic fishes, were also formed by this tectonic movement. From these, it is concluded that the speciation of endemic species in Lake Biwa and the extinction of the major elements of the Iga Cyprinid Fauna such as xenocypridines and cultrines have occurred only recently in the history of Lake Biwa.

11. 6 Fish remains from archeological sites

A part of them, however, survived in Lake Biwa with mankind in the Jomon Period. Their tooth remains occurred in Jomon Shell-mounds as the evidence (Nakajima et al., 1996, 1998; Nakajima, 1997). Why have they become extinct by now? Did the Jomon People eat them up? We suppose that the Jomon People did not have advanced fishing techniques.

The xenocypridines and cultrines, which survived in the Jomon Period and have become extinct now, were not able to inhabit the offshore of deep lake and were littoral zone dwellers. People who settled around Lake Biwa became involved in the lake gradually and changed the coastal environments of Lake Biwa after the Jomon Period. The people began to cultivate rice in paddy fields in wetlands around the lake in the Yayoi Period, 4th century BC to 3rd century AD. The expanse of paddy fields around the lake seems have to been profitable for fish in the lake, because many spawning sites were formed in the rainy reason. Artificial Environmental change of the lake shore may have been mortal rather than beneficial for relict fish which have decreased in population.

These extinct fish which had withstood drastic environmental changes in the lake during the Middle to Late Pleistocene, met mankind in the Jomon Period and have become extinct by the present. Recently, an extinct fish except for xenocypridines and cultrines occurred in another archeological site also. We suppose that human activity led to the extinction of many littoral fish of Lake Biwa.

11. 7 Conclusion

The fossil data lead to the following conclusion. The new elements, xenocypridines and cultrines evolved in the large rift valley lakes formed at the eastern margin of the Asiatic Continent during the late Paleogene to Early Miocene. The new cyprinids spread from the marginal to the inner parts of the continent. The Miocene cyprinid fauna kept on surviving in Southwest Japan, and their descendants inhabited Paleo-lake Biwa. Xenocypridines and cultrines were major elements of the cyprinid fauna in Paleo-lake Biwa. But they have become extinct with the drastic change of the environments, which was brought by the tectonic movements during the Pleistocene, by which Lake Biwa became large and developed the open and deep off-shore environments. According to such Environmental change, endemic fishes speciated in Lake Biwa. Speciation of the endemic fishes in Lake Biwa and extinction of xenocypridines and cultrines in the Japanese Islands have occurred only recently in the history of Lake Biwa. Some of them survived in recent Lake Biwa and became extinct with the influence of human activities.

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Chapter 12

Current technology in limnology (3) Algal species classification by image processing

Ross F. Walker

In the following work we describe the application of image processing and pattern recognition techniques to the area of cyanobacteria detection and classification. Specifically, we target the species *Microcystis* sp. for detection and classification from among several other cyanobacteria species endemic to Lake Biwa: *Anabaena flos-aquae, A. smithii, A. planctonica,* and *A. ucrainica.* High-resolution microscope images containing a mix of the above species and other non-algal objects are analysed, and any detected objects are removed from the image for further analysis. Following image enhancement, object properties are measured and compared to a previously compiled database of species characteristics. Classification of an object as belonging to class membership '*Microcystis*' or '*other*' is performed using parametric statistical methods. Leave-One-Out classification results suggest an error rate of approximately 2.3%.

12.1 Introduction

The increasing occurrence of algal bloom contamination in both lakes and sea serves as a worrying indicator of increasing environmental stress on water ecosystems. Such blooms have the potential to become a serious issue in terms of a government's ability to supply drinking water that meets national health standards, not to mention the devastating effects such blooms can have on the environment. Lake Biwa, Japan's largest lake and source of drinking water for over 14 million people, has experienced such blooms with increasing frequency over the last decade (Kumagai 1996).

The majority of these blooms are caused by three endemic species of cyanobacteria - *Microcystis* sp., *Anabaena* sp., and *Planktothrix* sp.

Monitoring of water supplies (for the presence or absence of targeted species) usually involves the manual analysis of water samples by trained experts - a very time-consuming and, therefore, expensive operation. Recent advancements in computer performance and image analysis now allow the possibility of assisted or 'adjunct' screening of water samples by image processing and pattern recognition systems. However, this area of research has seen minimal progress over the last decade, with very little published literature. Apart from Thiel 1994, there appears to be no other major published works on this subject, and very few active researchers working on this significant problem.

In this correspondence, we detail the implementation and evaluation of an image processing system for automatically detecting and classifying cyanobacteria taxa, and report classification results. We firstly introduce the topic of cyanobacteria image analysis and discuss several problems that make such analysis inherently difficult. We then discuss the hardware, software, and general image processing methodology that has resulted from the approximately one-year life of this project. Finally, we present the significant results of our research and discuss relevant points that need further investigation.

12. 2 Cyanobacteria Image Analysis

While being very similar to other forms of image analysis, cyanobacteria classification presents the image analyst with its own inherent difficulties. For example, the types and numbers of objects (bacteria, zooplankton, debris etc.) that may be present in any one sample of lake water is both unknown and effectively unlimited. Also, intra-species variation of characteristics (such as size and colony shape) can be large, and is often seasonally dependent. Furthermore, the bulk size of two targeted species may be an order of magnitude or more apart, making decisions such as image magnification setting a difficult choice. The dynamic and variable nature of the lake microcosm thus creates a formidable challenge to the design of a robust pattern recognition (P.R.) system with the ideal characteristics of high accuracy but with wide generalisation ability

The work we present here is the second stage of a preliminary study originally published in Walker, Tsujimura, Kumagai, 1998. The image processing system has been totally re-designed and built from scratch, and following training, can now operate completely autonomously. Figure 2 shows the system, consisting of purpose-built light microscope with water sample feed system, high-resolution digital imaging camera, image server computer, and several image processing computers. Sample water is passed as a continuous stream under the microscope's objective. Digital images of this water are sequentially captured by the image server, which then transfers each image to an available image processing computer. Objects contained within any image are analysed, and the analysis results returned to the server for display - see Figure 1.

For the purposes of this study, we classified image objects as being either from the class '*Microcystis*' or from the class '*other*'[1]. By the class '*other*' we mean all image objects that are not from the genus *Microcystis*. Such objects include other cyanobacteria species such as *Anabaena*, zooplankton, weed, sediment, air bubbles, etc.

12. 2. 1 System Hardware

Imaging hardware consists of a custom-built optical microscope, high-resolution greyscale digital camera, and digital frame grabber - see Figure 2. Image magnification and focus are controlled via a single remote x-y joystick. However, once appropriate magnification is chosen, it is not varied. Sample water is passed through a water channel cell. This was manufactured with a channel depth of 0.8 mm, to allow for large objects to flow through the cell channel without clogging. However, at the magnification used, focal depth of the microscope optics was approximately 0.2 mm. As we have no control over where in the 0.8 mm channel depth objects will appear, poorly focused objects can and do occur. We handle this problem by measuring focal over

[1] In previous research presented in Walker, Tsujimura, Kumagai, 1998, we classified two geneses comprising of six species of cyanobacteria, using a hierarchical classification system.

where in the 0.8 mm channel depth objects will appear, poorly focused objects can and do occur. We handle this problem by measuring focal accuracy of each image object prior to processing, and only classifying those objects with adequate focus. We chose to image the lower 0.2 mm of the 0.8 mm channel depth, as gravity helps to shift floating objects to this level.

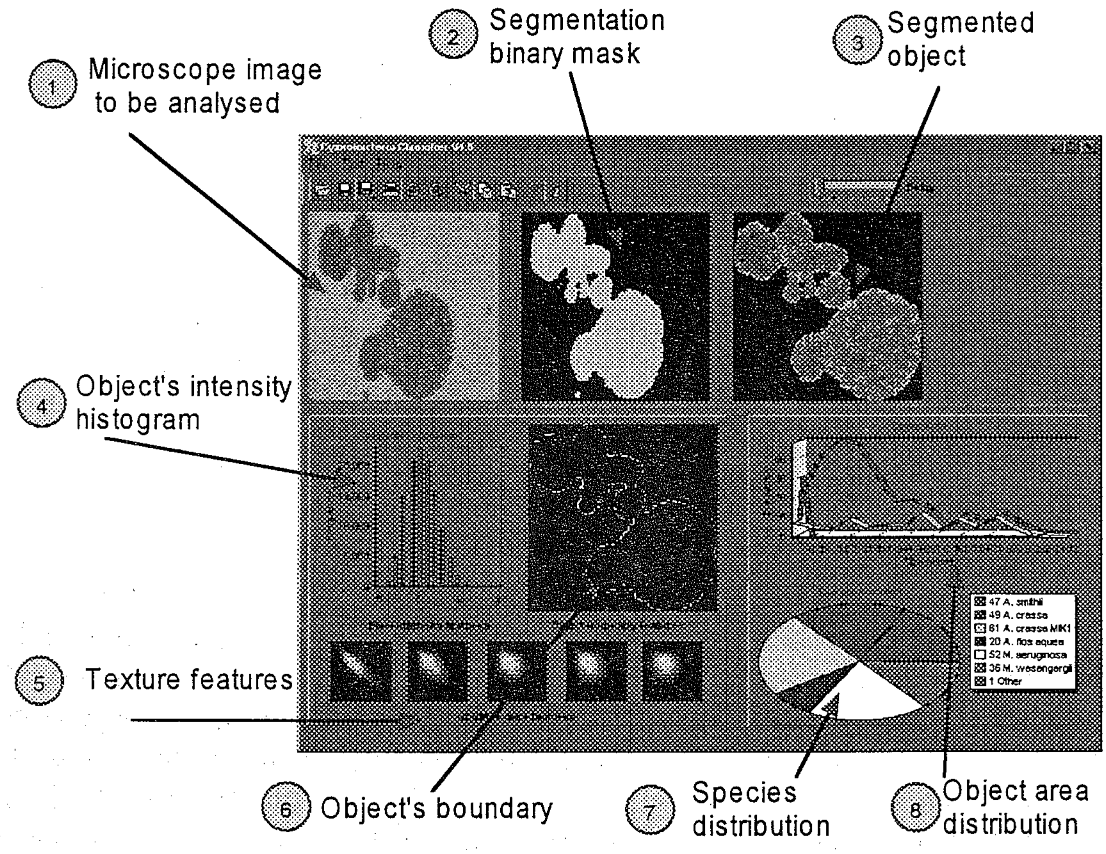

Figure 1 – The image analysis process. (1) Microscope image of water sample is transferred to computer for analysis; (2) Segmentation mask is determined; (3) Object to be classified is removed from the surround- ing image background; (4-6) object characteristics are quantitatively measured; (7) Relative distribution of species numbers found in the water sample; (8) Distribution of object areas.

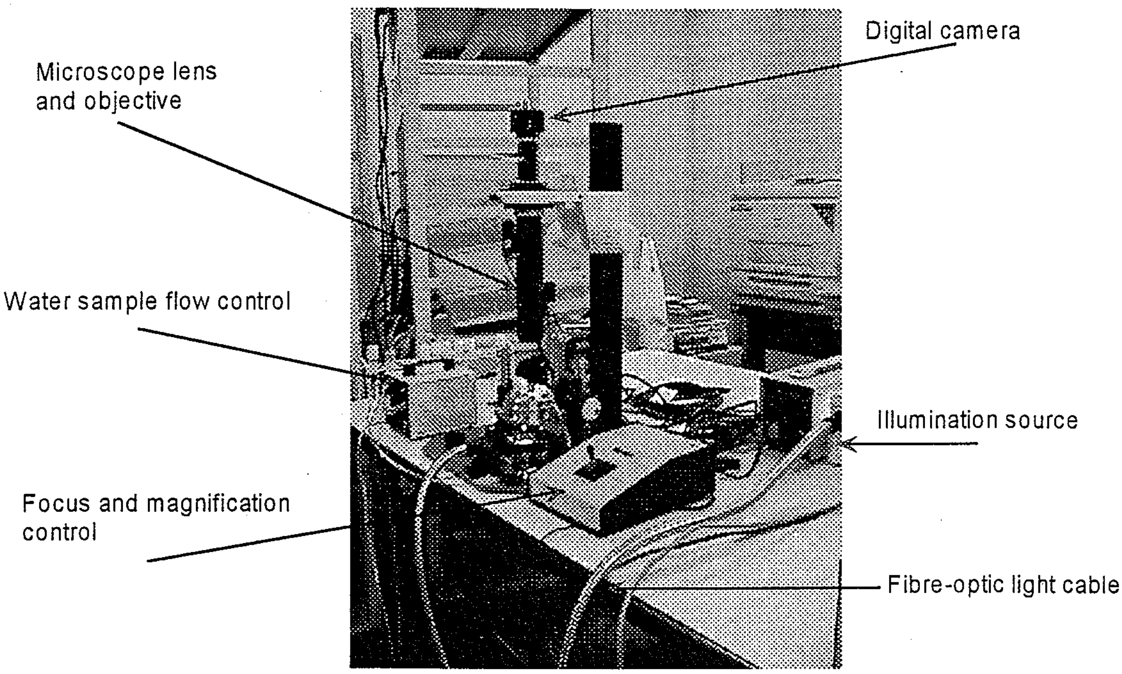

Figure 2 – Microscope and high-resolution digital imaging system.

12. 2. 2 Image Processing Methodology

12 .2. 2-1 Non-uniform illumination correction

Digital images received for analysis are pre-processed to reduce the effects of non-uniform illumination. Such an undesirable characteristic, which represents a non-linear transformation of the true image data, can present a severe challenge to subsequent image processing algorithms such as segmentation. In the present system, non-uniform illumination is crudely corrected by cropping the image borders. However, in a soon to be implemented step, the microscope's illumination transfer function will be measured and used to correct the images. Figure 3 shows the illumination response of the microscope currently in use.

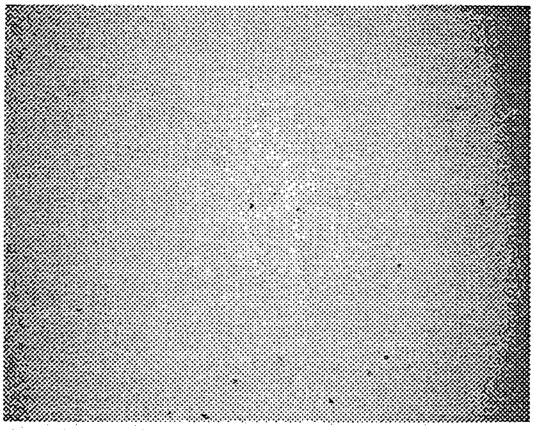

Figure 3 – Illumination response of the microscope (in false colour). Notice the strong non-uniform characteristic that can lead to classification inaccuracies if not corrected.

12. 2. 2-2 Object segmentation

Objects within each image are separated from the image background via the process called *segmentation*. By *object*, we mean any body (group of image pixels) that appears darker than the image background. This can include cyanobacteria, as well as dirt, non-bacteria species, weed, etc. We achieve segmentation by forming a binary segmentation *mask*, and overlaying this mask on the original greyscale image. Areas of the image that show through the mask (the objects) are then removed from the image and processed.

Initially, a rough mask is formed by a simple thresholding of the image at an intensity level determined by the intensity statistics of the image. This mask is then further processed to remove small imaging 'noise' particles or other objects smaller in size than the minimum expected size of the targeted cyanobacteria species. Finally, mask edge pixels are smoothed to form more uniform object boundaries. These steps are performed via morphological image processing algorithms based on mathematical morphology (Serra 1982, Vincent & Beucher, 1989). Figure 4 details the segmentation of a typical water sample image.

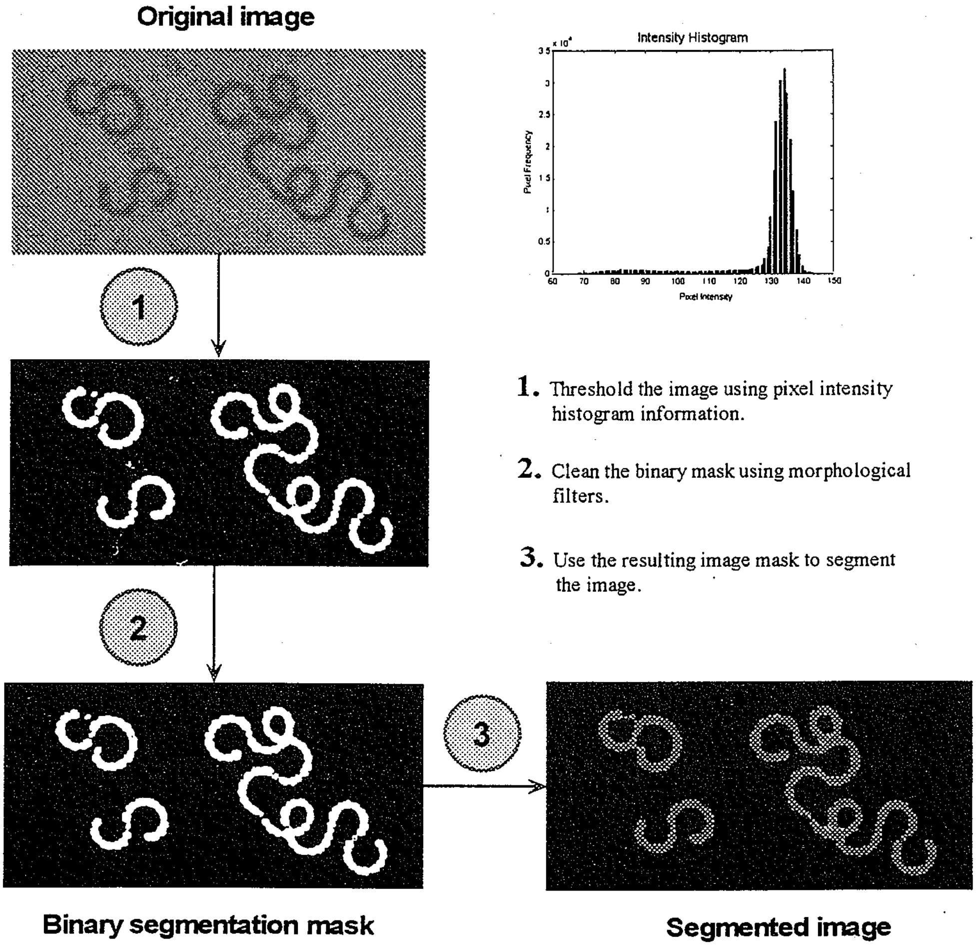

Figure 4 – Segmentation of a typical water sample image.

12. 2. 2-3 Focus check

Segmented objects are individually checked to ensure they possess an adequate level of focus. This step is vitally important. Because the water source is a 3-dimmensional column, there is no control over whether an object will fall within the in-focus portion of the microscope's view. As a consequence, there can be great variability in the focal accuracy of objects appearing in the microscope's field of view. Objects with adequate focus are subsequently processed and classified. Objects that do not achieve a minimum average focus limit are analysed to measure simple characteristics such as area and shape, but are not subsequently classified. This is because the defocus effect adversely influences many of the statistical properties of the image, and thus may have a strong negative influence on classification accuracy.

Focal quality is measured by isolating the middle to high spatial frequency components of the object image, and averaging the remaining power spectrum across one image dimension (Oliva, Bravo-Zanoguera & Price, 1998),

$$F(I) = \sum_i \sum_j \left(h(i) \otimes I(i,j)\right)^2 / \left(\sum_i \sum_j I(i,j) / A\right)^2 , \qquad (1)$$

where $F(I)$ is the focal quality measure for greyscale image I of spatial domain $A = i_{\max} \times j_{\max}$ pixels, and $h(i)$ is the spatial domain response of the 1-D high-pass filter kernel. This is a widely used technique and is computationally light.

Image objects of adequate focal quality and exceeding minimum size requirements are sequentially extracted from the image for further processing.

12. 2. 2-4 Object feature extraction

To accurately classify an object into one of several classes, i.e., *Microcystis, Anabaena,* etc., it is necessary to quantitatively measure characteristics of the object that may indicate its class membership. For example, the characteristic 'area' is a good discriminator of class membership when classifying *Microcystis* and *Anabaena* cyanobacteria, as these two geneses differ substantially in size - *Microcystis* usually being an order of magnitude larger in area. In pattern recognition terms, we call these characteristics *'features'*, and the process of measuring an object's characteristics as *'feature extraction'*. We measure a total of 123 object features including morphometric properties, object boundary shape properties, frequency domain properties, and second-order statistical properties (see Table 1).

Table 1 – Types of features extracted from each image object.

Feature type	Examples	Number measured
Morphometric	area, circularity	4
Boundary shape	curvature properties	5
Frequency domain	Fourier components of boundary	14
Second-order statistical properties	Grey level co-occurrence matrix features	100

12. 2. 2-5 Feature selection

Without a-priori knowledge, it is difficult to know which of the 123 object features will be useful for distinguishing between cyanobacteria species. By the term 'useful' we mean features whose statistical properties (mean and variance/co-variance etc.) differ between the various classes of data we are trying to classify. We call such features 'discriminatory', in that they can be used to discriminate between classes of data (see Figure 6).

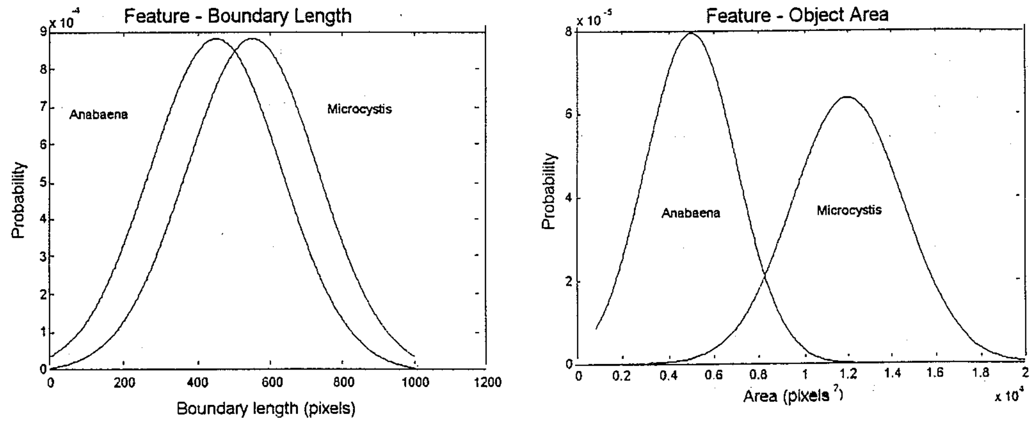

Figure 5 – An example that illustrates discriminatory power. The feature on the left possesses low discriminatory power, while the one on the right possesses high discriminatory power. Features whose class-conditioned distributions overlap the least will have greater discriminatory power.

Selecting a subset of discriminatory features from a larger set is called 'feature selection'. The process is arguably one of the most important steps in pattern recognition. Generally, there will exist a high dimensional feature space, with a limited number of data samples to accurately characterise the class distributions within this space. By removing redundant features that do not discriminate between classes, we can better represent this now lower-dimensional space, allowing us to design a more robust classifier.

To find an optimal feature subset, we used a feature selection process called sequential forward-selection/backward-elimination (Hand, 1981). Specifically, our algorithm adds two new features and then removes one feature, thus capturing feature pairs that possess higher-order discriminatory power. Kittler 1978 reported that this method almost always gave optimal results and computationally was comparable to less optimal approaches. Using this method, we found that a total of five features from the original set of 123 possessed significant discriminatory power to classify the object data as being either from the classes *Microcystis* or *Other*.

12. 2. 2-6 Classification

We performed classification using a general Bayes decision function for assumed Gaussian feature distributions with unequal variance-covariance matrices (Gonzalez and Woods, 1993). The resulting decision surface (where $d_1 = d_2$) is of hyperquadric form:

$$d_i(\mathbf{x}) = \log P_{\omega_i} - \frac{1}{2}\log|\mathrm{C}_i| - \frac{1}{2}\left[(\mathbf{x}-\bar{\mathbf{x}}_i)'\mathrm{C}_i^{-1}(\mathbf{x}-\bar{\mathbf{x}}_i)\right] \quad d = \{1,2\}, \tag{2}$$

where $\mathbf{x}$ is the feature vector of the object to be classified, $d_i(\mathbf{x})$ represents the discriminant measure for $\mathbf{x}$, P_{ω_i} is the a-priori probability of class ω_i, and C_i and $\bar{\mathbf{x}}_i$ are the variance-covariance matrix and mean vector respectively for class i data (determined from a database of objects from known class). Because we are only classifying image objects into 2 classes – *Microcystis* or *other* – only one classification stage is required. Our previous work (Walker, Tsujimura, & Kumagai, 1998) has shown that the extension to classifying multiple species is both straightforward and relatively accurate when abundant images of high quality are used.

12. 3 Results

12. 3. 1 Classification Results

A total of 1529 image objects were extracted from among the 1468 images of the five cyanobacteria species. Of these, 1348 were found to have adequate focus and were subsequently classified into the two classes of *Microcystis* or *Other.*

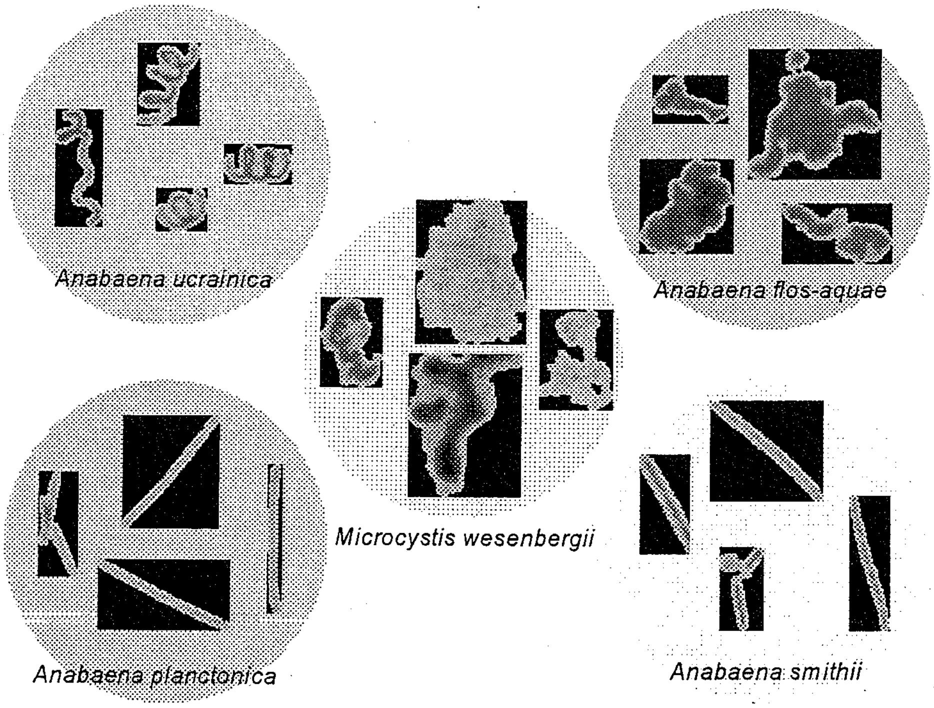

Figure 6 – Examples of individual cyanobacteria that were extracted from high-resolution images, captured using the hardware described in this document.

Table 2 is a confusion matrix of general classification results, where the class '*Other*' has been separated into its four constituent species. Total real error was measured to be 2.3% using the leave-one-out technique (Weiss & Kulikowski, 1991). We notice that the species *A. flos-aquae* has a higher rate of misclassification than the remaining classes. We suspect this is because *A. flos-aquae,* while being of spiral shape like *A. planctonica,* forms itself in very tight, condensed spirals - see Figure 6.

As a result, the physical shapes of some *A. flos-aquae* specimens had attributes similar to the dense colonies of *Microcystis,* and were subsequently misclassified. However, the 9 misclassified samples represents an error rate of only 2.7%, which we feel is sufficiently low.

Table 2 – Confusion matrix of classification results, showing species-specific results.

	Classified as Species:	
Species	***Microcystis***	***Other***
M. wesenbergii	247	19
A. flos-aquae	9	322
A. planctonica	0	102
A. smithii	2	336
A. ucrainica	1	310

12. 4 Discussion and Conclusions

The work presented in this correspondence represents the latest phase of research that began in early 1998, and was documented in two publications (Walker, Tsujimura, & Kumagai, 1998-1; Walker, Tsujimura, & Kumagai, 1998-2). The initial intent of this research was to determine whether it was feasible to automatically classify cyanobacteria species contained in lake water samples, using image processing and pattern recognition techniques. If proven successful, such a system could be used to augment work currently done by trained bacteria experts, with significant benefits:

- Automatic classification can reduce the tedium and fatigue associated with manual classification;
- The amount of time required to analyze a sample of water can be significantly reduced;
- The expense involved in the purchase of an image processing system is offset by the significant reduction in labour costs associated with manual classification. In fact, we feel that using such a system will result in considerable cost reductions within several years (or equivalently, higher productivity);
- The flexibility of such a system allows for targeted species to be changed (increased or decreased) at will.
- Because species are classified using quantitative measures of object characteristics (as opposed to the subjective, qualitative nature of manual classification by trained experts), the system facilitates research by allowing the easy compilation of cyanobacteria characteristics into a database.

A number of questions remain to be answered by future research. Firstly, the bacteria samples used throughout this work were laboratory specimens. This was necessary due to the lack of available natural (lake) species at the times when image databases were compiled. As such, the intra-species variability which exists in lake species did not exist in the lab specimens. Moreover, the range of possible non-targeted species (zoo-plankton, weed, sediment, etc.) is far greater in the lake environment. As such, we need to stress that the results presented in this report are optimistic, and will without doubt degrade when natural lake water samples are used. The extent to which the results degrade will be the focus of our continuing research. We are looking forward to the summer months when most cyanobacteria species will be in abundance.

Despite the above reservations, we feel that the significantly low error rates reported in this and previous reports indicates that the automatic classification of cyanobacteria is indeed a feasible and relatively accurate alternative to manual classification.

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Supplementary Lecture

Misunderstanding of slow sand filtration in Japan and the biological mechanism of its system

Nobutada Nakamoto

We had a custom of drinking raw water. Recently, problems like odor problem, trihalomethane production, parasites etc. have been appeared in tap water. These problems have been reported in the area where is supplied by the modern system of rapid sand filtration. After the trihalomethane problem in USA, in 1974, safe treatment system has been sought. The refocusing on the timeless technology of slow sand filter has been started.

Slow sand filtration system for drinking water was completed in 1829 in London. This system was a safe treatment for pathogenic bacteria and parasite. However this system has a weak point against turbid water. In 1882, rapid sand filtration using coagulant was developed in USA. And the filtrate was disinfected by chlorine gas in 1910. People loved this new technology to make a safe drinking water to pathogenic bacteria. This chlorine treatment had been popular and it was trusted to every people. After the famous consumer report on trihalomethane in tap water and cancer in United States of America in 1974, a safe treatment for drinking water has been searched. In 1980's the slow sand filtration was refocused and massive people attacked with diarrhea was reported. It was caused by the contaminated tap water of the pathogenic protozoa of *Cryptosporidium* and *Giardia*. The oocyst of the pathogenic protozoa was tolerant to chlorine treatment. The old technology of slow sand filtration as a safe treatment was rediscovered.

Odor problem of tap water occurred in Ueda city, Japan in 1970's.

Ueda city(120 thousands inhabitants) was supplied by the treatment of slow sand filtration. However, at that time, the raw water was pretreated by chlorineas an algaecide. The algal bloom in the filter pond was disliked. After the trihalomethane problem, the pretreatment of chlorine was stopped. Odor problem was disappeared and the filter clogging became better. However, a bloom of filamentous algae in a filter pond has been observed and the filter became a continuous culture system of filamentous algae. Filamentous algae act as an oxygen supplier, an eliminator of suspended matter and a nutrient absorber. The filtrate was clean water like as underground water. The water contains low nutrient similar to the upper mountainous stream.

Slow sand filtration system was recognized as a biological treatment system. It must be under suitable condition for all organisms. The application of coagulant for the turbid water was misunderstood and the pre-chlorination to the intake water was also a misunderstand treatment. Sudden change of water quality and toxic chemicals into the raw water were unsuitable treatment for this biological system. At the present time, the timeless technology of slow sand filtration for modern application has been refocused to distribute the safe, reliable and delicious drinking water.

Excursion of Japan north Alps lakes (Lake Aoki, Lake Nakatuna and Lake Kizaki) and Kurobe Reservoir

Conducted by Prof. Hidetake Hayashi and assisted by Prof. Nobutada Nakamoto

The aim of this excursion is to show the most well studied lakes in the history of Japanese Limnology. These lakes are Japan North Alps Lakes (Lake Aoki, Lake Nakatuna and Lake Kizaki). Akamaro Tanaka surveyed on these lakes during 20 years from 1907 to 1928. After Tanaka, many limnologists studied on the phenomena in these lakes. Hayashi is a research leader of Shinshu University in recent 20 years. Recent change of fauna and flora was reported at the Kizaki Field Station of the branch of Suwa Hydrobiological Station, Shinshu University.

Fresh water red tide by *Peridinium* bloom was caused in recent year. *Anabaena* bloom and the occurrence of its grazer of protozoa was reported. Wax and wane of *Elodea* (water weed) and the related phenomena was also reported. Artificial change of water level at Lake Aoki was reported. This change was caused by an electric power station that related directly with an aluminum industry. Littoral vegetation was disappeared by this artificial water level change. The activity of the group of Shinshu University trying to recover the natural vegetation was reported. We visited Kurobe reservoir that is the biggest and the highest reservoir among Japanese Alps. The history of this reservoir for an electric power station was reported. We discussed the natural phenomena and the human impact in the field of lakes and reservoirs.

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Part Ⅱ

Field Studies on

Chap.13 Lake Suwa

&

Chap.14 Lake Biwa

Chapter 13

Lake Suwa

Takayuki Hanazato, Tokio Okino and Kenji Kato

13. 1 Physical and chemical measurements

13.1.1 Temperature

The greatest source of heat in lake water is solar irradiance by direct absorption, thus the heat is, in general, given from water surface. This often makes a complicated gradient in vertical profile of temperature in the lake water. To know this profile is important because temperature is an essential factor controlling activity, distribution and life cycle of organisms.

Vertical profile of temperature is measured with a thermistor electrical thermometer (Fig. 1).

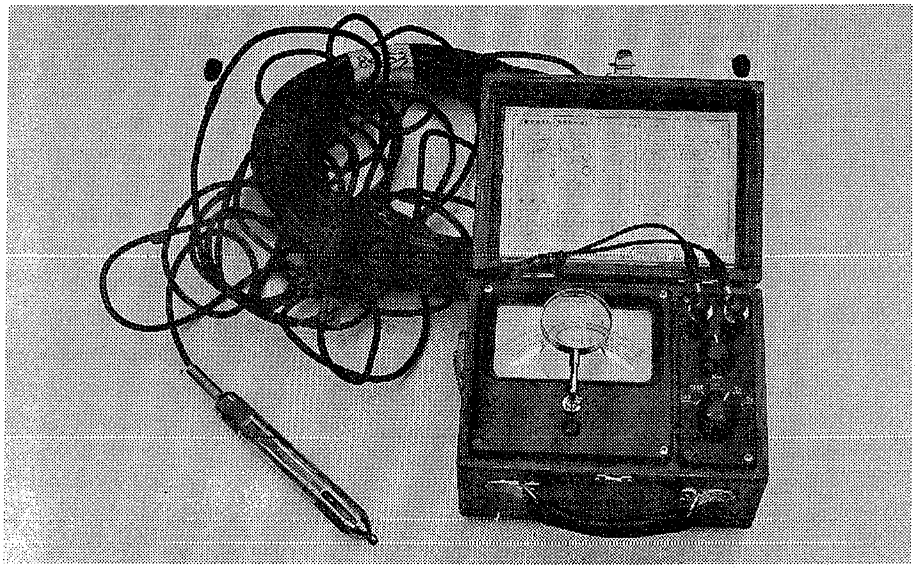

Fig. 1 Thermistor electrical thermometer (Toho Dentan Model ET-5)

13.1.2 Dissolved oxygen

Dissolved oxygen concentration (DO) is also an important factor affecting activity and distribution of aquatic heterotrophic organisms. The concentration in water varies largely from far above the saturation level to zero depending on the water bodies; e.g., in eutrophic lakes, the DO exceeds the saturation level in epilimnion while anoxic zone develops in hypolimnion and littoral vegetation area. The oxygen in water is supplied from atmosphere and is produced by aquatic plants through the photosynthesis process.

On the other hand, oxygen is consumed by organic respiration. Consequently, the dissolved oxygen concentration in water is determined mostly under a balance between the production and consumption. That is, it depends strongly on biological factors. In recent times, major advances have occurred in the development and application of oxygen sensitive electrodes for the rapid and sensitive measurement of dissolved oxygen, and therefore the oxygen electrodes (Fig.2) are commonly used for the field measurement.

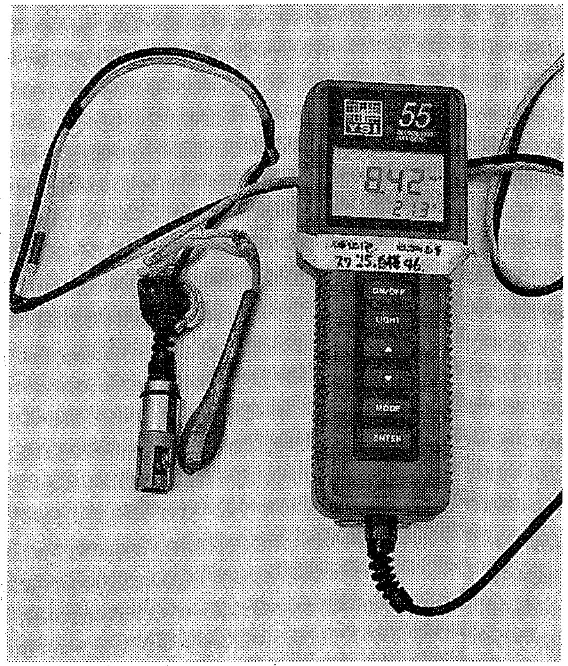

Fig. 2 Dissolved oxygen meter (YSI Model 55).

13.1.3 pH

pH is an important chemical factor in lake water. It changes according to biological activities such as photosynthesis and respiration, which alter the equilibrium of carbonate, bicarbonate and carbon dioxide. pH affects largely the organic community in lakes. Many aquatic organisms are intolerant to low pH (< 5), while some other organisms are sometimes killed by high pH (> 10) achieved by intensive photosynthesis of blooming algae.

The measurement is easily done with electrodes (Fig. 3).

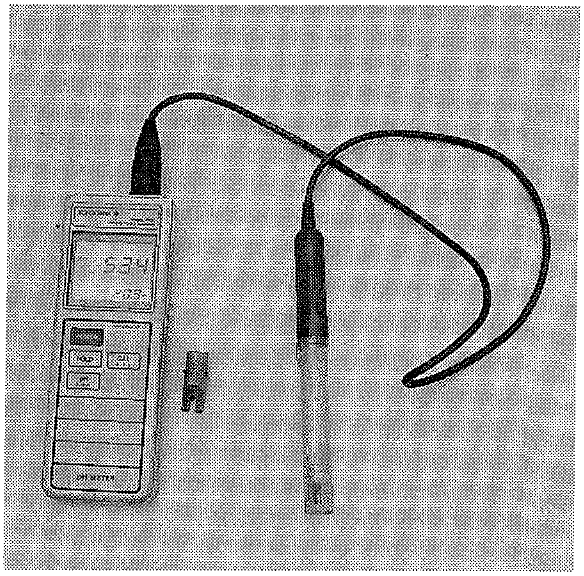

Fig. 3 pH meter
(Yokogawa Model PH81).

13.1.4 Solar irradiance underwater

Autotrophic organisms composed mostly of algae (phytoplankton) in lake water require solar irradiance with a spectral range between 400 and 700 nm to make photosynthesis. These primary producers are basically important organisms supporting production of lake ecosystems.

Intensity of solar irradiance underwater, which is measured with an irradiance meter (Fig. 4),depends much on the water turbidity and decreases with increasing water depth with an attenuation coefficient K.

$$K = ln(I1/I2)/(z2\text{-}z1)$$

Where, In = solar irradiance at water depth of zn.

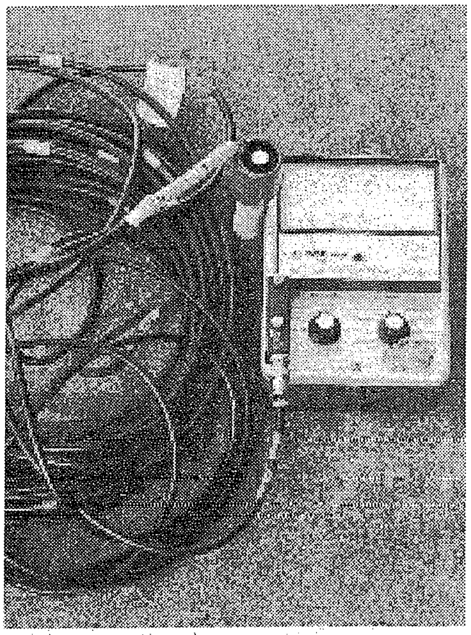

Fig. 4 Solar irradiance meter
(LI-COR Model LI-185B
Light meter).

13.1.5 Secci disc transparency

Although the attenuation coefficient is commonly measured with the irradiance meter, an approximate evaluation of transparency of water can be made with Secci disc, which is a weighted white disc with 30 cm in diameter (Fig. 5). The Secci disc transparency is the mean of the depths at which the Secci disc disap-pears when viewed from the shaded side of the boat and at which it reappears upon raising after it has been lowered beyond visibility.

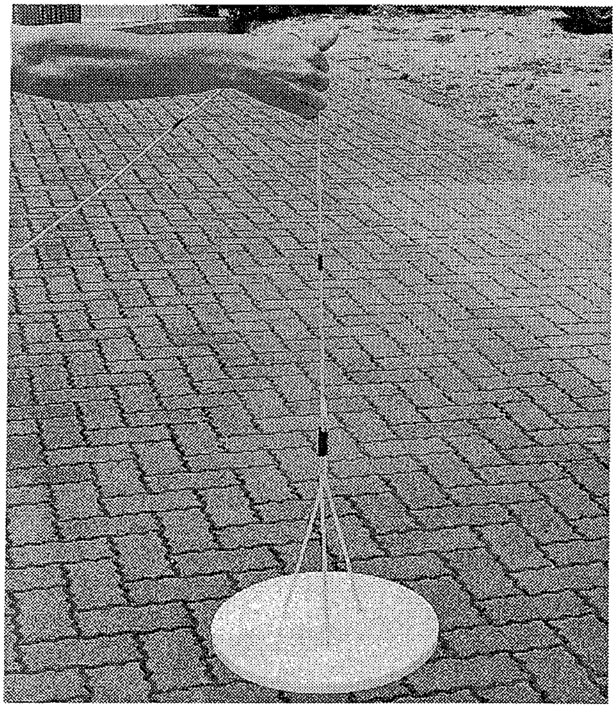

Fig.5 Secci disc for the measurement of transparency.

13.2 Measurement of abundance and species composition of aquatic organisms

13.2.1 Microbial analysis

13.2. 1-1 Direct count of Bacteria

a. *Equipment*

- Epifluorescence microscope · Filtration apparatus
- Blender(Electric sonicator, if necessary) · Counter

b. *Reagents and other materials*

- Irgalan black · Acridine orange(AO)
- 4′-,6-Diamidino-2-phenylindole dihydrochloride (DAPI)
- Formaldehyde(neutralized with e.g., hexamethylenetetramine)
- Nuclepore filter (0.2 um pore-size, ca. 13 m/m diameter)
- Glassfiber filter · Slide glass · Cover glass · Immersion oil

c. *Procedure*

A portion with 1 to 3ml of well mixed sampled water is poured into the funnel of filtration apparatus equipped with a 0.2μm Nuclepore filter and add AO (final concentration;0.01%) or DAPI(final concentration ; 0.00001%). If the sample volume is less than 1 ml, add particulate free distilled water (filtrate of 0.2 μm Nuclepore filter) of a few ml. Stain the sample with either reagent for 3min. Filtrate and rinse the funnel with particulate free distilled water. Remove the Nuclepore filter and dry it quickly with a blower and place it onto a glass slide. Drop immersion oil onto the filter and cover it with a cover glass. Keep the sample in a box with dark until examination. Check the stain and distribution of bacterial particles quickly under the microscope with low magnification and start to count with ca. x 1,000. Count the particles at least randomly selected 10 fields or at least a few hundreds particles. Number(N, cells/ml) is calculated using the equation;

$$N\ (\text{cells/ml}) = n \times S/s \times 1/V$$

where n is the mean of counted bacterial number per field, S is an area of filtrated, s is an area of the counted field at the given magnification, and V is a volume filtrated in ml.

13.2.2 Phytoplankton

Phytoplankton is a primary producer in open water and thus plays an important role in lake ecosystems. A characteristic that phytoplankton has but other organisms do not in open water is that phytoplankton posesses chlorophyll pigments. Therefore, chlorophyll concentration in lake water could be a good indicator of phytoplankton abundance.

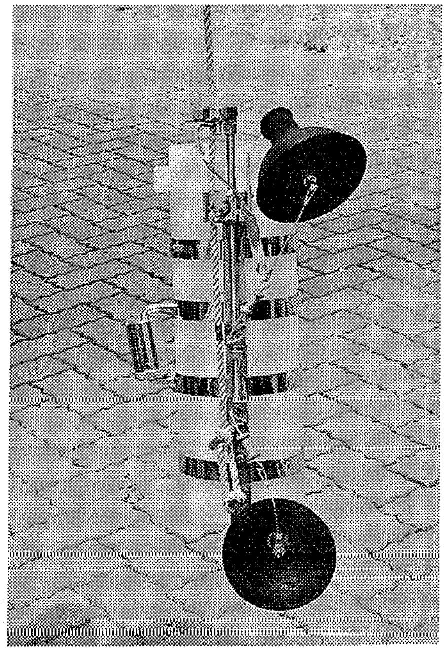

Fig. 6 Van-Dorn water sampler (6 liter in volume) (Rigosha Co. & Ltd.)

The chlorophyll concentration in open water is determined as follows:

Lake water is collected from a certain depth by a water sampler as a Van Dorn sampler (Fig. 6). Particles (> 1μm) in the sub-samples of the collected water are filtered with Whatman GF/C filter, and chlorophyll pigments trapped are extracted with 90% acetone. It is necessary to grind or homogenize the material (particles with filter) to ensure thorough extraction. The material and acetone are moved to vials for centrifugation, and then centrifuged at 3,000 rpm for 10-15 min. The supernatant is taken up and its volume is measured. Finally, the absorbance of the supernatant at 750nm, 663nm, 645nm, 630nm are determined using a spectrophotometer (Fig. 7). Then, chlorophyll a, b and c are calculated:

$$\text{Chlorophyll a } (\mu g/L) = (11.64\ E663 - 2.16\ E645 + 0.10\ E630) \times a/(V \times L)$$
$$\text{Chlorophyll b } (\mu g/L) = (20.97\ E645 - 3.94\ E663 - 3.66\ E630) \times a/(V \times L)$$
$$\text{Chlorophyll c } (\mu g/L) = (54.22\ E630 - 14.81\ E645 - 5.53\ E663) \times a/(V \times L)$$

where, V is volume of sampled water, a is volume of acetone extract (supernatant) in ml, L is length of spectrophotometer cell in cm, E663 is absorbance at 663 nm less the absorbance at 750nm, E645 is absorbance at 645nm less the absorbance at 750nm, and E630 is absorbance at 630nm less the absorbance at 750nm.

To know species composition and cell density of phytoplankton community, phytoplankton cells are counted under a microscope. For this

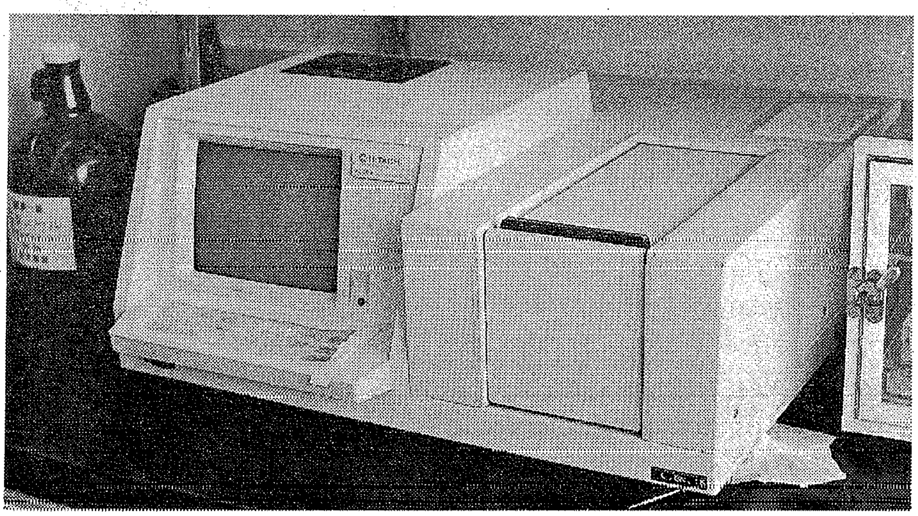

Fig. 7 Spectrophotometer (HITACHI U-2000).

purpose, lake water (50 - 1000 ml) collected with the water sampler is preserved in a 0.5 to 2% buffered formalin solution or Lugol's solution. Several drops of the water are put on a haemocytometer and the phytoplankton cells are counted under a microscope. If the phytoplankton density is low, the cells in the sampled water should be concentrated by settling a relatively large amount of the water in a cylinder for a day or longer before the counting. The density is expressed as cells/ml.

In Lake Suwa, phytoplankton community is dominated by the diatom *Melosira* in cool water seasons (fall–spring) and the cyanobacterial *Microcystis* in warm water seasons (summer–fall).

13.2.3 Zooplankton

In lakes, crustaceans (Cladocera, Copepoda) and rotifers are major zooplankton groups. They are herbivorous and/or carnivorous, and are taking an intermediate position in the food chain from primary producer (algae) to top predators (fish). Thus, getting the data on abundance and species composition of zooplankton is essential to understand lake ecosystems.

To collect Zooplankton, lake water of a certain volume is taken by a water sampler (e.g., a Van-Dorn sampler). Then the sampled water is passed through a 40μm mesh net (Fig. 8) and the collected zooplankton are preserved in a 4% formalin solution. The zooplankton are mounted on a counting chamber (Fig. 9), and identified and counted under a microscope. Finally, the density is expressed as individuals/L.

The dominant zooplankton taxa in Lake Suwa are the rotiferan *Keratella, Polyarthra* and *Trichocerca* in spring and the cladoceran *Bosmina* and *Diaphano soma* in summer - fall.

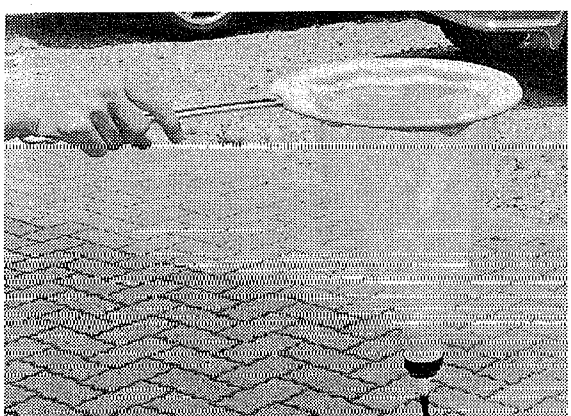

Fig. 8 Plankton net with a grip.

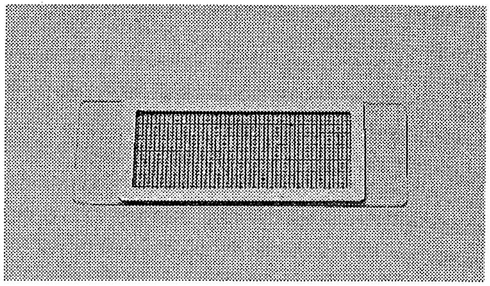

Fig. 9 Chamber for zooplankton counting under a microcsope.

13.2.4 Macrophytes

Macrophytes (rooted aquatic plants) inhabit littoral areas of lakes. They are grouped into three; emergent macrophytes, floating-leaf macrophytes, and submerged macrophytes, which appear from near shore to off shore depending on the water depth in the order (Fig. 10).

Their standing crop is estimated by cropping macrophytes in a quadrate (e.g., 1m x 1m). The cropped macrophytes are identified and weighed after being dried up.

In Lake Suwa, the following macrophytes are commonly observed in the littoral area.

Emergent macrophytes:	*Phragmites australis, Zizania latifolia*
Floating-leaf macrophytes:	*Nymphoides peltata, Trapa japonica*
Submerged macrophytes:	*Potamogeton crispus, P. perfoliatus, P. maackianus, P. malaianus, Hydrilla verticillata*

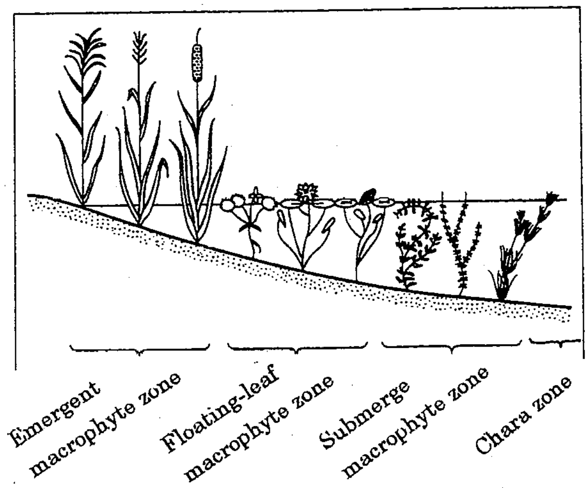

Fig. 10 Vegetation area in a lake littoral zone (redrawn from Saijo and.Mitamura, 1995, "SHINPEN KOSHO-CHOSAHO", Kodansha Scientific)

13.2.5 Zoobenthos

Macroinvertebrate benthic organisms are living in sediment of lakes. In the profundal zone, four main groups are present: oligo-chaete worms, amphipods, insect larvae, and sphaerid and unionid clams. They are collected by Ekman-Birge dredge (Fig. 11), which takes up sediment of 15cm x 15cm horizontally and ca. 10cm deep. Organisms therein are collected by passing the sediment with a net with a course mesh size (ca. 300μm), and counted. Their densities are expressed as individuals/m2.

Chironomid larvae (*Propsilocerus akamusi, Chironomus plumosus*) and Oligochaeta are the dominant zoobenthos in the Lake Suwa profundal zone.

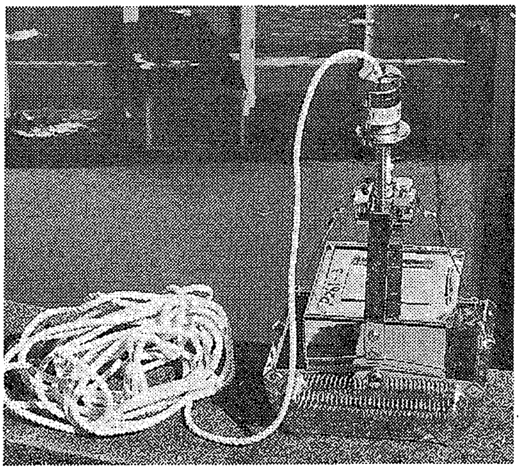

Fig.11 Ekman-Birge dredge (Rigosha Co. & Ltd.)

Chapter 14

Lake Biwa

Chunmeng Jiao

14. 1 The Research Vessel "Hakken"

Hakken was built in 1993 for Lake Biwa Research Institute at Mokube Ship Building for use of field experiment as a research vessel on Lake Biwa. The vessel is equipped with a hydraulic double drum main winch with 200m of 6mm stainless wire and 200m of 5mm armored cable which can bear 500kg working load, and a hydraulic single drum CTD winch with 200m of 6mm stainless wire for light working load up to 100kg.

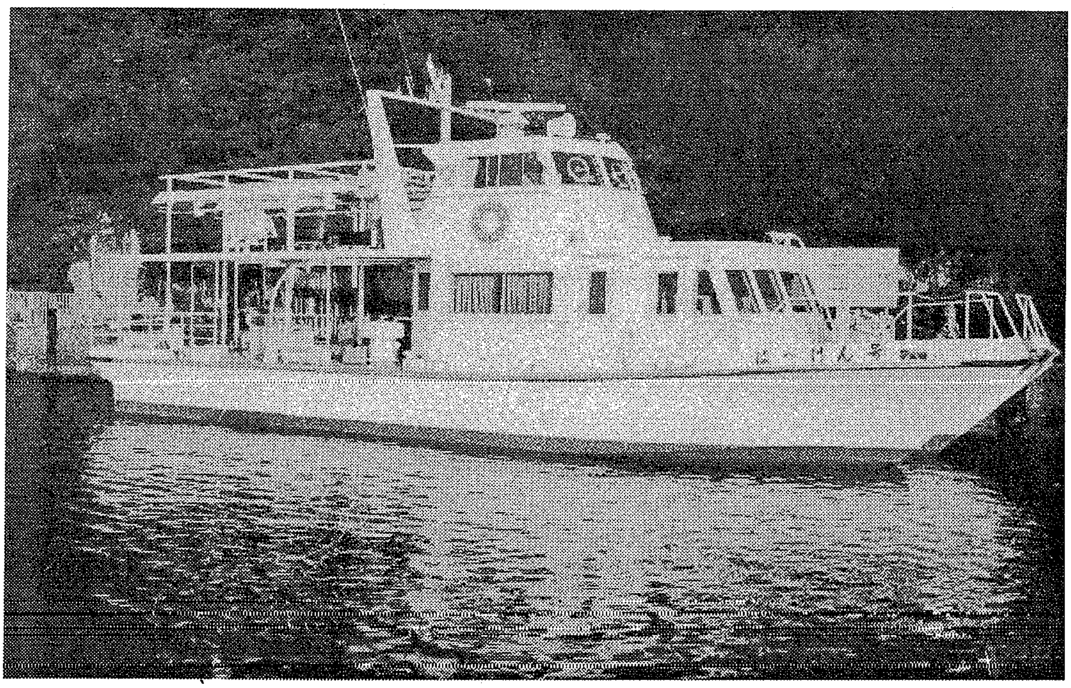

Fig. 1 The Vessel "Hakken"

Electronic and navigation equipment include a radar, a magnetic compass, a gyro-compass, a color plotter, a differential GPS, a meteorological facsimile, and a recording echo sounder for use as a depth detector and as a scientific investigation aid.

There are two permanent laboratory spaces aboard: a wet lab equipped with a refrigerator, a freezer and a vessel mounted water sampler, and a dry lab equipped with a main computer which supports LAN in the dry lab, a controller of fine scale profiler (F-Probe), a laser phytoplankton counter, a controller of differential GPS , and a controller of acoustic doppler current profiler (ADCP). A small locker room for skin diving is attached to the wet lab. Also, the vessel is equipped with a multi water sampler of 24 bottles, and an underwater video camera.

The name of Hakken means "discovery" in Japanese, and it is expected to discover new academic phenomena or scientific founding, and contribute to improve water quality in Lake Biwa.

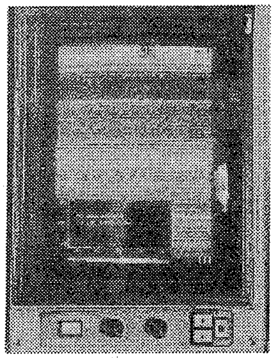

Fig. 2 A recording echo sounder for use and as a scientific investigation aid.

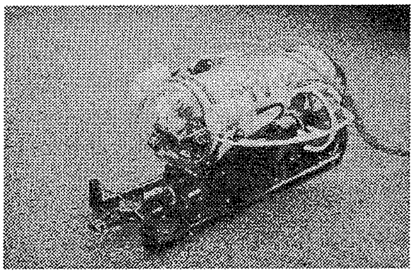

Fig. 3 A video camera robot

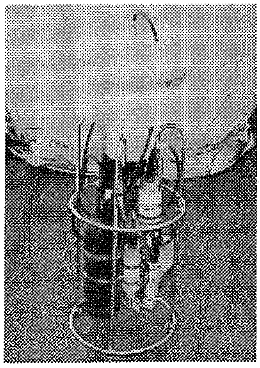

Fig. 4 A fine scale profiler

14. 2 Acoustic Doppler Current Profiler (ADCP)

This instrument measures current profiler by Doppler's effect of ultrasonic waves. By several East-West transect course measurement, a three-dimensional current distribution in Lake Biwa can be acquired. In summer, there are three gyres or circulation in Lake Biwa. This measurement let's us know the detail current distribution in the gyres. Following is a figure which shows an example of this observation.

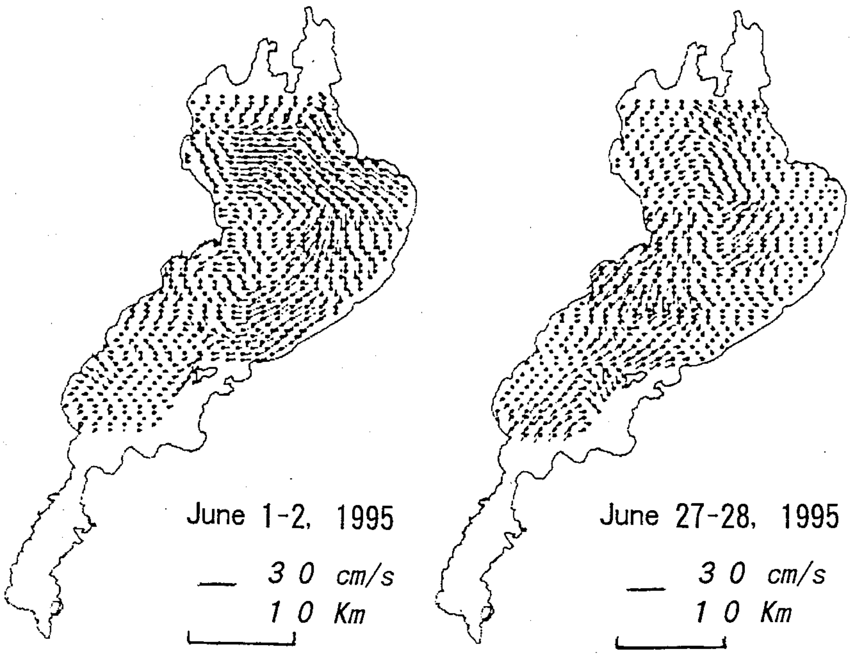

Fig. 5 Surface layer water current distribution measured by ADCP.

14. 3 Fine Scale Profiler

Most lakes, estuaries, and coastal waters are characterized by a well-defined density stratification of the water column. Advection is usually such that the overall pattern of turbulence and stratification are short-lived with the flow rarely retaining the same structure for longer than about ten minutes. For this reason, a rapid sampling system is essential in any studying of the mixing and dispersion of temperature, nutrients, oxygen any other water-borne substance. Regular grid type monitoring is not effective since the scales of motion range from millimeters to many kilometers and, as such, the sampling will invariably miss the major feature of the turbulence field frontgenesis and density layering. An intelligent profiler is required. This fine scale measurement, at scales ranging from centimeters to kilometers, allow the assessment of standing stock concentrations and their evolution.

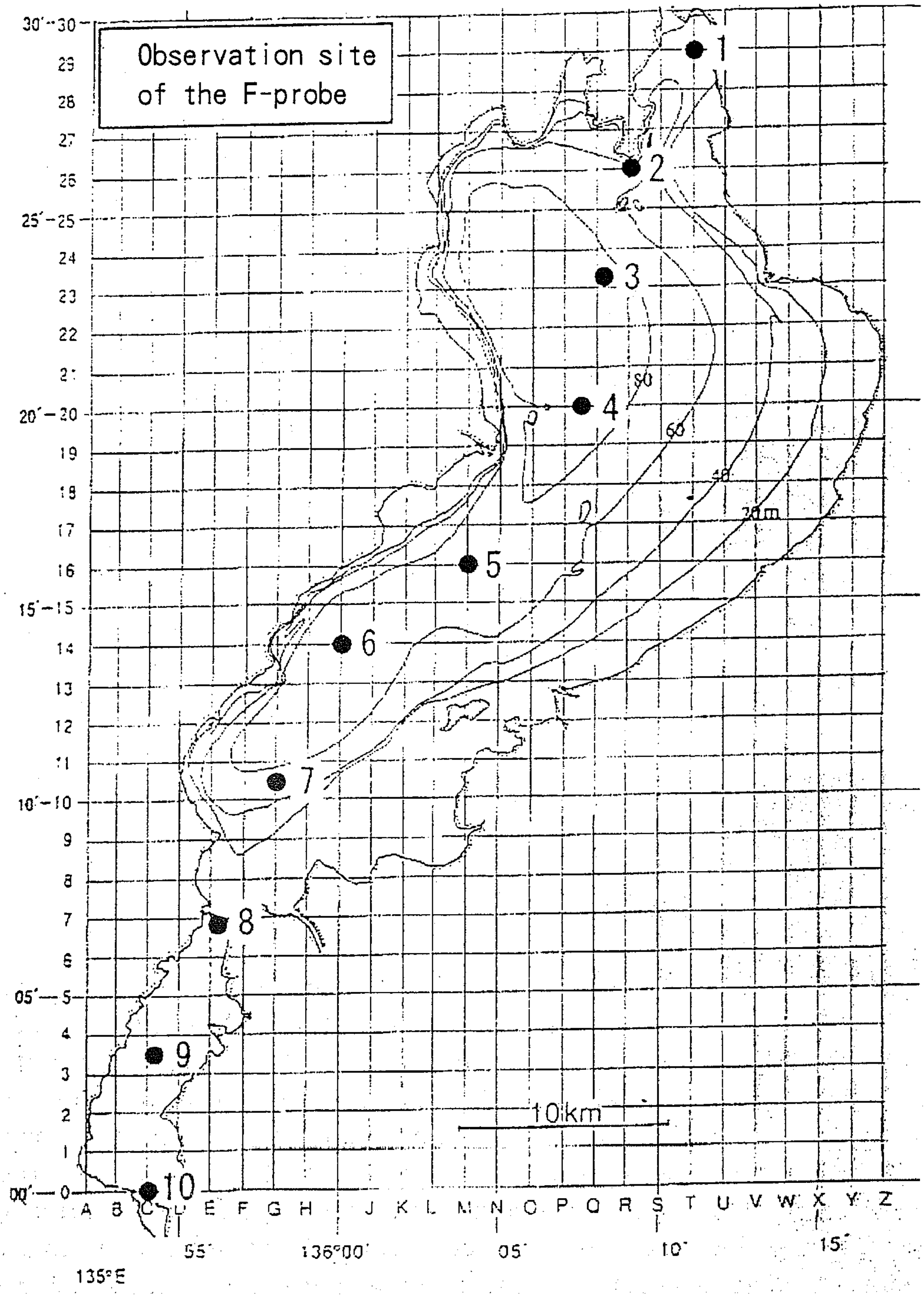

Fig. 6 Observation sites for the F-probe.

All the sensors are mounted directly onto the profiler. The control software allows the user to adjust the rate of sampling (up to 50 Hz). Position fixing is provided by a portable satellite Global Positioning System, which gives accurate three-dimensional positioning data at any location, provided there is satellite availability. Figure 7 shows an example of this observation.

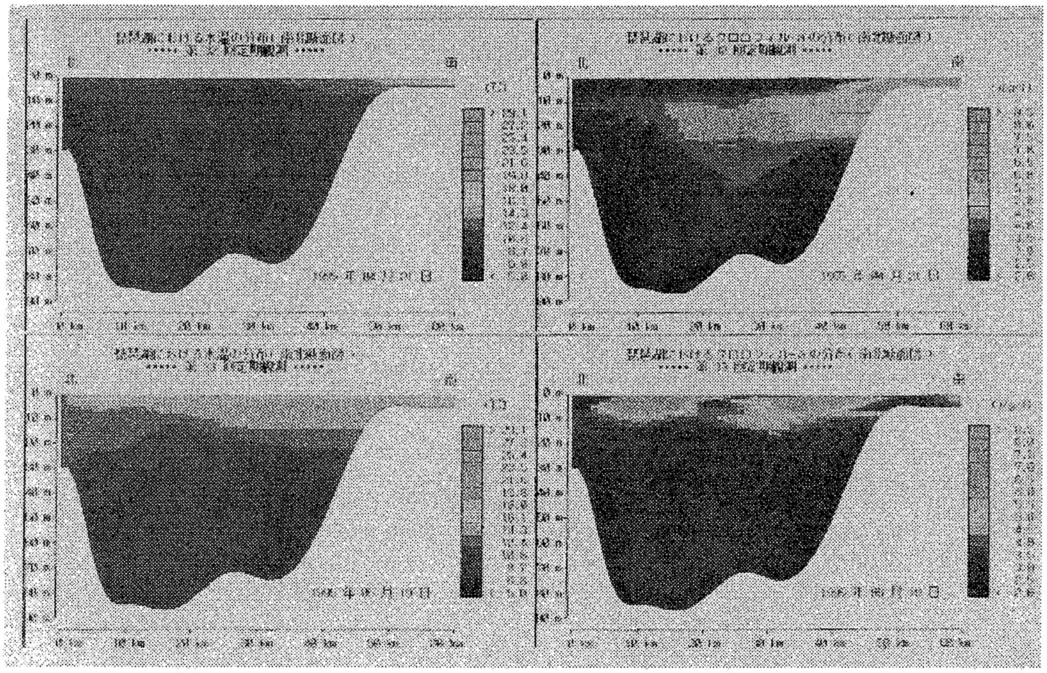

Fig.7 An example of F-probe observation.

Upper: Distribution of Water temperature (left) and Chlorophyll-a (right) on 21 April, 1995.

Lower: Distribution of Water temperature (left) and Chlorophyll-a (right) on 19 May, 1995.

Part Ⅲ

Outline of the Training Course

Chapter 15

The Training Course in 1999 Summer

15. 1 Limnology

Limnology is a field of study on terrestrial water ecosystems such as lakes, rivers, reservoirs, ground waters and wetland. Human activities have been linked very closely to those water ecosystems and changed them directly or indirectly through global environmental changes. We have to learn basic limnological processes and how to manage and conserve those water ecosystems with sustainable development through the next century.

Limnological studies in Japan only began in 1899 and we are celebrating their centennial history. The following programs have been prepared to welcome trainees of the IHP training course in limnology in the summer of 1999.

15. 2 Lectures

L1 Material cycling in deep and shallow water Ecosystems

H. Terai

Limnology has been developed through comparison between deep and shallow lakes by August Thienemann in the early 20th century. Recently shallow water ecosystems have been seriously affected by human activities. Importance of shallow water ecosystems in the material cycling will be covered in comparison with deep-water ecosystems.

L 2 Low-cost water treatment systems using constructed wetlands

K. Ichino

We have much experience of water treatment using natural or constructed wetlands in the world. In order to treat municipal wastewater, reed beds are often used in Europe. We used rice paddies instead of reed beds to improve quality of polluted river waters. On the basis of these experiences, it is supposed that we can construct low-cost water treatment systems by combining reed beds and rice paddies.

L 3 Current technology in limnology (1) Stable isotope ecology

T. Yoshioka

It has been widely recognized that stable isotope abundance of light elements, such as carbon and nitrogen, are useful indicators for assessing the dynamics of material cycle in natural environments. Recent progress in stable isotope study on freshwater ecosystem will be presented.

L 4 A historical review of limnology in Japan and a case study on Lake Suwa

T. Okino

One hundred years ago, Dr. Akamaro Tanaka came back from Europe, and introduced limnological knowledge for the first time to Japan. The development of limnological studies in Japan during a century will be reviewed. Studies on Lake Suwa based upon analysis of the lake ecosystem including the material cycling of the watershed will be also reviewed, as one of the successful application of limnology.

L 5 Current technology in limnology (2) Microbial ecology

K. Kato

Microbes are key organisms not only as a decomposer of aquatic ecosystems but a major constituent of the microbial loop. Recent advancement in molecular techniques enable us to elucidate their phylogeny and population dynamics directly. However, there is a great gap in the number of culturable and directly counted bacteria under the microscope. The basic concept and technique of microbial ecology today will be shown in the course.

L 6 Global environment and lake ecosystems

T. Hanazato

Environmental stress induced by human activity, such as contamination with toxic chemicals, acidification and global warming, may affect in a similar way the structure and functioning of lake ecosystems. That is, it decreases mean body length of organisms in the community and reduces energy transfer efficiency from primary producers to the top predators. The mechanisms will be explained in the lecture.

L 7 Water resources and environmental problems of Lake Biwa

H. Fushimi

Snow cover plays an important role in the quantity and quality of water resources, such as supplying the dissolved oxygen as well as acid material to Lake Biwa in relation to climatic changes and anthropogenic activities.

L 8 Eutrophication and management of freshwater environments

M. Sakamoto

Lake eutrophication is an overall change of the aquatic ecosystem induced by increasing loading of nitrogen and phosphorus, especially by human activities. What is needed for the sustainable management of lake ecosystem will be covered along with some successful and unsuccessful stories.

L 9 Integrated management of water environment

M. Nakamura

This lecture reviews and discusses the past experience and current issues associated with management of Lake Biwa and its watershed, with particular reference to the so-called integrated management approach versus the conventional piecemeal management approach.

L 10 Ecological inhomogeneity due to dynamic variability in Lake Biwa

M. Kumagai

The nature of Lake Biwa is not simple, because it has various scales of physical processes in space and time. The variability of such processes has produced inhomogeneity of the lake ecosystem from inshore to offshore, and from surface to bottom. The Lake Biwa Research Institute has devoted itself to understanding the process dynamics and the response of the ecosystem, by the use of highly developed sensing technology. Some examples of ecosystem inhomogeneity related to dynamic variability will be presented at this lecture.

L 11 Evolution and distribution of cyprinid fish in East Asia during Neogene

T. Nakajima

Cyprinid fish fauna in East Asia originated in rift valley lakes formed along the East margin of the Eurasia Continent in Early Miocene. They expanded into the inland region of China, and the cyprinid fauna of East Asia were established by Pliocene. After that, the Japanese Archipelago underwent the tectonic movements in Middle Pleistocene and the Japanese cyprinid fauna became different from the Chinese one.

L 12 Current technology in limnology (3) Algal species classification by image processing

Ross F. Walker

A new technique for cyanobacteria detection and classification by image processing and pattern recognition was recently developed. Specifically, *Microcystis* sp. was targeted for detection and classification from among several other cyanobacteria species. Details of image analysis and classification using parametric statistical methods were lectured.

Supplementary lectures:

by Nobutada Nakamoto and Hidetake Hayashi of Shinshu University were given on the following subjects.

(1) Misunderstanding of Slow Sand Filtration in Japan and the Biological Mechanism of its System.

(2) Morphological, Physical and Chemical parameters of Lake Kizaki and Lake Aoki.

Special lecture on current IHP activities in Asia Pacific Region:

by M. Overmars from UNESCO Jakarta Office.

15. 3 Field studies and technical tours

- **Field study on Lake Suwa,** a shallow eutrophic lake, will be conducted. Observation of environmental factors and sampling of water and sediment for chemicals (nutrient, chlorophyll and suspended mater) and biological (phytoplankton, zooplankton, bacteria and benthos) analysis will be done comparing between river estuarine, littoral and profundal zones of the lake.

- **Field trip including observation and sampling** on subalpine lakes, Lake Shirakoma and Lake Kizaki, will also be conducted to recognize the differences in human impact on the lake ecosystems.

- **Field study on Lake Biwa,** the largest mesotrophic lake in Japan, will be conducted by the research vessel equipped with fine-scale CTD, ADCP, UV profiler, underwater microscope, and other instrumentation.

- **The course also includes technical tours at**
  - Institute for Hydrospheric-Atmospheric-Sciences, Nagoya University
  - Lake Kizaki Limnological Laboratory of Shinshu University
  - Fisheries Experiment Station, Shiga Prefecture, in Hikone
  - The house of water benevolence "Aqua -BIWA"
  - Shiga Prefectural Environmental Science Museum for Water
  - Lake Biwa Museum in Kusatsu

15. 4 Schedule 26 July - 8 August, 1999

July 26 (Mon)	Arrival at Nagoya, Japan
27(Tues)	• Guidance, • Lectures at IHAS • (Icebreaker reception in the evening)
28(Wed)	• Move to Suwa Hydrobiological Laboratory, • Guidance and Lecture
29(Thurs)	Field trip on Lake Suwa, • Observation and sampling • Chemical and biological analysis of water and sediment samples
30(Fri)	• Lecture and practical training on microbial community at Matsumoto

31(Sat)	Field trip to Lake Shirakoma • Observation and sampling (Reception in the evening)
August 1 (Sun)	Technical tour to Kurobe Reservoir and Nishina subalpine lakes
2 (Mon)	Lake Kizaki Laboratory, Travel to Hikone by train
3 (Tues)	• Lecture at The University of Shiga Prefecture • Visit Fisheries Experiment Station, Move to Otsu
4 (Wed)	Lecture and field trip to Lake Biwa on the research vessel "Hakken"
5 (Thurs)	• Lecture and technical tour to "Aqua-BIWA" and Environmental Science Museum for Water
6 (Fri)	• Lecture and technical tour to Lake Biwa Museum, Back to Nagoya and Reception
7 (Sat)	• Closing Ceremony • Special lecture on current IHP activities in Asia Pacific Region
8 (Sun)	• Departure from Nagoya

Chapter 16

Past Activities of the IHP Training Course

16. 1 Past activities of the IHP Training Course (1991-1998)

The *IHP Training Course in Asia and the Pacific Region* has been executed since 1991 by the Working Group for IHP Training Course, under the direction of the Sub-Committee for IHP, Japanese National Commission for UNESCO. The Training Course was aimed at giving the participants an opportunity to learn observation technology of hydrology and to have practical experience in hydrological observation in the field.

In the First to Sixth- sessions of the Training Course, the training began with two or three preliminary lectures to introduce the subjects to be studied throughout the remainder of the course schedule. After this introduction, students have been taken around to several specialized institutes, in the days following, to hear about what was actually done there, and to see modern instrumentation in general hydrology. It has been found, however, that this training approach possibly encourages passiveness on the part of the students because they spend an inordinate amount of time travelling daily to the host institutions where they can only listen and observe rather than participate actively.

Some innovations, therefore, was made at the Seventh-session, both in the educational content and in the schedule. Firstly, we decided to focus the training course on more clearly defined targets, and the first year's programme concentrated on Snow Hydrology. Secondly, we decided to include practice sessions such as a field programme to allow the students, themselves, the opportunity to carry out experiments and make relevant observations / analyses. Finally, we decided to prepare a newly edited textbook for the participants in the training course.

Last Japanese fiscal year which ended in March 1999 the Eighth-session was concentrated on Remote Sensing.

16. 2 First to Sixth- session on General Hydrology (1991-1996)

16.2.1 T1 The First IHP Training Course, 1991

T1.1 Participants

Ms. Zhao Ling (China): Student of the Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Mr. Zhao Jing (China): ibid.

Ms. Hidajat Bernadia Irawati Tjandradewi (Indonesia): ibid.

Mr. Geng Biao (China): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Ms. Sri Mulat Yuningsih (Indonesia): The Research Institute for Water

Mr. Roslan Bin Sahat (Malaysia): Resources Development, Department of Public Works Hydrology Branch, Department of Drainage and Irrigation

T1.2 Schedule and Program

Opening lectures, held at Water Research Institute, Nagoya University, were given by the following specialists:

Takagi, F.	(Professor, Department of Civil Engineering, Faculty of Technology, Nagoya University): Runoff processes in river watersheds.
Fujiyoshi, Y.	(Associate Professor, Laboratory of Atmospheric Environment, Water Research Institute, Nagoya University): Precipitation and water resources in Asia, part 1.
Kato, K.	(Assistant Professor, ibid.): ibid., part 1.
Ishizaka, Y.	(Associate Professor, Laboratory of Atmospheric Physics, ibid.): ibid., part 2.
Ageta, Y.	(Professor, Laboratory of Hydrospheric Physics, ibid.): ibid., part 3.
Sakamoto, M.	(Professor, Laboratory of Aquatic Ecology, ibid.): The matter cycle and water quality in the hydrosphere, part 1.

Handa, N. (Professor, Laboratory of Organic Geochemistry, ibid.): ibid.,part 2.

Ohta, K. (Associate Professor, ibid.): ibid., part 3.

The Training Course was presented from March 2 to 19, 1992 according to the following schedule:

Mar. 2 – 3 Water Res. Inst., Nagoya Univ. (Nagoya)

- Lecture on runoff processes in river watersheds
- Lecture and Practice Session on precipitation and water resources in Asia
- Lecture and Practice Session on the matter cycle and water quality in the hydrosphere

Mar. 4 – 6 Chubu Regional Construction Bureau, Min. of Construction (Chubu Region)

- Technical tour of hydrological facilities for river control

Mar. 7- 8 (Sat-Sun): holidays

Mar. 9 Water Resources Res. Center, Disaster Prevention Res. Inst., Kyoto Univ.

- Laboratory experiment on evaporation from bare soil

Mar.10 Kiryu Experimental Catchment, Faculty of Agriculture, Kyoto Univ.

- Meteorological and hydrological observations at a small catchment in hilly terrain

Mar. 11 (Kyoto to Tsukuba)

Mar. 12 Forestry & Forest Products Res. Inst., Min. of Agriculture, Forestry & Fisheries (Hitachi-Ohta)

- Training on evaporation and soil moisture measurements, and hydrological observation

Mar.13 National Inst. for Environmental Studies, Environment Agency (Tsukuba)

- Technical tour of research facilities for water quality conservation

Mar. 14-15 (Sat-Sun): holidays

Mar. 16-17 Public Works Res. Inst., Min. of Construction (Tsukuba)

- Lectures on hydrological observations and models of water discharge

Mar.18 Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)

- Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS (automated meteorological data acquisition system).

Mar. 19 Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)
- Technical tour of Meteorological Satellite Center.

16.2.2 T2 The Second IHP Training Course, 1992

T2.1 Participants

Ms. Thapa, Arati (Nepal): Student of Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University
Mr. Kayastha, Rijan Bhakta (Nepal): ibid.
Mr. Sarwono, Pitoyo Sudibyo (Indonesia): ibid.
Mr. Le Cong Thanh (Vietnam): ibid.
Mr. Xu Guangxiang (China): ibid.
Mr. Adisak, Suriyavanagul (Thailand): Electricity Generating Authority
Mr. Pham Van Tan (Vietnam): Network Operation Department, Hydrometeorological Service
Mr. Ekanayaka M. Wimalasena (Sri Lanka): Investigation Section, National Water Supply and Drainage Board
Mr. S. Mahmoud Borghei (Iran): Assistant Professor, Department of Civil Engineering, Sharif University of Technology

T2.2 Schedule and Program

Opening lectures were given by the following personnel from the Water Research Institute, Nagoya University:

Ohata,T. (Assistant Professor, Laboratory of Hydrospheric Physics): Precipitation and water resources in Asia, part 1.
Kato, K. (Assistant Professor, Laboratory of Atmospheric Environments): ibid., part 2.
Ishizaka ,Y. (Associate Professor, Laboratory of Atmospheric Physics) ibid., part 3.
Terai, H. (Associate Professor, Laboratory of Aquatic Ecology): The material cycle and water quality in the hydrosphere.

The Training Course was presented from March 1 to 18, 1993 according to the following schedule.

Mar. 1- 2 Water Res. Inst., Nagoya Univ. (Nagoya)

- Lecture and Practice Session on precipitation and water resources in Asia
- Lecture and Practice Session on the matter cycle and water quality in the hydrosphere
- Technical tour

Mar. 3- 5 Kanto Regional Construction Bureau, Min. of Construction (Nagoya to Tokyo, Kanto Region)

- Technical tour of hydrological facilities for river control

Mar. 6- 7 (Sat-Sun): holidays

Mar. 8- 9 Environmental Res. Center, Univ. of Tsukuba (Tsukuba)

- Observation and data analysis of evapotranspiration

Mar. 10-11 National Res. Inst. for Earth Science & Disaster Prevention, Science & Technology Agency (Tsukuba-Ichihara, Chiba)

- Laboratory experiment of rainfall
- Technical tour of an experimental hydrological catchment

Mar. 12-14 (Fri-Sun): holidays

Mar. 15-16 National Res. Inst. of Agricultural Engineering, Min. of Agriculture, Forestry & Fisheries (Tsukuba)

- Analysis of irrigation and drainage
- Study of experimental ground water facilities

Mar. 17 Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)

- Lecture and technical tour for short-range precipitation forecasting using radar and the AMeDAS

Mar. 18 Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)

- Technical tour of Meteorological Satellite Center

16.2.3 T3 The Third IHP Training Course, 1993

T3.1 Participants

Mr. Kamal, Md. Syeeduzzaman (Bangladesh): Student of the Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University.

Ms. Sipayung, Sinta Berliana (Indonesia): ibid.

Ms. He Kaiqing (China): ibid.

Mr. Zhu Yan (China): Department of Hydrology, Hohai University

Mr. Wu Yongxiang (China): Nanjing Institute of Hydrology & Water Resources, Ministry of Water Resources

Ms. Suva, Imelda Manalastas (Philippines): Bureau of Research & Standards, Department of Public Works & Highways

Mr. Dwivedi, Ashok Kumar (India): Hydrological Investigations Division, National Institute of Hydrology, Roorkee

Mr. Ahmad, Bashir (Pakistan): Centre of Excellence in Water Resources Engineering, University of Engineering & Technology, Lahore

T3.2 Schedule and Program

Opening lectures were presented by the following specialists from the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:

Kato ,K.	(Assistant Professor, Division of Water Cycle): Multi-scale cloud distributions in monsoon regions of Asia.
Tanaka, H.	(Professor, Division of Material Cycle): Cloud physics and chemistry in climate studies.
Ageta ,Y.	(Professor, Division of Water Cycle): Asian cryosphere and changes in water resources.
Nakawo, M.	(Associate Professor, Division of Water Cycle): Water cycle and stable isotopes.

The Training Course was presented from August 16 to September 2, 1993 according to the following schedule:

Aug. 16-17 Inst. for Hydrospheric-Atmospheric Sci., Nagoya Univ. (Nagoya)

- Lectures on the International Hydrological Programme.
- Lecture and Practice Session on precipitation and water resources in Asia.
- Lecture and Practice Session on the matter cycle and water quality in the hydrosphere.

Aug. 18-20 Chubu Regional Construction Bureau, Min. of Construction (Chubu Region)

- Technical tour of hydrological facilities for river control.

Aug. 21-22 (Sat-Sun): holidays

Aug. 23 Water Resources Res. Center, Disaster Prevention Res. Inst., Kyoto Univ.

- Lecture on control of run-off water.

Aug. 24 Kiryu Experimental Catchment, Faculty of Agriculture, Kyoto Univ.

- Meteorological and hydrological observations at a small catchment in hilly terrain.

Aug. 25 (Kyoto to Tsukuba)

Aug. 26 Forestry & Forest Products Res. Inst., Min. of Agriculture, Forestry & Fisheries (Hitachi-Ohta)

- Training on evaporation and soil moisture measurements, and hydrological observation.

Aug. 27 Public Works Res. Inst., Min. of Construction (Tsukuba)

- Lectures on hydrological observations and models of water discharge.

Aug. 28-29 (Sat-Sun): holidays

Aug. 30 Public Works Res. Inst., Min. of Construction (Tsukuba)

- Lectures on hydrological observations and models of water discharge.

Aug. 31 National Inst. for Environmental Studies, Environment Agency (Tsukuba)

- Technical tour of research facilities for water quality conservation.

Sep. 1 Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)

- Technical tour of Meteorological Satellite Center

Sep. 2 Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)

- Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.

16.2.4 T4 The Fourth IHP Training Course, 1994

T4.1 Participants

Mr. Sunil Adhikary (Nepal): Student of the Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Mr. Zhang Wan Chang (China): ibid.

Mr. Mohammad Rezwanul Islam (Bangladesh): ibid.

Mr. Birbal Rana (Nepal): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Ms. Y.K. Handapangoda (Sri Lanka): Teaching Assistant in Civil Engineering, University of Peradeniya, Peradeniya

Ms. Byambaagiin Oyunchimeg (Mongolia): Ministry of Nature and Environment, Institute of Water Problems, Ulaan Baatar

Mr. M. Fakhruddin (Indonesia): Puslitbang Limnology, LIPI, Bogor

Ms. Gadis Sri Haryani Bengen (Indonesia): Research and Development Center for Limnology, Indonesian Institute of Sciences, Bogor

T4.2 Schedule and Program

Opening talks were presented by the following lecturers from the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:

Kato, K. (Assistant Professor, Division of Water Cycle): Asian monsoon and water cycle.

Handa, N. (Professor, Division of Material Cycle): Carbon cycling with water cycle.

Terai, H. (Associate Professor, Division of Material Cycle): Aquatic micro-organisms and water quality.

The Training Course was presented from August 15 to September 1, 1994 according to the following schedule:

Aug. 15-16 Inst. Hydrospheric-Atmospheric Sci., Nagoya Univ. (Nagoya)

- Lecture on the International Hydrological Programme.
- Lecture and Practice Session on precipitation and water resources in Asia.
- Lecture and Practice Session on the biogeochemical cycle and water quality in the hydrosphere.

Aug. 17-19 Kanto Regional Construction Bureau, Min. of Construction (Nagoya to Tokyo, Kanto Region)

- Technical tour of hydrological facilities for river control.

Aug. 20-21 (Sat-Sun): holidays

Aug. 22-23	Environmental Res. Center, Univ. of Tsukuba (Tsukuba) • Observation and data analysis of evapotranspiration.
Aug. 24-25	National Res. Inst. of Agricultural Engineering, Min. of Agriculture, Forestry & Fisheries (Tsukuba) • Analysis of irrigation and drainage. • Study of experimental facilities for ground water.
Aug. 26	National Inst. for Environmental Studies, Environment Agency (Tsukuba) • Technical tour of research facilities for water quality conservation.

Aug. 27-28 (Sat-Sun): holidays

Aug. 29-30	National Res. Inst. for Earth Science & Disaster Prevention, Science & Technology Agency (Tsukuba-Chiba Pref.) • Large scale rainfall experiment. • Technical tour of an experimental hydrological catchment.
Aug. 31	Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo) • Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.
Sep. 1	Meteorological Satellite Center, Japan Meteorological Agency (Kiyose) • Technical tour of Meteorological Satellite Center

16.2.5 T5 The Fifth IHP Training Course, 1995

T5.1 Participants

Ms. Meng Xiao (China): Student of the Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Sciences, Nagoya University

Mr. Talukder Abul Bashar MD. Alauddin (Bangladesh): ibid.

Mr. Liu Jing Shi (China): ibid.

Mr. Begkhutod Perapol (Thailand): ibid.

Mr. Bhatt Maya Prakash (Nepal): ibid.

Mr. Ma Xieyao (China): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

T5.2 Schedule and Program

The Training Course was presented in three parts according to the following schedule: Part 1 from December 13 to 15, 1995, Part 2 from February 13 to 16, 1996 , and Part 3 from March 11 to 15, 1996.

<Part 1: Chubu Region>

Dec. 13-15	Chubu Regional Construction Bureau, Min. of Construction (Aichi and Gifu) • Technical tour of hydrological facilities for river control.

<Part 2: Kinki Region>

Feb. 13	Lake Biwa Res. Inst., Shiga Pref. (Otsu) • Lecture and technical tour for Lake Biwa.
Feb. 14	Branch Office of Kinki District of Public Works, Min. of Construction (Otsu) • Lecture and technical tour for mountain conservation. Dept. of Forestry, Kyoto Univ. (Otsu) • Lecture and technical tour of an experimental basin.
Feb. 15	Disaster Prevention Res. Inst., Kyoto Univ. (Uji) • Lecture and technical tour on disaster prevention. Hirakata Operation Center, Min. of Construction (Hirakata) • Lecture on river water control.
Feb. 16	Section of River Management, Kyoto Pref. (Kyoto) • Technical tour concerning river management.

<Part 3: Kanto Region>

Mar. 11	Inst. for Forestry and Forest Products, Min. of Agriculture, Forestry and Fisheries (Hitachi-Ohta) • Training on evaporation and soil moisture measurement, and on making hydrological observation.
Mar. 12	National Inst. for Environmental Studies, Environment Agency, (Tsukuba) • Technical tour of research facilities for water quality conservation.
Mar. 13	Public Works Res. Inst., Min. of Construction (Tsukuba) • Lecture on hydrological observation and models of water discharge.
Mar. 14	Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo) • Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.
Mar. 15	Meteorological Satellite Center, Japan Meteorological Agency (Kiyose) • Technical tour of Meteorological Satellite Center

16.2.6 T6 The Sixth IHP Training Course, 1996

T6.1 Participants

Mr. Zulkefle bin Ghazali (Malaysia): Hydrology Division, Department of Irrigation and Drainage

Mr. Rhoel C. Villa (Philippines): National Hydraulic Research Center, U.P. College of Engineering

Mr. Luong Tuan Anh (Vietnam): Institute of Meteorology and Hydrology, Hanoi Hydrometeorological Service of Vietnam

Mr. Atthaporn Buddhapolit (Thailand): Hydrology Division, Royal Irrigation Department

Ms. Rungkarn Krishnamra (Thailand): Soil and Water Conservation Division, Land Development Department

T6.2 Schedule and Program

Opening lectures were presented at the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University by the following lecturers:

Kuraji, K. (Professor, University of Tokyo): Hydrological characteristics of tropical forests.

Nakamura, K. (Professor, Institute for Hydrospheric-Atmospheric Sciences, Nagoya University): Remote sensing from space.

Tachikawa ,Y. (Professor, Kyoto University): Development of distributed rainfall-runoff model by using digital elevation models.

Takeuchi, K. (Yamanashi University): The new thrust of IHP activities in Southeast Asia and Pacific, Asian/Pacific FRIEND (Flow Regimes from International Experimental and Network Data).

The Training Course was presented from August 19 to September 5, 1996 according to the following schedule:

Aug. 19-20 Inst. for Hydrospheric-Atmospheric Sciences, Nagoya Univ. (Nagoya)

- Lecture on International Hydrological Programme
- Lecture concerning forest effects on the hydrological cycle in tropical regions
- Lecture on precipitation measurement by remote sensing
- Lecture on hydrological modelling.
- Lecture on Asian FRIEND.

Aug. 21-23 Kanto Regional Construction Bureau, Min. of Construction (Kanto Region)
- Technical tour of hydrological facilities for river control.

Aug. 24-25 (Sat-Sun): holidays

Aug. 26-27 Environmental Research Center, Tsukuba Univ. (Tsukuba)
- Lecture and Practice Session on evapotranspiration measurements.
- Lecture on the role of the biosphere for climate systems.

Aug. 28-29 National Res. Inst. of Agricultural Engineering, Min. of Agriculture, Forestry & Fisheries (Tsukuba)
- Analysis of irrigation and drainage.
- Technical tour to an irrigated paddy field.

Aug. 30 Public Works Res. Inst., Min. of Construction (Tsukuba)
- Technical tour of research facilities for water quality conservation.

Aug. 31-Sep. 1 (Sat-Sun): holidays

Sep. 2-3 National Res. Inst. for Earth Science & Disaster Prevention, Environment Agency (Chiba Pref.)
- Large-scale rainfall experiment.
- Technical tour to the hydrological catchment basin.

Sep. 4 Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)
- Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.

Sep. 5 Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)
- Technical tour of Meteorological Satellite Center.

16.3 T7 The Seventh IHP Training Course, 1998: Snow Hydrology

The general aim of the IHP short course is to help participants develop their basic knowledge of hydrological systems and of their sensitivity to climate changes as well as to contribute to solving current global environmental problems. The cryosphere is most vulnerable to the projected global warming trend that has recently become a major concern in many countries. The seventh training course focuses on snow hydrology. The topics covered range from basic knowledge of the role of the cryosphere in the global environment to technical applications, including observations and measurements in snow packs.

16.3.1 T7.1 Participants

Mr. D. B. Chettri, Executive Engineer, Meteorology Unit, Div. Power, Ministry of Trade and Industry(Bhutan)
Mr. Liang, Zhongmin, Teacher, Dept. Hydrology, Hohai University (China)
Mr. Om Ratna Bajracharya, Senior Hydrologist, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Mr. Shiva Bhakta Prajapati, Hydrologist, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Mr. Aurangzeb Khattak, Assistant Director, WRRC (Pakistan)
Mr. Edvin Aldrian, M2, IHP Student, IHAS Nagoya University (Indonesia)
Mr. Dang Xuan Phong, M2, IHP Student, IHAS Nagoya University (Vietnam)
Mr. Li, Jianjun, M2, IHP Student, IHAS Nagoya University (China)
Mr. Yudi Iman Tauhid, M2, IHP Student, IHAS Nagoya University (Indonesia)
Mr. Bhuwan Chandra Bhatt, M1, IHP Student, IHAS Nagoya University(Nepal)
Mr. Zhou Shiqiao, M1, IHP Student, IHAS Nagoya University (China)
Mr. Kayastha Rijan Bhakta, Research Fellow, IHAS (Nepal)
Mr. Suresh Chandra Pradhan, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Scienceand Technology (Nepal)
Mr. Keshav Raj Sharma, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Mr. Chok Bahadur Gurung, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Dr. Dorji Wangdu, Head, Division of Geology and Mines (Bhutan)
Ms. Diraagiin Erdenetsetseg, Expert, Centre for Climate and Environmental (Mongolia)
Mr. Nozomu Naito, D3, Graduate Student, IHAS Nagoya University (Japan)
Mr. Fumio Nakazawa, M1, Graduate Student, IHAS Nagoya University(Japan)
Mr. Yosihiro Yoshioka, M2, Graduate Student, Nagaoka University of Technology (Japan)

16.3.2 T7.2 Schedule and Program

Lecturers

Ageta, Y.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University
Aoki , T.	Meteorological Research Institute
Goto-Azuma, K.	Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth Science and Disaster Prevention
Hayakawa, N.	Department of Civil and Environmental Engineering, Nagaoka University of Technology
Iida ,H.	Sediment Control Division, Department of Civil Engineering, Toyama Prefectural Government

Kamiishi , I.	Centre of Snow and Ice Technology, ARGOS Co. Ltd.
Kobayashi, S.	Research Institute for Hazards in Snowy Areas, Niigata University
Lu, M.	Department of Civil and Environmental Engineering, Nagaoka University of Technology
Mizuno, H.	Meteorological College
Nakawo, M.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University
Ohno, H.	Japan International Research Centre for Agricultural Sciences
Satow, K.	Civil Engineering, Nagaoka National College of Technology
Takeda, T.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University
Takeuchi, Y.	Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth Sciences and Disaster Prevention
Yokoyama, K.	Hokuriku National Agricultural Experiment Station

Schedule (9 March, 1998 - 22 March, 1998)

Mar. 9 (Mon) Arrival at Nagoya, Japan

Mar. 10 (Tues) (IHAS, Nagoya University)

- Guidance
- Lecture on Glaciers and the water cycle
- Lecture on precipitation process
- Lecture on synoptic conditions and snow fall precipitation process
- Icebreaker reception in the evening

Mar. 11 (Wed) (IHAS, Nagoya University)

- Technical Tour
- Move from Nagoya to Myoko (4 hour's train ride)

Mar. 12 (Thurs)

- Lecture on water circulation over the earth: the roles of snow and ice
- Radiation processes and remote sensing of snow
- Practice session for spectral albedo observations on a snowfield

Mar. 13 (Fri)

- Lecture on snowmelt hydrology
- Practice session for Hydrographical Observations
- Fabrication of the Endo-type snow-water content meter (1)

Mar. 14 (Sat)

- Lecture on metamorphism of deposited snow
- Lecture on snow changes in snow pack and melt water chemistry during snowmelt
- Lecture on heat budget of a snow pack

Mar. 15 (Sun) Technical bus tour to

- Niigata Experiment Laboratory, Public Works Research Institute
- Tohkamachi Experiment Station, Forestry and Forest Products Research Institute
- Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth
- Science and Disaster Prevention(Stay overnight at a Spa, Yomogihira Hot Spring, in the snowy region)

Mar. 16 (Mon)

- Technical bus tour continues to Myoken Weir, Shinano River
- Facilities for snow removal by melting in Nagaoka City
- Shinano River Work Office, Hokuriku Regional Construction Bureau
- Oukouzu Division Work, Shinano River and the Division Work Museum
- Arai Weir, Shinano River
- Fabrication of the Endo-type snow-water content meter (2)

Mar. 17 (Tues)	• Practice session for heat exchange over a snow surface
Mar. 18 (Wed)	• Practice session for snow pit observations
Mar. 19 (Thurs)	• Data handling exercise (reception in the evening)
Mar. 20 (Fri)	• Report preparation
	• Move from Myoko to Nagoya (train ride)
Mar. 21 (Sat)	• Closing ceremony
Mar. 22 (Sun)	• Departure from Nagoya

16.4 T8 The Eighth IHP Training Course, 1999 on Remote Sensing

Recently, the environmental problems attracts strong attentions. The spatial scales of the problems range from very local one to global one. Environmental problems have close connection to atmospheric and hydrospheric phenomena. For the atmospheric and hydrospheric sciences, satellite remote sensing is very useful and essential because of its capability to observe the atmosphere and hydrosphere in a big scale. For example, recently launched TRMM (Tropical Rainfall Measuring Mission) is providing us a unique three-dimensional rain structures regardless of the location over tropical and a part of midlatitude regions. ADEOS (Advanced Earth Observing Satellite) gave us beautiful images of global phytoplankton distribution over global ocean.

Ground-based remote sensing which includes radars and lidars is also useful for the atmospheric observation.

The lectures give: the basic theory of remote sensing, technogy and applications, and current Earth observation satellites, etc.