NOTE

Yasuhiro Satoh · Keiko Kikuchi · Shingo Kinoshita
Hiroko Sasaki**Potential capacity of coprecipitation of dissolved organic carbon (DOC) with iron(III) precipitates**

Received: March 15, 2006 / Accepted: August 1, 2006 / Published online: October 31, 2006

Abstract Hypolimnetic anoxic water of Lake Onogawa was subjected to aeration experiments. When the samples were agitated by magnetic stirrers for 24 h, dissolved oxygen increased from 0 to more than 7.6 mg l^{-1} , dissolved iron decreased from 98% to about 5% of the initial total iron, and from 32% to 48% of the dissolved organic carbon (DOC) disappeared. On the other hand, when the anoxic waters were left unstirred, dissolved oxygen increased from 0 to 2.2 mg l^{-1} , dissolved iron decreased from 98% to 31%, and 20% of the DOC disappeared within 48 h. Further 24-h incubation had little effect on the DOC loss, although dissolved oxygen increased to 3.9 mg l^{-1} and dissolved iron decreased to 5%. These rates of DOC disappearance are too large to be explained by bacterial decomposition. It is quite conceivable that a part of the DOC is coprecipitated with iron(III) precipitates. When Fe(II) in the anoxic hypolimnion is oxidized by autumnal water mixing, probably anoxic water is mixed with aerobic water. The anoxic water must receive oxygen from the aerobic water during this mixing and be simultaneously diluted with the aerobic water. Because the present experimental conditions, especially the stirred one, significantly differ from in situ conditions, the present results are thought to be a potential capacity of DOC coprecipitation.

Key words Lake Onogawa · Anoxic water · Aeration · Manganese

Introduction

The distribution, production, decomposition, and ecological role of dissolved organic matter in natural waters have attracted the attention of many scientists since the early twentieth century (e.g., Pütter 1908; Krough 1930; Birge and Juday 1934). The technological progress of dissolved organic carbon (DOC) analyses (Menzel and Vaccaro 1964; Sugimura and Suzuki 1988; Sharp et al. 1995) and bacterial abundance (Hobbie et al. 1977) and production methodologies (Fuhrman and Azam 1980) have revealed the importance of DOC in aquatic ecosystems and led to the concept of the “microbial loop” (coined by Azam et al. 1983). The microbial loop stems from the detrital organic pool, which is mostly in a dissolved form. Recently our knowledge of DOC has been markedly advanced (Wetzel 2001; special issue of *Hydrobiologia* edited by Salonen et al. 1992). Wetzel (2001) reviewed the recent development of carbon metabolism in lakes, concluding all lakes and streams are essentially heterotrophic in which the decomposition of detrital organic matter through the microbial loop exceeds autochthonous organic matter production. Thus, the fate of DOC, which partially sustains lakes energetically, is one of the most important subjects in lake metabolism.

Hypolimnetic dissolved oxygen in a stratified productive lake is often exhausted. Reduced iron(II) and manganese(II) are released from the sediment when the hypolimnion becomes anoxic (Mortimer 1941, 1942; Wetzel 2001). These dissolved metals are then oxidized to iron(III) and manganese(IV) when they are exposed to oxygen during seasonal water circulation. The solubility of the iron(III) and manganese(IV) compounds is sufficiently small to form precipitates. The most common species of Fe(III) in natural waters is hydrated iron(III) hydroxide oxide, which is commonly positively charged (Wetzel 2001). The iron(III) precipitates electrostatically coprecipitate negatively charged colloids and dissolved substances, including organic matter. According to Gu et al. (1994), ligand exchange is the main binding mechanism between hematite ($\alpha\text{-Fe}_2\text{O}_3$) and dissolved organic matter.

Y. Satoh (✉) · K. Kikuchi · S. Kinoshita · H. Sasaki
Faculty of Science, Yamagata University, Yamagata 990-8560, Japan
Tel. +81-23-628-4589; Fax +81-23-628-4510
e-mail: hirosato@sci.kj.yamagata-u.ac.jp

Contribution No. 26 from the Urabandai Limnological Station,
Yamagata University

Knowledge of the coprecipitation of dissolved organic matter with iron(III) precipitates is limited. Akiyama (1971) microscopically confirmed the existence of the aggregates of iron and organic matter in natural waters by using a staining technique, although the aggregates appeared to originate from mostly decomposed organisms. Akiyama and Hanya (1968a) mixed some natural and artificial waters with iron(III) chloride to examine the controlling factors on the coprecipitation of DOC with iron(III) precipitates. The coprecipitation was pH dependent, having an optimum pH of 4.8–5.0. In similar results shown by Hori et al. (1998), DOC in waters of Lake Biwa most effectively coprecipitated with iron(III) precipitates at pH ranging from 4 to 6. Temperature, salinity, and the degree of stirring scarcely affected the maximum amount of DOC coprecipitation (Akiyama and Hanya 1968a). Akiyama and Hanya (1968b) found carboxyl and hydroxyl groups in the coprecipitated organic matter. Hori et al. (1994) studied the adsorption behaviors of carboxylates and their analogues onto iron(III) precipitates. The coprecipitation capacity of iron(III) precipitates was also used for the characterization of dissolved organic matter (Hori et al. 1998; Sugiyama and Kumagai 2001).

The present study provides experimental evidence of the potential capacity of the coprecipitation of naturally occurring dissolved organic carbon at the time when iron(III) precipitate is formed by artificial oxidation of naturally occurring iron(II) in lake water.

Materials and methods

Hypolimnetic anoxic water of Lake Onogawa was used for the experiments. Lake Onogawa (37°40' N, 140°06' E) lies on the Urabandai Plateau, northeast Japan (see map in Satoh et al. 2001). It is a dammed dimictic lake formed at the time of the volcanic eruption of Mt. Bandai in 1888 (Murayama 1973). Its altitude is 794 m above mean sea level. The maximum depth is 21 m, and it covers an area of 1.4 km² (Horie 1962). The water volume is approximately 0.014 km³ (Satoh et al. 1995). The trophic status of this lake is on the boundary between meso- and eutrophic (Satoh et al. 1996).

Water samples from 40 cm above the lake bottom were collected from the same station as by Satoh et al. (2001) using a handmade water sampler (Fig. 1). A vinyl tube 7 mm in inner diameter was weighted and lowered from a boat. The mouth of the tube was connected in air tight fashion to a tandem series of three 1-l glass bottles, and the water was then sucked up with a hand pump. The water sample was fed into the bottom of the first bottle. When the first bottle was full, the water was then fed into the bottom of the second bottle from the top of the first bottle. After the third bottle was filled with lake water, the water in the third bottle was discarded and the third bottle was refilled again. The water in the first bottle was calculated to be renewed four times and the second bottle three times by this procedure. The first bottle was sealed airtight and trans-

Fig. 1. Water sampler

ported to our field station near the lake. The water in the second bottle was used for the time zero sample for dissolved oxygen. The water in the first bottle was filtered through a 60- μ m nylon net in a plastic globe bag filled with nitrogen gas. To enhance oxygen penetration, about 130 ml water was removed from the bottle just before the experiments started so as to enlarge the surface area from about 9 to 60 cm². The prepared water samples were then used for the aeration experiments.

The aeration experiments were conducted twice. The first experiment was carried out from October 18 to 21, 2005. There were triplicates for each treatment as follows unless otherwise stated. Twenty-seven bottle samples were prepared as already described. Three bottles were randomly selected for time zero samples for chemical analyses. The time zero samples were filtered through preignited Whatman GF/F glass fiber filters in the nitrogen-filled globe bag as soon as possible. The six randomly selected samples were agitated with magnetic stirrers. After 24 h, 3 of the 6 bottles were selected for determining dissolved oxygen. The other 3 samples were filtered through preignited Whatman GF/F glass fiber filters for chemical analyses. The filtrates of time zero and incubated samples were stored frozen until the chemical analyses could be conducted. The rest of the 18 bottles were left unstirred. After 24, 48, and 72 h, 6 bottles were randomly sampled for the dissolved oxygen and chemical analyses on each occasion. The second experiment was conducted from November 1 to 2, 2005. Only the 24-h stirred experiment was carried out at this time.

Dissolved oxygen was determined by the Winkler method. Water samples were siphoned from the sample bottles for dissolved oxygen measurements. As the oxygen penetration into the water samples was expected to be depth dependent, the determination of dissolved oxygen after the incubation was carried out four or five times per bottle so as to use the water from near the surface to near the bottom of the bottle. Iron and manganese were measured by atomic absorption spectrometry (Perkin Elmer model 3100). Analytical grade concentrated nitric acid (Wako Pure Chemical Industries) was added to a part of the unfiltered water samples to a final concentration of 1% immediately after sample collection for total metal analyses. The acid also was added to a part of the filtered sample through Whatman GF/F glass fiber filters for dissolved

metals analyses. DOC was determined by using a TOC meter (Shimadzu model TOC-5000).

The concentrations of total iron and total manganese before the incubations were used to calculate the percentages of dissolved metals after the incubations, because it was impossible to measure the total iron and total manganese after the incubations for the following reasons. In agitated incubations, the formed precipitates quickly deposited when subsamples for total metals were taken from the bottles, which would have resulted in an underestimation of the total metal concentrations. In unagitated incubations, the metals were lost as dark orange films that adhered to the glass above the water line.

Results

Lake conditions

Table 1 shows the results of some physicochemical analyses in the layer above 40 cm from the lake bottom, from which the water samples used for the experiments were collected. This layer became anoxic in August. The anoxic layer lasted until early November. The concentrations of both total iron

Table 1. Water temperature (WT, in °C), dissolved oxygen (DO, in mg l⁻¹), pH, dissolved organic carbon (DOC, in mg l⁻¹), total iron (Fe, in mg l⁻¹), and total manganese (Mn, in mg l⁻¹) in the layer at 40 cm above the lake bottom

	WT	DO	pH	DOC	Fe	Mn
April 29	7.8	10.7	6.80	2.0	0.14	0.16
May 26	9.0	7.8	5.51	2.0	0.17	0.20
June 22	9.4	3.5	5.36	2.1	0.80	0.39
July 20	9.4	0.2	6.18	1.6	6.0	1.5
August 18	9.4	0.0	6.85	–	9.2*	1.9*
September 8	9.4	0.0	6.81	2.9	8.5	1.8
September 26	9.5	0.0	6.11	3.1	8.3	1.8
October 20	9.5	0.0	5.94	6.7	16.5	2.4
November 1	9.5	0.0	–	10.4	26.7	3.4
November 10	10.1	9.3	5.70	2.6	0.78	0.24

* Data not from 40cm but 70cm above the lake bottom

Table 2. Results of the stirred experiments

October 18–19									
Time (h)	DO	Total Fe	Dis. Fe	Dis. Fe (%)	Total Mn	Dis. Mn	Dis. Mn (%)	DOC	Lost DOC
0	0.00 ± 0.00	16.5 ± 0.7	16.1 ± 0.7	98	2.4 ± 0.1	2.4 ± 0.1	100	6.7 ± 0.3	–
24	7.96 ± 0.47	–	1.0 ± 0.2	6	–	2.3 ± 0.1	94	4.6 ± 0.5	31%*
November 1–2									
Time (h)	DO	Total Fe	Dis. Fe	Dis. Fe (%)	Total Mn	Dis. Mn	Dis. Mn (%)	DOC	Lost DOC
0	0.00 ± 0.00	26.7 ± 2.4	26.1 ± 2.1	98	3.4 ± 0.2	3.4 ± 0.2	100	10.4 ± 1.3	–
24	7.63 ± 0.53	–	1.4 ± 0.4	5	–	2.6 ± 0.2	78	5.4 ± 0.7	48%*

Dis., dissolved

Values are averages and standard deviations of three replicated incubations

Units of dissolved oxygen (DO) and metals are in mg l⁻¹

* Significance level, <0.01

and total manganese were less than 0.2 mg l⁻¹ in spring. Total iron increased with time to 26.7 mg l⁻¹ in early November and total manganese to 3.4 mg l⁻¹. The concentrations of DOC were about 2 mg l⁻¹ in spring and early summer. DOC increased with time to 10 mg l⁻¹ in early November. After the autumnal water circulation, total iron, total manganese, and DOC decreased to 0.78 mg l⁻¹, 0.24 mg l⁻¹, and 2.6 mg l⁻¹, respectively.

Stirred experiment

Twenty-four hours of stirring resulted in an increase in dissolved oxygen from 0 at time zero to more than 7.6 mg l⁻¹ (Table 2). Based on a room temperature around 20°C, this concentration was more than 85% saturation level. Almost all iron and manganese in the time zero samples was in dissolved form: 98% for iron and 100% for manganese. After the 24-h incubation, the color of the water samples changed from transparent to dark orange, and the dissolved iron decreased to about 5% of the total. The dark orange substances were retained on Whatman GF/F glass fiber filters when the samples were filtered, resulting in transparent filtrates. In contrast, the dissolved manganese only decreased to 78%–94%. From 31% to 48% of the DOC disappeared during this incubation.

Unstirred experiment

Dissolved oxygen in the samples gradually increased from 0 to 3.9 mg l⁻¹ with time (Table 3). The final concentration of dissolved oxygen was about 45% saturation level. At the beginning of the incubation, almost all metals were in dissolved form, as previously mentioned. Dissolved iron gradually decreased to 5% together with the color change of the samples, as mentioned, whereas dissolved manganese remained almost unchanged. Three percent of the DOC was lost as compared with time zero samples in the first 24 h. However, this difference was insignificant. Another 24-h incubation resulted in a 20% loss of DOC. This difference was significant at $P < 0.01$. Further 24-h incubation had little effect on the decrease in DOC.

Table 3. Results of the unstirred experiments (October 18–21)

Time (h)	DO	Total Fe	Dis. Fe	Dis. Fe (%)	Total Mn	Dis. Mn	Dis. Mn (%)	DOC	Lost DOC
0	0.00 ± 0.00	16.5 ± 0.7	16.1 ± 0.7	98	2.4 ± 0.1	2.4 ± 0.1	100	6.7 ± 0.3	–
24	1.00 ± 0.41	–	12.9 ± 0.3	79	–	2.3 ± 0.1	94	6.5 ± 0.6	3%
48	2.15 ± 0.48	–	5.1 ± 0.1	31	–	2.5 ± 0.0	102	5.4 ± 0.3	20%*
72	3.94 ± 0.21	–	0.8 ± 0.0	5	–	2.3 ± 0.1	97	5.4 ± 0.7	20%**

Dis., dissolved

Values are averages and standard deviations of three replicated incubations

Units of dissolved oxygen (DO) and metals are in mg l⁻¹

* Significance level, <0.01

** significance level, <0.1

** The incubation was started in triplicate; however, one bottle was lost during the experiments, resulting in duplicate incubation

Discussion

The decrease of dissolved iron after the stirred and unstirred incubations must be attributed to the formation of insoluble Fe(III) compounds, mostly hydrated iron(III) hydroxide oxide (Wetzel 2001). The formation of the dark orange precipitates after the incubation supports this speculation. The reason why dissolved manganese remained almost unchanged is thought to be as follows: (1) the manganese redox potential is higher than that of iron and (2) the rate of oxidation of Mn(II) to Mn(IV) is slower than that of Fe(II) to Fe(III) (Wetzel 2001).

Two possible reasons are conceivable for the DOC loss shown in Tables 1 and 2: (1) microbial decomposition and (2) coprecipitation with iron(III) precipitates. Yagi (1986) observed that suspended manganese increased and DOC decreased at the redox zones in Lake Fukami-ike and Lake Suigetsu. The decrease of DOC was attributed not to coprecipitation with manganese precipitates but to bacterial decomposition. However, the main reason for the DOC loss in the present study is thought to be coprecipitation, as follows. The rate constants for microbial decomposition of DOC ranged from 0.0004 to 0.052 day⁻¹ for DOC derived from *Scenedesmus* (Ogura 1972a), from 0.0052 to 0.033 day⁻¹ for DOC in water from the north equatorial Pacific Ocean (Ogura 1972b), and from 0.0013 to 0.028 day⁻¹ for DOC in bog pool water (Sato and Abe 1987). From these rate constants, a maximum of 5% of the DOC would be decomposed in a day. In the minimum case, only 0.04% would be decomposed in a day. In the present experiments, from 32% to 48% of the DOC was lost in the stirred incubations within 24 h and 20% in the unstirred incubation within 48 h. The present DOC losses are too large to be explained by the microbial decomposition of DOC. The most common species of the oxidized form of iron in lake water, hydrated iron(III) hydroxide oxide, is usually positively charged (Wetzel 2001). Negatively charged functional groups of DOC such as the dissociated carboxylic group and phenolic hydroxyl group, which are some of the most common functional groups of DOC (Akiyama and Hanya 1968b; Thurman 1985), might react with the positively charged iron(III) precipitates, resulting in coprecipitation. In addition to these electrostatic interactions, H₂O and OH⁻ of iron(III) precipitates are replaced by

other ligands such as hydroxyl, phosphoryl, and carboxyl groups (Sugiyama and Kumagai 2001), which might also result in the coprecipitation of dissolved organic matter.

Agitation of the water sample had no effect on the formation of iron(III) precipitates. Finally, about 93% of the iron, which was the difference in the percentage of dissolved iron between time zero samples (98%) and incubated samples (5%), was oxidized in both the stirred and unstirred incubations, although their oxidation speeds differed (see Tables 2, 3). On the other hand, lost percentages of DOC were significantly different. From 1.6- to 2.4-fold DOC was coprecipitated with iron(III) precipitates in the stirred incubations as compared with the unstirred incubations. The present results are inconsistent with those of Akiyama and Hanya (1968a) in that the degree of stirring in their experiments showed little effect. It is interesting that although the amount of formed iron(III) precipitates was the same, much more DOC was removed when the samples were agitated. Undoubtedly the agitation greatly increased the number of collisions between the iron(III) precipitates and DOC, which was what drove the reaction. It is quite conceivable that this condition enhanced coprecipitation of DOC.

Another possible reason for this difference is pH. One of the most important factors controlling the coprecipitation between iron(III) precipitates and dissolved organic matter is pH. Sixty percent of dissolved organic matter in Lake Biwa water was coprecipitated with artificially added iron(III) precipitates at a pH ranging from 4 to 6 (Hori et al. 1998). Artificial iron(III) adsorbent removed 70% of dissolved organic matter in water from the canal of Lake Biwa at a pH ranging from 4 to 5 (Sugiyama and Kumagai 2001). The pH values of water samples in the layer above 40 cm from the bottom of Lake Onogawa were sometimes in the optimum range and sometimes slightly higher than the optimum range of the coprecipitation. If the pH of the samples after the agitated incubations was significantly lower than those of the unagitated incubations, higher coprecipitated percentages of DOC would be expected. However, we cannot discuss this further as we did not determine pH after the incubation. Even if agitated, the percentages of coprecipitated dissolved organic matter in the present study were smaller than the 60% of Hori et al. (1998) or 70% of Sugiyama and Kumagai (2001) with artificially added iron(III) hydroxide oxide. The difference in the pH and/or in the nature of dissolved organic matter in oxic and ano-

oxic waters might cause the difference. Agitated mixing of anoxic lake water such as was done in the present experimental conditions would never occur in a natural environment. From this point of view, the results of the stirred incubations are considered to be potential maxima.

It is noteworthy that there was no difference in the lost DOC percentages between 48-h and 72-h unstirred incubations (see Table 3). The present results suggest that (1) the coprecipitation of DOC under unstirred conditions finished relatively quickly within 48 h, when about 70% of the iron precipitates was formed, and (2) although potentially up to about 50% of the DOC was coprecipitable, it only partially coprecipitated in the unstirred incubations. The results of unstirred incubations may still be a potential capacity because the unstirred experimental conditions also differed from the in situ conditions. Fe(II) in the anoxic hypolimnion is oxidized upon autumnal water mixing in natural environments. Probably anoxic water is mixed with aerobic water. The anoxic water must receive oxygen from the aerobic water on this mixing and be simultaneously diluted by the aerobic water.

Thus, the coprecipitation of DOC with iron(III) precipitates makes a part of the DOC unavailable to the microbial loop in the water column. At the same time, it makes a part of the DOC available to the microbial loop at the lake bottom. On the other hand, when iron(III) is reduced to iron(II) in anoxic conditions, a part of the trapped DOC will be released to the lake water, resulting in an increase in the available DOC for the microbial loop in the water column. The influence of the iron cycle on DOC availability is worthy of further study.

In conclusion, the present study demonstrated that (1) it is quite possible that naturally occurring iron(II) in the hypolimnetic anoxic waters coprecipitates naturally occurring DOC when iron(II) is oxidized to iron(III); (2) up to about 50% of the DOC is potentially coprecipitable; and (3) only a part of the potentially coprecipitable DOC may coprecipitate in situ. Simulation of in situ conditions is expected to be the next step in this study.

Acknowledgments The authors are grateful to Dr. R. Jordan of Yamagata University for his helpful criticism on an earlier draft of this paper. Thanks are extended to Dr. M. Ochiai of Tokushima Bunri University and the two anonymous peer reviewers for their helpful comments and suggestions. This study was supported in part by a Grant-in-Aid for Scientific Research (C16510003) from the Japan Society for the Promotion of Science.

References

- Akiyama T (1971) Microscopic determination of iron-organic aggregates in sea and lake waters. *Geochim J* 5:39–56
- Akiyama T, Hanya T (1968a) Formation of particulate organic matter by coprecipitation with ferric hydroxide. 1. Coprecipitation capacity of Fe in natural waters (in Japanese). *J Chem Soc Jpn Pure Chem Sect* 89:933–938
- Akiyama T, Hanya T (1968b) Elemental composition and IR spectrum of coprecipitated organic matter (in Japanese). *J Chem Soc Jpn Pure Chem Sect* 89:939–943
- Azam F, Fenchel T, Field FG, Gray JS, Meyer-Reil L-A, Thingstad F (1983) The ecological role of water-column microbes in the sea. *Mar Ecol Prog Ser* 10:257–263
- Birge E, Juday C (1934) Particulate and dissolved organic matter in inland lakes. *Ecol Monogr* 4:440–474
- Fuhrman JA, Azam F (1980) Bacterioplankton secondary production estimates for coastal waters of British Columbia, Antarctica, and California. *Appl Environ Microbiol* 39:1085–1095
- Gu B, Schmitt J, Chen Z, Liang L, McCarthy (1994) Adsorption and desorption of natural organic matter on iron oxide: mechanisms, and models. *Environ Sci Technol* 28:38–46
- Hobbie JE, Daley RJ, Jasper S (1977) Use of Nuclepore filters for counting bacteria by fluorescence microscopy. *Appl Environ Microbiol* 33:1225–1228
- Hori T, Sugiyama Y, Sugiyama M (1994) Systematic comparison of adsorption behaviors of carboxylates and their analogues onto hydrous iron (III) oxide (in Japanese). *Bunseki Kagaku* 43:965–970
- Hori T, Sugiyama Y, Sugiyama M (1998) Chemical and physicochemical characteristics of dissolved organic carbon circulating in harmonic Lake Biwa, Japan. *Jpn J Limnol* 59:39–52
- Horie S (1962) Morphometric features and the classification of all the lakes in Japan. *Mem Coll Sci Univ Kyoto (B)* 29:191–262
- Krogh A (1930) Über die Bedeutung von gelösten organischen Substanzen bei der Ernährung von Wassertieren. *Z Vgl Physiol* 12:668–681
- Menzel DW, Vaccaro RF (1964) The measurement of dissolved organic and particulate carbon in seawater. *Limnol Oceanogr* 9:138–142
- Mortimer CH (1941) The exchange of dissolved substances between mud and water in lakes. *J Ecol* 29:280–329
- Mortimer CH (1942) The exchange of dissolved substances between mud and water in lakes. *J Ecol* 30:147–201
- Murayama I (1973) Volcanic activity and topography (in Japanese). Taimeido, Tokyo
- Ogura N (1972a) Decomposition of dissolved organic matter derived from dead phytoplankton. In: Takenouchi AY, Anraku M, Banse K, Kawamura T, Nishizawa S, Parsons TR, Tsujita T (eds) *Biological oceanography of the Northern North Pacific Ocean*. Idemitsu Shoten, Tokyo, pp 507–515
- Ogura N (1972b) Rate and extent of decomposition of dissolved organic matter in surface water. *Mar Biol* 13:89–93
- Pütter A (1908) Die Ernährung der Wassertiere. *Z Allg Physiol* 7:283–320
- Salonen K, Kairesalo T, Jones RI (1992) Dissolved organic matter in lacustrine ecosystems: energy source and system regulator. *Hydrobiologia* 229:1–291
- Satoh Y, Abe H (1987) Dissolved organic matter in colored water from mountain bog pool in Japan. II. Biological decomposability. *Arch Hydrobiol* 111:25–35
- Satoh Y, Nakamura S, Ochiai M (1995) Submerged grove in Lake Onogawa. *Jpn J Limnol* 56:45–48
- Satoh Y, Nakamura S, Katoh K, Sagisaka H (1996) Distribution of some physicochemical parameters and trophic status of Lake Onogawa. *Jpn J Limnol* 57:145–152
- Satoh Y, Sasaki M, Miyamori Y, Sugawara K, Nishi T, Nishizuka M, Inamura K, Yamagami Y (2001) Perturbation of a water column of Lake Onogawa by local heavy rainfall. *Limnology* 2:11–18
- Sharp JH, Benner R, Bennett L, Carlson CA, Fitzwater SE, Peltzer ET, Tupas LM (1995) Analyses of dissolved organic carbon in seawater: the JGOFS EqPac methods comparison. *Mar Chem* 48:91–108
- Sugimura Y, Suzuki Y (1988) A high-temperature catalytic method for the determination of non-volatile dissolved organic carbon in seawater by direct injection of a liquid sample. *Mar Chem* 24:105–131
- Sugiyama Y, Kumagai T (2001) Chemical characterization of organic carbon dissolved in natural waters using inorganic adsorbents. *Anal Sci* 17:77–82
- Thurman EM (1985) *Organic geochemistry of natural waters*. Nijhoff/Junk, Dordrecht
- Wetzel RG (2001) *Limnology*, 3rd edn. Academic Press, San Diego
- Yagi A (1986) Dissolved organic carbon and manganese in the boundary of the oxic and anoxic layers in Lakes Fukami-ike and Suigetsu-ko. *Jpn J Limnol* 47:291–298