Factors controlling organic pollution in Lake Kiba with shallow and semi-closed environment

Dissertation

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Abstract

Lake Kiba is located at Komatsu City, Ishikawa Prefecture, Japan and is a small, shallow and semi-closed lake environment. The chemical oxygen demand concentration was at a maximum, 11 mg l^{-1} in 1990 and has remained about double the national standard of this lake class during the last decade. The objective of this study is to investigate present organic pollution and its controlling factors. We determined organic matter content and its characteristics recorded in the sediment core samples. Organic matter flux increased from 3.9 to 7.5 mgC cm^{-2} y^{-1} during 1989–2012, and $\delta^{13}C$ and $\delta^{15}N$ also changed during the time interval. During 2012–2016, a strong positive correlation was found between the COD concentration and physicochemical parameters such as water temperature, pH, and chlorophyll-a concentration. Similar results were observed for particulate and dissolved organic matter in the lake water throughout one year. The carbon isotopes ($\delta^{13}C$, $\Delta^{14}C$) showed seasonal variation with higher concentrations in summer and positive correlations with POC content. The results suggest that the characteristics of POC and DOC are controlled by a mixture of two endmembers: organic matter produced by phytoplankton activity within the lake and watershed organic matter under shallow and semi-closed environments.

Lakes play important roles in the carbon cycle through carbon sequestration in sediments and efflux of CO_2 to the atmosphere. Some lake environments in developing countries have been facing organic pollution over the last decade because of rapid economic development and an increase in the human population around watersheds. In Japan, results of water quality surveys of lakes and reservoirs in 2014 indicated that the compliance rate of environmental quality standards for living environmental items is 55.5% for chemical oxygen demand (COD) concentration. Another water quality problem is the slight increase in COD concentrations in lakes, though total nitrogen, phosphorus and biochemical oxygen demand (BOD) concentrations are constant or decrease with time. The increasing annual averages of COD appear to be caused by accumulation of refractory organic matter in the lakes. Therefore, the dynamics of organic matter are important to understand mechanism of organic pollution in lake systems.

Lake Kiba is located at Komatsu City, Ishikawa Prefecture, Japan and is a small, shallow and semi-closed lake environment. The chemical oxygen demand (COD) concentration was at a maximum, 11 mg L^{-1} in 1990, corresponding to the second worst in Japan. It has remained about double the national standard of this lake class (3 mg L^{-1}) during the last decade, though treatments for water quality improvement has been performed since 1991.The objective of this study are to understand present situation of organic pollution and its controlling factors in Lake Kiba.

To understand organic pollution in Lake Kiba over the last 100 years, we analyzed organic matter content and its characteristics recorded in the sediment core samples collected in the central part of the lake. Organic matter flux increased from 1.1 to 2.3 and from 3.9 to 7.5 mgC cm^{-2} y^{-1}, during 1903–1974 and 1989–2012 respectively,

although it was similar with the flux recorded for 1974–1989 following reclamation. The C/N ratio, $\delta^{13}C$ and $\delta^{15}N$ also changed during these time intervals. These results indicate that primary production is increasing with time and the recent contribution of phytoplankton to productivity has exceeded the level of past contributions.

During 2012–2016, a monitoring study was conducted for lake water environments. A strong positive correlation was found between the COD concentration and physicochemical parameters such as water temperature, pH, and chlorophyll-a concentrations. This indicates that the COD variation is controlled by phytoplankton activity in the lake. Particulate COD was 8–51% of total COD concentration, with an average value of 34 ± 11%. A positive correlation exists with particulate and dissolved COD concentrations. Results suggest that the input and output of particulate and dissolved COD in Lake Kiba are apparently similar year-round.

To understand more detailed variation mechanisms, we focused on the dynamics of particulate and dissolved organic matter in lake water throughout one year based on monthly observations during 2014–2016. The simultaneous use of $\Delta^{14}C$ and $\delta^{13}C$ values adds a second dimension to carbon cycling in surface aquatic environments. During the sampling period, we ascertained the basic physicochemical parameters, particulate organic carbon (POC) concentration and carbon isotopes. POC concentrations ranged from 0.44 to 5.01 mg l^{-1}. $\delta^{13}C$ and $\Delta^{14}C$ values were –30.3 to –22.8 ‰ and –156 to –33 ‰, respectively. The organic matter in suspended solid samples was consistently depleted for ^{14}C and an averaged $\Delta^{14}C$ value of –81 ± 37‰. The carbon isotopes showed seasonal variation with higher concentrations in summer and positive correlations with POC content (r = 0.73 – 0.82, p< 0.01). The results suggest that the characteristics of POC are controlled by a mixture of two endmembers: organic matter

produced by phytoplankton activity within the lake and watershed organic matter under shallow and semi-closed environments. Dissolved organic carbon (DOC) concentrations were higher in summer and had strongly relations with water temperature and water pH. Fulvic-like materials, which have refractory properties and are a major component of organic matter, were correlated well with DOC concentrations. However, maximum fluorescence peak position in water samples collected in spring-summer is shifted to shorter excitation wavelengths than that of autumn-winter. These results suggest that sources of fulvic-like materials are different from the spring-summer to autumn-winter seasons.

The results of this study provide basic and useful information of understanding organic pollutants in shallow lakes and lagoons.

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学位論文審査報告書（甲）

１．学位論文題目（外国語の場合は和訳を付けること。）

Factors controlling organic pollution in Lake Kiba with shallow and semi-closed environment　（半閉鎖性浅水湖沼の木場潟における有機汚濁の原因解明）

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３．審査結果の要旨（600～650 字）

標記学位論文を全審査委員が個別に審査した後、各委員による申請者への個別の面談等による予備審査を実施した。その後、口頭発表会を平成 29 年 2 月 2 日に開催し、発表終了後、論文審査委員会において論文を審査した。審査結果を以下に記す。湖沼環境の水環境問題は地球規模での環境問題の 1 つとして位置づけられ、水深が浅く閉鎖的な水環境の有機汚濁が進行している。本研究で対象とする木場潟は平均水深が約 2m と浅く、洪水被害や周辺の潟の埋め立てによる可動式ゲートの設置により半閉鎖的な環境を呈している。本研究では、2014 年から 2016 年まで 1 ヶ月に 1 回の水質観測を実施するとともに、湖底堆積物を採取し、過去から現在までの有機物の堆積状況を調べた。その結果、1)現在の有機物の堆積量は約 100 年前に比べて 6 倍程度高く有機物の生産性が増加していること、2)有機汚濁指標の COD は、溶存態と粒子態の有機炭素濃度とともに夏季に高くなる季節変動を示し、水温・ｐH・クロロフィル a 濃度と高い正の相関性が認められた。また、三次元蛍光分光光度法、炭素同位体比（$\delta^{13}C$、$\Delta^{14}C$）から夏季の有機炭素濃度の増加は湖内生産、冬季の濃度低下時には流域からの有機物の寄与が相対的に増加することを明らかにした。本成果は、木場潟や同様の水環境を有する湖沼に関して有機汚濁対策に有効なデータを提供できる。従って、本博士論文は博士（理学）の学位に値すると判断した。

４．審査結果　(1) 判　　定（いずれかに○印）　○合　格　・　不合格

(2) 授与学位　　博　士（　理学　）