学位論文の要旨

Abstract of Thesis

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学位論文題目 Title of Thesis（学位論文題目が英語の場合は和訳を付記）

The process of seasonal and vertical dynamics of nutrient cycle in Lake Biwa
（琵琶湖における栄養塩循環の季節および鉛直変動過程）

学位論文の要旨 Abstract of Thesis

Lake Biwa is the largest lake in Japan ranked 130th among the world's freshwater lakes. The lake is separated into two parts, the northern main and deeper basin and the southern small and shallower one. There are many rivers of various sizes flowing into the lake. However, only one outflow from the lake (the Seta River), apart from canals constructed during early modern times. The difference in the physical structure and nutrient status between the two basins have given rise to a valuable diversity of biological and chemical ecosystem in the lake. In the North basin, with the deep averaging 44 m, thermal stratification occurs from spring to autumn, typically monomictic with the turnover period between February and March, creating a specific ecosystem and biogeochemical processes. While the South Basin is warm polymictic due to the shallowness (Tezuka, 1992). In the North Basin, regarding the current trophic status, total nitrogen (TN) and total phosphorus (TP) assessed by Sakamoto (2011) the grade is mesotrophic in terms of TN but oligotrophic in terms of TP.

Currently, Lake Biwa has undergone progressive eutrophication in the past few decades. It is facing the issues of toxic algal blooms and may be affected by eutrophication and global warming. Nutrients as phosphorus (P), Nitrogen (N), and Silicon (Si), in particular, hold the key roles for the water quality of lakes (Goto et al., 2007, Kowalczewska-Madura et al., 2018). It is a strong requirement for primary production through elucidating phytoplankton biomass - nutrients relationship in lakes (Søndergaard et al., 2001, 2007, Kuczyńska-Kippen et al., 2010, Filstrup and Downing, 2017). Chlorophyll-a (Chl-a), on the other hand, is well-known as an indicator of phytoplankton biomass. Increasing nutrient loading to the aquatic eco-system results in an enhanced primary production that leads to undesirable changes in aquatic resources. Moreover, physical,

chemical, and biological processes and water quality formation processes are closely affected by water currents. There are mainly currents caused by great gyres and periodic currents caused by internal waves in the lake. However, the effect of both biological and physical factors on the fluctuation of nutrients and Chl-a. Therefore, the overarching objective of this thesis was to improve understanding of the seasonal and vertical dynamic of nutrient cycle and phytoplankton change under the effect of biological and physical processes in Lake Biwa

In the first study, the external loading process to Lake Biwa was described using a hydrological tank model and loading-discharge curve. The model was applied to collective drainage basins of the lake's Imazu (northwest), Hikone (northeast), and Otsu (south) areas. The hourly model was conducted using particular discharges from the Kita (Ado) river, Takatoki (Ane) river and the trunk of Yasu River to obtain loading curves for phosphate (PO_4) and silica (SiO_2) by assimilating the collected concentrations (2002-2003). The model was updated by adding an evapotranspiration routine and direct paths to lacustrine groundwater discharges of the lake floor. The daily model was calibrated through an analysis of water budget among the basin, inflow, lake, and outflow (1991-1995), then validated. The daily tank model was established and combined into a loading-discharge curve to determine the long-term external nutrient loads entering the lake. However, the relationship between nutrient loading and nutrient concentration offshore station was still unclear and the role of seasonal fluctuation of loading on the lake nutrient was questioned.

The second study describes nutrient patterns using biochemical and physical measurements in Lake Biwa. Seasonal variation in profiles of water temperature, pH, SiO_2, TN, TP, and Chl-a was compiled and analyzed. By using the flux profiles which were the monthly averaged flux profiles from 1980 to 2015 consisting of five successive periods of averaged for seven years each, temporal evolution could be elucidated, including decomposition in winter, blooming in spring, sustaining in summer, and settling in autumn. The downward flux value showed the sedimentation rate of biomass. It was inferred that nutrients and Chl-a fluxes in the North basin were influenced by the gyre in summer and internal seiches in autumn. On the other hand, the relationship of external loading and lake water quality showed that the flows affected the distribution of phosphorus and silicate concentrations in the epilimnion and metalimnion while strong sedimentation was observed in the hypolimnion. It is suggested that phytoplankton composition and reed biomass has been related to the fluctuation of nutrient supply from rivers surrounding Lake Biwa.

The final study focuses to analyze the physical transport including the gyres-internal wave effect on the distribution of Chl-a and nutrients. Water temperature profiles were recorded at stations, 17B-North and 12B-South in the north basin of Lake Biwa. Buoyancy fluxes at the stations were of

opposite phases, and amplitude was higher at the South for which representative area is narrower than the North. The summer lake became stably stratified, and the internal seiches period was shortest at 46 hours in July to August before increasing to 54 hours in September, and 66 hours in October as the literature suggested. The stability at 17B is due to the first gyre, established in July to suppress internal seiches, while the third gyre at 12B was advective, causing vertical mixing. On the other hand, the surface data of Chl-a and nutrients in several inshore (A and C) and offshore stations (B) surrounding the Lake were compared. It found that phytoplankton was transported from inshore to offshore, south to north. The Chl-a was kept within the epilimnion by the gyre activity in summer. Then convective Chl-a fluxes downward were seen in the thermocline in September to October when the stirring efficiency of water was highest in the deep lake with basin-scale internal waves, and destratification of the monomictic lake was shown with a frequency modulation due to a reduction in internal celerity.

Finally, we conclude that the nutrient cycle and phytoplankton dynamics in Lake Biwa are complicated which be affected by not only internal processes (thermal mixing, gyres, internal waves, resuspension nutrient supply) but also long-term external process (nutrient loads and accumulation). From our results, we suggest the BGSD (Bloom-Gyre-Seiching-Decomposition) processes with the concept as blooming in spring, sustaining in summer, settling in autumn, and decomposition in winter. This concept could explain the seasonal and vertical change of nutrient transport and biochemical succession in Lake Biwa.

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