論文内容の要旨

論文題目　Stable isotopic analyses of organic matter dynamics in aquatic ecosystems

（水圏生態系における有機物動態の安定同位体解析）

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Chapter 1

General introduction

Water columns of large lakes and the oceans can be divided into two layers; the shallow, euphotic layer where net photosynthesis proceeds, and the deeper, aphotic layer characterized by the prevalence of heterotrophic processes. Vertical transport of organic matter is mediated by dissolved organic matter (DOM) and particulate organic matter (POM). Transformation and remineralization of organic matter in the aphotic layer represent one of the key processes that control nutrient cycling, O_2 consumption, and food web dynamics in aquatic environments. However, sources and transformation pathways of organic matter in the aphotic layer are not fully understood. C and N stable isotope ratios of organic matter change systematically by reaction-dependent isotope fractionation and subsequent mixing. Stable isotope approaches have been increasingly used in studies of ecology and biogeochemistry in aquatic environments. In this dissertation, I developed novel stable isotope approaches to examine sources and transformation of organic matter in the aphotic layer of pelagic ecosystems. My objectives were: (1) to examine the source of semi-labile dissolved organic carbon (DOC) in a large freshwater lake (Lake Biwa) (Chapter 2), and (2) to examine relative importance of bacteria and zooplankton for POM transformation in the aphotic layer of Sagami Bay and Lake Biwa (Chapter 3).

Chapter 2

Autochthonous origin of semi-labile dissolved organic carbon in a large monomictic lake (Lake Biwa, Japan): Carbon stable isotopic evidence

Semi-labile DOC plays an important role in the transport and hypolimnetic remineralization of C in large freshwater lakes. However, sources of semi-labile DOC in lakes remain unclear. The present study used a C stable isotope approach to examine relative contributions of autochthonous and allochthonous sources to semi-labile DOC. Vertical and seasonal variations in the concentration and carbon stable isotope ratio ($\delta^{13}C$) of DOC were determined in large, monomictic Lake Biwa. A sharp vertical gradient of $\delta^{13}C$ of DOC ($\delta^{13}C$-DOC) during the stratification period (mean ± SE: −25.5 ± 0.1‰ and −26.0 ± 0.0‰ in the epi- and hypolimnion, respectively) indicated the accumulation of ^{13}C-rich DOC in the epilimnion. Vertical mixing explained the intermediate values of $\delta^{13}C$-DOC (−25.7 ± 0.0‰) measured throughout the water column during the overturn period. Both DOC concentration and $\delta^{13}C$-DOC decreased in the hypolimnion during stratification, indicating selective remineralization of ^{13}C-rich DOC. Using a two-component mixing model, I estimated the $\delta^{13}C$ value of semi-labile DOC to be −22.2 ± 0.3‰, which was close to the $\delta^{13}C$ of particulate organic carbon collected in the epilimnion during productive seasons (−22.7 ± 0.7‰) but much higher than the $\delta^{13}C$-DOC in river waters (−26.5 ± 0.1‰). Semi-labile DOC appeared to be mainly autochthonous in origin, produced by planktonic communities during productive seasons.

Chapter 3

Transformation of particulate organic matter in the aphotic layer of aquatic systems: Analysis of compound specific nitrogen stable isotope composition of amino acids

POM plays important roles in the vertical delivery of organic matter. Transformation of POM in the aphotic layer is known to be accompanied by the increase in nitrogen stable isotope ratio ($\delta^{15}N$) due to the isotopic fractionation during remineralization by bacteria and zooplankton. However, relative contributions of bacteria and zooplankton to the $\delta^{15}N$ enrichment of POM are not well understood. Recent studies have revealed that the extent of $\delta^{15}N$ enrichment differs among different amino acids residing in zooplankton. The $\delta^{15}N$ values of alanine, valine leucine, isoleucine, and glutamic acids (AA-I) increase with the increase in the trophic position, whereas the $\delta^{15}N$ values of methionine and phenylalanine (AA-II) do not deviate from the values of the food source. This pattern appears to differ from that of bacteria, although changes in $\delta^{15}N$ of amino acids ($\delta^{15}N$-AAs) of bacteria have been understudied. In this study, I examined systematically changes in $\delta^{15}N$-AAs of bacteria grown on different types of substrate with different C:N ratios. I also collected samples in the water columns of Sagami Bay and Lake Biwa to determine the depth profiles of $\delta^{15}N$-AAs of POM. I found that patterns in changes of $\delta^{15}N$ values of AA-I and AA-II of bacteria differed depending on the type and C:N ratio of the substrate. When glutamic acid was used as a single N source (C:N ratio = 5), both AA-I and AA-II of bacteria were enriched with ^{15}N to the same extent, suggesting that the pattern is distinctive from that of zooplankton. From the euphotic layer to the aphotic layer in Sagami Bay, the extent of the elevation in $\delta^{15}N$ of AA-I of POM over depth (5.4–8.0‰) was more pronounced than that of AA-II (1.5–2.8‰). In contrast, in Lake Biwa, both AA-I and AA-II of POM increased by 11.3‰ with depth. To interpret the above data, I constructed a model (IER model) to explain contributions of bacteria and zooplankton to POM transformation.

The results suggested that bacteria were the major mediator of POM transformation in Lake Biwa, whereas both bacteria and zooplankton contributed to POM transformation in Sagami Bay.

Chapter 4

General discussion

The present study used C and N stable isotope approaches to examine sources and transformation processes of organic matter in the aphotic layer of aquatic ecosystems. My findings in Chapter 2 suggest that hypolimnetic remineralization is affected by pelagic primary production during productive seasons of the preceding year. Thus, changes in the extent of semi-labile DOM production may impact on the extent of nutrient regeneration and O_2 depletion in the aphotic layer. In order to understand the controlling factor of the semi-labile DOM production, future studies should identify the organisms that are responsible for the formation of semi-labile DOM. The IER model developed in Chapter 3 is useful to evaluate relative importance of bacteria and zooplankton in organic matter transformation and remineralization in the aphotic layers. However, in order to improve the precision of the assessment, further studies are required to better understand patterns in changes of δ^{15}N-AAs when bacteria use a complex mixture of organic matter in natural environments.