Seasonal Changes in Phytoplankton characteristics in a Hyper-eutrophic Water Area under Nitrogen Limitation

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Abstract

In recent years, eutrophication has increased, leading to deterioration of the aquatic environment due to hypertrophication causing the appearance of water blooms over a long period of time over the entire water surface. This study was aimed to elucidate the mechanisms of how abnormal proliferation of phytoplankton occurs in a hypertrophic agricultural reservoir. As an example of such reservoir, we considered a pond extremely high in PO_4-P and highly nitrogen limited (Pond A) and conducted quantitative analysis on the dynamic characteristics of the water quality through detailed aquatic environmental survey. Furthermore, the characteristics of seasonal changes in phytoplankton within hypertrophic waters were investigated by analyzing the data on the water quality obtained for an agricultural reservoir (Pond B located near the Pond A) as an eutrophicated waterbody. The seasonal variations in Chl.a in Pond A were characterized by the dominance of cyanobacteria and an increase in NO_3-N due to the high water inflow load during the rainy season. However, the different situation was observed for Pond B. Specifically, cyanobacterial Chl.a exceeded 150 μg/L during the period from August to October in 2018, and this was caused by the nitrogen inflow due to the heavy rainfall in early July. As a result of the phytoplankton growth, despite having the shallow water depth of approximately 2 m, the water near the bottom became strongly reductive having Oxidation-Reduction Potential (ORP) < -150 mV due to anoxia. It was implied that the occurrence of such a strong reductive state led to diminution of PO_4-P and NH_4-N, and consequently, to the generation of H_2S, indicating the severity of aquatic environmental problems in the studied hypertrophic shallow waterbody.

Keywords: *Cyanobacteria, Water quality, Agriculture reservoir, Nutrients, Inflow load*

Introduction

One of the most important aquatic environmental issues presented in closed bodies of freshwater such as lakes and reservoirs is the abnormal proliferation of phytoplankton associated with eutrophication. In recent years, the situation has worsened leading to deterioration of the aquatic environment due to hypertrophication leading to water blooms over an extended period of time across the entire water surface. Considering the task of aquatic conservation in eutrophied water bodies, it is necessary to quantitatively evaluate the characteristics of seasonal variations in aquatic environment by measuring key factors such as the amount of phytoplankton and nutrients including nitrogen and phosphorus. This study aimed to elucidate the mechanisms of abnormal proliferation of phytoplankton occurring in agricultural reservoirs, where hypertrophication is apparent, conducting the quantitative analysis on the dynamic characteristics of the water quality using the detailed aquatic environmental survey.

Materials and Methods

In this study, an agricultural reservoir where hypertrophication was apparent was used. As a hypertrophic waterbody, we selected a pond (Pond A), used as an agricultural reservoir in the Ito Campus of the Kyushu University (**Fig. 1 and 2**). The target site was a hypertrophic area, where water blooms

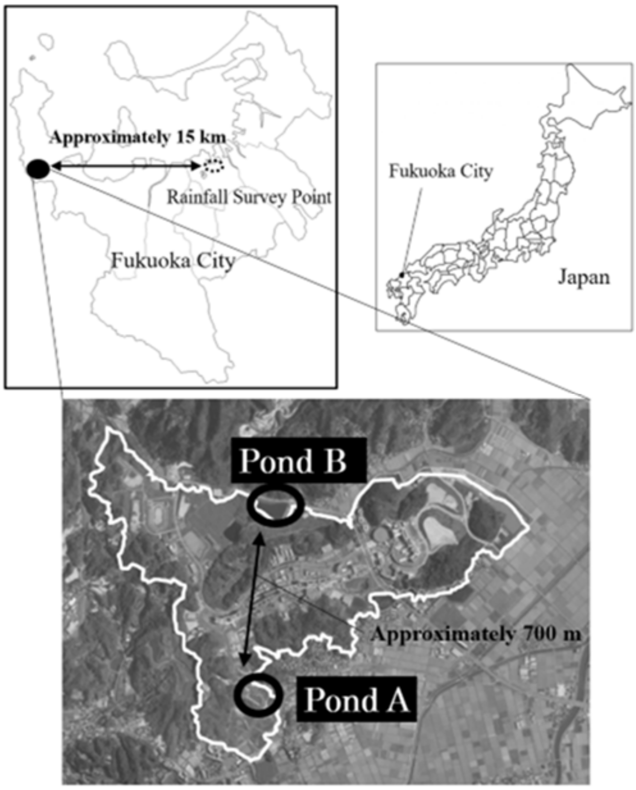

Fig. 1 Aerial photographs of Pond A and Pond B. The black line depicts the Ito Campus of the Kyushu University, and the dashed circle shows the location of the Meteorological Agency.

Fig. 2 Overall view of Pond A on May 29, 2018.

were observed on the water surface from September to November due to inflow loading through a box culvert. Furthermore, seasonal changes in phytoplankton characteristics in hypertrophic waters were investigated by analyzing the history of water quality data collected for another agricultural reservoir, Pond B, (Nguyen *et al.* 2014; Harada *et al.* 2013) located approximately 700 m from Pond A and considered as an eutrophied waterbody (**Fig. 3**). Matsumoto *et al.* (2008) reported that the surface of the water was covered with bluegreen algal blooms and water chestnuts during the summer months (June to October in 2007). The data on the water scale in these reservoirs are provided in **Table 1**. The surveys parameters included water temperature, Dissolved Oxygen (DO), transparency and Oxidation-Reduction Potential (ORP) based on on-site observations and water sampling. The collected water samples were used for the laboratory analysis of Chl.a for each class of algae, total Chl.a, NO_3-N, NH_4-N, PO_4-P, TN, and TP. The surveys on the water quality were conducted every week from May to November in 2018. Rainfall data for Fukuoka City were obtained from the Japan Meteorological Agency **(Fig. 4)**.

Fig. 3 Overall view of Pond B on July 10, 2018.

Table1 Description of Pond A and Pond B

	Pond A	Pond B
Catchment area (ha)	15.1	15.6
Depth (m)	4.5	3.0
Surface area (m^2)	2 700	2 050
Total water storage capacity (m^3)	12 200	622 200

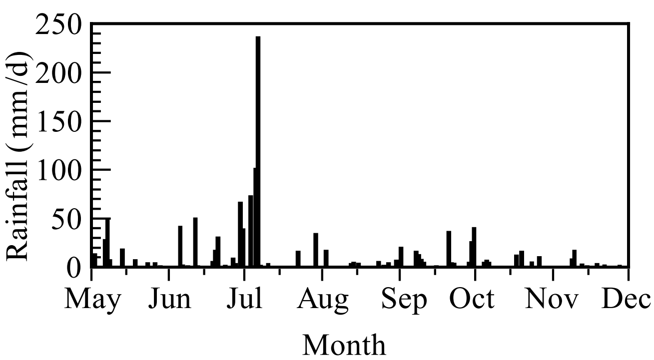

Fig. 4 Daily rainfall data for Fukuoka City in 2018.

Results and Discussion

The observed results on Chl.a for each class of algae and total Chl.a (**Fig.5**), and NO_3-N, NH_4-N, PO_4-P and N/P ratio (**Fig. 6**) are shown, respectively. The concentration values of TP and Ch1.a in Pond A were observed to be much higher than those in Pond B. In addition, the mean transparency of Pond A was 1.1 m, with the lowest value being 0.3 m. The observations of TP, Chl.a, and transparency indicated that Pond A was in a hypertrophic state. The seasonal variations in Chl.a in Pond A could be categorizeded as a period of low concentration from May to July, growth from August to early October, and decline beginning from mid-October, with cyanobacteria being dominant during each period.

In the period from May to July, Chl.a in Pond A was at low levels of 10 μg/L or less despite high levels of PO_4-P from 0.1 to 0.3 mg/L, and Chl.a in Pond B was 10 to 20 μg/L. The comparison of both results suggests that the low levels of Chl.a in Pond A were influenced by other environmental factors in addition to the meteorological factors of air temperature and solar radiation. While Pond B was phosphorus limited, the N/P ratio of Pond A was as small as 3 to 10, indicating extremely severe nitrogen limitation. In other words, low DIN levels appear to have acted as a limiting factor that inhibited phytoplankton growth. Moreover, Chl.a suddenly increased to about 30 μg/L immediately after rainfall exceeding 200 mm/d in early July. This is thought to have been caused by nitrogen inflow from the heavy rain, which caused NO_3-N levels in the waterbody to exceed 0.4 mg/L.

Chl.a increased linearly in both waterbodies from August to early October. The rate of the Chl.a increase in Pond A was 0.7 μg/ (L d), which was significantly higher than that in Pond B (0.35μg/ (L d)). The increase of Chl.a in Pond A might be attributed to the presence of optimal environmental conditions for the dominant cyanobacteria, such as involving high water temperatures and high levels of solar

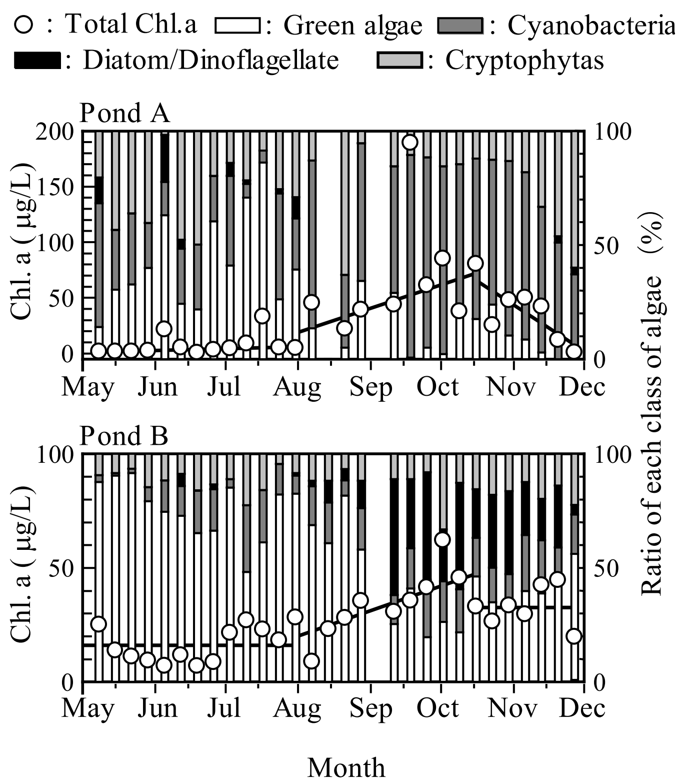

Fig. 5 The observed results of Chl.a by each class of algae and total Chl.a.

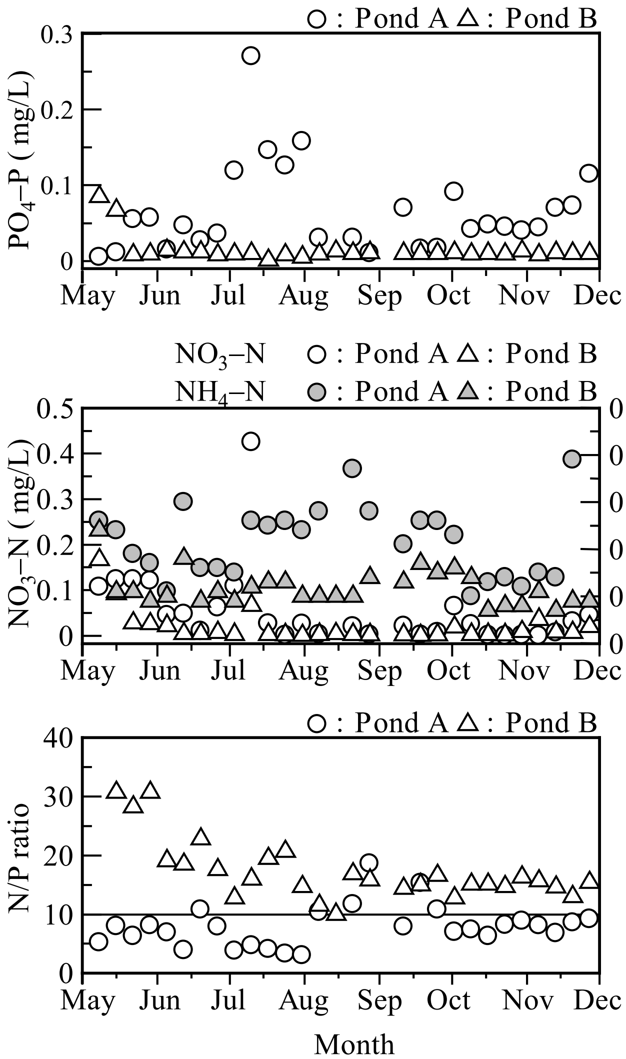

Fig. 6 Results of the water quality analysis.

radiation. In addition, the fact that the N/P ratio remained in the range of 10 to 18 starting from August indicated that nitrogen limitation was relaxed compared to the period of low Chl.a. The effects of the aforementioned increase in the nitrogen supply to the waterbody in early July manifested in a major way beginning in August. The changes in Dissolved Inorganic Nitrogen (DIN) over time indicated the selective uptake of NO_3-N over NH_4-N as a nitrogen source for photosynthesis. In particular, as cyanobacteria can prefer NO_3-N for photosynthesis, relaxation of the nitrogen limitations in Pond A due to NO_3-N was considered as one of the causes for the increase in Chl.a levels. During the same period, cyanobacterial Chl.a exceeded 150 μg/L, which, unlike the case of Pond B, was followed by extensive algal blooms for approximately 1 month. As a result of the increase in phytoplankton, DO became supersaturated in the surface layer of the water with concentration exceeding 200 % (**Fig. 7**). In addition, transparency was extremely low at 0.3 m due to the overgrowth of phytoplankton in the surface layer, indicating that the waterbody had experienced insufficient underwater light conditions during summer. Furthermore, despite a shallow water depth of approximately 2 m from August to October, the area near the bottom was strongly reductive with ORP < -150 mV due to anoxia. such strong reductive state could lead to the diminution of PO_4-P and generation of H_2S, indicating the severity of aquatic environmental problems in the studied hypertrophic shallow waterbody.

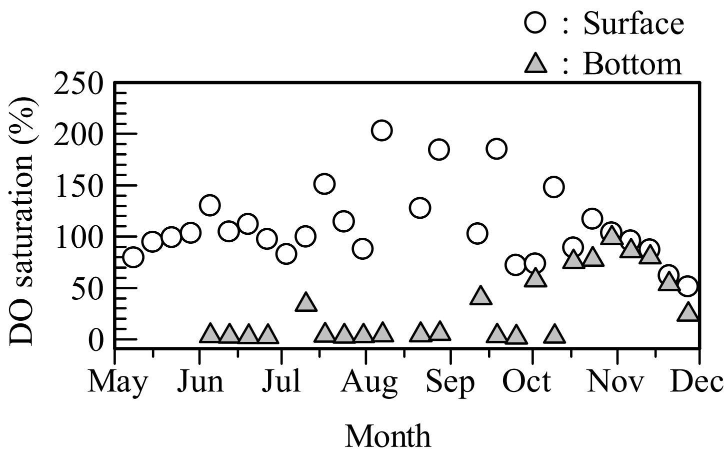

Fig. 7 Results of DO saturation at the water surface and the bottom of Pond A.

Starting from mid-October, Pond B was characterized by high Chl.a levels, while Chl.a in Pond A decreased linearly depicting a steep slope. This difference was observed during the period when water temperatures were decreasing markedly, and was considered to be caused by the difference in the dominant phytoplankton in both the ponds studied. Hence, it was concluded that low water temperatures limit the photosynthetic rate more in cyanobacteria than in green algae, which was considered as a reason for the large decrease in Chl.a in Pond A.

Conclusions

In this study, we examined the status of hypertrophic waterbodies considering the reservoirs that were extremely high in PO_4-P and highly nitrogen limited. The seasonal variations in Chl.a in Pond A can be attributed to the dominance of cyanobacteria and increase in NO_3-N due to the inflow load during the rainy season. Therefore, we would intend to analyze the aquatic environments by focusing on the dynamic characteristics of cyanobacteria and nutrients, and quantify these changes in future studies.

Acknowledgements

The authors greatly appreciate the support under JSPS KAKENHI Grant Number JP18H02300 and JP18H03968.

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