TS3-1

The interactions between eutrophication, damming and climate change on the role of inland aquatic systems in the global carbon cycle

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ABSTRACT

Lakes and rivers of the world are subjected to multiple and simultaneous environmental changes. How these changes have already affected the greenhouse gas footprint of lakes is largely unknown and even less can be predicted for the future. In this paper, we will use intermediate climate change scenarios from the IPCC as well as projected human population growth to assess their likely combined effects of GHG emissions. For the Asia-Oceania region, our simulations suggest that inland waters will respond to these environmental pressures with substantial increases in GHG emissions, in particular for methane (about 60%). The role of lakes on the global C cycle is therefore changing and constitute an additional source of GHG to the atmosphere.

1. Introduction

Lakes and rivers of the world emit naturally large amounts of greenhouse gases (CO_2 and CH_4) to the atmosphere with the latest current estimate exceeding 3.5 Pg C yr-1 (Drake et al. 2018). This figure is a significant component of the global carbon cycle and corresponds to about a third of annual anthropogenic emissions (fossil fuel and land use change, Le Quéré et al. 2016). As such the exact magnitude of the inland water emission is not critical as it is part of the natural cycling of organic carbon derived from terrestrial primary productivity. However, its magnitude is already known to be sufficiently large such that any changes to these emissions resulting from other anthropogenic perturbations could significantly enhance (or decrease) the role played by inland waters in the global carbon budget.

At the local scale, the main environmental factors known to affect lake GHG emissions are temperature (Rasilo et al 2014, Yvon-Durocher et al. 2014), trophic status (Delsontro et al. 2017, 2018) and DOC concentration (Lapierre et al. 2015), all of which are strongly modulated by lake size (Roehm et al. 2009, Rasilo et al. 2014) with small lakes having larger emission rates per unit area. Many of these factors are known to be changing globally as a result of other perturbations and the largest threats from a global carbon footprint perspective are eutrophication and climate change. For example, increase in population density and fertilizer use has led to greater nutrient loadings to lakes and eutrophication. Similarly, climate change has already increased surface water temperatures (O'Reilly et al. 2014) and is expected to continue albeit at different rates depending on the particular scenarios of anthropogenic GHG emissions. However, the possibility of interaction between these factors and their geographic distribution has not been to date clearly explored.

In addition to natural lakes, a large number of impoundments have been created (ICOLD, Lehner et al. 2011) totaling about 350,000 km^2 (Prairie et al., in prep) and a boom in the construction of dams is currently underway (Zarfl et al. 2014).

In this paper, I explore the likely combined consequences of eutrophication and climate change on the carbon footprint of both lakes and reservoirs in a spatially explicit analysis. Our results suggest that on a 2050 horizon, the GWP exerted by inland water emissions will have increased by about 30% relative to year 2000.

2. Effect of climate change on lake surface temperature

Lakes warm mostly by absorbing direct solar radiation but they lose heat through exchange with the atmosphere. Thus, the air temperature above lakes is a useful proxy of the minimum lake surface temperature and, over intermediate time scales, corresponds roughly to the average temperature (Tofollon et al. 2014). This is useful to estimate how climate change is likely to further enhance surface water temperature and, in turn, GHG emissions.

Using the global inland water distribution of Feng et al.

(2015) for waterbodies larger than 0.5 ha and the intermediate climate predictions of the IPCC (CCMS4, scenario 4.5), we derived the distribution the lake surfaces subjected to various degrees of warming. Focusing on the Asia-Oceania region, we can see that large parts of China and India are very rich in surface water (Fig.1).

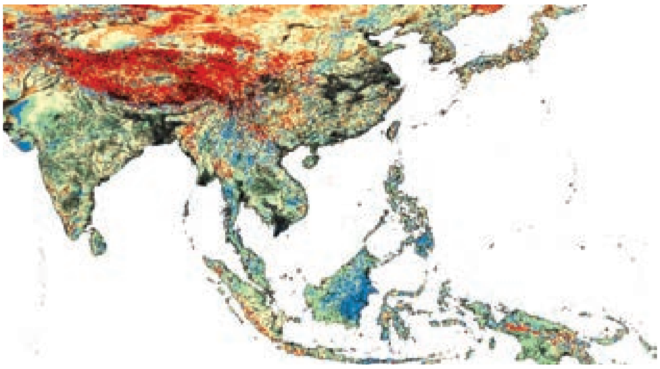

Figure 2 The distribution of waterbodies in the Asia region (black lines) overlaying a color-coded map of the expected change in temperature following the IPCC RCP4.5 scenario (warmer colors correspond to higher expected changes).

As a whole, this region comprises 2.6 million individual water bodies collectively covering a surface area of 522,000 km^2. Because climate is not expected to affect all regions equally, lakes will be impacted differently as well. Our analysis (Fig. 2) shows that, in this region, 50% of the lake surface will experience an average annual warming of 1.9 °C or more.

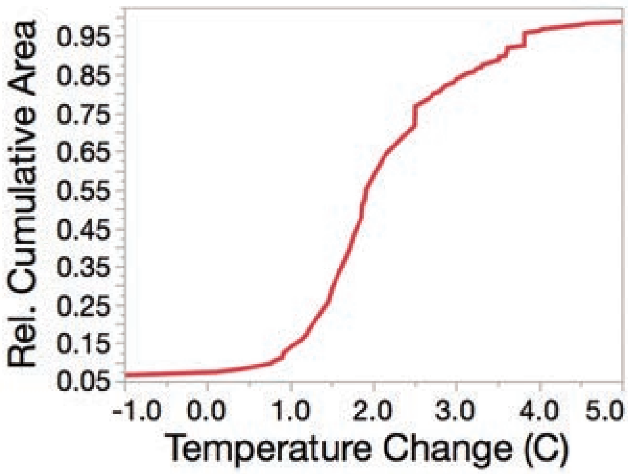

Figure 1. The fractional cumulative surface area of lakes with expected changes equal or greater than the Temperature Change axis. Analysis restricted to the Asia-Oceania region.

Furthermore, the top 25% of the lakes'total surface will warm by at least 2.5 C while only a few percent will experience average changes of more than 4 °C. This average increase on an annual scale is not uniformly distributed over the year and is usually greatest in the winter and spring. The next step in this analysis will be therefore to account for changes at a finer time scale. Nevertheless, the average annual increase can serve as an initial basis to predict the impact of this warming on GHG emission. Assuming that heterotrophic respiration has a temperature dependency (expressed as a Q10) averaging 2 (Berggren et al. 2012), we can estimate the expected increase in CO2 production for each individual water body as $e^{(0.069 \cdot \Delta Temp)}$ attributable to climate change by the year 2050 (relative to average 1970-2000 conditions). Similarly, we can assume for methane that the average Q10 is 4 (Yvon-Durocher et al. 2014), yielding an increase in methane emissions that can be estimated as $e^{(0.139 \cdot \Delta Temp)}$. This calculation does not consider the disproportional increase in bubbling emission (Delsontro et al. 2017) with temperature (Q_{10}>5) and is therefore conservative. Calculations based on these 2 assumptions yielded an area-weighted increase in CO_2 and CH_4 emissions of 16% and 36%, respectively, in response to the temperature increases alone.

As a comparison, the same exercise on the European continent (about 650,000 water bodies) suggest a similar pattern, with 50% of the lake surfaces experiencing an average warming of 1.9 °C or more. This would lead to an increase in CO_2 by 13% and that of CH_4 by 30% in this region.

3. Increase in CH_4 emission from eutrophication

The impact of eutrophication on the GHG footprint is more difficult to resolve spatially as we do not have eutrophication scenarios for each lake. Instead, we used the projected human population growth of each country as a proxy for the nutrient load that will ultimately reach surface waters of that particular country. In this contest, we simply assumed that eutrophication was proportional to nutrient enrichment. The country-specific population growth estimates that we used here represent the expected fractional increase in human population between 2000 and 2050 (World Bank statistics). Assuming further that that CH_4 emission rises as the 0.75 power of trophic status (as measured from chlorophyll or nutrients, see Delsontro et al. 2018), we calculate that eutrophication would cause an additional increase of 30% in CH_4 emissions. In this work, we did not calculate the effect of eutrophication of CO_2 flux as they differ systematically between large and small lakes (Delsontro et al. 2018) but would likely lead to a further increase in GHG footprint.

Our estimates are therefore conservative again.

Combining the effects of eutrophication and climate change therefore suggest that the methane output from lakes would increase by nearly 65% at the 2050 horizon. However, because of the relatively smaller contribution of CH_4 relative to CO_2 emissions (see Bastviken et al. 2011, Drake et al. 2018), the overall combined impact of these two perturbations would amount to an increase in GWP exerted by GHG emissions from inland waters of about 30%.

4. Implication for the global carbon cycle

Our preliminary analysis suggests that, in the first half of the 21st century, the carbon footprint of lakes will be significantly increased by both climate change and eutrophication in about equal proportion (at least in the Asia-Oceania region). Considering that the highest climate changes are expected to occur in northern latitudes precisely in lake-rich regions (Canada, Scandinavia, Russia), the effect is therefore probably even more pronounced at the global scale. Our analysis also ignored alterations that had occurred previously (during the 1900's) which certainly had already enhanced GHG emissions from inland waters. Reservoirs are new aquatic ecosystems and also constitute new sources of GHG to the atmosphere (Prairie et al. 2017) and the magnitude of the associated GHG emissions are likely to be further modulated by climate change and eutrophication as well. Because inland waters collectively constitute a sizeable share of the natural carbon cycle at the global scale (see Drake et al. 2018 for recent review), the higher emissions estimated as a result of the combined eutrophication and climate change effects constitute a new anthropogenic source of GHG to the atmosphere and will require accounting in future global assessments.

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TS3-2

A Unique Microbial Loop in the Hypolimnion of Lake Biwa with Special Reference to Long-term Changes in Water Quality

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Keywords: Eutrophication, Chemical Oxygen Demand, Dissolved Organic Matter, Phytoplankton, Bacteria, Decomposition, Microbial loop, Protists

ABSTRACT

We have clarified the presence of a unique microbial loop in the hypolimnion of Lake Biwa, the largest freshwater lake in Japan. In the epilimnion of the lake, phytoplankton biomass is produced through primary production, followed by sinking into the hypolimnion. In the hypolimnion, a part of the phytoplankton biomass is converted into and released as humic-like DOM through decomposition by planktonic bacteria. Fluorescence *in situ* hybridization (FISH) showed that bacterial clade, CL500-11 (phylum *Chloroflexi*), predominated in the hypolimnion. We made further analyses on prokaryotic community composition by high throughput 16S rRNA gene amplicon sequencing which showed the dominance by members of *Planctomycetes* exclusively occurred in the hypolimnion. In addition, FISH on eukaryotes showed that bacterivorous kinetoplastid flagellates are the dominant eukaryotes in the hypolimnion. So, the results suggest the presence of a unique microbial loop in the hypolimnion of Lake Biwa, where humic-like DOM is produced by the hypolimnion bacterial assemblages, and those bacteria are grazed by the dominant kinetoplastids and other hypolimnion dwelling bacterivorous protists. The water quality of Lake Biwa has been improved during the last 40 years. However, chemical oxygen demand (COD_{Mn}) in the lake has been gradually increasing every year. In the present talk, we will introduce the hypolimnion microbial loop, with special reference to long-term increase in COD_{Mn} of the lake.

1. INTRODUCTION

The planktonic food linkage from dissolved organic matter to bacteria to protists, microbial loop[1], has been intensively studied in marine and freshwater ecosystems. It was regarded that the herbivorous food chain where phytoplankton are preyed on zooplankton functions major matter cycling in pelagic ecosystems. On the other hand, microbial loop also functions as an important process for the matter cycling in pelagic food webs. Phytoplankton release dissolved organic matter (DOM) as intermediate products of photosynthesis and/or as autolytic products[2]. DOM thus released is used for growth of heterotrophic bacteria, followed by protistan grazing on bacteria. The roles of planktonic protists, such as heterotrophic nanoflagellates and ciliates, in microbial loop are to consume bacteria that are too small to serve directly as major prey items for most zooplankters, and to be themselves utilized by the zooplankton[1].

Lake Biwa is the largest and the most socially important lake in Japan. About 15 million people who live in Kinki Area use the water of the lake. Microbial loop in Lake Biwa has been intensively studied during the last three decades with special reference to DOM production through phytoplankton primary production[3], because matter cycling or DOM dynamics in a pelagic system is mainly driven by microbial loop.

2. HYPOLIMNION MICROBIAL LOOP IN LAKE BIWA

We have clarified the presence of unique microbial loop in the hypolimnion of Lake Biwa. In the lake's epilimnion, phytoplankton biomass usually dominated by diatoms and chlorophytes is produced through primary production, followed by sinking into the hypolimnion. In the hypolimnion, a part of the phytoplankton biomass is converted into and released as humic-like DOM through decomposition by planktonic bacteria[4] (in [4], "humic-like DOM" is expressed as "humic-like fluorescent dissolved organic matter, $FDOM_M$). Usually, humic substances including humic-like DOM are biologically refractory (not easily degradable) and/or semi-labile, and, due to this, bacterial decomposition of the humic-like DOM is slow. The genus *Synechococcus,* which is the free-living cyanobacterial genus with small cell size (usually <2 μm), sinks so slowly (no faster than 0.01–0.02 μm s^{-1}) that the motion of the water is believed to keep them in suspension. Thus, it has been considered that they are too small to sink to the lake hypolimnion. However, recently, we have found that *Synechococcus* also sank to the hypolimnion of Lake Biwa, and that the contribution of *Synechococcus* chlorophyll *a* amount accounted for about 30% to total chlorophyll *a* concentration[5],[6]. So, it is likely that *Synechococcus* biomass is also converted into humic-like DOM.

In the hypolimnion of Lake Biwa, we have found that bacterial clade, CL500-11 (phylum *Chloroflexi*), predominates in the hypolimnion[7], using fluorescence *in situ* hybridization (FISH). Further analyses on prokaryotic community composition by high throughput 16S rRNA gene amplicon sequencing demonstrated that ubiquitous tribes in the epilimnion can also dominate in the hypolimnion (e.g. bacI-A1 & acI-B1), and that members of *Planctomycetes* (e.g. CL500-15, CL500-37 & CL500-3), together with CL500-11 exclusively occurred in the hypolimnion[8]. In addition, FISH on eukaryotes showed that bacterivorous kinetoplastid flagellates are the dominant eukaryotes in the hypolimnion[9]. Furthermore, high throughput 18S rRNA gene amplicon sequencing showed the presence of possibly novel hypolimnion dwelling bacterivorous flagellates (e.g. cercozoans, choanoflagellates and telonemids).

The seasonal changing pattern of vertical abundance of kinetoplastid flagellates was similar to that of CL500-11 bacterium, suggesting that similar environmental conditions may favor the growths of those two microorganisms in Lake Biwa. Large size and curved shape of CL500-11 bacteria might protect them from grazing and thus allow this group of bacteria to dominate in the hypolimnion of Lake Biwa. However, some flagellates, especially bodonids which belong to kinetoplastid flagellates, are capable of feeding on large bacteria. Therefore those kinetoplastids might have an advantage over other flagellates in the hypolimnion due to their ability to feed on large bacteria dominant in the deeper layers of Lake Biwa. Further research is needed to clarify whether CL500-11 bacteria would have high grazing pressure by protists such as kinetoplastids, or to identify major consumers on the bacteria.

3. LONG-TERM CHANGES IN WATER QUALITY IN LAKE BIWA

During 1960' and 1970's due to the large loading of phosphorus and nitrogen, eutrophication in Lake Biwa was serious, leading to phytoplankton blooms (since the late 1960's), freshwater red tides (since the late 1970's) and cyanobacterial blooms (since the early 1980's). In 1970's, Japanese Government and Shiga Prefectural Government had started some measures to reduce high phosphorus loading in Lake Biwa. Due to the efforts by multiple stakeholders, the water quality of the lake has been improved during the last 40 years.

Mysteriously, a portion of organic matter expressed by chemical oxygen demand (COD_{Mn}) in the lake has been gradually increasing every year[10]. COD_{Mn} is the indicator of organic matter loading, and a large portion of organic matter in Lake Biwa water is dominated by DOM. DOM in Lake Biwa is mainly derived from primary production by phytoplankton[11],[12], and some researchers have reported that the increase in COD_{Mn} might be due to the accumulation of refractory and/or semi-labile DOM[10]. As previously mentioned, we have clarified that humic-like DOM is probably intermediate products through bacterial decomposition. So, the reason for the increase in COD_{Mn} in Lake Biwa might be partly due to the accumulation of refractory and/or semi-labile DOM produced through and released after bacterial decomposition.

4. CONCLUSION

Our results indicate the presence of unique microbial loop in the hypolimnion of Lake Biwa, where humic-like DOM is produced and released by the hypolimnion bacterial assemblages, and those bacteria are grazed by the dominant kinetoplastids and other hypolimnion dwelling bacterivorous protists. Thus, the deep waters of Lake Biwa harbor active microbial loop consisting of novel hypolimnion-specific groups, which might play an important role in the production of refractory DOM. In addition, we have partly clarified the microbial processes with special reference to production and accumulation of humic-like DOM which may be the reason for the increase in COD_{Mn} in Lake Biwa.

5. ACKNOWLEDGEMENT

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O3-1

Application of non-powered water circulation system using wind and wind-driven current for shallow reservoirs

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Keywords: Water circulation, Eutrophication, Stratification, DO improvement, Water quality management of reservoirs

ABSTRACT

A large number of reservoirs in Korea have experienced severe deterioration of water quality due to eutrophication. The problems include (1) inflow of pollutants, (2) occurrence of algal blooms, (3) increased oxygen consumption and anaerobic condition near the bottom, and (4) elution of nutrients from the sediments. As more than 90% of reservoirs in Korea have average water depth less than 5 m, we need appropriate technologies coping with these situations. A non-powered water circulation system has been developed to improve water quality of reservoirs by inducing the descent flow of surface water using natural wind and wind-driven current. One of the functions of the system is to break thermal stratification and anaerobic condition near the bottom. Test-beds have been installed and operated at 2 reservoirs and monitored more than 1 year. The results have showed clearly that 1) continuous improvement of anoxic condition at deep layer (hypolimnion), 2) mitigation of DO supersaturation and 3) prevention of excessive increase of pH at surface layer (epilimnion).

1. INTRODUCTION

Many lakes and reservoirs in Korea have suffered from deteriorating water quality due to rapid eutrophication[1]. Stagnant areas such as lakes and reservoirs have problems including 1) eutrophication due to the inflow of pollutants, 2) occurrence of algal blooms due to decrease of flow rate, 3) anaerobic condition near the bottom, 4) massive death of fish due to lack of dissolved oxygen (DO), and 5) elution of nutrients (P, N, etc.) and metal ions from the sediment. In Korea, there are about 18,000 reservoirs, and more than 90% of them have average water depth less than 5 m[2]. Unfortunately, existing technologies have unsuitable characteristics such as 1) excessive energy needs, 2) maintenance difficulties, and 3) low efficiency of water circulation. This study has been conducted to overcome the limitations of existing technologies and to suggest an appropriate water circulation system for water quality management of shallow and small reservoirs.

2. METHOD

2-1. Principle of non-powered water circulation system

A water circulation system was developed to break thermal stratification and to mitigate anaerobic condition near the bottom by inducing the surface water's descent flow using wind and wind-driven current. The system was designed to use natural energy efficiently and to rotate by itself according to the direction of wind and wind-driven current continuously. Its typical image is shown in **fig. 1, (a)**.

The system, for the parts above water surface, is composed of (1) 'wind blade' to face with wind, (2) 'float' supporting the system by buoyancy. For the parts under water surface, it contains (3) 'guiding panel' inducing descent flow from the surface to the bottom, and (4) 'center shaft', located at the center of panel system, maintaining the rotation of total system around the axis of center shaft. Applying the Ekman spiral principle, the angle between wind blade and panel system is biased with 15°, and the direction of panel system and wind-driven current is always kept perpendicular to maximize the energy efficiency (**Fig. 1, (b)**).

2.2 Test-bed installation and monitoring

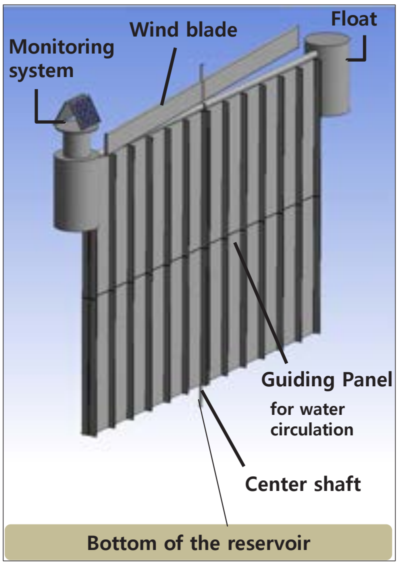
Test-beds have been operated to monitor the effects of water circulation system.

1) Gongneung reservoir (Paju-si, Gyeonggi province, Korea): This reservoir has a surface area of 0.4 km^2 and an average depth of 2.2 m. The upstream area of the reservoir is composed with mountains, golf courses, cultivated lands and residential areas. The scene of test-bed is **Fig 2, (a)**.

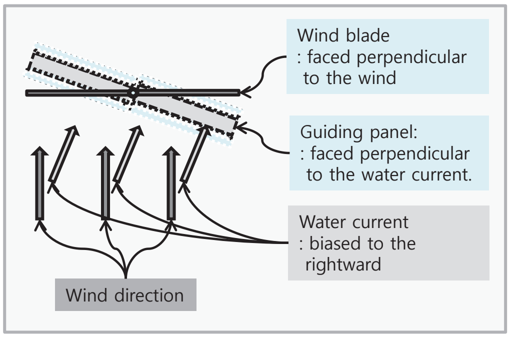
2) Giheung reservoir (Yongin-si, Gyeonggi province, Korea): The reservoir has an area of 2.6 km^2, an average

depth of 3.2 m. There are wastewater treatment facilities upstream of the reservoir (**Fig 2, (b)**).

A real-time monitoring system has been equipped at surface layer (within 30 cm from water surface) and at deep layer (0.5 ~ 1 m from the bottom) to observe the variation of each item including compass of the system, water temperature, pH, DO, DO saturation, and electric conductivity.



(a)



(b)

Fig. 1. (a) Feature of water circulation system, (b) Application of Ekman spiral principle

(a) (b)

Fig. 2. Test-beds of water circulation system: (a) Gongneung reservoir, (b) Giheung reservoir

3. RESULTS

Fig. 3 shows the results of (a) DO, (b) DO saturation, and (c) pH for the monitoring and control sites at Gongneung test-bed (period: 12th October ~ 23rd December, 2016, monitoring depth of 2.5 m). Several positive effects were observed through the operation of the system, which include that the system is able to (1) moderate the fluctuation of DO, (2) mitigate the supersaturation of DO, and (3) prevent the excessive increase of pH.

Fig. 4 illustrates DO variations of surface layer and deep layer (depth 2.5 m) at the monitoring site (period: 11th March ~ 20th May, 2017). The water quality of the reservoir had been deteriorated due to serious drought from April to June, and DO concentration of deep layer had been drastically reduced just after the stop of the system's normal rotation. During this period, anoxic states were observed at deep layer, that DO and DO saturation became closer to 0 mg/L and 0% respectively.

Fig. 5 represents the monitoring results at the second test-bed, Giheung reservoir. These graphs show that DO and water temperature of surface and deep layers at the monitoring site illustrate the system have mitigated the intensity of thermal stratification (**Fig 5, (a)**) and prevented anoxic states by prohibiting dropping of DO below 5.5 mg/L (**Fig 5, (b)**).

4. DISCUSSION

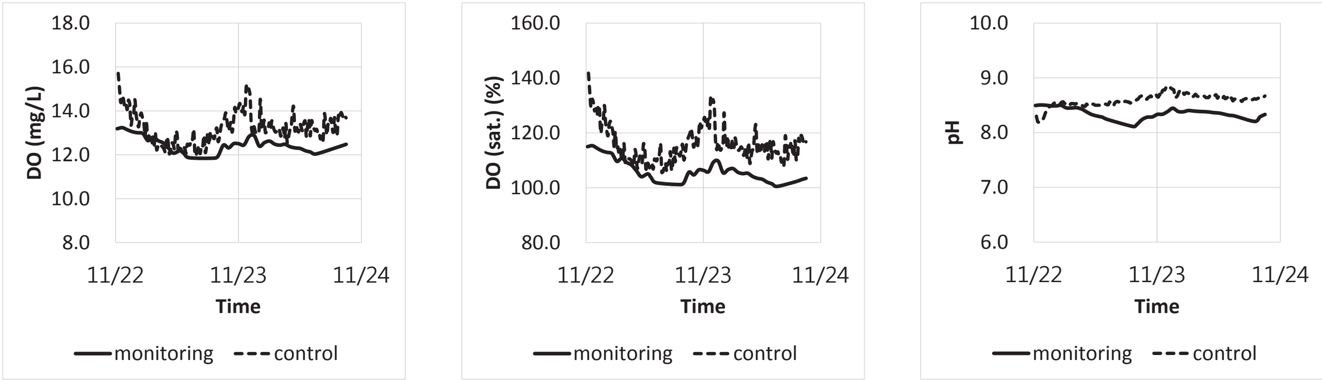
Based on the above results, the non-powered water circulation system is considered to be useful for Korean reservoirs experiencing periodic thermal stratification and turn-over events in spring and fall. In addition, this system is designed to be easy to apply to shallow and small reservoirs. Furthermore, it doesn't need any electric power supply, which is convenient to maintain and economically excellent.

5. CONCLUSION

A non-powered water circulation system has been developed to induce descent flow using wind and wind-driven current, and they have been installed and monitored intensively at 2 test-beds. The brief conclusions are as follows:

1) The water circulation system could maintain DO concentration upper certain level, 5 mg/L, and prevent anoxic states at near the bottom layer.

2) It could mitigate the excessive supersaturation of DO and increase of pH at surface layer by reducing the activity of algae.



(a) (b) (c)

Fig. 3.Water quality comparison between monitoring and control site: (a) DO, (b) DO saturation, and (c) pH

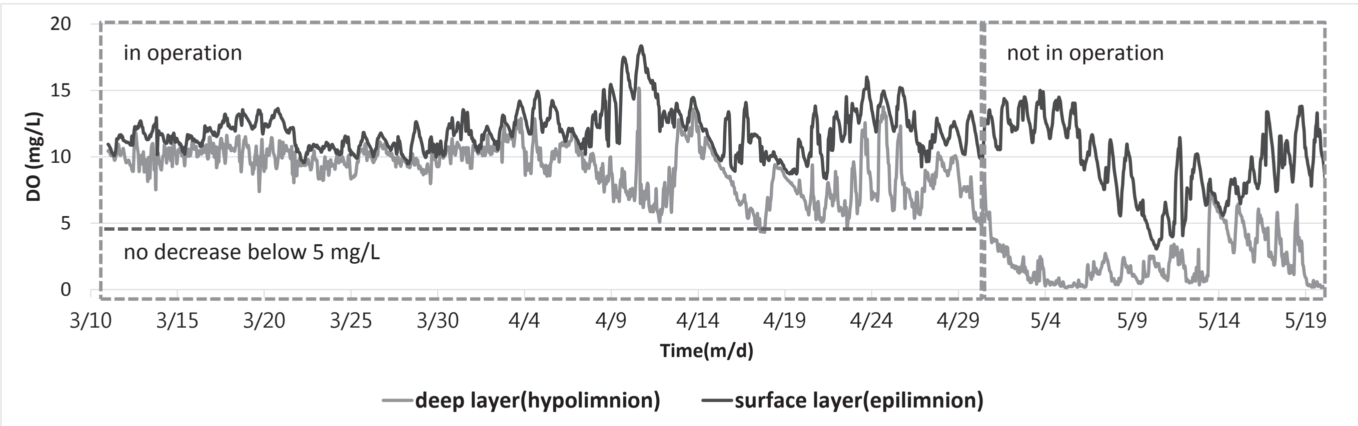
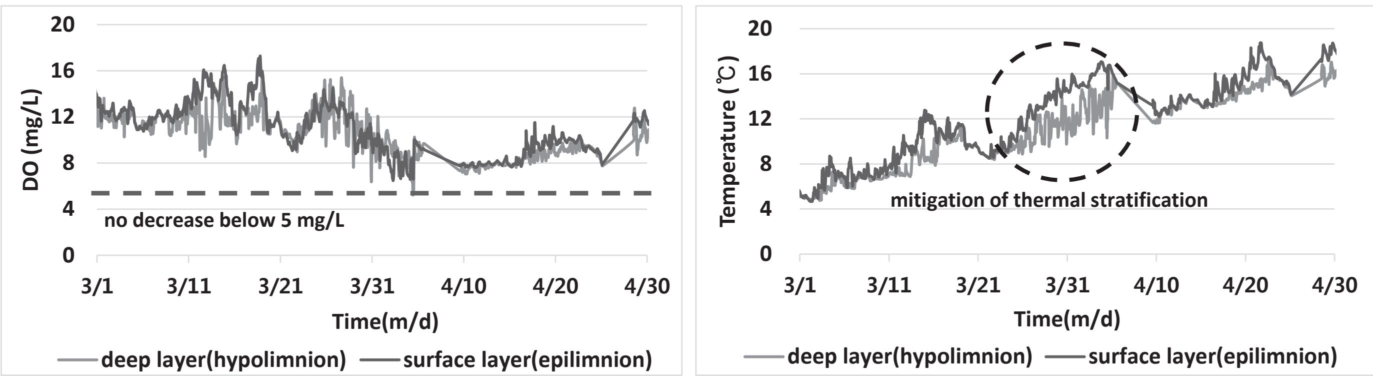


Fig. 4. Monitoring results of DO for deep and surface layer at Gongneung Reservoir



(a) (b)

Fig. 5. Monitoring results of DO and water temperature for deep and surface layer at Giheung Reservoir

ACKNOWLEDGMENTS

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O3-2

Oxygen nanobubble modified local soil (MLS) technology for sediment remediation and lake restoration

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Keywords: Eutrophication, Harmful algal blooms (HABs), anoxic sediment remediation, ecological restoration

ABSTRACT

Eutrophication, harmful algal blooms (HABs), and internal sediment release of nutrients represent increasing problems for public health, ecological restoration, and water quality worldwide. Modified Local Soil (MLS) materials are cost-effective in removing HABs at very large scale (Pan et al, Environ. Pollut. 2006, 141, 195; Environ. Pollut. 2006, 141, 201; Environ. Pollut. 2006, 141, 206; Environ. Sci. Technol. 2006, 40:1377; Environ. Sci. Technol. 2013, 47, 4555; Harmful Algae, 2011, 10, 381; J. Applied Phycology, 2016, 28, 357; Water Research, 2016, 97, 11; Water Research, 2016, 97, 19). MLS capping technology can reduce the release of nutrients or algae toxins from sediment and turn algal cells and the excessive nutrients in-situ into fertilizers for submerged machrophyte restoration in shallow water systems (Pan et al, Ecol. Eng. 2011, 37, 302; Environ. Sci. Technol. 2012, 46, 5077; Environ. Sci. Technol. 2015, 49, 426). MLS is also tested for manipulating nutrient limitation in natural water bodies (Pan et al., Water Research, 2016, 101, 25). Here, we report that surface oxygen nanobubbles can be loaded in MLS for effective and long-term remediation of sediment anoxia or hypoxia in deep water system (Pan et al, Sci Total Environ. 2018, in press). Combined with integrated management of external loads control, MLS technology can be used as environmentally friendly geo-engineering materials (Pan et al, Water Research, 2016, 97, 133; Environ. Sci. Technol. 2014, 48, 9977; J Environ. Sci. 2018, 65, 375) to achieve multiple functions for water quality improvement, sediment remediation, and ecological restoration.

1. INTRODUCTION

Eutrophication, harmful algal blooms (HABs), and internal sediment release of nutrients represent increasing problems for public health, ecological restoration, and water quality worldwide. The cause of these problems is complex, which can be partially due to the ever-increased nutrients run off from inland to natural waters because of agriculture, industrial, and other human activities. This nature determines that the mitigation of these problems are complicated and integrated management is often essential. External loads control and integrated basin management are important to prevent continuous input of nutrients from land to waters. When external loads are under control, the internal loads from polluted sediment often limits the improvement of water quality, and the latter is increasingly becoming compulsory in many countries within short period by local governance or environmental laws. Natural restoration of lake ecology or water quality often takes very long time, which is far beyond the above-mentioned requirement. With the help of geo-engineering materials, such as modified clays or soils, the improvement of water and sediment environment may be accelerated in an ecological friendly way[1] because particle-water interaction (suspended particles) represent an important natural process in scavenging pollutants from natural waters[2]. In return, the improved water and sediment environment is essential for ecological and biodiversity restoration.

Over the last decades, we have developed a series of modified local soil materials that use very small amount (usually less than 1% of soils) of natural products, such as natural polymers of chitosan[3-5], cationic starch[6], or oxygen [7], to modify clean local soil or commercially available clay/sand particles [8, 9], so that these modified soil particles can obtained multiple functions for algae flocculation, pollutants adsorption or decomposition (e.g. algae toxins [10]) in water or sediment environment. MLS can also be used for capping and locking the algae flocs or nutrients in the sediment so that the release of nutrients from sediment to the water column can be reduced [11]. MLS capping can also turn algal flocs and the excessive nutrients in-situ into fertilizers for the growth of submerged machrophyte in shallow water systems [12]. This will make it possible to put algae and excessive nutrients into food chain by flocculating and removing them from water into the sediment and then to utilize and convert them by submerged vegetation. Recently, we developed a surface oxygen nanobubble technology [13, 14] which allow us to load large amount of oxygen into the microporous of clays. These clays can hold the nanobubbles stably within period of months so that once the oxygen are delivered by settling the clay particles onto the sediment, it can form an aerobic sediment-water capping layer, which can prevent the consumption of dissolved oxygen in water column by the anaerobic sediment hence provide a new principle for combating oxygen depletion or anoxia/hypoxia problems that are crucial for eutrophication [7].The objective of this paper is to present a series of pilot tests in the field to examine the short-term, middle-term, and long-term effects of MLS for future engineering and scalability optimization.

2. METHOD

2.1 Materials

The soil/clay used in the experiments was collected from the bank of local lakes. The soil was sieved through 180 mesh (74 µm), washed with distilled water, and dried for 10 h at 90 °C before use. Chitosan (solid) was obtained from Qingdao Haisheng Bioengineering Co., Ltd (deacetylation degree was 83.6%). Cationic Starch was prepared by reacting corn starch (Unilever Co. Ltd., China) with cationic monomer, 2,3-epoxypropyl trimethyl ammonium chloride (GTA), using the microwave-assisted method [6].

2.2 Preparation of Modified Local Soil

The soil suspension was prepared with the concentration of 100 mg/L in all the flocculation experiments. Deionized water was prepared using a Milli-Q filtration system (Millipore, Bedford, MA). For Chitosan MLS preparation, chitosan was dissolved by adding 100 mg of chitosan to 10 mL of 1% HCl and mixing until all chitosan was dissolved. This solution was diluted with deionized water to obtain a working solution of 1 mg/mL. Then, a certain volume of chitosan working solution was added to soil suspension [3-5]. The mixture was well stirred and then ready for use in the experiment. For Cationic Starch MLS preparation, certain amount of synthetics Cationic Starch was added to the soil suspension prior to the flocculation experiments [6]. The oxygen nanobubble MLS was prepared through the high pressure loading method into a pressure-resistant and airtight container [7]. Pure O2 (99.99%) was used to achieve supersaturation of O_2 in the particle micropores.

2.3 Experimental sites

The series experiments were conducted in two field experiment sites, 1) Meiliang Bay in Taihu Lake, Wuxi city, Jiangsu Province, China **(Fig. 1)**; and 2) Datong, Shanxi province, China **(Fig. 2)**. Taihu Lake has serious HAB problems every year due to the polluted external wastewater discharge and internal nutrients loading from the lake. Six enclosures with total area of 50,000 m^2 were constructed for the proposed research to removal HAB using MLS technology from 2004. From 2012, three groups of research facilities were constructed in Datong research site, which include 8 natural water ponds (100 m^2 per each with same height of 1.7 m), 12 large mesocosm systems (Ø 2.5 m per each with same height of 2.5 m), and an indoor lab facilities. All the facilities were used to simulate various environmental process at an ecologically meaningful scale for the study of MLS technology.

Fig. 1 Experiment site in Taihu Lake, Wuxi city, Jiangsu Province, China

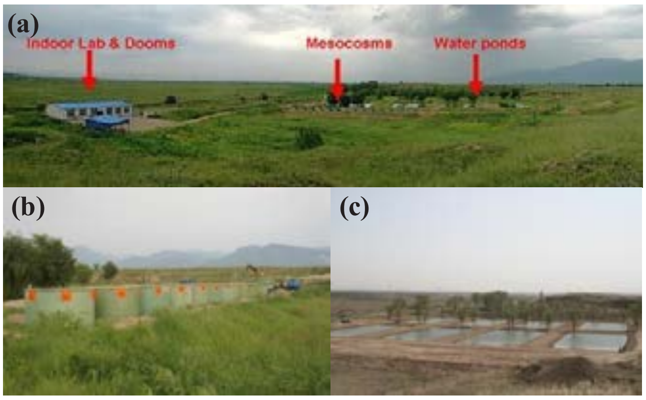

Fig. 2 Experiment site in Datong, Shanxi Province, China (a). (b) and (c) represent the mesocosms and water ponds experiment sites.

2.4 Sample analysis

For each experiment, the water samples were collected for turbidity and nutrient concentrations (TP, TN, NH_4^+-N, NO_3^--N, and NO_2^--N) analysis along the experiment. Turbidity was analyzed with portable turbidity meter (HANNA, HI98713). TP was determined using a potassium persulfate digestion-Mo-Sb-Vc colorimetric method, TN using an alkaline potassium persulphate digestion−ultraviolet spectrometer, NH_4^+-N with Nessler's colorimetric, and NO_3^--N, and NO_2^--N with ultraviolet colorimetric method with and without cadmium column reduction, respectively (APHA, 1998). The DO was measured using a Yellow Springs Instruments (YSI, Proplus). Moreover, the algae cell concentration were calculated under the optical density of 0.100 at the wavelength of 680 nm (OD 680 nm). Concentration of chlorophyll-a, calibrated against direct microscope cell counts was used to monitor the concentration change of algae cells during the flocculation experiment.

3. RESULTS

1) Water quality improvement and algal bloom control

A pilot engineering was conducted under the witness of the Mayer and expert panel of Wuxi city to clean up heavy algal blooms in a designated enclosure in Taihu Lake in 2008 **(Fig. 3)** and 2009 **(Fig. 4)**. Chitosan MLS of 2000 Kg was sprayed using a ship over the entire enclosure within 30 min. After 1 day, the secchi depth increased from less than 5 cm to 60 cm. DO increased from 0.2 mg/L to 3 mg/L. TP and TN removal rate > 50%, NH3 removal > 85%.

Fig. 3 Pond pilot test in Meiliang Bai of Lake Tai in August 2008.

Fig. 4. Application of MLS at open water by WUXI city government at Lake Tai in 2009.

2) Sediment remediation

A one year monitoring experiment was conducted in an open water at Meiliang Bay of Lake Tai during the four seasons in 2010. Throughout the year **(Fig. 5)**, TP peak in treated area (1 m2) was largely removed in the summer compared to the untreated surrounding area. Lake Taihu in 2010 (surrounding water was not treated, only the sediment was capped with MLS).

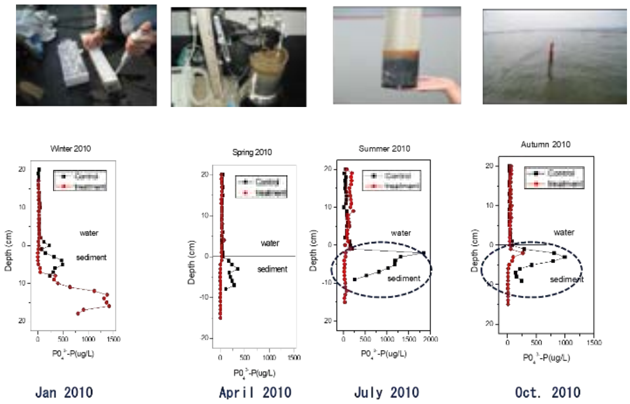

Fig. 5. MLS capping materials (about 1.5 cm) were placed (about 1 m2) in the open water in Meiliang Bay.

3) Ecological restoration.

Long term ecological effect of MLS treatment in replicated comparable whole water ponds were conducted in Cetian reservoir study site. The water quality in 140 days was presented in table 1. A 3 year's monitoring results were presented in **Fig. 6**.

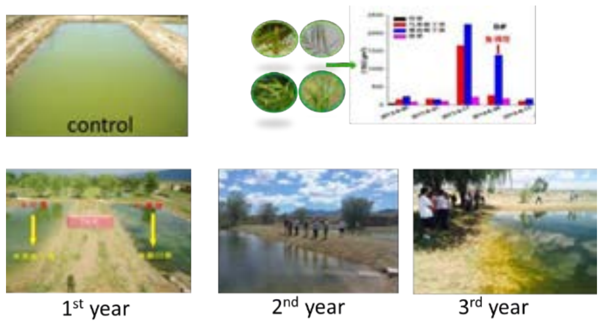

Fig. 6. A 3 year monitoring result after the application of MLS in replicated whole water response experiment.

4. DISCUSSION

The continued function and multiple principle of MLS are schematically summarized in **Fig. 7**. For practical lake restoration engineering, conditions are very complex and chanchable. There are many interfering factors in the field (such as wind and bio-disturbance) and there is a great need for more studies in order to make the principle studies into practice.

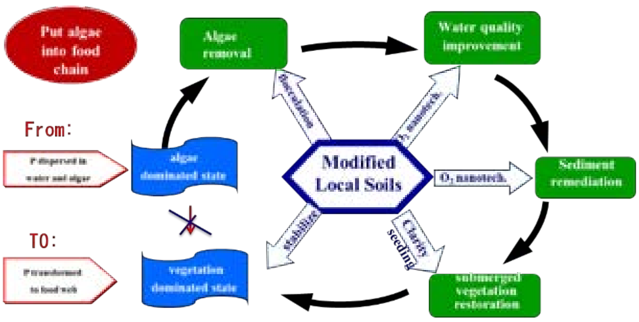

Fig.7. Multi-disciplinary principle of MLS technology

5. CONCLUSION

Combined with integrated management of external loads control, MLS technology can be used as environmentally friendly geo-engineering materials (Pan et al, Water Research, 2016, 97, 133; Environ. Sci. Technol. 2014, 48, 9977; J Environ. Sci. 2018, 65, 375) to achieve multiple functions for water quality improvement, sediment remediation, and ecological restoration.

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O3-3

水質浄化技術における実証試験場所の選定と評価手法

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キーワード：富栄養化，アオコ，水質浄化技術，水質改善，評価手法

抄録

湖沼等の閉鎖性水域において富栄養化に伴う植物プランクトンの異常増殖による景観の劣化，悪臭，アオコ等の水質問題が生じており，効果的・経済的な水質改善対策が求められている。国内におけるこれらの問題について，ベンチャー企業等により水質汚濁等の環境問題を改善するのに効果的と思われる先進的環境技術が開発・実用化されているが，いまだ環境問題を抱える現場にあまり導入されていない。環境省の環境技術実証（ETV）事業は，先進的環境技術の普及促進を目的として，エンドユーザーが安心して使用できるように第三者機関である実証機関が先進的環境技術の環境保全効果等について客観的に実証する。筆者らは，水質浄化技術における実証試験を合理的かつ適正に実施するために，実証対象技術（水質浄化技術）に応じた試験場所の選定と評価手法を検討してきたので事例を踏まえて紹介する。

1. はじめに

国内の湖沼の環境基準達成率に関しては，2015 年度では，COD(58.7%)，全窒素及び全りん(51.2%)と低い水準で推移し[1]，富栄養化に伴う植物プランクトンの異常増殖による景観の劣化，悪臭，アオコ等の水質問題が生じており，効果的・経済的な水質改善対策が求められている[2]。筆者らは，湖沼等の閉鎖性水域の水質を良好な状態に改善し，維持管理するための効果的かつ経済的な技術について数々の実証試験（技術性能の試験）を実施してきた。実証対象技術（水質浄化技術）に関しては，その原理，機器の規模・設置条件等がそれぞれ異なる。実証対象技術が持つ性能を合理的かつ適正に実証するために，試験場所の選定と評価手法について事例を踏まえて紹介する。

2. 方法

筆者らが平成 22 年度～平成 28 年度の期間に ETV 事業として実証試験を実施した実証対象技術を表 1 に示す[3]。浄化手法としては，機器に原水を導入し，処理水を放出する直接浄化が 4 技術と最も多く，浮島，浚渫及び撹拌がそれぞれ 1 技術であった。表 2 に各技術の浄化原理，機器の規模及び試験場所を示す。筆者らは，実証対象技術による水質改善の効果を評価するために，技術を導入している「試験区」と，導入していない「対照区」の水質等を比較する評価手法を基本としており，公園池内に池底が解放系の隔離水界（10m×10m，水深約 1m）を複数設置した試験場所を有している。技術Ⅰ，技術Ⅱ，技術Ⅳについては，隔離水界を試験場所として選定したが，その他の技術については各技術の特長・条件等により他の試験場所を選定した。

表 1 実証対象技術（平成 22 年度～平成 28 年度）

手法	実証対象技術（水質浄化技術）
浮島	【技術Ⅰ】花卉等陸生植物を用いた観賞式「グリーン生物浮島」
浚渫	【技術Ⅱ】生態系保全型底泥資源化システム
撹拌	【技術Ⅲ】環境配慮型撹拌装置「エムレボ エムレボエア」
直接浄化	【技術Ⅳ】移動式高性能湖沼浄化システム 【技術Ⅴ】ダイワエース（精密ろ過・生物膜ろ過システム） 【技術Ⅵ】促進酸化水処理システム 【技術Ⅶ】超高速凝集沈殿処理アクティフロプロセス

表 2 技術の浄化原理，規模，試験場所

技術	浄化原理	規模*（縦×横×高さ）	試験場所
技術Ⅰ	浮島+活性化石炭	0.9 m(直径)×0.5 m【3 基設置】	公園池内隔離水界
技術Ⅱ	浚渫+汚泥分離	9.0 m×6.0 m×4.5 m	公園池内隔離水界
技術Ⅲ	曝気+撹拌	1.98 m×1.94 m×1.4 m	ゴルフ場内調整池
技術Ⅳ	浮上分離+凝集沈殿	4.0 m×2.0 m×2.0 m	公園池内隔離水界
技術Ⅴ	凝集ろ過	2.5 m×3.0 m×4.0 m【12 基設置】	皇居外苑濠
技術Ⅵ	砂ろ過+促進酸化	2.3 m×2.4 m×2.0 m	申請者敷地内（観賞池）
技術Ⅶ	凝集沈殿	7.9 m×3.3 m×3.8 m【2 基設置】	皇居外苑濠

＊ 実証対象機器 1 基あたりの規模

技術Ⅲは，撹拌・曝気による物理処理が特長であり，その性能を実証するために，鉛直方向で水温差を生じ，底層が貧酸素化している調整池を選定した。技術Ⅴは，開発されたろ材が対象技術であったため，その技術が導入されている既設の施設を選定した。技術Ⅵ及びⅦに関しては，それぞれの技術の特長を維持するために必要な定期的な保守管理や，自社試験の実績等を考慮し，対象技術が導入された既設の施設を選定することで試験の効率化を図った。

筆者らは，実証対象技術の特長及び設置状況等に応じた実証試験を実施するために，上述した試験区と対照区の水質比較の他に，実証対象機器に流入する原水と機器から放流される処理水のそれぞれの水質より求めた除去率等による処理性能の評価手法や，処理水が放流される水域の浄化前と浄化後のそれぞれの水質から求めた改善率等による改善効果の評価手法を検討してきた。また，浄化手法が撹拌である技術Ⅲでは，機器稼働時と停止時の水平・鉛直方向における水質変化をそれぞれ調査・比較することで改善効果を評価した。既設の浄化施設を試験場所として選定した技術Ⅴ及びⅦでは，除去率による性能評価の他に，既存データを活用することにより改善効果についても評価した。

3. 結果

技術Ⅲの機器稼働時・停止時における溶存酸素（DO）の水平・鉛直分布を図 1 に示す（縦軸は水深（m），横軸はDO（mg/L），各折れ線は機器からの水平方向への距離（1m～21m）を示す）。

図 2 に技術Ⅶの実証試験期間（平成 28 年 6 月～9 月）における流入水（原水）・処理水・各濠のクロロフィル-a と気象データの推移を示す。

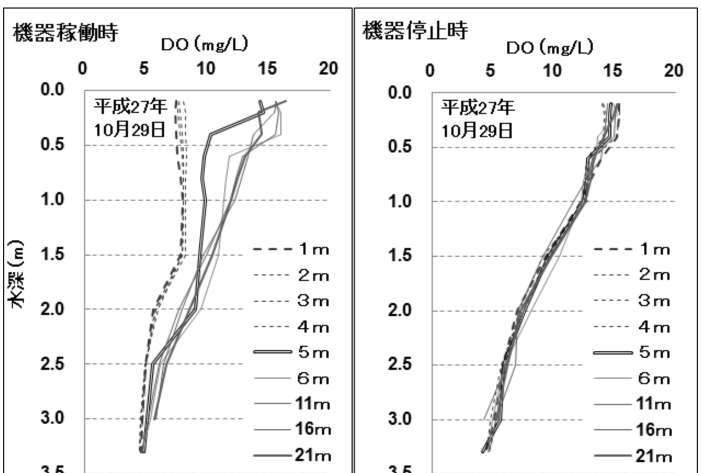
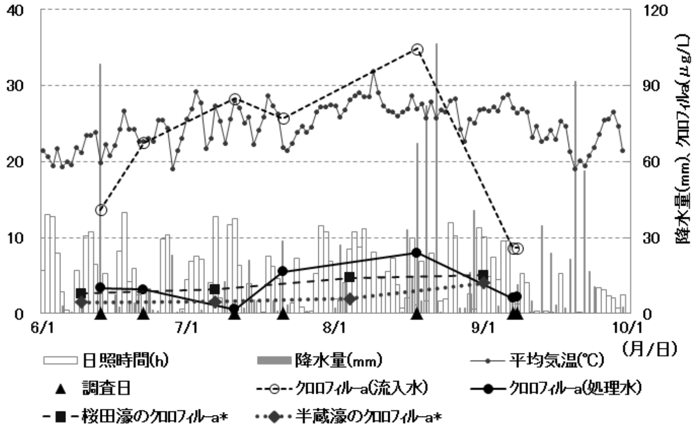


図 1 機器稼働時・停止時の DO の水平・鉛直分布



＊本データは平成 29 年 1 月現在速報値であり未確定のため参考値である。

図 2 クロロフィル-a と気象データの推移

（平成 28 年 6 月～9 月）

4. 考察

図1より，停止時（右図）は，DO の鉛直分布が水平方向（1m～21m）でほぼ同様の傾向を示したが，稼働時（左図）では，DO の鉛直分布が水平方向 5m を境に大きく異なり，機器による撹拌効果が水平方向 5m，鉛直方向 2m の範囲で示された。図 2 より，機器への流入水のクロロフィル-a は，植物プランクトンの増殖に伴い大きく変動（26～105μg/L）していたが，処理水は 1.7～24μg/L で推移し，除去率は 75.6～98.1%であった。また，放流先の各濠のクロロフィル-a（既存データ）に関しても処理水と同様なレベルで推移しており水質改善の効果がみられた。

5. 結論

筆者らは，実証対象技術に応じた試験場所の選定と評価手法を検討してきた。実証対象技術の特長及び設置状況等により，①試験区・対照区を用いた水質の比較・評価，②実証対象機器稼働前後の水質の比較・評価，③既存データによる水質改善効果の評価手法について検討し，実証試験を実施してきた。これらの方法を活用することで，気象条件等の影響を受ける野外での実証試験による水質浄化技術の性能評価が可能であり，より実態に近い状況での水質改善の効果を検証できることが示された。

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O3-4

A FUNDAMENTAL STUDY OF THE BLUE-GREEN ALGAE COUNTERMEASURES BY WASHOUT EFFECT IN LAKES

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Keywords: Blue-Green Algae, Specific Growth rate, Washout Effect

ABSTRACT

Algal bloom is a big problem that happens in lakes and reservoirs. Algal bloom is caused by blue-green algae and cyanobacteria increased and accumulated on the water surface. Blue-green algae thrive in warm, nutrient-rich water conditions in lakes, reservoirs with long retention times. The reason why blue-green algae become a problem is that: odors can be generated, and leads to landscape deterioration at the time of decomposition. In addition, it can be harmful to livestock and human health due to its liver poison. There is the drastic countermeasures in Japan, like water conduction which means using the river water and reclaimed wastewater to flush water bodies that suffered from algae bloom. The purpose of this study is to propose a method to simply define the safest required volume of water in order to prevent blue-green algae from growing by flushing out them. We know that we can tell whether the blue-green algae will die out or not by comparing the algae's growth rate and the rotation rate. In other words, it is better to conduct water more quickly than the growth rate of blue-green algae. Then, we evaluated applicability of this method by culture experiment about the blue-green algae.

1. INTRODUCTION

Algal bloom is one of the most common problems in lakes and reservoirs worldwide. Algal bloom is caused by blue-green algae and cyanobacteria increased and accumulated on the water surface. Blue-green algae thrive in nutrient-rich water conditions in lakes and reservoirs with long retention times. The reason why blue-green algae become a problem is that: odors such as 2-methylisoborneol and geosmin can be generated, and water body will turns into light blue and leads to landscape deterioration at the time of decomposition. In addition, it can be harmful to livestock and human health due to its liver poison. Fig.1 is Microcystis aeruginosa classified in Blue-green algae. Blue-green algae have high planktonic and adaptability compared to the other algae. Especially, they are resistant to high water temperature and high light intensity. And they're the optimum water temperature value are higher than other algae[1,2].In addition, It is feared that blue-green algae occur for water temperature rise due to global warming. There are mainly two types of countermeasures for improving blue-green algae problem, the first type is the temporary countermeasures, like constructed wetland, dredging, aeration, etc., the second type is the drastic countermeasures, like water conduction which means using the river water and reclaimed wastewater to flush water bodies that suffered from algae bloom. Generally, there is a method of decide the required volume of water in order to prevent blue-green algae using ecosystem and hydraulic model. Although ecosystem model can predict biomass in spatial and temporal detail, it is difficult to require a lot of variables and input parameters as the model structure becomes more complex. The purpose of this study is to propose a method to simply decide the required volume of water in order to prevent blue-green algae from growing by flushing out them. More specifically, considering the eutrophic environment, we propose the simple method to decide the safest required volume of water to flush out them by numerical analysis. In order to proof the applicability of the method, we made a culture experiment with blue-green algae using laboratory equipment.

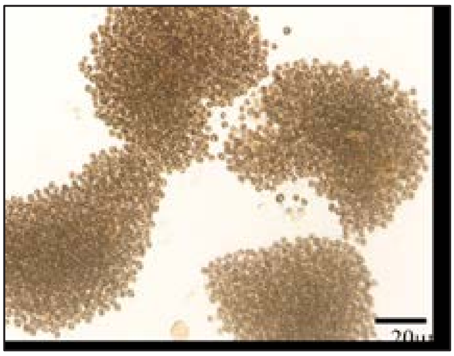

Fig. 1 Microcystis aeruginosa

2. THEORY AND METHODS

2.1 A METHOD OF DECIDE THE REQUIRED VOLUME OF WATER IN ECOSYSTEM MODEL.

Generally, Chlorophyll-a concentration which show the amount of phytoplankton in ecosystem model can be expressed by photosynthesis, extracellular secretion, respiration, feeding by zooplankton, mortality, sediment. Among them, the specific growth rate of algae by photosynthesis is expressed by the following formula.

$$r = r_{max} \cdot \left(\frac{N}{N+K_N}\frac{P}{P+K_P}\right) \cdot \frac{I}{I_{opt}} \exp\left(1-\frac{I}{I_{opt}}\right) \cdot \frac{T}{T_{opt}} \exp\left(1-\frac{T}{T_{opt}}\right) \quad (1)$$

r is the specific growth rate of algae (day^{-1}). r_{max} is the maximum specific growth rate of algae (day^{-1}). N is the Inorganic nitrogen (mg L^{-1}). K_N is the half saturation constant nitrogen (mg L^{-1}). P is the Inorganic phosphorus (mg L^{-1}). K_P is the half saturation constant phosphorus (mg L^{-1}). I is the Light intensity (MJ m^{-2}day^{-1}). $Iopt$ is the most suitable Light intensity (MJ m^{-2}day^{-1}). T is the water temperature (°C). $Topt$ is the most suitable water temperature (°C). The growth term by photosynthesis can be expressed by the specific growth rate multiplying Chlorophyll-a concentration. The specific growth rate is the incremental Chlorophyll-a concentration per unit time divided by Chlorophyll-a concentration. The specific growth rate can be expressed by the maximum specific growth rate, nutrients (inorganic nitrogen and phosphorous), the light intensity and the water temperature. The nutrients can be expressed by Monod type equations. The light intensity and water temperature can be expressed the growth of algae by the equations inhibition of high light intensity and water temperature considering environmental conditions[3,4,5]. In this study, we made a basic study using only the maximum specific growth rate removed the environmental conditions showing a value lower than 1 to propose the countermeasures toward the case of the worst water quality environment (eutrophication)($r = r_{max}$).

3. A METHOD TO SIMPLY DECIDE THE REQUIRED VOLUME OF WATER

Equation 1 is an exponential growth type (Malthus model) expressed by the maximum specific growth rate (r_{max}) multiplying the chlorophyll-a concentration when proposing countermeasures on the most safe side. However, it is necessary to consider the environmental capacity K that shows the maximum value can be grow because of algae is not able to grow exponentially forever. Equation 2 is an expressed that replaces the maximum specific growth rate with a function which decreases with the number of individuals. Generally that equation is called a logistic equation.

$$\frac{dC}{dt} = r_{max}\left(1-\frac{C}{K}\right)C \quad (2)$$

We added the washout effect to the logistic equation and found out that. The relation between the algae's maximum specific growth rate and rotation rate will decide the required volume of water in order to prevent blue-green algae. (Residence time is the water storage volume divided by the water conducting, rotation rate (day^{-1}) is its reciprocal number). In other words, blue-green algae cannot grow if the growth rate was lower than the rotation rate, that is, algae cannot grow if the washout effect is strong enough, and on the other hand it can grow as a solution asymptotically approaching the environmental capacity K if the rotation rate was higher than the growth rate. That is an important idea about the proposed equation in this study. Figure 1 shows the case of the number of algae when the maximum specific growth rate is faster than the rotation speed and lower than the rotation speed. As a previous study, about the relation between the algae's maximum specific growth rate and rotation rate, Amano(2008) evaluated the water conducting project of Lake Inbanuma by using the equation which added wash out effect proportional to algal to an exponential growth type[6] (Malthus model). However, detailed verification has not been done. Therefore, in order to prove this relation between the algae's maximum specific growth rate and rotation rate, we conducted a culture experiment.

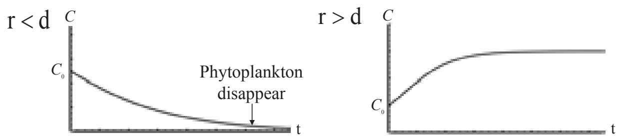

Fig.2 The relations of growth rate and rotation rate

4. PROVE BY CULTURE EXPERIMENT

We reanalyzed the data of continuous culture experiment using the retention time of dam and phytoplankton of algae growth by Kudo and Yamada (2004) from a point of view of specific growth rate and rotation rate of algae[7].

4.1 OVERVIEW OF THE CULTURE EXPERIMENT

In order to the culture condition be close to actual condition which increase of Blue-green algae in reservoir, we made a continuous chemostat culture. The condition of this culture experiment is water temperature is 20℃, light intensity is 2000 lux and complete mixing system. In addition, we used the phytoplankton at the experiment that is Phormidium which is a kind of the Blue-green algae and cause of the odors at reservoirs. The incubator is a mixed state using an air pump and air stone. Fig.3 shows the overview of the culture experiment. We made a culture experiment under phosphorous restriction and various retention time (0.7, 1, 1.2, 2, 3, 5, 7, 10, 20 day), and the specific growth rate r was calculated by the relationship between retention time and chlorophyll-a concentration (μg L^{-1}) in the exponential growth phase in the culture experiment.

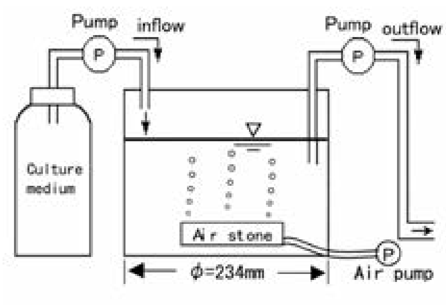

Fig.3 Overview of the culture experiment

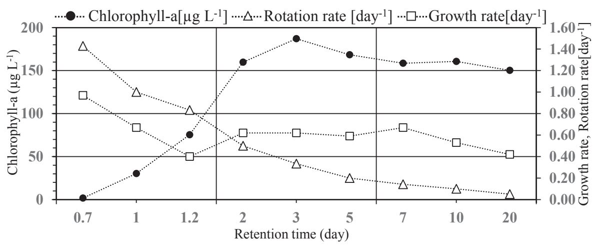

Fig.4 This figure is experiments results. Horizontal axis is retention time, vertical axis are chlorophyll-a (μg L^{-1}), rotation rate (day^{-1}) and growth rate (day^{-1}).

5. RESULT OF EXPERIMENT

Fig. 3 shows the results of the rotational rate, the specific growth rate and Chlorophyll-a concentration at each retention time obtained by the experiment. When the retention time is 0.7,1, and 1.2 days algae cannot grow because the rotation rate is higher than the growth rate ($d>r$). Whereas when retention time is 2,3,5,7,10,20 (days) algae can grow because the growth rate is higher than the rotation rate ($d<r$). Therefore, we found that the algae cannot grow as the retention time shorter because of algae flush out of the incubator faster than algae grow. Then, we evaluated applicability of this method by culture experiment about the blue-green algae.

6. CONCLUTION

The purpose of this study is to propose a method to simply define the safest required volume of water in order to prevent blue-green algae from growing by flushing out them. In order to prove this relation between the algae's maximum specific growth rate and rotation rate, we conducted a culture experiment.

We know that we can tell whether the blue-green algae will die out or not by comparing the algae's growth rate and the rotation rate. In other words, it is better to conduct water more quickly than the growth rate of blue-green algae. Then, we evaluated applicability of this method by culture experiment about the blue-green algae.

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O3-5

Flood Pulse in A Tropical Floodplain Lake and Its Implication on Aquatic Habitat Dynamics
Case study in the Sentarum Lakes Area, Kalimantan - Indonesia

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Keywords: Floodplain lake, flood pulse, water level, water quality, fish diversity

ABSTRACT

The Lake Sentarum in West Kalimantan, Indonesia, refers to a complex of large and small floodplain lakes in the middle part of the Kapuas River system. Apart from its great ecological and economic importance, the Sentarum lakes complex and its catchment area are generally threatened by deforestation, fire, monoculture agroindustry, and pollution. The objective of this research is to establish the hydrological characteristics of the Sentarum lakes area and to reveal the dynamics of aquatic habitat resulted from changing water levels. The water level was measured using a pressure sensor, while rainfall data were obtained from the data portal of the Tropical Rainfall Measuring Mission. Inundation monitoring was carried out using a time-lapse camera. A hydrological model is used to simulate water levels beyond measurement period. Water quality and fish sampling were carried out representing the seasons. Vegetation observation was carried out by field observation as well as analysis using satellite images. Water level records show that the Sentarum floodplain lakes have two peaks of inundation period following the bimodal pattern of rainfall in the equatorial Kapuas catchment. This water level dynamics induced changes in water quality, nutrient availability, vegetation cover, and fish diversity found in the Sentarum lakes area. Despite its seasonal changes, water quality of Sentarum lakes is generally good and suitable for aquatic biota. Fish diversity of the Sentarum lakes is relatively higher during high water period.

1. INTRODUCTION

The Lake Sentarum in West Kalimantan, Indonesia, refers to a complex of large and small floodplain lakes in the middle part of the Kapuas River system. As wetland area characterized by seasonal inundation, the Sentarum floodplain lakes have flood pulse that is determined by hydrological factors in the area as well as the upstream part of the Kapuas catchment. In wetland with flood pulse, there is a strong correlation between hydrological variation and aquatic biodiversity with apparent spatial and temporal variability [1]. Therefore, a synthesis from hydrological and ecological studies will enhance understanding on how and why water chemistry properties and aquatic biodiversity are varied among different times and locations.

The Sentarum lakes area is a vast natural reservoir with a maximum area of 1000 km^2 (Fig. 1) that can store as much as 3 billion m^3 of water [2], and consists of peat swamp forest and freshwater swamp forest. During the long dry season, most of the lake is dry, while during the rainy season the swamp and peat forest of the Sentarum lakes area are inundated forming a large shallow lake as shown in the Landsat images (Fig 2).

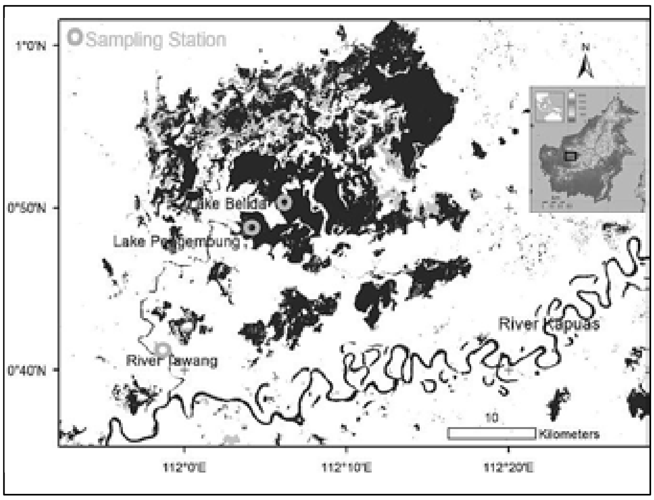


Fig. 1. Map of the Sentarum lakes area.

The Sentarum lakes area is an important source of livelihood of local people. The lake cluster produces about 18,000 ton of freshwater fish annually [3]. Apart from its great ecological and economic importance, the Sentarum lakes complex and its catchment area are generally threatened by deforestation, fire, monoculture agroindusty, and pollution.

The objective of this research is to establish the hydrological characteristics of the Sentarum lakes area and to reveal the dynamics of aquatic habitat resulted from changing water levels.

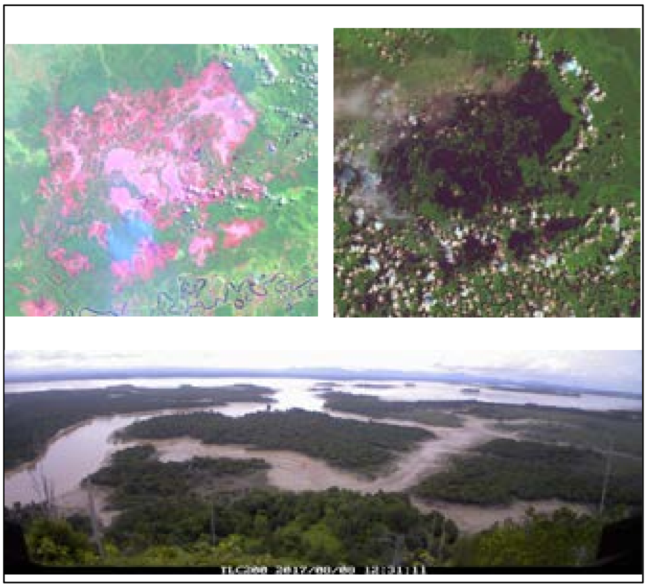


Fig. 2. Dry condition on 1 July 2004 (left), fully inundated on 1 October 2015 (right) of Lake Sentarum from Landsat images, and nearly dry condition on 8 August 2017 captured by time-lapse camera (bottom).

2. METHOD

Water level was measured using a pressure sensor, while rainfall data were obtained from the data portal of the Tropical Rainfall Measuring Mission. Inundation monitoring was carried out using a time-lapse camera. A hydrological model is used to simulate water levels beyond measurement period. Water quality and fish sampling were carried out representing the seasons. Vegetation observation was carried out by field observation as well as analysis using Landsat satellite images.

Water quality and vegetation sampling were carried out in 2013, 2016, dan 2017. Water samples were taken using Kemerrer Water Sampler at the lake surface and bottom analyzed for water quality Parameter including pH, DO, conductivity, nitrite, nitrate, ammonium, Total N, Total P, and organic matter (TOM). Vegetation sampling was carried out using the line transek method of 50 x 20 m with three replicates.

Fish samples were taken in March, June, October 2013, and March, June 2014. Fish sampling was carried out by experimental gill net with the total length of 350 m and height of 2 m. Different net mesh size was udes in every 50 meters distance: 12.70 mm, 19.05 mm, 25.40 mm, 38.10 mm, 50.80 mm, 76.20 mm, and 88.90 mm.

3. RESULTS AND DISCUSSION

Water level records show that the Sentarum floodplain lakes have two peaks of inundation period following the bimodal pattern of rainfall in the equatorial Kapuas catchment. Fig. 3 Shows measured water level of the Sentarum lakes.

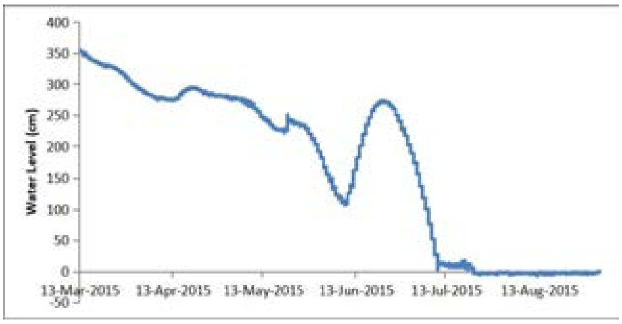
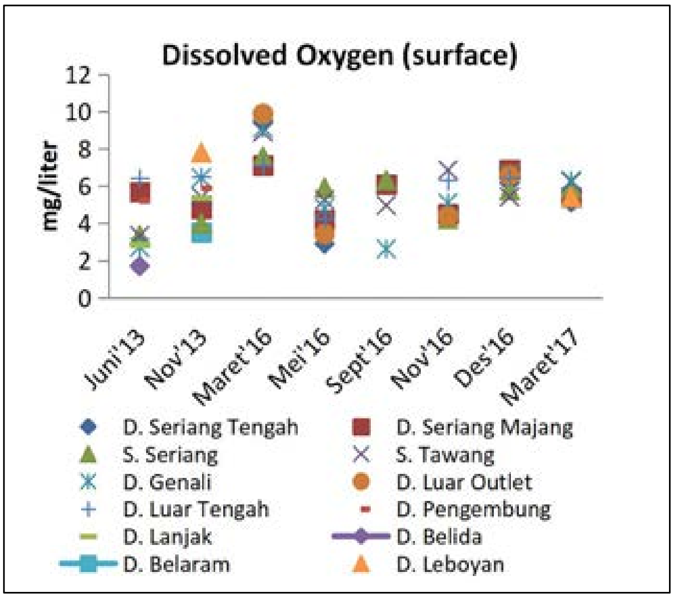
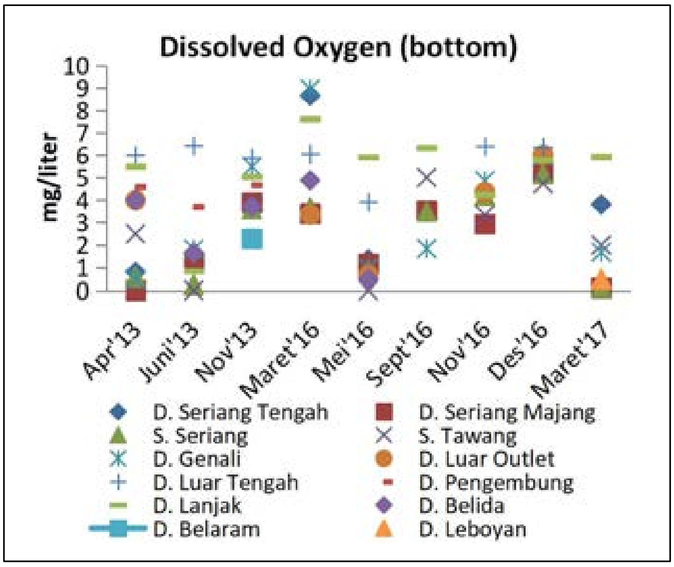


Fig. 3. Measured water level of Lake Sentarum.

Water quality observations show that aquatic environment of the Sentarum lakes area is relatively good for aquatic biota except that at the Seriang station Oxygen concentration of nearly zero was found at the lake bottom (Fig. 4). Fourteen riparian vegetation species were found in the lakes area, three of them are dominant species namely *Barringtonia acutangula* (Putat), *Ixora salicifolia* (Mentangis), dan *Maranthes corymbosa* (Melayak). The swamp forest provides feeding, refuge, spawning, and nursing grounds for fish [4].

Six orders, 15 families, and 39 species of fish were found in Tawang River, Lake Pengembung and Lake Belida in the Sentarum lakes area in the 2013 and 2014 fish sampling. The observed species diversity can be explained by the water level – hydrology – habitat – aquatic productivity – migration nexus as exemplified by the 'flood – pulse' concept [5]. Total number of species found in the dry season was less (20 species) than that in the rainy season (32 species). During low water level and low water depth, the highest number of species was found in River Tawang (16 species) compared to that of Lake Pengembung (5 species) and Lake Belida (3 species). Whereas during high water, the highest number of species was found in Lake Belida (24 species) and the lowest species was in River Tawang (15 species).





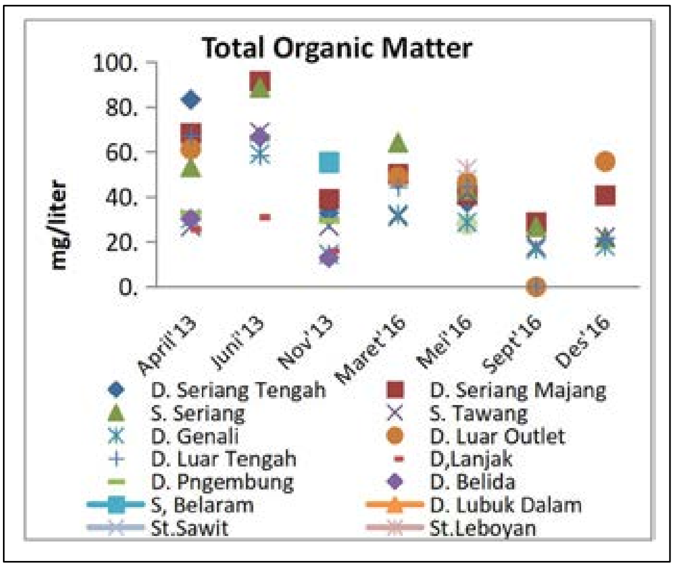


Fig. 4. Dissolved Oxygen at the surface (top) bottom (Middle) and Total Organic Matter during observation.

4. CONCLUSION

Hydrological characterization of the Sentarum Lakes area had been carried out considering the influence of water level changes to aquatic habitat dynamics. Water level dynamics induced changes in water quality, nutrient availability, vegetation cover, and fish diversity found in the Sentarum lakes area.

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O3-6

Dissolved oxygen profiles and its problems at Lake Maninjau, West Sumatera - Indonesia

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Keywords: water quality, dissolved oxygen, fish cage area and Lake Maninjau

ABSTRACT

In general, tropical lake in Indonesia is one of the unique ecosystems which are functioning in both ecological and economic services. The objective of this study is to analyze the dissolved oxygen profile of caldera tropical lake represented by Lake Maninjau at West Sumatera, Indonesia and its impact. Lake Maninjau, not only for fisheries culture, but also serves as important hydroelectricity power. Surveys at Lake Maninjau was conducted in August 2006, March 2014, September 2017 and April 2018. The results on the survey in Lake Maninjau showed that the average depth is 105 m. It covers 13,260 ha of area with a height of 461.5 m above sea level and maximum depth of 165 m. The lake water comes from rainfall, small rivers and the surrounding ground water and one outflow in Batang Antokan River. Based on the measurement results, it obtained that dissolved oxygen from the surface layer to a depth of 40 m (2006) has decreased to a depth of 12 m (2018), indicating the worse condition of water quality in 2018 compared with previous years. Currently, bad water quality and mass mortality fishes often occurred. Next, the percentage value of fish cages at Lake Maninjau in 2017 was 0.43%. Besides human activities, it suggested also that the potential impact from fish cages constributed pollutant concentration into this lakes. In order to maintain the sustainability of the lake, basic ecological information is necessary for the next study.

1. INTRODUCTION

Lake Maninjau is a large lake which including in the type of caldera lake. This lake is located in Agam District - West Sumatra and has an important role for daily life and the beauty of the lake (Fig.1). Further, it has become the pride of the surrounding community. Currently, Lake Maninjau has economic functions as a power plant that produces the annual rate of 205 GWH of energy, sources of irrigation water, fishing fish farming in floating cages and catching, and tourism destination [1 & 2]. In addition, from the view of ecological functions, Lake Maninjau could control the water balances of soil, microclimate and habitat for organisms.

Besides hydropower, utilization Maninjau also for fish farming activities in the floating net. Cultivation of fish in floating net began in 1990. Fish farming activities in floating net have increased the high economic growth for local communities. But since 1997, this activity began to decrease because of frequent death of fish caused the loss of business. Since when was there a public complaint that a decrease in water quality of the lake is causing economic loss to the community or local government from both fish farming activities in the cages and tourism. Besides for fish farming in floating cages, Lake Maninjau is also used for tourist activities, especially by foreign tourists [3]. The development of tourism activities also led to the growth of the hotel or inn and restaurant around the lake. But the water quality of the lake such as murky water and odor caused a decline in tourist numbers and the impact on the economy of the community and local government.

In early January 2009, more than 13 thousand tons of disaster death of fishes occurred at Lake Maninjau. From measuring the water quality of lake from observation by Limnology station - Research Centre for Limnology LIPI, on January 2009, reported a drop of dissolve oxygen (DO) 1.05 mg/l in water surface (normal conditions approximately 7 mg/l) with temperatures 28°C and pH 7.17. At three meters of water depth, dissolved oxygen (DO) content had reached 0.46 mg/l and temperature 27.2°C. The water column is normally used for floating cage. The low oxygen content was causing mass death of fishes. This disaster is related to what is called by local people as "tubo sulfur." Generally sulfur turbo phenomenon has been frequently occurs at the beginning of the year. In addition, there is a possibility of circulation influence on the vertical profiles of dissolved oxygen in some of the lakes, where related to the seasonal meteorological patterns [4].

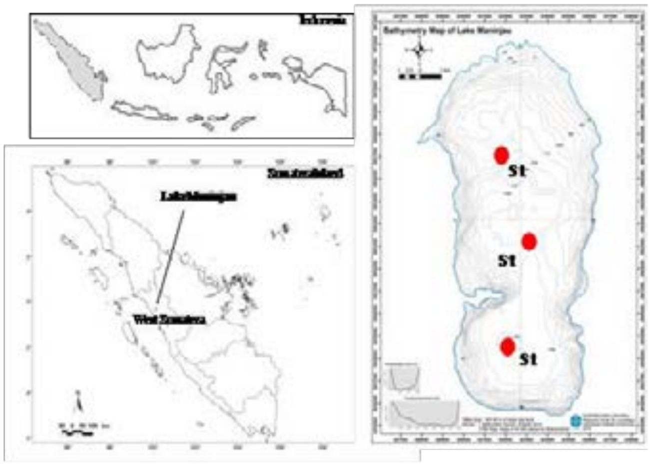

Fig. 1 Locations of study area

2. METHOD

Survey at Lake Maninjau was conducted in August 2006, March 2014, September 2017 and April 2018. Not only survey at field, but also to collect the secondary data for supporting the analyze.

We conducted dissolved oxygen (DO) profile measurememt in August 2006 by multi-probe sensor YSI 6600. Measurements were carried out until to the depth of 50 m with an interval of 0.4 m. Dissolved oxygen (DO) profiles was obtained with ranged 0 to 50 mg/L and resolution 0.01 mg/L. Meanwhile, DO profile measurement in March 2014, September 2017 and April 2018 were taken from three locations at Lake Maninjau by ringko profiler, supported by University of Tsukuba, Japan. The logger version CTD profiler with optical fast DO sensor RINKO-Profiler was used for survey. Depth (semiconductor pressure sensor with ranged 0 to 600 m and resolution 0.01m) and dissolved oxygen/DO (phosphorescence with ranged 0 to 20 mg/L and resolution 0.001mg/L) were obtained at each station. Measurements were carried out until to the depth of 160 m with an interval of 0.1 m.

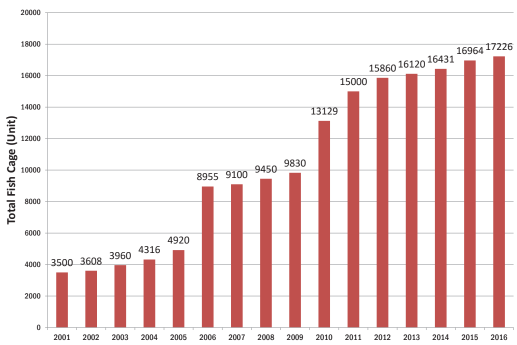

Fig. 2 The amount of fish cage at Lake Maninjau since 2001

Source : Agam Regency – West Sumatera (2016)[6]

Finally, fish aquaculture cages established at lake Maninjau was also observed and accounted (Fig. 2). At Lake Maninjau, there are approximately 16,000 unit fish culture cages in 2017, in general with sized 5 x 5 m [5].

Through campaigning "Save Maninjau" by local government [6], they succeed to hold the growth rate of fish cage and the total fish cage were 16,776 unit and 17,226 unit for 2017 and 2016, respectively.

3. RESULTS AND DISCUSSION

Lake Maninjau is located at an altitude of 461.5 m above sea level with a surface area of 9,737.5 ha and a maximum depth of 165 m. Lake Maninjau is a caldera lake formed by volcanic activity in 60,000 years ago [7]. The source of water comes from rain water lakes and streams as well as the surrounding ground water. This lake has a water line out called Batang Antokan flowing into the Indian Ocean, on the West coast of West Sumatra.

In Lake Maninjau, since 1983 is used for power generation that the average annual production of 205 GWH, by building a dam at the outlet (Antokan River, which is the basis of the river at an altitude of 462 m). The dam raised the water level of the lake from a height of 462 m from sea level to 464 m. In addition, outflow from the lake is used for power generation through the intake structure at a height of between 457.15 m to 453.75 m from sea level.

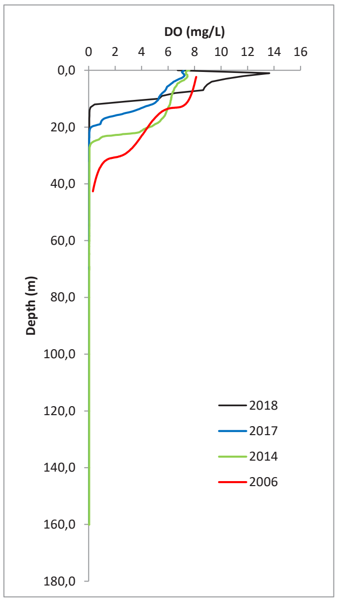

Fig. 3 DO profiles at Lake Maninjau (August 2006, March 2014, September 2017 and April 2018)

Based on Fig. 3, high dissolved oxygen content in the surface layer and the base of diminishing. Dissolved oxygen from the surface layer to a depth of 40 m (2006) has decreased to a depth of 12 m (2018), indicating the worse condition of water quality in 2018 compared with previous years.

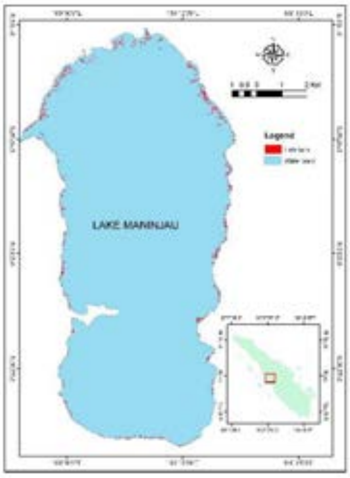

Fig. 4 Distribution of fish cage (red colour) in 2016

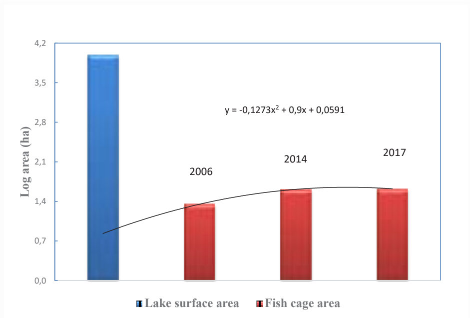

Fig. 5 Comparison between lake surface and fish cage areas for 2006, 2014 and 2017

Based on survey and secondary data, we obtained the distribution of fish cage (Fig 4). Next, in Fig. 5 showed comparison among fish cage areas (log area (ha)) in three years observed. The fish cage area were 22.4 ha, 41.1 ha and 41.9 ha for 2006, 2014 and 2017, respectively. It suggested the growth of fish cages as pollutant also influenced water quality at Lake Maninjau.

4. CONCLUSION

Lake Maninjau function in ecological and economic services as a caldera tropical lakes has faced in various problems. The decreasing of dissolved oxygen layer from the surface layer compared with previous years, indicating the larger impact from human activities constribute to the water quality on the lake.

It found the percentage value of fish cages at Lake Maninjau was higher in 2017 (0.43%) than that in 2006 (0.23%). Based on this ratio, the density of aquaculture which indicated the potential impact i.e. pollutants from fish cages at Lake Maninjau. Consequently, in order to maintain the sustainability of these lakes, basic ecological information is necessary for the next study.

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O3-7

霞ヶ浦外浪逆浦の浚渫窪地での水温成層形成とそれによる水質への影響

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キーワード：浚渫窪地，水温成層，水質変動

抄録

浚渫窪地は，外部水域との水の交換が起こりにくいことから，成層の形成で生じる貧酸素化を原因としたりんの溶出を生じる一因となっている。霞ヶ浦にもかつての土壌採取等による浚渫窪地が存在し，特に南東部に位置する外浪逆浦に大規模な浚渫窪地があるが，これまで調査報告例はないため，霞ヶ浦外浪逆浦の浚渫窪地を対象にして水温成層の形成状況及び水質の状況を調査した。窪地の内部では，水温成層の形成と破壊が繰り返し生じ，水温成層の破壊は主に気温の低下と強風により生じることが明らかになった。また，水温成層の状況と水質との関係を検討したところ，水温成層形成時には下層で DO 濃度が低下し，PO_4-P が高濃度となっていることが確認できた。

1. はじめに

海洋や湖沼の底には，局所的に深くなった窪地が存在しているところがある[1,2]。この窪地は東京湾・三河湾・大阪湾の三大湾，瀬戸内海及び九州沿岸に多く存在し，多くは砂利採取や海底掘削等により生じたものである。

窪地内部では，外界との水の交換が起きにくいため成層を形成して貧酸素水塊を生じるため青潮発生の原因や生物への悪影響になるとともに，底泥からのりんの溶出が生じて水質を悪化させる。例えば三河湾では，平成 13 年度及び平成 14 年度に窪地内部での貧酸素化により青潮が発生し，周囲のアサリ漁に壊滅的な打撃を与え，このことを受けて三河湾では平成 15 年度から窪地の埋め戻しが行われた[3]。この他にも東京湾，大阪湾，瀬戸内海でも窪地の埋め戻しが行われており，加えて平成 17 年 3 月の交通政策審議会答申及び平成 17 年 5 月の中央環境審議会答申において，窪地の積極的な埋め戻しが提案された[4,5]。これらのように窪地が水質や生物に与える悪影響が指摘され，埋め戻しの必要性が提唱されている。

茨城県南部に位置する霞ヶ浦においても，かつての砂利採取による窪地が存在し，特に外浪逆浦では，水深 20 m にもなる窪地が確認されている。この窪地が，りん等の溶出により水質に影響を及ぼす可能性が考えられるが，この窪地が水質に与える影響について評価した例はない。

そこで本研究では，外浪逆浦の北部に位置する水深約 11m の窪地を対象として，水質への影響を評価したので報告する。

2. 方法

2.1 調査地点諸元

外浪逆浦は，日本の茨城県南部に位置する霞ヶ浦の一水域で，湖面積 6.0 km^2 の淡水湖である。主要部の水深は 2～3 m であるが，図 1 に示すように一部にかつての土壌採取や砂利採取により水深 10 m 以上の窪地が生成されている。流入河川は，西浦と接続する北利根川と，北浦と接続する鰐川の 2 河川で，流出河川は常陸川の 1 河川のみであり，常陸川には海水の流入を防ぐための水門があり，その水門の開閉により外浪逆浦の湖流が変化することが報告されている[6]。

2.2 調査概要

調査対象は，外浪逆浦の北部に位置する，長辺 1 km，短辺 500 m，水深 11.5 m の窪地（周辺部は水深約 2 から 3 m）とした。

調査期間は，2016 年の 6 月 3 日から 8 月 31 日にかけて行った。

図 1　調査地点図

調査地点に水温ロガー（HOBO 製　Pro v2）を水面下 1 m から 10 m まで 1 m 間隔で設置し，1 時間ごとに連続測定を行った。また概ね 2 週間に 1 回程度の頻度で 0.5 m，2 m，4 m，6 m，8 m，10 m の深度で現地で DO の測定及び採水を行った。DO の測定には HACH 製　HQ 30d を用い，採水にはバンドーン採水器（離合社製，50260）を用いた。

2.3　分析方法

PO_4-P は，JIS K 0170-4 6.3.4 モリブデンブルーCFA 法で測定した。

2.4　気象等データ

気温及び降水量は，気象庁の鹿嶋の測定結果を用いた。風速は，国土交通省関東地方整備局霞ヶ浦河川事務所の潮来（調査地点より西北西に 4.7 km）の測定値を用いた。水門の開閉時間は，国土交通省霞ヶ浦河川事務所の測定値を用いた。

3.　結果

水温の連続測定結果を図 2 に，DO 及び PO_4-P の測定結果を図 3 及び図 4 に示す。また，DO 及び PO_4-P については，茨城県公共用水域及び地下水の水質測定結果及び霞ケ浦環境科学センター定期調査結果の中で，窪地水質調査日に最も近い測定結果を参考として示す。

図 2 は上層との水温差を示し，濃色部分が水温差が大きいところになる。水温の上下層差は，6 月から 8 月の間に断続的に変化し，調査期間中では計 7 回水温成層の破壊が生じた。

DO は，6 月 7 日，6 月 29 日は下層で顕著な貧酸素化が見られなかったが，7 月 14 日，8 月 10 日，8 月 26 日の調査時には下層で顕著に DO が低下していた。

PO_4-P は，6 月 7 日，6 月 29 日，及び 8 月 26 日は下層で PO_4-P の上昇は見られなかったが，7 月 14 日，8 月 10 日では下層で PO_4-P が上昇した

4.　考察

4.1　水温成層の破壊要因の検討

水温成層の形成状況及び破壊条件を把握することは，下層の DO 状況を推定する上で重要である。そこで，水温成層の破壊条件について検討することにした。なお，霞ヶ浦においては 1℃以下の水温差で湖水の上下流が抑制されるという報告があるため[7]，水温の上下層差が 1℃以上の時を，水温成層が形成されていると定義した。水温成層の破壊要因としては，主に気温の低下による表層水の冷却，強風による撹拌，降雨の影響，常陸川水門の開閉の 4 項目が主に考えられたため，これらの関係について検討を行った（図 2)。

初めに，水温成層と気温との関係を検討した。これを見ると，水温成層が破壊された時期には，8 月 17 日を除き直前に急激な気温の低下が見られた。このことから気温の低下は水温成層の破壊に寄与すると考えられたが，ほかの要因も寄与していると考えられた。

次に，水温成層と風速の関係を検討した。調査期間中では，日平均値で 5 m/s 以上の風が吹くと水温成層が破壊される傾向が見られた。気温との関係が見られなかった 8 月 17 日の水温成層破壊時にも 6.2 m/s の風が吹いていたことから，8 月 17 日の成層破壊は風の影響と考えられた。なお，8 月 8 日には 6.8 m/s の風が吹いていたが水温成層の破壊が見られなかった。前日の 8 月 7 日における水温差は，調査期間中最大の 4.4℃と大きく，水温成層の完全破壊までは至らなかったと考えられた。

次に，水温成層と降水量の関係を検討した。6 月 29 日，7 月 17 日，8 月 17 日の成層破壊時には直前に降雨があり，この期間については降雨との関計が考えられるが前述の気温低下も同時期に見られていることから，詳細な関係は不明である。

最後に，水温成層と水門の開閉について検討した。調査期間中における水温成層形成時の水門開閉は 8 月 6 日に 1 回行われたが，その時には成層破壊は見られなかったことから，水門の開閉は成層破壊に寄与しないと考えられた。

以上のように，外浪逆浦の窪地における水温成層の破壊要因としては，気温の低下，強風の影響が主に考えられた。なお，降雨の影響は不明なため，今後さらなる検討が必要である。

4.2　水温成層形成が水質へ及ぼす影響

水質調査を行った 5 日のうち，6 月 7 日，6 月 29 日には水温成層が形成されておらず，7 月 14

日，8 月 10 日，8 月 26 日には水温成層が形成されていた。これらの時の水温成層の状況と水質との関係の検討を行った。

まず水温成層と DO の関係の検討を行った。水温成層が形成されていなかった期間は下層での DO の顕著な低下が見られず，逆に水温成層が形成されていた期間は DO が顕著に低下していた。このことから，外浪逆浦においても他地域と同様に成層の形成による貧酸素水塊の形成が確認できた。

次に，水温成層と PO_4-P の関係を検討した。こちらも同様に，水温成層が形成されていなかった期間は下層の PO_4-P の上昇が見られなかった。また水温成層が形成されていた時期では，7 月 14 日と 8 月 10 日は下層で PO_4-P の上昇が見られた。一方で水温成層が形成されていた 8 月 26 日に PO_4-P の上昇が見られなかった原因については，8 月 26 日は水温成層が形成されてからの期間が短かったために，PO_4-P の溶出量がほとんどなかったことが原因と考えられた。

5. 結論

外浪逆浦にある，水深 11.5 m の窪地を対象にして，温度躍層の破壊条件及び水質への影響調査を行った。今回の結果からは，水温成層は主に気温の低下及び強風により破壊されると考えられた。また，成層形成時には DO の低下及び PO_4-P の溶出が確認できた。

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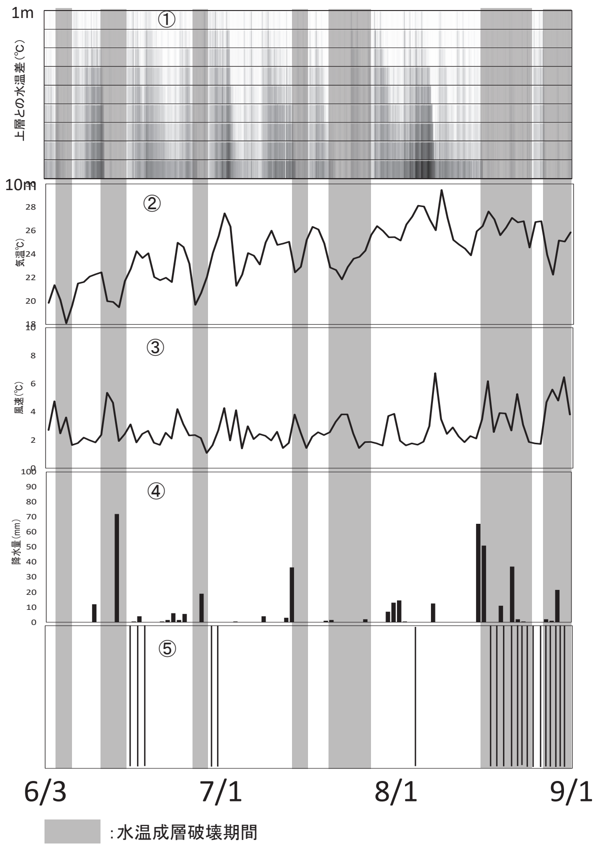

図 2　水温成層と各水質項目の関係
（①：水温成層，②：気温，③：風速
④：降水量，⑤：水門の開閉）

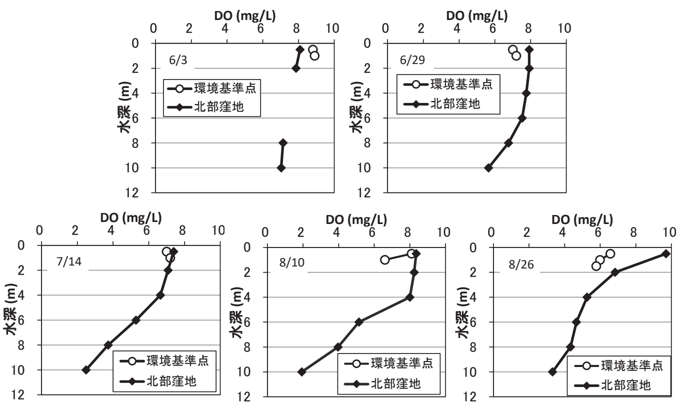

図 3　DO の測定結果

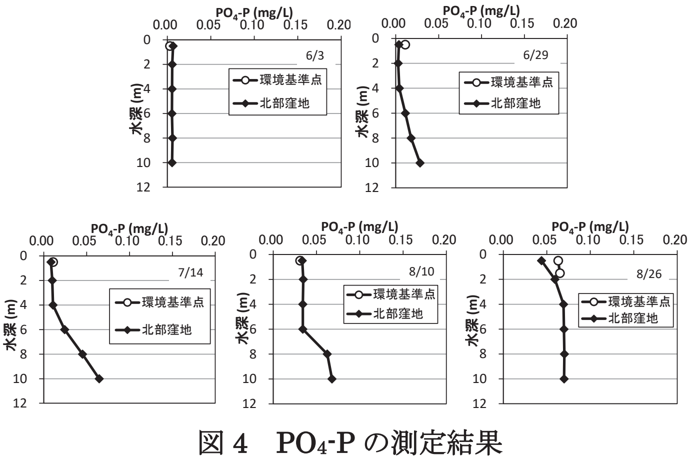

図 4　PO_4-P の測定結果

O3-8

Effects of Three Gorges Dam on spatiotemporal distribution of silicon in the tributary: evidence from the Xiangxi River

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Keywords: Silicon; Spatiotemporal distribution; tributary; Three Gorges Dam;

Abstract

In order to get insight into the impact of dam construction on silicon distribution pattern due to the altered hydraulic and environmental conditions, the Xiangxi River was chose as the delegate of the tributaries in the Three Gorges Reservoir to screen the effects of the Three Gorges Dam on silicon distribution. Dissolved silica (DSi), biogenic silica (BSi) and lithogenic silica (LSi) were investigated monthly from November 2015 to October 2016, the hydrodynamic conditions were addressed synchronously. DSi was significantly lower in the wet season than the dry season ($P<0.05$), BSi and LSi were significantly higher in the wet season than the dry season ($P<0.05$). DSi was dominant component in the total silicon (> 90%) and it has a relatively higher concentration in the upstream than the downstream in the main channel. BSi was higher in the upstream than the downstream. LSi was significantly higher in the upper tributaries than the main channel ($P<0.05$). Statistical analysis showed that DSi was linearly negatively correlated with water discharge（$P<0.05$）. BSi concentration showed a negative correlation with DSi ($P<0.05$). Water velocity and discharge exhibited a positive correlation with LSi concentration ($P<0.05$). DSi had a negative correlation with Chl *a* while BSi had a positive correlation with Chl *a* ($P<0.05$). The backwater area retained 2.59% bioavailable silicon (DSi+BSi). It was concluded spatio-temporal heterogeneity of silicon distribution related to hydrodynamics was determined by the regulation of dam, backwater area was the main deposition area for silicon.

1. Introduction

River is an important place for the silicon cycle because approximately 80% of silicon empties into the ocean through river, which pass from the lithosphere to the hydrosphere. Silicon in river is originally from rock weathering. At a global scale, tropical rivers have relatively higher dissolved concentrations than non-tropical rivers due to their high temperature and runoff, thus, high weathering rate, which influence the distribution of silicon. Dam construction will decrease DSi in a river. For instance, DSi concentration in the Nile River decreased by 200μg/L after the construction of the High Dam at Aswan. Similarly, DSi in the Black Sea showed a 60% decrease in wintertime after the construction of the Iron Gates dams. An obvious decline in DSi was observed when water passed through cascade reservoirs in Jiulong River.

In this study, we hypothesize that the silicon distribution and retention in the tributary were closely related to the hydraulic dynamics caused by dam operation in the Three Gorges Reservoir.

2. Materials and methods

2.2 Sampling and analytic methods

Twelve sample sites were set along the river (Figure1).

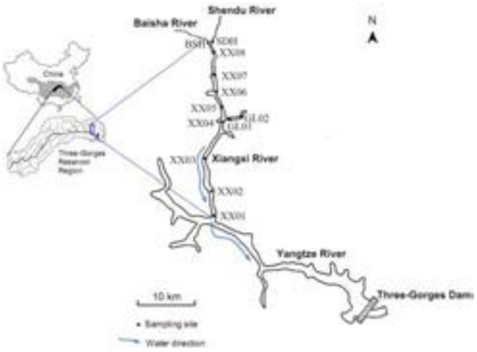

Figure 1 .Sketch map of sampling stations in the Xiangxi River

3. Results

3.1 Hydrodynamics

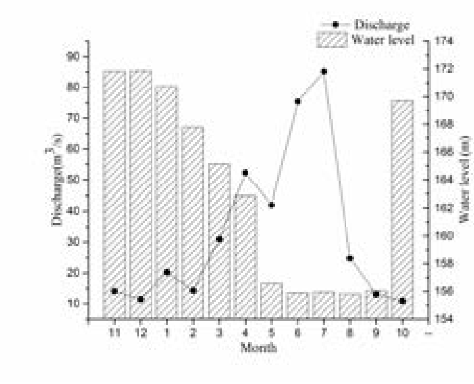

Figure 2. Variation of water level in the TGR and discharge in the Xiangxi River during the study period

3.2 Temporal distribution of silicon

Positive correlation was found between LSi concentration and discharge (Fig. 4)

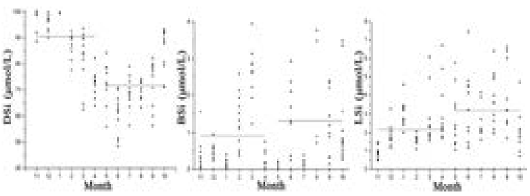

Figure 3. Variation of silicon monthly in the Xiangxi River, Spring is March ~ May, Summer is June ~ Augest, Autumn is September ~ November, Winter is December ~ next February.

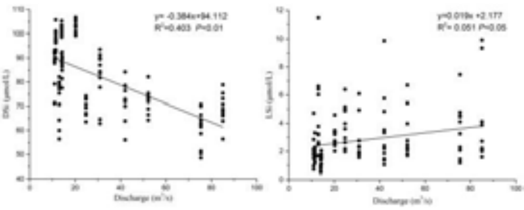

Figure 4. Relationship between water discharge and concentrations of DSi and LSi in the Xiangxi River

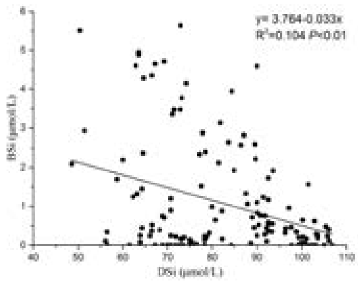

Figure 5. Relationship between DSi and BSi in the Xiangxi River

3.3 Spatial distribution of silicon

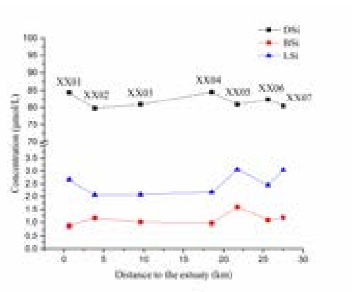

Figure 6. Longitudinal distribution of silicon in the main channel of the Xiangxi River

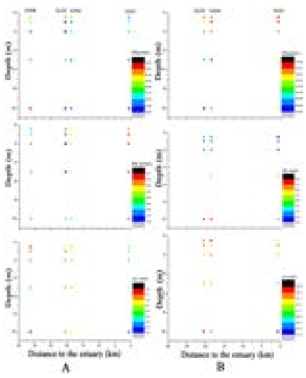

Figure 7. Vertical distribution of silicon at three sites in the dry season(A) and wet season(B)

3.4 Silicon retention in the backwater area

2.59% of the inflow total bioavailable silica (DSi+BSi) was retained. 3.67% of the TSi inflow was removed through the backwater area.

4. Discussion

4.1 Silicon fluxes in the Xiangxi River

Approximately 3.14% of DSi and 0.04% of BSi retained in the TGR were captured in the Xiangxi River. Silica retention efficiency in the reservoir was affected by the trophic state and reservoir age.

4.2 Silica dynamics and its influencing factors

DSi flux is controlled by the runoff and concentration of DSi. It is indicated that the BSi is primarily controlled by phytoplankton.

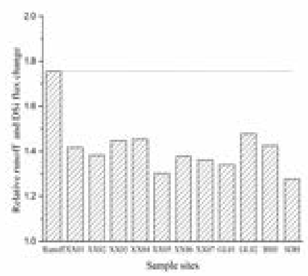

Figure 8. The relative changes of runoff and DSi at each site. The relative change were calculated by dividing the annual runoff and DSi fluxes in the wet season by those in the dry season. The upper broken line represents the runoff change. DSi fluxes that changed to the same degree as the runoff are controlled by runoff, and the one that differ from the runoff change are influenced by the DSi concentration.

4.3 Impacts of dam on the distribution of silicon

Dam will push Yangtze River water back to the tributary, which can also influence the distribution of silicon. The water intrusion process in the Xiangxi River has been investigated in detail .Silicon species structure changed under the intrusion process. The present study exhibited an increase DSi proportion in the downstream (XX01~XX04) but a decline of LSi proportion. Meanwhile, an obvious higher DSi and LSi at XX01 than other sites was observed (Fig 6).

5. Conclusion

Dam construction affects silica variation mainly through altering hydraulic conditions. It was concluded that silicon flux was determined by discharge, backwater area was the main retention area for silicon, and spatio-temporal heterogeneity of silicon distribution determined by regulation of dam was related to hydrodynamics.

O3-9

秋田県八郎湖における魚類による藍藻の餌利用状況

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キーワード：アオコ, 富栄養化, 食物連鎖

抄録

アオコを形成する藍藻類は、フロックの形成や毒素生産などの特徴から水生動物から摂食されにくいと考えられてきたが、実際の湖沼生態系で藍藻が水生動物によって餌として利用されているか調べた事例は少ない。本研究では魚類による藍藻の餌利用の状況を調べるために、秋田県八郎湖において、2016 年 6 月から 11 月にかけて月 1 回の建網調査を行った。そして、採集した魚類筋肉中の脂肪酸組成を調べることで、魚類が藍藻を餌として同化しているか検討した。7 月には藍藻が優占し始め、8 月から 10 月にかけてアオコ状に藍藻が発生している様子が確認された。本調査で採集された各魚類体内における藍藻に由来する脂肪酸（18:2ω6 および 18:3ω3）の含有率は 8 月までほぼ一定で推移したが、9 月に急激に上昇した。アオコ発生の初期においては魚類による藍藻の餌利用は認められなかったが、アオコ発生が継続すると、魚類が藍藻を餌として利用し始めると考えられた。

1.　はじめに

富栄養化が進行した湖沼においてしばしばアオコが発生する。アオコとは異常増殖した藍藻類が水面を緑色に染める現象のことを指す。アオコを形成する藍藻類は、フロックの形成や毒素を生産することで、動物プランクトンによる摂食から逃れやすい。そのため、湖沼生態系において藍藻は餌として利用されにくく、アオコが発生すると生食連鎖が断ち切られると考えらえてきた。しかし、実際の湖沼生態系において、藍藻がどの程度餌として利用され、藍藻に由来する有機物が高次の動物に餌利用されているか検証した事例は少ない。

藍藻を餌利用しているか検証する方法として脂肪酸分析が挙げられる。藍藻にはリノール酸（18:2ω6）やリノレン酸（18:3ω3）といった脂肪酸が含まれており、これらの脂肪酸は動物からは合成されない。そのため、動物体内からこれらの脂肪酸が検出されれば、藍藻に由来する有機物を同化していると推定することができる。

そこで本研究では、魚類による藍藻の餌利用の状況を明らかにすることを目的として、毎年夏季にアオコが発生する秋田県八郎湖を対象に、魚類の脂肪酸組成の経月変化を調べることで、魚類が藍藻を餌として利用しているか検証した。

2.　方法

2.1　調査地概要

八郎湖は秋田県男鹿半島の付け根に位置する淡水湖である。富栄養化が進行し、夏季にアナベナ属やミクロキスティス属によるアオコの発生が報告されており[1]、平成 19 年度には湖沼水質保全特別措置法に基づく指定湖沼となっている。八郎湖は農業用水として利用されているほか、漁業も営まれている。ワカサギが八郎湖総漁獲量の 90％以上を占めており[2]、ワカサギが優占種となっている状況が伺える。

2.2　調査内容

2016 年 6 月から 11 月にかけて月に 1 回、八郎湖の湖心付近に一晩建網を設置し、魚類を採取した。また、表層水をポリ瓶で採水した。採取した魚類はクーラーボックスに入れて実験室に持ち帰り、尻ビレ付近の筋肉を切り出し、脂肪酸分析まで冷凍保存した。水試料はガラスフィルター（GF/F）でろ過し、ろ紙上にトラップされた粒子を懸濁物質サンプルとして脂肪酸分析に供試した。

脂肪酸分析は凍結乾燥した、魚類の筋肉、ガラスフィルターを対象として、One-step method [3]を用いて、脂質の抽出および誘導体化を行った。抽出・誘導体化した脂肪酸メチルエステルはキャピラリーカラム（アジレント社、Select FAME）を装填したガスクロマトグラク（サーモフィッシャーサイエンティフィック社、Trace1310）で定性・定量を行った。

3.　結果

目視および顕微鏡観察によって、8 月、9 月、10 月にアオコの発生が確認された。懸濁物質中の藍藻由来脂肪酸含有量は 9 月まで増加し続けた（図 1）。調査期間を通して、コイ、ギンブナ、ジュズカケハゼ、ヌマチチブ、

ワカサギが採取された。ワカサギは体長から当歳魚(≤50 mm)と1歳魚(≥80 mm)に分けて解析した。各魚類ともアオコが発生前の6月時点では藍藻由来の脂肪酸含有率が1～4%程度と低く、アオコの発生が認められた8月まで、低含有率のまま推移した(図2)。しかし、9月にワカサギ 1 才を除くすべての魚種において、藍藻由来脂肪酸含有率の増加が認められた(図2)。

4. 考察

これまで藍藻は湖沼生態系において食物連鎖に組み込まれにくいと考えられてきた。本研究においても、藍藻が優占し始めた 7 月およびアオコの発生が確認された 8 月時点では、魚類体内の藍藻由来脂肪酸含有率は増加せず、魚類が藍藻に由来する有機物を餌として同化していないことが示された。藍藻は最大数 mm のフロックを形成することで動物プランクトンからの摂食を逃れることができるが、本調査で採取した魚の口のサイズは数 mm よりも大きく、藍藻によるフロックの形成は摂食の妨げにならないと考えられる。それでも、8月まで魚類による藍藻の餌利用は認められなかった。藍藻はエイコサペンタエン酸やステロールなど動物に不可欠な脂質栄養素を含んでいないことから、餌として低価値であるとことが指摘されており、魚類が藍藻の摂食を避けていた可能性が考えられる。しかし、9 月には魚類体内の藍藻由来脂肪酸の含有率が急上昇し、魚類が藍藻を餌として同化していることが明らかとなった。アオコが継続して発生し、藍藻優占の状況が続くと、魚類も藍藻を餌として利用し始めるのかもしれない。ただし、脂肪酸含有率の結果からは魚類が藍藻を直接摂食・同化しているのか、動物プランクトンなど他の動物を介して藍藻由来の脂肪酸を獲得しているかは判断することが出来ない。もし、後者であれば、藍藻の優占化に伴って、藍藻を餌利用できない動物プランクトン種から、藍藻を餌として利用できる動物プランクトン種に変遷していくまでの期間が、9 月以降に魚類から藍藻由来脂肪酸の増加を検出するというタイムラグを生じさせた要因である可能性がある。なお、本研究ではワカサギ 1 才からは藍藻由来脂肪酸の急激な増加は見られなかったが、ワカサギは動物プランクトン食者であることから、ワカサギ 1 才が摂食・同化していた動物プランクトンが藍藻を食べていなかった可能性が高い。今後、藍藻優占に伴う動物プランクトンの種構成の変遷や、各動物プランクトン種の藍藻摂食・同化能力を解明し、魚類の脂肪酸組成の変化と合わせて解析することで、アオコの発生する富栄養湖沼の食物網の理解が深まると期待される。

5. 結論と今後の展望

脂肪酸組成を指標として、魚類による藍藻の餌利用の状況を解析した結果、これまで食物連鎖に組み込まれにくいと考えられてきた藍藻が、魚類によって餌利用されていることが明らかとなった。今後は、魚類が直接藍藻を摂食・同化しているのか、動物プランクトンなど他の動物を介して藍藻由来の脂肪酸を獲得しているのか検討していく予定である。

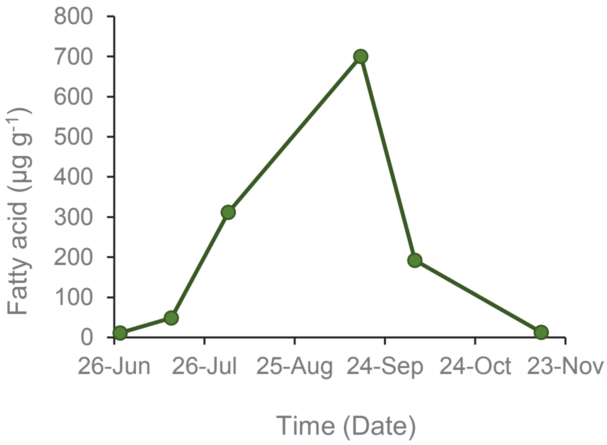

図 1 懸濁物質中に含まれる藍藻由来脂肪酸(18:2ω6 + 18:3ω3)含有量の経月変化

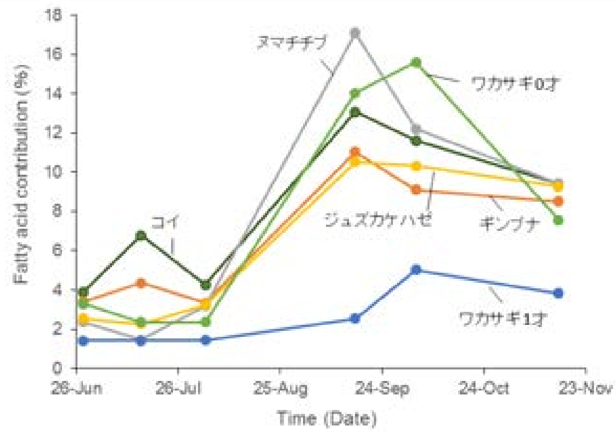

図 2 魚類筋肉に含まれる藍藻由来脂肪酸(18:2ω6 + 18:3ω3)含有量の経月変化

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O3-10

Cyanobacterial carbon transfer to higher trophic level in eutrophic lake Taihu

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Keywords: Cyanobacteria, algal blooms, carbon transfer, eutrophic lakes, fatty acid biomarker, stable carbon isotope

ABSTRACT

Cyanobacteria have been considered an inadequate food source due to a lack of vital nutrients, toxin production, and floc formation. This may interrupt carbon transfer to higher trophic level animals, including fishes. In this study, to elucidate the contribution of cyanobacteria for benthic animals in Taihu, we examined cyanobacterial carbon transfer in a eutrophic lake by using a fatty acid biomarker, stable carbon isotope ratios of fatty acid, and stable isotope ratios of bulk nitrogen. Terrestrial plant and animals (benthic animals, primary consumer) were collected via in July, from Lake Taihu, China. Combined dual stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) and fatty acid biomarkers, the results revealed that there were only subtle differences in the diets of benthic and pelagic animals and cyanobacteria were their main food source. Concomitantly, results of $\delta^{13}C$ of bacteria-specific fatty acids demonstrated that bacteria equally and profoundly affected organics accumulation or preservation in the sediments, because they preferentially utilized labile cyanobacteria as their carbon source instead of terrestrial plants (>95% within these two sources). Consequently, these novel findings clarify that not only in deep lakes, but also shallow eutrophic ones, the extensive losses of autochthonous organic matter can be expected during sedimentation coupling with the dramatical modifications of biogeochemical processes.

1. INTRODUCTION

1. Introduction

Organic matter in lakes generally derives from autochthonous sources produced by phytoplankton and terrestrial (allochthonous) subsidies delivered by river discharge and runoff[1]. Therein, a critical portion provides carbon and energy sources for consumers and forms the base of the diverse food web, the residuals sink through the water column and are ultimately preserved in sediments[2]. The verti cal migration of organic matter drives the development of benthic communities; however, continuously increasing of sinking fluxes probably results in hypoxic or anoxic conditions coupling with the release of nutrients and deteriorates of the benthic habitats[3]. Therefore, a profound knowledge of organic matter dynamics including the fate of organic matter in water column, alternatively, the origin of organic matter in the sediments is crucial for understanding material flow and cycling in lake ecosystems and for decision-making in lake management.

The migration process of organic matter from the water column to the sediments is known to be affected by various biotic and abiotic factors. In deep lakes, vertical mixing above the thermocline induced by winds and waves or thermo convection prolongs the exposures of organic matter to oxidation. As a result, nearly 85% of the organic carbon losses before leaving the epilimnion (Eadie et al., 1984). Aquatic animal utilization by zooplankton or filter-feeder fishes and microbial degradation by heterotrophic organisms within the water column play a substantial role in decreasing the sinking flux of organic particles[1]. On the other hand, the sinking flux may significantly increase through light-mediated as well as microbially-induced flocculation of dissolved organic matter in the water column. These observations imply that organic particles sinking from surface water with long residence time in deep lakes are not necessarily proportional to the organic matter contents of underlying sediments. In contrast to the deep lake ecosystems, the information from shallow lakes especially eutrophic lakes is scarcely known. For tracking organics behaviors in shallow andeutrophic lakes, the suspended particulate organic matter (SPOM) in the water column and sedimentary organic matter (SOM) were systematically investigated in Lake Taihu, China. The sources and composition of SPOM and SOM were analyzed, and their relationships were compared with fatty acid biomarkers. Aquatic animals and benthic bacteria were also performed for the interpretationof their roles in alternation of organics dynamics in the lake. In shallow eutrophic lakes, organic matter would have shorter sinking time and consequently shorter exposures to oxidation in the water column. Especially for photosynthetic organisms, export onto the sediments (as live or dead cells) is probably their fates with intensively and high-frequency sedimentation. Hence, we hypothesized that in large shallow and eutrophic lakes, organics in surface water are proportional to the contents of the sediments with faint influence of animal consumption and microbial utilization.

2. RESULTS

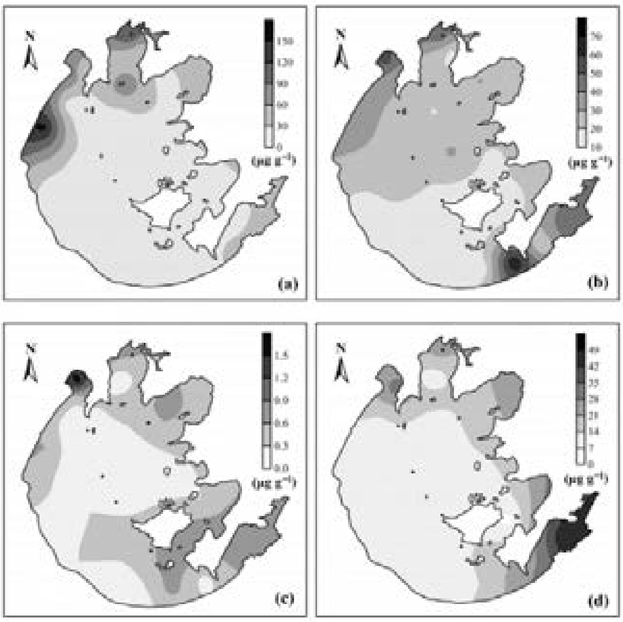

Fig.1 Spatial concentration variations in (a) cyanobacteria in suspended particles (μg/g), (b) terrestrial plants in suspended particles (μg/g), (c) cyanobacteria in sediments μg/g), (d) terrestrial plants in sediments (μg/g) from Lake Taihu, China.

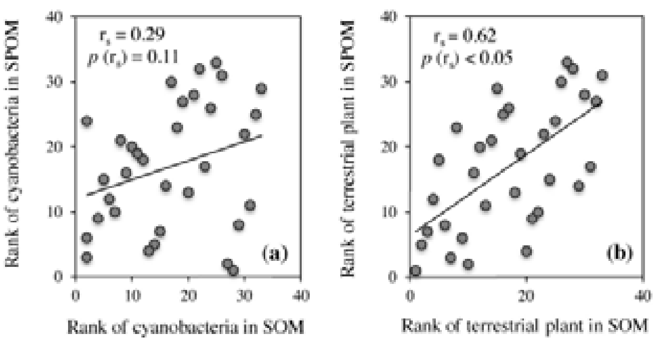

Fig. 2. Spearman's rank correlations between (a) cyanobacteria in SPOM and SOM, (b) terrestrial plants in SPOM and SOM from Lake Taihu. SPOM: suspended particulate organic matter, SOM: sedimentary organic matter.

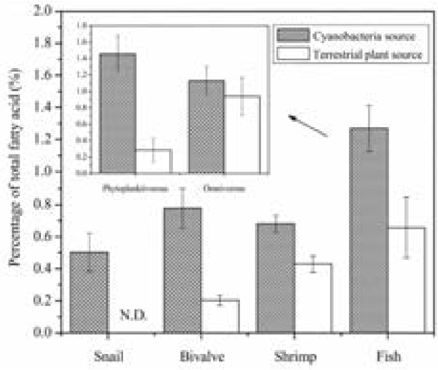

Fig. 3. Contributing percentage of cyanobacteria and terrestrial plants as food sources for aquatic animals including snails (n = 8), bivalves (n = 8), shrimps (n = 3), fishes (n = 7; therein, phytoplanktivorous (n = 3) and omnivorous (n = 4)) from Lake Taihu. ND: not detected

3. DISCUSSION

Asymmetry between SPOM and SOM indicated by fatty acids. As a prerequisite to the simultaneous comparison of multiple organics under the same condition, fatty acid biomarkers related the benthic organics to pelagic sources in Lake Taihu. Interestingly, against the aforementioned hypothesis, results exhibited the asymmetric phenomena between SPOM and SOM for cyanobacteriaand terrestrial plants, which were proposed as the major organics due to the faint contributions of other sources such as diatoms and dinoflagellates to both surface water and sediments. In surface water, not surprisingly, cyanobacteria showed a considerably higher prevalence. Their spatial pattern coincided with those studies of Lake Taihu, which were indicated by Chl-a concentrations. Compared with cyanobacteria, terrestrial plants displayed a relatively lower concentration level, although they spatially fluctuated within the range of other eutrophic lakes. In the sediments, the relatively low level of cyanobacteria was found to be spatiotemporally consistent together with the previous findings. Generally, there is a loss for organics during sinking, as it is easily subjected the strong influence by aquatic animal consumption and microbial degradation. However, if assumed that terrestrial plants did not vary and used the maximum concentration of organics to represent the entire lake, the loss of cyanobacteria would roughly decrease by 60 times during sinking (larger than 2 times in SPOM and smaller than 1/30 in SOM, Fig. 2). These observations suggested that the asymmetric phenomenon in essence was a more considerable loss of cyanobacteria compared with terrestrial plants during the migration process from surface water to sediments. Concomitantly, the asymmetric phenomenon also occurred for the spatial pattern of cyanobacteria abundance, which were not site-to-site symmetrical between surface water and sediments (Fig. 2). It is probably related to the spatial heterogeneity of biological abundance and community structure. For instance, the maximum concentration of cyanobacteria lakewide shifted from the western freshwater entrance tothe Zhushan Bay during sinking (Fig. 1(a) and (c)). The extensive losses of cyanobacteria in the western freshwater entrance may be consumed by the higher abundance and biomass of macroinvertebrates compared with the Zhushan Bay, due to the influence of trophic status, wind-induced disturbance and habitat complexity. However, further investigation is necessary to analyze their correlations. Compared with cyanobacteria, the benthic terrestrial plants probably undergo slight or escape modifications by these biogeochemical processes and proportionate to the surface water, owing to their indigestible or refractory nature. Therefore, although shallow eutrophic lakes are characterized by the more highly productive and shorter residence time than deep ones, a disproportionate loss of autochthonous organics can be expected during sinking, caused by the modifications of biogeochemical processes with different degree.

Influence of animal consumption on organics dynamics

Based on fatty acid and stable isotope results, it appeared that terrestrial plants and cyanobacteria contribute, to different degrees, to the diets of pelagic and benthic consumers, and indicated that the food web in hypereutrophic Lake Taihu depends on both allochthonous and autochthonous organics. These, in turn, influence the quantity and quality of suspended and sedimentary organic matter. Interestingly, although the contributions of terrestrial plants and cyanobacteria as a direct food source were not as high as expected (<2% of the total fatty acids, Fig. 3), it clearly supported cyanobacteria served as a better food source than terrestrial plants to their consumers. Further evidence of this phenomenon is the $\delta^{13}C$ and $\delta^{15}N$ signatures exhibited a closer relationship between cyanobacteria and all kinds of consumers, rather than terrestrial plants. These results are congruent with previous studies that the relative importance of allochthonous and autochthonous resources for consumers shifts to the latter in nutrient-rich lakes. The benthic consumers utilize carbon from settled cyanobacteria detritus, while their pathways for deriving energy may differ from those of shrimps and fishes that directly filter cyanobacteria in the water column. Considerable studies have clarified that phytoplankton especially cyanobacteria were used as a food source by shrimps and fishes. However, cyanobacteria and terrestrial plants seemed to be equally important for shrimps and omnivorous fishes in the examined lake according to the results of fatty acids (Fig. 3). These observations are not surprising as a great variety of shrimps and omnivorous fishes showed a wide range of organic carbon sources including vascular plants, and particularly, some species of them may have the ability of selective predation among food types. Furthermore, the fatty acid results of omnivorous fishes appeared to be appalling with their $\delta^{13}C$ and $\delta^{15}N$ signatures, which were far away from the other consumers. It suggested that omnivorous fishes positioned at a higher trophic level of the local food web, because a general enrichment in $\delta^{13}C$ and $\delta^{15}N$ signatures, known as trophic fractionation, occurred from assimilated food sources to consumers with varying values of 0–1‰ and 2.5–3.4‰, respectively. Together with other consumers, they significantly correlated to cyanobacteria, which may not fully describe the whole food web in Lake Taihu as further studies on the separate benthic and pelagic food chains may need to be conducted, however, at least, describing a pathway for carbon flow based on cyanobacteria in Lake Taihu. Generally, compared with allochthonous organic matter, endogenous production such as various types of algae are higher in diet quality and more important for consumer production as they contain essential fatty acids such as eicosapentaenoic acids and docosahexaenoic acids or their precursors. These fatty acids are structurally important in cell membranes and play an important role in animal physiology such as growth and reproduction. In contrast, terrestrial vascular plants are little consumed by animals that graze directly on them, because they have a relatively high content of indigestible fiber and a low content of nitrogen. Therefore, consumers may preferentially utilize cyanobacteria rather than terrestrial plant in freshwater lakes, which is one of the crucial reasons that cyanobacteria do not appear to contribute significantly to the sedimentary organic carbon pool.

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O3-11

猪苗代湖の中性化が一次生産を担う生物の分布に及ぼす影響

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キーワード: 水質汚濁, 一次生産, 富栄養化

抄録

猪苗代湖は pH の上昇が進み, それとともに湖内の一次生産の増加を示唆する水質の悪化が報告されている。一次生産に関する既往の報告では, 北岸部の水生植物調査, 北岸部の植物プランクトンの年変化の解析, 及び南岸部における植物プランクトンの調査と一部地域を対象とした研究が中心であった。そこで本研究では, 湖内で一次生産を担う生物（植物プランクトンと水生植物）について猪苗代湖全体を俯瞰して, pH 上昇による影響を調査, 考察した。湖水の pH は猪苗代湖全域で中性化していたが, リンの濃度は北岸部と南岸部で上昇傾向にあった。これらの環境因子は植物プランクトン数と種組成に猪苗代湖全域で影響を及ぼしていた。一方で水生植物の生息域は他の制限要因に強く影響されることが示唆された。

1. はじめに

猪苗代湖に流入する最大の河川は長瀬川であり, 全流入水量の約 50%以上を占める[1]。この長瀬川は上流河川の影響を受けて酸性を示す（pH 5.2, 2015 年 9 月）[2]。その結果, 猪苗代湖の pH は 1995 年頃までは 5.0 程度を示していた[3]。それと共に酸性の長瀬川から供給される凝集塊の効果によるリンの沈殿が起こり[4], 湖内における一次生産が抑制されてきた。その結果プランクトンは種類数と存在量ともに少ないとされていた[1]。しかしながら, その後湖内の pH は急激に上昇して中性化が進み, 2015 年には 6.8 を示した[2]。この pH の上昇は流入河川から猪苗代湖へ供給される硫酸イオン濃度の減少が大きな原因であると考えられている[5]。

このような水環境の変化は湖内における植物プランクトンや水生植物による一次生産に大きな影響を及ぼすと考えられる。Sutani et al. (2014) [6]は福島県の水質年報を 1984 年から 2011 年に渡って解析し、猪苗代湖湖心と北岸部の植物プランクトン相が pH の上昇に影響されて大きく変化したと報告している。また 1998 年から 2008 年に猪苗代湖の湖心と南岸部で菊池＆佐藤 (2010) [5]によって行われた調査によると, pH の上昇に伴って植物プランクトンの種類と量が増加していることが明らかとなった。一方で, 黒沢ら(2011) [7]は猪苗代湖北岸部の水生植物相の変化を調査した。その結果, エゾノヒルムシロやコウホネ群落の消滅, マコモやヒメガマの減少, セキショウモの増加などの変化を報告している。

猪苗代湖は pH の上昇が進み, それとともに湖内の一次生産の増加を示唆する水質の悪化が報告されている。しかしながら今までは, 多数の群落が形成されている北岸部の水生植物調査[7], 湖心と比較した北岸部の植物プランクトンの年変化の解析[6], 及び南岸部における植物プランクトンの調査[5]と, 一部地域を対象とした研究が中心であった。そこで本研究では湖内で一次生産を担う生物（植物プランクトンと水生植物）の分布について猪苗代湖全体を俯瞰して, pH 上昇による影響を調査, 考察した。

2. 調査方法

調査対象湖沼

本研究で対象とした猪苗代湖は福島県の奥羽山脈の西側に位置し（湖心, 37°28′N 及び 140°06′E）, 湖面標高 514 m, 面積 104.8 km^2, 最大深度 94.6 m である[1]。日本の湖沼の中で, 琵琶湖, 霞ヶ浦, サロマ湖に次ぐ面積を持つ大型湖沼である。

植物プランクトン数及び理化学性

猪苗代湖の 8 地点（高橋川河口付近, 天神浜, 安積疎水取水口, 浜路浜, 舟津港, 青松浜, 小石ヶ浜水門, 及び湖心）の植物プランクトン数及び理化学性（pH, T-N 及び T-P）のデータを水質年報[2, 3]から収集し、解析に用いた。データ収集期間は 1988～1992 年と 2011～2015 年とした。図 1 に対象とした調査地点を示す。

水生植物の分布調査

2015 年 9 月に水生植物の分布状況を調査した。猪苗代湖の湖岸から湖心に向け観測線を 1000 m 間隔で設定した。船で測線上をゆっくりとした速度で走り, 目視及び魚群探知機により, 水生植物の種相と分布状況を把

握した。測線の湖心側の終点は水深3 mの地点とした。

猪苗代湖北岸では水生植物の分布が密であったため，観測線を 100 m 間隔で設定し，より詳細な調査を行った。

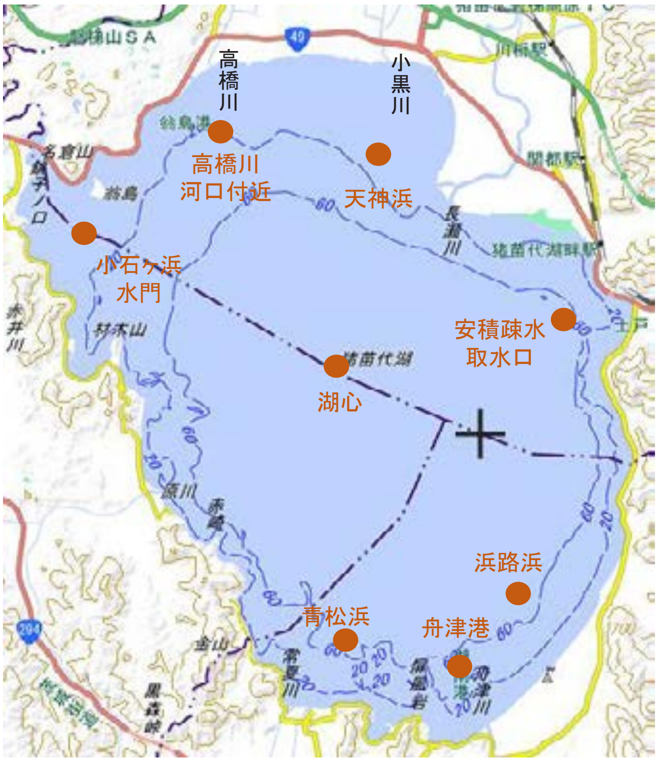

図 1　水質年報における植物プランクトン数及び理化学性の調査対象地点（地理院地図を加工して作成した[8]）

3.　結果及び考察

湖水のT-N濃度は0.24～0.28 (1988～1992年)と0.20～0.26 (2011～2015 年)であり，ほとんど変化がなかった。一方で，pH は 1988～1992 年に全地点で 5.5 以下と酸性を呈していたが，2011～2015 年には 6.8～7.2 と中性となった。また T-P 濃度は湖心，小石ヶ浜水門及び安積疎水取水口では変化が見られなかった（≤0.005，1988～1992 年；≤0.004，2011～2015 年）一方で，北岸部（≤0.008，1988～1992 年；≤0.014，2011～2015 年）と南岸部（≤0.005，1988～1992 年；≤0.013，2011～2015 年）では約 2 倍の年平均値を示す調査対象地点が存在した。

図 2 に 1988～1992 年と 2011～2015 年の植物プランクトン数の平均値を示す。全ての調査地点で細胞数は増加した。負荷量が非常に大きい高橋川と小黒川の影響を受ける北岸部（高橋川河口付近と天神浜）は他地点よりも極めて多い植物プランクトン数を示し，増加は1000 倍以上と高かった。注目すべきは湖心とともに，比較的負荷量の影響が低いと考えられる南岸部（浜路浜，舟津港及び青松浜）において 1000 倍以上の植物プランクトン数の増加が明らかとなったことである。植物プランクトンの生長を制限するリンの濃度は北岸部とともに南岸部で増加していた。一方で光合成に関わる鉄等の金属の湖水への供給は減少していると報告されている[5]。以上の結果より，pH の上昇による炭酸制限の解除が猪苗代湖全域における植物プランクトン数へ影響を及ぼし，一次生産の増加が進んでいることが示された。

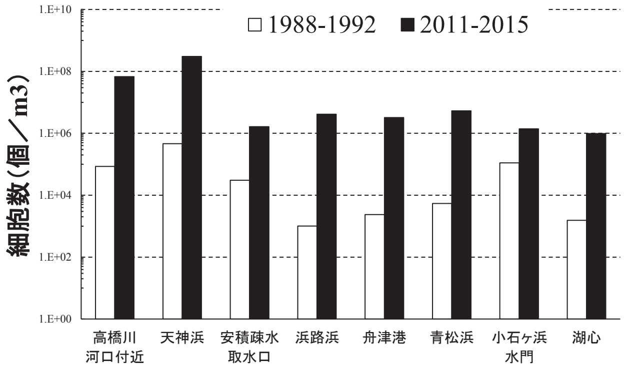

図 2　植物プランクトン数の変化（5 年間の平均値）

図 3 と 4 にそれぞれ 1988～1992 年と 2011～2015 年の植物プランクトンの分類群の構成割合を示す。1988～1992 年では湖心や南岸部を含めた多くの地域で珪藻類が優占していた。一方で 2011～2015 年には北岸部と南岸部で大きな違いが見られた。すなわち北岸部では珪藻類の割合が上昇したが，南岸部では鞭毛類と緑藻類の割合が大きく増加した。今後の研究で、湖水のケイ素濃度分布などを測定することが植物プランクトンの構成割合が変化した原因の解明につながるかもしれない。

2015 年の植生調査により，猪苗代湖の北岸部（高橋川河口・天神浜の周囲）では広く水草が生息していることが確認された。浮遊，沈水，浮葉，抽水，及び湿生植物に属する 24 種が確認されたが，特にオニビシ・ヒシ・アサザ（浮葉植物）及びクロモ（沈水植物）が優占していた。一方で北岸部以外では南岸の鬼沼と東岸の志田浜北側のみで水生植物の生息が確認された。鬼沼ではコウホネ，ヒシ，アサザ，コカナダモ，クロモ，セキショウモ，ヒルムシロ，及びヒメホタルイの計 8 種が確認された。志田浜北側ではコウホネ，ヒシ及びコウキクサの 3 種が確認された。猪苗代湖の北岸部では黒沢ら(2011) [7]の報告と同様に，多様な水生植物が広範囲に渡って生息していた一方で，その他の地域では貧弱な植生であ

ることが明らかとなった。pH の中性化は猪苗代湖全域で進んでいるが，水生植物の生息分布は広範囲に及んでおらず，底泥の堆積量などの他の制限要因に生長が強く影響されることが示唆された。

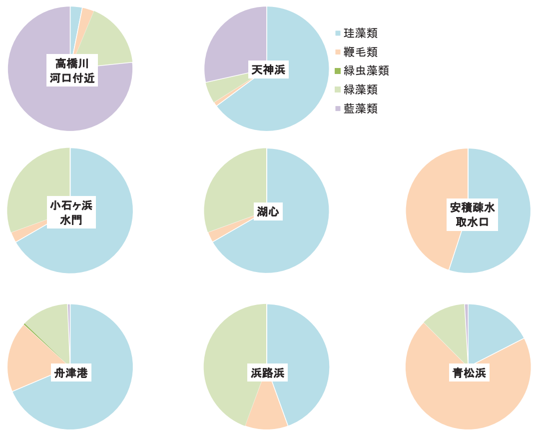

図 3 植物プランクトン分類群の構成割合（1988～1992）

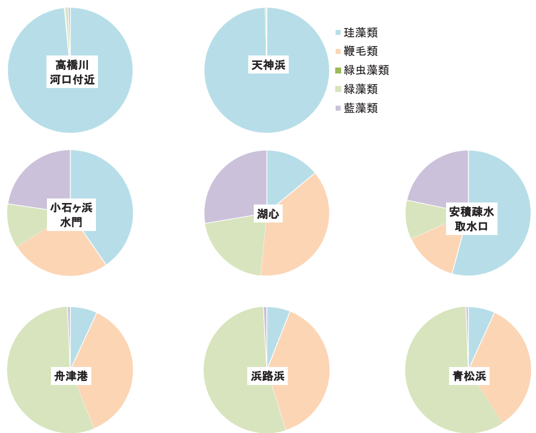

図 4 植物プランクトン分類群の構成割合（2011～2015）

4. 結論

猪苗代湖における pH の上昇が湖内の一次生産を担う生物の分布にどのような影響を与えているのかを調べるために，植物プランクトンと水生植物に着目して調査，考察した。

1）湖水の pH は猪苗代湖全域で中性化していたが，リンの濃度は北岸部と南岸部でのみ上昇傾向にあった。

2）植物プランクトン数は猪苗代湖全域で増加し，一次生産の増加が顕在化していることが示された。北岸部では珪藻類の割合が上昇したが，南岸部では鞭毛類と緑藻類の割合が大きく増加した。

3）水生植物の生息は北岸部に偏っており，pH よりも他の制限要因に強く影響されることが示唆された。

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O3-12

霞ヶ浦土浦入を対象に構築したアオコ予測システムの紹介

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キーワード：アオコ, 回帰, 生態系モデル, 深層学習, 行政利用

抄録

霞ヶ浦土浦入におけるアオコ発生の問題に対し，迅速な対策のためにアオコ発生の予測が求められている。そこで本研究では，アオコ予測のため，アオコのシードとなる湖底泥中の *Microcystis* に着目し，その存在量を明らかにした。また生態系モデルを用いて，アオコ発生メカニズムを検証した。その結果，底泥中には *Microcystis* が存在し，湖水中に回帰している可能性が示された。一方で生態系モデルによる検証からは，底泥中からの回帰だけでなく，風による輸送の影響も大きいことが示され，底泥中の存在量のみでは予測が難しいことが示された。これらの結果を受け，生態系モデルに深層学習モデルを組み合わせたハイブリットモデルを構築したところ，過去のアオコ発生状況を再現でき，アオコ予測システムが構築できた。

1.　はじめに

霞ヶ浦では，夏季に *Microcystis* を主とするアオコが発生することがある。なかでも土浦港をはじめとする土浦入湾奥部（図1）は JR 土浦駅に近く周辺人口が多いため，景観の悪化や腐敗臭などの面からアオコの発生が社会問題化しやすい。茨城県ではアオコフェンスの設置や，アオコ回収，土浦港浄化施設の設置などの対策を講じているが，効果的な運用のためにアオコの発生場所や量の予測が必要とされている。これに対し，茨城県霞ケ浦環境科学センターでは，水質調査結果をまとめた「アオコ情報」を発信している。そのなかでは，湖水質と気象予報から翌週のアオコの発生しやすさを A~C で評価しているが，もっと早いタイミングでの予報や，面的な分布の情報が必要とされている。

アオコが発生する水域では藍藻類のコロニーや休眠細胞が底泥中に高密度で存在していることが多く，これらが水中へ回帰することで，アオコの発生を促進させていると考えられている[1]が，霞ヶ浦全域において，底泥に堆積した *Microcystis* 細胞濃度を測定した例はなく，回帰量も不明である。

また，アオコの発生予測は需要があるものの極めて難しく，運用事例・研究事例は少ない[2]。北澤ら[2]は，湖水流動と水質変動のシミュレーションモデルを構築し，アオコの発生を説明できるモデルが構築できたとしているが，実運用については言及がない。芹沢ら[3]は神奈川県の相模湖と津久井湖を対象に2変数数理モデルを作成して検討した結果，アオコの発生量，発生パターンの変動には生態学的，生理学的要因とともに偶発的要因も深く関与していると考察している。

これらのことから，本研究では①底泥中の *Microcystis* 量を把握し，回帰量を検討した[4]。次に，②土浦入におけるアオコ発生メカニズムを検討した[5]。そしてこれらの知見をもとに③アオコ予測システムを構築し，その応用可能性について検討した[6]。

2.　方法

2. 1　底泥中の *Microcystis* 量の把握[4]

2015 年に，新川河口，土浦港，土浦沖，掛馬沖，湖心（図 1）で底泥を採取した。なお，新川河口の調査地点は，図1に示すよりも河道内に寄っている。改良した湖沼型コアサンプラー（離合社）を用いて 0~1cm 深さの底泥を採取し，rDNA 用チューブにいれ-80℃で保存した。その後，Extrap Soil DNA Kit Plus ver.2 （J-BIO）を用いて rDNA を抽出・精製し，リアルタイム PCR（7500

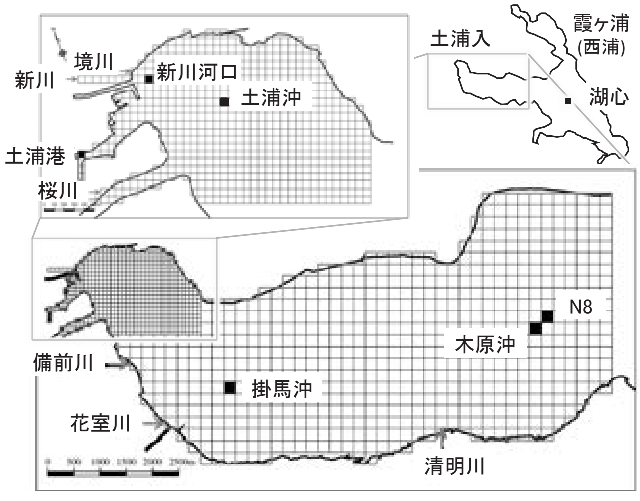

図 1 対象水域と地点図[5]

Real-Time PCR System, Applied Biosystems）を用いて遺伝子量を測定した。その際，既知細胞濃度培養液からの rDNA 抽出液を段階希釈したものを標準列として用いて，細胞濃度が未知であるサンプルの Ct 値から細胞濃度へと換算した。

2. 2　アオコ発生メカニズムの検討[5]

Microcystis の底泥からの回帰，鉛直移動，風による輸送に着目し，アオコ発生を説明する生態系シミュレーションモデル（以下，生態系モデル）を構築した。生態系モデルは，流体力学の基礎方程式を直交座標系において差分化して解く流動サブモデルと，物質循環を考慮した水質サブモデルから構成した。計算範囲・格子サイズは図 1 のとおり，層分割は 0.5m である。植物プランクトンは *Microcystis* とその他の植物プランクトンを想定し，水温と栄養塩に対する応答を変化させて表現した。また，底泥からの *Microcystis* の回帰フラックスは，底泥中の存在量と湖底に到達した光量で説明されると仮定した。鉛直移動は，沈降速度を時間別に与えることで表現した。風による輸送は，水柱第 1 層上部にアオコ用の仮想層(第 0 層)を設定することで表現した。アオコ発生メカニズムの検討は，構築した生態系モデルを用い，表 1 に従ってそれぞれの因子の寄与を変化させ，計算結果と実測値を比較することで行った。

2. 3　アオコ予測システムの構築[6]

アオコの予測可能性を，二つのモデルを用いて評価した。一つは方法 2. 2 で構築した生態系モデル，もう一つは生態系モデルに統計モデルを組み合わせたモデル（以下，ハイブリッドモデル）である。統計モデルは，畳み込みニューラルネットワーク（Convolutional Neural Network: 以下，CNN）と変分オートエンコーダ（Variational Autoencoder: 以下，VAE）を組み合わせた。統計モデルのための学習用データは湖心（36º 02' 17" N, 140º 24' 15" E）表層 20 または 50 cm におけるフィコシアニン濃度とし，既存モデルを用いて算出した計算値を日平均値に圧縮したものと，実測値を基に補間した日平均値のデータセットを用いた。期間は 2007 年から 2016 年とし，*Microcystis* が増殖する 6 月から 9 月を対象とした。実測値は，2012 年から 2017 年は，およそ週に 1 度の頻度で当センターによって配信された「アオコ情報」におけるフィコシアニン濃度を用いた。 2012 年以前は，国立環境研究所の霞ヶ浦データベース[7]の *Microcystis* 細胞体積を用いて補間した。*Microcystis* 細胞濃度からフィコシアニン濃度への換算は，2013-2015 年の *Microcystis* 細胞濃度とフィコシアニン濃度の関係から求めた係数 7.3×10^6 を掛けて行った。

また，生態系モデルは気象条件によって計算結果が変化するため，将来予測のためには気象予測が必要であった。そこで，気象庁の暖候期予報と三カ月予報を利用した。2007 年から 2016 年までの気温と降水量から，平年より高い（多い）年と平年より低い（少ない）年を割り出し，暖候期予報と三カ月予報の結果に従って適当な年度を選び，その年の気象を予測値として与えた。

3.　結果と考察

3. 1　底泥中の *Microcystis* 量[4]

土浦入の底泥表層には *Microcystis* 細胞が存在し，6 月初旬に減少し 8 月にかけて増加する傾向がみられた（図 2）。底泥表層中の *Microcystis* 細胞数の減少要因として，底泥からの回帰のほかに，降雨に伴う流出と，底泥中での分解が考えられたが，降水量と濁度には特徴的な上昇が見られなかったため，湖水中への回帰に伴うものであると示唆された。そこで，この期間における 5 地点の平均減少濃度を日数で割り，土浦入の底泥におけるMicrocystis 細胞のみかけの回帰速度を算出したところ，5.6×10^2cells/g-wet sediment/day と示された。

3. 2　アオコ発生メカニズム[5]

流動サブモデルを用いた物理場の再現状況は良好であった。アオコ発生機構検討のための比較結果を図 3 に示す。Case 1 と Case 2 を比較すると，風による拡散の影響が加わったことで 2013 年や 2014 年の再現性が向上したと考えられた。また，底泥からの回帰量は現存量の増加を促進したが，実測ベースの底泥中現存量を用いる必要が示唆された。また，実測値で見られるような，局所的かつ一時的な集積を表現するためには，風による輸送の影響を加えることが有効であることが示された。

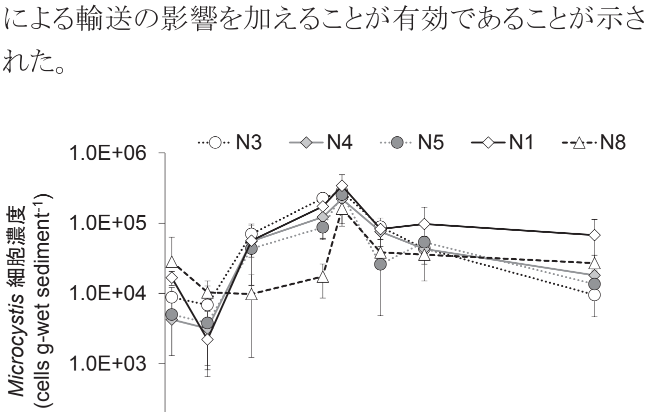

図 2　霞ヶ浦土浦入における各地点の底泥表層中の *Microcystis* 細胞濃度。なお，N3 は湖心，N4 は掛馬沖，N5 は土浦沖，N1 は土浦港，N8 は新川河口を示す。[4]

3. 3　アオコ予測システムの検討[6]

生態系モデルで計算されたフィコシアニン濃度と過去の実測値を比較した結果，相関性は高くなかった。一方で，2007 年から 2016 年までの湖心フィコシアニン濃度と実測値のデータセットを用いて学習させたところ，深層学習モデルは生態系モデルと実測値の差異をうまく学習した。湖心における，2007 年から 2016 年までの実測値と (a) 生態系モデルの計算値，(b) 生態系モデルに深層学習モデルを組み合わせたモデル（以下，ハイブリッドモデル）の計算値を比較した（図 4）。その結果，ハイブリッドモデルにおいてのみ実測値と有意な正の相関が示された($n=97$, (a): $r = -0.08$, n.s., (b): $r=0.75$, $p<0.05$)。また，掛馬沖，土浦沖，土浦港でも同様の検討をした結果，同様にハイブリッドモデルのほうが高い相関性を示すことが分かった。

4.　結論

霞ヶ浦土浦入におけるアオコの発生予測のために底泥中の *Microcystis* 量を把握し，生態系モデルを用いて発生メカニズムを検討した。その結果，底泥中には *Microcystis* が存在し，湖水中への回帰が示唆された[4]が，発生メカニズムの検討からは，風による輸送の影響が大きいことが示唆された[5]. これらの研究結果をもとにアオコ予測モデルを構築した結果，深層学習モデルの組み込みは，過去の再現精度を向上させた[6]。過去 9 年の再現性について，どの地点でも向上が見られたことから，霞ヶ浦におけるアオコ予測に対し，今までの生態学モデルを中心としたものよりも，高い精度で予測できることが期待される。今後は，今回の学習に用いていないデータセットや気象データを用いてテスト運用を行い，将来予測の可能性について検証していく。

謝辞

底泥中の *Microcystis* rDNA の測定に関しては国立環境研究所の冨岡典子先生にご尽力いただき，重要なご助言を数多く頂いた。本研究で使用した *Microcystis* の細胞体積データは，国立環境研究所の霞ヶ浦長期モニタリング事業によって提供された。ここに記して感謝を記す。

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表 1　計算ケース一覧とその条件[5]

	輸送	(第0層)	回帰	(vmax)	鉛直移動	(Setvel)
Case 1	-	無	-	0	-	0
Case 2	+	有	-	0	-	0
Case 3	+	有	+	1	-	0
Case 4	+	有	+	1	+	0.24, -4.0
Case 5	-	無	-	0	+	0.24, -4.0

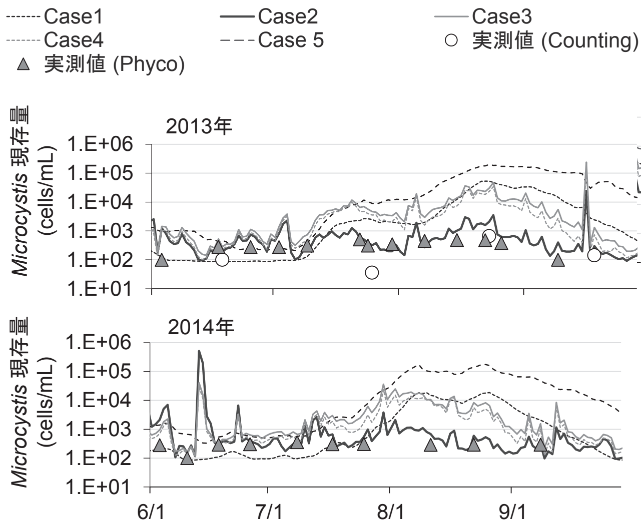

図 3　土浦沖表層における *Microcystis* の現存量の経時変化の実測値と一時間毎の計算値．実測値(Counting)は検鏡値，実測値(Phyco)はフィコシアニンからの換算値[5]（一部改）

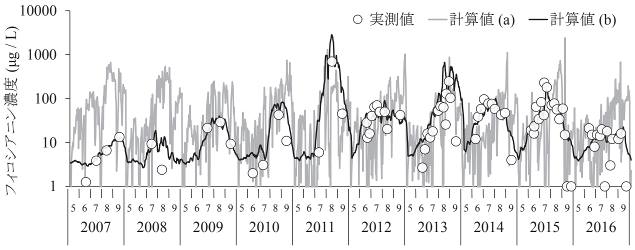

図 4 土浦沖におけるアオコ予測モデル計算値と補間された実測値の比較[6]

O3-13

Warming and eutrophication effects on phytoplankton community of two tropical systems with different trophic states – an experimental approach

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Key words: global warming; eutrophication; cyanobacterial blooms; trophic state

Abstract

Global warming and eutrophication are predicted to promote cyanobacterial blooms but how tropical phytoplankton from different trophic state systems respond to temperature is less known. To explore the effect of temperature changes and nutrient addition on phytoplankton and to verify possible resistance to these effects, we conducted an experiment with phytoplankton from two aquatic ecosystems differing in trophic state. Water samples from eutrophic and oligo-mesotrophic systems were collected and incubated in 25 and 30ºC. Treatments that received a surplus of N and P were included as eutrophication treatments. Temperature variation itself did not promote cyanobacteria growth in either water from the oligo-mesotrophic or the eutrophic system. However, nutrient enrichment of water from the eutrophic system significantly boosted cyanobacteria, and biomass increased 10 times in both 25ºC and 30ºC treatments. In contrast, eutrophication of water from the oligo-mesotrophic system did not change the relative contribution of phytoplankton groups and response ratios were much lower than those from eutrophic water. Although using a simple experimental design, the results suggest that in eutrophic systems cyanobacteria dominance can be favored by further addition of nutrients, independently of a direct temperature effect and that more pristine environments possess some resistance against eutrophication. Since global warming is assumed to intensify eutrophication indirectly, our study underscores the importance of nutrient control.

1. Introduction

Human activities are causing severe alterations in ecosystems worldwide and freshwater ecosystems are being transformed rapidly (Carpenter et al., 1992). These systems have experienced altered precipitation patterns, more intense and longer periods of thermal stratification, modified hydrology, elevated carbon dioxide concentration, increased nutrient loading and elevated temperatures as a consequence of global change (Carey et al., 2012; Paerl and Huisman, 2008). These changes will probably be intensified in the next decades following the expected increase in global temperatures and inputs of anthropogenic nutrients (O'Neil et al., 2012). Phytoplankton, as primary producers of aquatic ecosystems, can be considered a target to experience these environmental changes since nutrient availability and temperature are among the main conditions that drive competitive advantage and regulate phytoplankton species distribution. Some studies indicate that increasing nutrients and temperature may exert a synergistic effect on cyanobacteria dominance (Jöhnk et al., 2008; Paerl and Paul, 2012). In this context, the objective of this study was to examine the effect of temperature alone and in combination with high nutrient addition on phytoplankton communities from tropical ecosystems of two different trophic states. We tested hypotheses that 1) temperature variation favours cyanobacteria growth more than eukaryote competitors, 2) temperature variation will have a
stronger effect on cyanobacteria dominance in tropical eutrophic water than in oligo-mesotrophic water and 3) nutrient addiction will promote a stronger effect on cyanobacteria favoring in oligo-mesotrophic water than eutrophic water.

2. Methods

To evaluate the effect of temperature variation and nutrients addiction on phytoplankton from tropical ecosystems of different trophic states, water samples from an eutrophic system (Jacarepaguá lagoon, RJ) and from an oligo-mesotrophic system (Samuel reservoir, RO) were collected and incubated at 25 and 30°C, with and without addition of nutrients. The lowest temperature (25°C) tested was chosen based on the annual average temperature in the water body from southeast of Brazil, and the highest temperature (30°C) considered an increase of 5°C to the annual mean (predicted by IPCC 2013 as result of global warming).

Eutrophication was simulated by the addition of 7.0 mg N. L^{-1} as $NaNO_3$ and 0.8 mg P. L^{-1} as K_2HPO_4, to N+P treatment. Flasks were incubated under 60µmol photons m^{-2} s^{-1}, photoperiod of 12 h and shaken manually twice every day. Total-cyanobacteria and eukaryote chlorophyll-*a* concentrations were measured using a PHYTO-PAM phytoplankton analyzer, during 7 days.

The response ratio of cyanobacteria (RR_{cyano}) and eukaryote algae (RR_{algae}) was calculated as a ratio between the growth rate of each treatment *T* (30ºC, 25ºC+N+P and 30ºC+N+P) and the growth rate in the sole 25ºC incubations (used as control, *C*) following $RR_x = \ln(T/C)$ (Elser et al., 2007), for eutrophic water system. However, for oligo-mesotrophic system, we used the growth rate in the sole 30ºC incubations as control (*C*), since 30ºC was closest the annual average water temperature of that system. A two-way ANOVA was performed to test whether temperature and nutrients addition affect the response ratio of cyanobacteria and eukaryotic algae. All the statistical analysis was performed using tool-pack SigmaPlot, Version 12 (Systat Software, Inc).

3. Results

The 5ºC temperature variation was not an important factor to change the phytoplankton composition, in both experimental conditions (Fig. 1a,c and 2a,c). At start of the experiment, the phytoplankton community from the eutrophic system was dominated by cyanobacteria (88%) with an average biomass of 127µg chl-*a*. L^{-1}. At the end of the experiment, cyanobacteria (70%) remained dominant over eukaryote algae (30%) in both treatments, 25ºC and 30ºC (Fig 1a,1c). When nutrients were added cyanobacteria remained dominant (97.3%). However, nutrient additions boosted cyanobacteria biomass that increased from about 125µg L^{-1} to about 1330µg L^{-1} in 25ºC N+P and 30ºC N+P treatments (Fig. 1b, 1d).

In oligo-mesotrophic system at start of the experiment, eukaryote algae were more abundant (66.4%) than cyanobacteria (33.6%) (Fig. 2a, 2c). The temperature variation, from 30ºC to 25ºC, did not change the contribution of phytoplankton groups and total biomass without nutrient additions remained < 20 µg chl-*a* L^{-1} (Fig. 2a, 2c). Addition of nutrients caused a slight increase to about 30 µg L^{-1} in the 30ºC N+P treatments (Fig. 2d) and a stronger increase from 11 to 60 µg L^{-1} in the 25ºC N+P treatments (Fig. 2b).

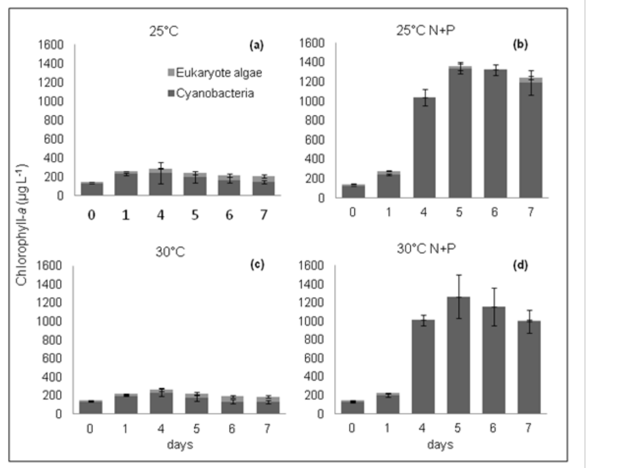

Figure 1: Eukaryote algae and Cyanobacteria biomass in the experiments with Eutrophic system phytoplankton community. Error bars indicate plus or minus one standard error.

Warming in itself led to negative response ratios for both cyanobacteria (RR_{cyano}) and eukaryote algae (RR_{algae}) in eutrophic system, reflecting a decrease in biomass compared to the sole 25ºC incubations. The temperature decrease from 30ºC to 25ºC, in oligo-mesotrophic system, promoted the positive response ratios for both cyanobacteria (RR_{cyano}) and eukaryote algae (RR_{algae}), indicating the biomass increase with decrease of 5 ºC. In water from the eutrophic system, nutrient addition caused a strong positive response ratio of cyanobacteria, while eukaryote algae remained a negative response ratio. The elevated temperature and nutrient addition (30ºC N+P) intensified the negative response ratio of eukaryote algae. In contrast, RR_{algae} in water from the oligo-mesotrophic system were positive in both in nutrient enriched treatments, but significantly higher than RR_{cyano} only in 25ºC N+P treatment ($p<0.001$).

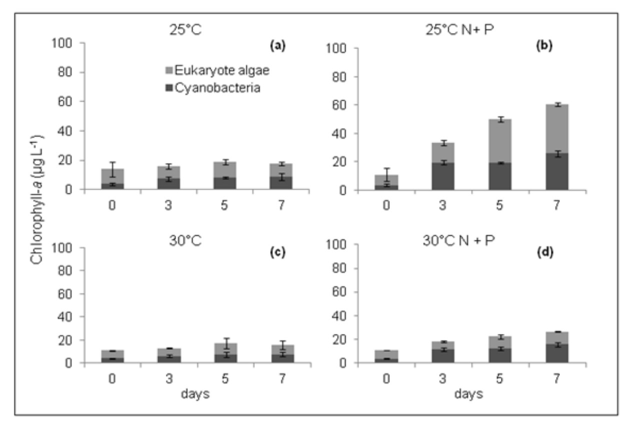

Figure 2: Eukaryote algae and Cyanobacteria biomass in the experiments with Oligo-mesotrophic system phytoplankton community. Error bars indicate plus or minus one standard error.

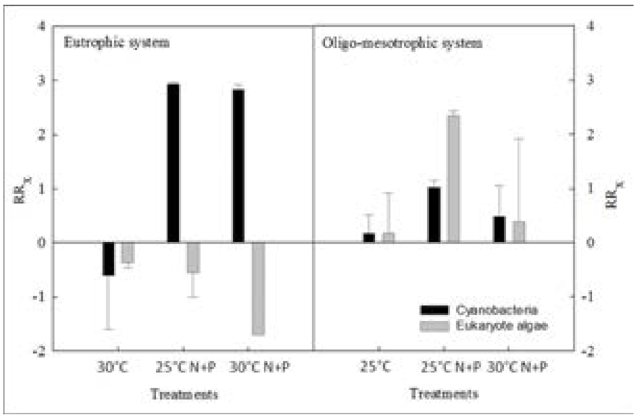

Figure 3: Response ratio of cyanobacteria and eukaryotic algae growth rate to each treatment (25ºC, 30ºC, 25ºC N+P and 30ºC N+P) in Eutrophic system and Oligo-mesotrophic system experiments. Error bars indicate plus or minus one standard error.

4. Discussion

Our results clearly showed that temperature in itself did not lead to higher cyanobacteria biomass in water from an oligo-mesotrophic and a eutrophic system. In fact, response ratios even were negative meaning phytoplankton biomass declined in eutrophic system. Hence, the importance of a direct warming effect on freshwater phytoplankton - and particularly on stimulation of cyanobacteria - may be questioned. It seems more likely that indirect effects of warming such as increased thermal stratification and water column stability will promote cyanobacteria (with buoyancy control) over non-flagellate eukaryote algae (Carey et al., 2012). However, by far the most important driver of cyanobacteria blooms is increased nutrient concentrations (Brookes and Carey, 2011). The nutrient addition response was much stronger in water from the eutrophic system in which cyanobacteria biomass was boosted to higher level. However, there was no synergism between nutrient addition and temperature in the cyanobacteria development, as was suggested by Rigosi et al. (2014).

The difference in response to nutrient addition between water from the oligo-mesotrophic and the eutrophic system underpins that lowering the nutrient status of lakes will render them less vulnerable to predicted effects of global changes (Brookes and Carey, 2011). These are likely the indirect effects that favor cyanobacteria biomass accumulation either at the water surface as a consequence of water column stability, or when populations are fueled from enhanced internal nutrient release and pulsed nutrient additions following precipitation. The lower biomass observed in oligo-mesotrophic systems seems to enhance resistance against nutrient pulses as is evident from the lower RR_{cyano} found in this study.

Some studies have addressed that indirect effects of climate change through nutrient loading may be more important than direct effects of temperature increase (Carey et al., 2012; De Senerpont Domis et al., 2013), which points to eutrophication.

5. Conclusion

It is widely believed within the scientific community that global warming and the corresponding increases in water temperatures will promote cyanobacteria blooms. Our results shows that an increase of temperature itself is not necessarily the main case because warming alone does not significantly change the phytoplankton community but rather the process of eutrophication contributes more to such changes than warming.

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O3-14

Evaluation of the Degradation Function of Microcystin-LR on Sediment Collected from Isahaya New Pond and Isahaya Bay

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Keywords: Eutrophication, Water blooms, Microcystin-LR in sediment, Isahaya new pond and Isahaya bay

ABSTRACT

Microcystin species (MCs) produced by toxic cyanobacteria has become a serious problem in the world. Up until the present, it has been focused on MCs degradation in freshwater bodies only, although all lakes and ponds connect to the sea. Therefore, the aim of this study was to estimate the behavior of MCs discharged from freshwater bodies to sea such as the degradation, through the degradation of MC-LR in surface-water combined with sediment collected from the Isahaya new pond and the Isahaya bay as a model for effluent source and discharged estuary. The result showed that no MCs have accumulated long-term in surface water and sediment of the Isahaya new pond as an effluent source to the Isahaya bay. Moreover, these both areas have a potential of a degradation of MC-LR lower than 0.01 $\mu g \cdot l^{-1}$ for 17 days at 30℃ and 21 days at 20℃. Interestingly, a sea water component had no effect. As a result of bacterial isolation, the decrease of concentration was probably caused by the degradation bacteria. These results supports that no MCs accumulate in the Isahaya new pond and the Isahaya bay, and thus it was strongly suggested no MCs was concentrated biologically into the aquatic organism via benthos. These results will contribute to the estimation of MCs behavior in sediment of the lake and estuary such as Lake Kasumigaura.

1. INTRODUCTION

Recently, the eutrophication and water blooms have become a serious problem world-wide in closed water bodies such as lake and pond. Water blooms are a massive growth of cyanobacteria, which is mainly *Microcystis* sp. This species can produce a hepatotoxin, Microcystin species (MCs), thus many researchers have studied this topic and reported some useful results, including the degradation bacteria of MCs collected from lakes and ponds. On the other hand, it is also important whether these degradation bacteria have the activity in sea water or not, because all lakes and ponds connect to the sea via a river and MCs can contaminate sea and accumulate in the sediment. Therefore, the aim of this study was to determine the MCs degradation activity in raw sediment collected from sea. In this study, we choose the Isahaya bay, Japan, as a model. Isahaya bay was divided by the dike since 1997. Fresh water from rivers has remained inside of the dike, thus the artificial freshwater pond has been made, which is called the Isahaya new pond. Because of the elevation of water surface level, sometimes water is discharged from the Isahaya new pond to the Isahaya bay. Recent years, toxic cyanobacteria, *Microcystis* sp., and produced MCs have been observed in the Isahaya new pond. Therefore, Isahaya bay is proper to the experimental model area.

2. METHOD

Measurement of MCs concentration in Isahaya new pond

To estimate the MCs loading to the Isahaya bay, MCs concentration has been measured in surface water and sediment collected from the Isahaya new pond since 2009. Sampling points are B1, B2 and the bridge of the north drainage gate (BNDG) where is the monitoring points of MAFF (Fig. 1) [1]. Collected surface water was combined with acetic acid, and sediment was freeze-dried and combined with 50 % methanol and 50 % phosphate buffer (pH 3.0). Then, each sample was shaken, centrifuged and filtrated. Supernatants were stored in -20℃ until MCs extraction and HPLC analysis.

MC-LR degradation activity in raw samples

MC-LR was used in this study because the toxicity is higher than other MCs. MC-LR was extracted from *Microcystis aeruginosa* NIES-298 strain (National Institute for Environmental Studies, Japan). Sediment samples were collected from S21, S24, S25 point in the Isahaya new pond and B3, S1, S4, S6 point in the Isahaya bay (Fig. 1). 100 g-wet weight (W.W.) of each sediment was charged into Erlenmeyer flask and combined with 250 ml of surface water collected from same collecting point with MC-LR (100 $\mu g \cdot l^{-1}$). Flasks were cultivated at 20 and 30℃ without shaking, and 1 ml of surface water was collected weekly. Then, collected surface water was filtrated and MC-LR was extracted. After a month later, sediments in each flask were collected and MC-LR was extracted with same method as above section.

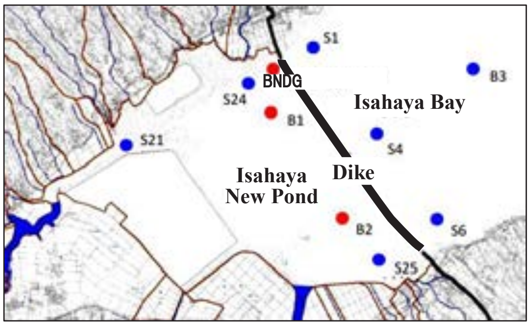

Fig. 1. Sample collecting points

MCs Extraction and HPLC analysis

MCs were extracted and pre-purified from samples by the solid phase extraction method using C18 (ODS) and silica column (Wako Chem.). Finally, MCs are analyzed by HPLC (Shimadzu Co., Ltd.).

Isolation of MC-LR degradation bacteria

To determine the presence of MC-LR degradation bacteria in sediment, isolated bacteria group was cultivated in M-11 media with 100 μg•l^{-1} of MC-LR under 30℃. Carbon source in this media is only MC-LR, thus grown bacteria would likely be able to use MC-LR.

3. RESULTS

MCs concentration in the Isahaya new pond

Long-term observation revealed that MCs in surface water had been detected and maximum concentration was 13 μg•l^{-1} until 2014 (Fig. 2). Meanwhile, almost surface water samples collected after 2015 had no MCs and detected concentration was lower than 1 μg•l^{-1}, which is the guideline value for the drinking-water on source water proposed by WHO[2]. Results in sediment also showed almost samples accumulated no MC-LR and sometimes detected concentration was much lower.

Characteristics of MC-LR concentration decreasing

In this study, samples collected from B3, S1, S4 and S6 are seawater, and samples from S21, S24 and S25 are fresh water. 0.11 and 0.16 μg•l^{-1} of MC-YR were detected from surface water at S6 and S24, respectively. However, no MCs were observed from sediments in B3, S1, S4 and S6. This indicates that no MCs accumulate in the sediment of the Isahaya bay.

Fig. 3 shows MC-LR concentration in surface water of flask depending on cultivation time. About a week later, 3.20-6.04 μg•l^{-1} of MC-LR was detected at 20℃

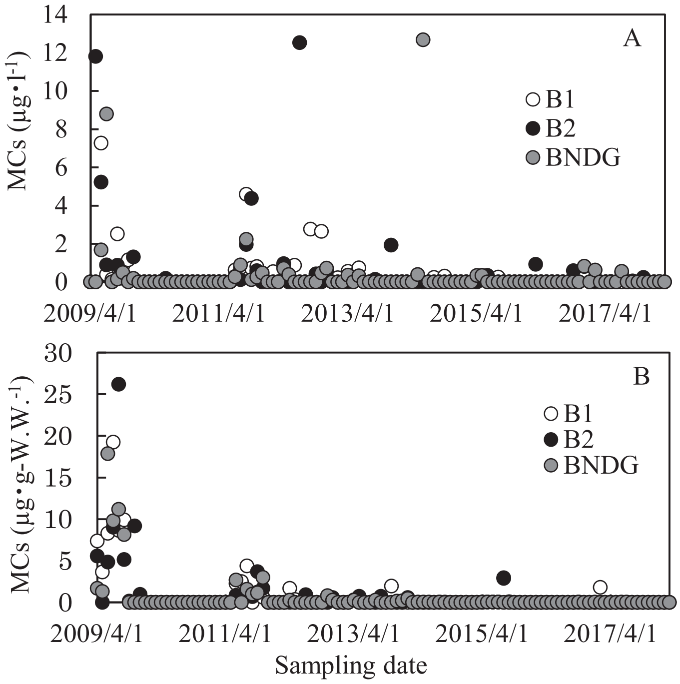

Fig. 2. Change of MCs concentration in the Isahaya new pond (A: Surface water, B:Sediment)

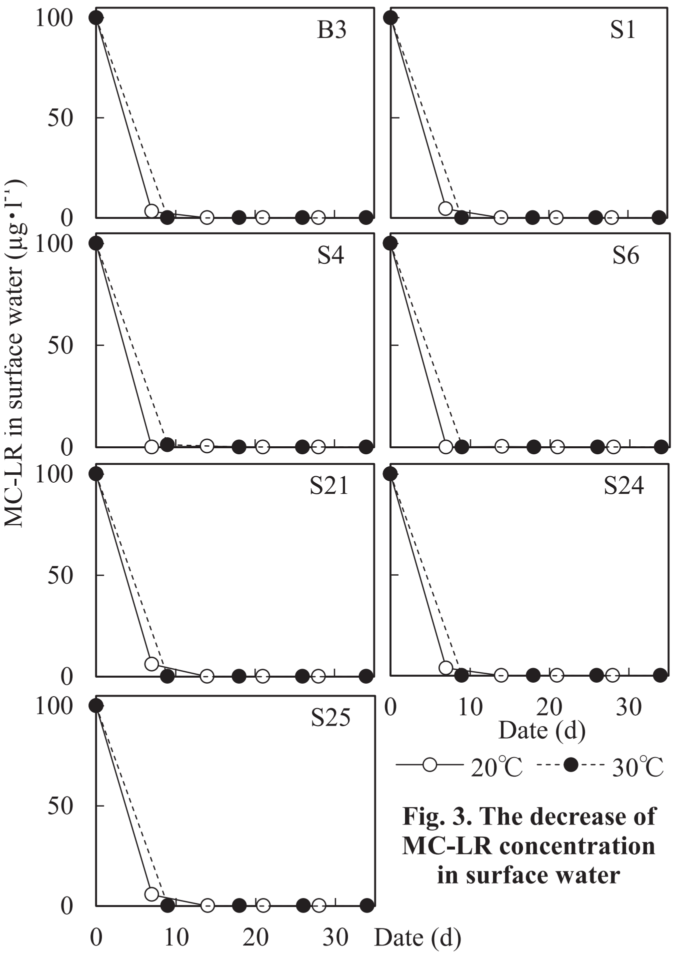

Fig. 3. The decrease of MC-LR concentration in surface water

excluding S4 and S6, and 1.11 μg•l^{-1} in S4 at 30℃. No MC-LR was observed in S4 and S6 at 20℃, and flask under 30℃ cultivation excluding S4. No MC-LR was observed after 21 day at 20℃ cultivation and 16-17 day in S4 at 30℃. Therefore, the degradation speed of MC-LR increased with the increase of temperature.

Furthermore, MC-LR in surface water was decreased, whether seawater or fresh water condition. After the experiment, each sediment in flask was analyzed and MC-LR concentration of all cultivation condition was lower than 0.01μg・g-wet weight (W. W.)$^{-1}$.

Isolated MC-LR degradation bacteria from sediment in the Isahaya new pond and the Isahaya bay

As a result of bacteria cultivation using M-11 media combined with MC-LR, many colonies were grown on agar plates not only at fresh water samples but also from seawater. These bacteria were classified into 4 general groups based on morphological characteristics of colony.

4. DISCUSSION

This study revealed a trend of MCs concentration in the Isahaya bay in Nagasaki prefecture, Japan. Although over 10 μg・l^{-1} of concentration had been detected in the past, MCs are not accumulated in surface and sediment in the long-term. Recent observed MCs concentration is lower than the proposed concentration by WHO[2)], thus MCs concentration is much lower in the Isahaya new pond. These results suggest that MCs is degraded by the bacteria. At the same time, a microscopic observation indicates that dominant cyanobacteria have been changed from *Microcystis* sp. to *Arthrospira* sp. in recent years (Fig. 4). Mussagy et al.[3] reported no cyanotoxin was produced by *Arthrospira* sp., thus above succession also might cause the decrease of MCs concentration in the Isahaya new pond.

The degradation study of MC-LR with the sediment was to determine the behavior of MCs surrounding sediment in the Isahaya new pond and the Isahaya bay. The result revealed that MC-LR concentration was decreased lower than 0.01 μg・l^{-1} by 21 days at a realistic water temperature between 20 to 30℃ when water blooms has been observed, in the presence or absence of the component of seawater. HRT in the Isahaya new pond is approximately a month, thus MCs produced in this pond will be removed from freshwater bodies, and it will be also degraded in the Isahaya bay if MCs are discharged from the Isahaya new pond. Especially, MC-LR concentration in surface is lower than the guideline value for the recreational water quality proposed by Health Canada (20 μg・l^{-1})[4] during about a week, and the guideline value by WHO[2] until 17 days. This decrease of MC-LR was probably caused by the bacteria because the decrease of concentration was enhanced by the increase of temperature and MC-LR amount in sediment was lower than 0.01 μg・g-W. W.$^{-1}$ after the experiment. In addition, bacterial degradation was also supported by HPLC chromatogram which has some peak like a degradation product of MC-LR in some experimental series. Especially given that isolated bacteria from all sediment samples have a possibility of MC-LR degradation, the result strongly suggests that isolated bacteria play a prominent role in the degradation of MCs in these areas. Moreover, it was suggested that no accumulation of MCs into sediment and biological concentration to aquatic organisms via benthos.

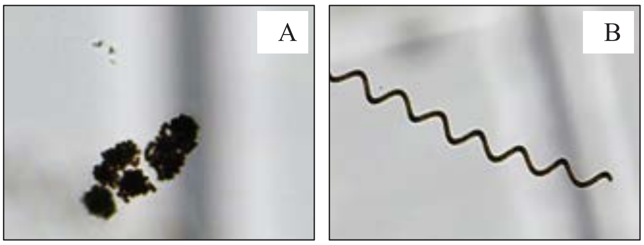

Fig. 4. Main cyanobacteria observed in water bloom of Isahaya new pond (A: *Microcystis* sp., B: *Arthrospira* sp.)

5. CONCLUSION

1) No MCs have accumulated long-term in the surface water and the sediment of the Isahaya new pond up until the present. 2) Whether the presence of the component of sea water or absence, there is a potential of the degradation of MC-LR in the Isahaya new pond and the Isahaya bay. 3) The degradation time is 17 days at 30℃ and 21 days at 20℃. 4) Isolated bacteria probably have an ability of MC-LR degradation in the Isahaya new pond and the Isahaya bay. 5) The result from this study suggested no MCs accumulate in sediment, and thus it was suggested no MCs accumulate into the aquatic organism as the biological concentration. Furthermore, through the relationship with the physicochemical characteristics of sediment, applying the result in this study will contribute to the advancement of environmental countermeasure of MCs in other lake such as Lake Kasumigaura.

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O3-15

Influence of environmental factors on cyanobacterial biomass and microcystins concentration in the Dau Tieng Reservoir, a tropical eutrophic water body in Vietnam

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Keywords: cyanotoxins; harmful algae blooms; total phosphorus; Dau Tieng reservoir

ABSTRACT

Cyanobacterial blooms can be harmful to environmental and human health due to the production of toxic secondary metabolites, known as cyanotoxins. In the present study, we examined the effects of environmental parameters on cyanobacterial community structure and MCs concentrations in the Dau Tieng reservoir (DTR), a tropical, eutrophic water body in Southern Vietnam. Cyanobacterial biomass and MCs contents were monitored monthly from March 2012 to February 2013, when MCs were present in the DTR. The highest concentrations of intracellular MCs were found in September and February when cyanobacteria biomass reached maximum values, with 2.50 and 2.13 μg/L, respectively. Multivariate analysis showed that MCs concentration was positively correlated with the biomass of the cyanobacterial order Chroococcales, whereas total phosphorus (TP) was the primary abiotic factor influencing cyanobacterial biomass and MCs concentrations in the DTR.

1. INTRODUCTION

The frequent occurrence of toxin-producing from harmful cyanobacterial blooms (HCBs) poses a serious threat to environmental and human health because of their ability to produce a wide variety of toxic secondary metabolites including hepatotoxins, neurotoxins, and dermatotoxic compounds throughout the world [1].

Numerous studies have shown that an increase in the biomass of MCs producing species is typically associated with elevated total MCs concentrations in the water column. In tropical regions, nutrient levels may be play the most important factors influencing cyanobacterial blooms [2]. The objective of this study was to investigate environmental variables influencing on MCs concentrations and cyanobacterial biomass in the Dau Tieng reservoir.

2. METHOD

Cyanobacteria and environmental parameters were collected monthly on the same day for each sampling event at five different sites (DT1–DT5) in the Dau Tieng Reservoir (DTR), Vietnam.

Chemical parameters were analyzed colorimetrically in triplicate with a spectrophotometer using the APHA (2005) [3] methods. Living and Lugol-fixed cyanobacterial species were morphologically identified and counted under a light microscope. Biovolume was calculated based on geometrical cell- or colony volumes [4,5].

Intracellular MCs (MC-LR, MC-RR, and MC-YR) were extracted with 100% methanol (MeOH) and analysed by using a HPLC system.

Principle component analysis (PCA) was used to investigate the association of MCs concentrations and cyanobacterial biomass according to the method of Leps and Smilauer (2003) [6] .

3. RESULTS

Physical and nutrient characteristics

The concentration ranges and averages of water quality variables between March 2012 and February 2013 are shown in Table 1. the TN and TP concentrations (0.28 to 16.4 mg/L and from 0.03 to 0.36 mg/L, respectively) are characteristic of eutrophic conditions according to Reynolds (2006) and were no limiting factors for cyanobacterial development at any time during the sampling period.

Cyanobacterial species composition

During one year of monitoring, a total of 3 orders, 16 genera and 42 cyanobacterial species were recorded in the DTR.

Table 1. Environmental variables in the DTR

	Mean	Min	Median	Max	C.V.
Tem (°C)	31.0	27.5	31.2	34.0	0.04
pH	7.04	6.30	6.90	8.70	0.06
Trans (cm)	115.5	40	115.0	210	0.34
TIN ($mg.L^{-1}$)	0.24	0.06	0.105	1.55	1.49
TN (mg.L–1)	3.22	0.28	1.78	16.4	1.1
TP ($mg.L^{-1}$)	0.06	0.03	0.06	0.36	0.67
TN:TP ratio	55.7	6.0	33.0	274.	1.05
Chro ($mg.L^{-}$	0.35	0.0	0.08	7.54	2.87
Nost ($mg.L^{-1}$)	4.71	0.01	1.00	192.	5.25
Oscil ($mg.L^{-}$	0.03	0.0	0.01	0.60	2.47
TCB ($mg.L^{-}$	5.09	0.02	1.20	200.	5.04
MCs ($\mu g.L^{-1}$)	0.47	0	0.23	2.50	2.46

Trans: Transparency; TIN: Total inorganic nitrogen; TN: Total nitrogen; TP: Total phosphorus; Chro: Chroococcales; Nost: Nostocales; Oscil: Oscillatoriales; TCB: Total cyanobacterial biomass.

Cyanobacterial biomass

The cyanobacterial biomass of Chroococcales, Oscillatoriales and Nostocales were shown in table 1 and Fig. 1. Total biomass ranged between 0.55 and 41.72 mg fresh weight (FW)/L and was especially high in

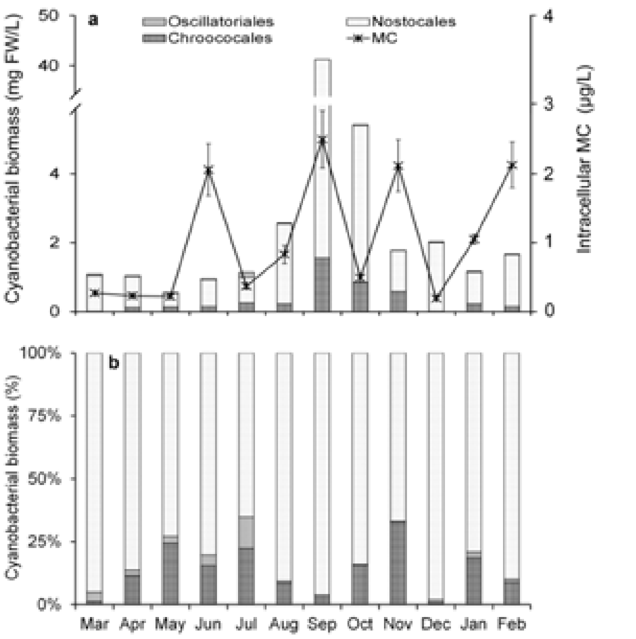

Fig. 1. Variations of (a) cyanobacterial biomass and intracellular MC

September 2012 due to a bloom of *Dolichospermum flos-aquae*. The biomass of Nostocales was the dominant component of the cyanobacteria, contributing 65.2 to 98.5% of the total biovolume (ranging from 0.40 to 40.16 mg FW/L). Biomass of Chroococcales ranged from 0.013–1.55 mg FW/L with peak in September 2012. Oscillatoriales accounted for a small proportion of total cyanobacterial biomass in many sampling events (ranging from 0.006 to 0.14 mg FW/L) (Fig. 1a).

Intracellular MC concentration

The HPLC results revealed that intracellular MCs were detected in all samples except 2 samples (DT2 and DT3) in December 2012. The concentrations of intracellular MCs (only the three most dominant MC variants MC-RR, -LR and -YR were measured) ranged from 0.19 to 2.50 µg/L. The maximum concentration was measured in September 2012 (2.50 µg/L at station DT3) Variant dominance followed the order MC-RR>MC-LR>MC-YR across all sites and time (Fig. 1b).

Relation between abiotic and biotic variables

Using a PCA correlation biplot revealed the first axis (PC1) represented by the biomass of Chroococcales, Nostocales and MCs concentrations and explained 55.7% of total variation, whereas the second axis (PC2) was mainly related to biomass of Oscillatoriales and explained 25.5% of total variation. Measured MC concentrations were closest related to the biomass of their producing group Chroococcales (Fig. 2).

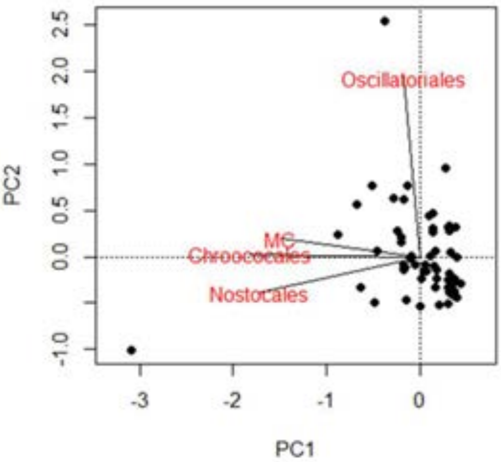

Fig. 2. Variations of cyanobacterial biomass and intracellular MC

4. DISCUSSION

The DTR is a large tropical water body; hence the temperature did not vary much over the seasons and was favorable for cyanobacterial growth [7,8]. The pH values ranged from slightly acidic to slightly alkaline and were within a similar range observed in the Nui Coc and Tri An Reservoirs in Vietnam [7,9]. Although transparency in the reservoir revealed a low trophic state, the TN and TP concentrations (0.28 to 16.4 mg/L and from 0.03 to 0.36 mg/L, respectively) are characteristic of eutrophic conditions according to Reynolds (2006) [10].

Our results showed that light, temperature and nutrient availability support both *Microcystis* and *Dolichospermum* growth. Therefore, other factors may govern the bloom of *Dolichospermum,* e.g. high light intensity, iron or other micronutrient limitation, water column mixing and extracellular allelochemicals [11]. The exact environmental factors, which favour *Dolichospermum* blooms at certain times, need further investigation.

Our results indicated that the cyanobacterial proliferation and measured MCs concentration in the DTR were positively correlated with phosphorus and nitrogen, with the strongest correlation found for TP. Our observations were consistent with Lee et al. (2015) [12] who found that TP was the main environmental variable influencing the abundance of *Dolichospermum*, total cyanobacteria abundance, and intracellular MCs concentration from *Microcystis* sp. in the temperate Vancouver Lake.

In the present study, intracellular MCs concentrations were strongly associated with the abundance of Chroococcales, and to a lesser extent with the biomass of Nostocales. Since no MCs production was detected from a culture of *D. flos-aquae* isolated from the the DTR (unpublished results), we concluded that the detected MCs could be attributed to the toxic *Microcystis* species, as proven in a previous investigation by Pham et al. (2015) [13].

Microcystins concentration in raw water from the DTR was sometimes higher than the WHO guideline value of 1 µg/L. Hence, during periods of high MCs concentrations in the reservoir, local residents may be prone to suffer from hepatotoxic effects via their daily consumption of MC-contaminated drinking water or contaminated field products from spray irrigation.

5. CONCLUSION

Our findings reveal that the biomass of Chroococcales could be used as indicator for increased phosphorus levels and measured MCs concentrations in the reservoir, whereas Nostocales could be used in more productive waters. We propose that phosphorus supports the growth of the potentially toxic cyanobacteria, *Microcystis* spp., and may be the limiting factor in measured MCs production during the growing season.

6. ACKNOWLEDGMENTS

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O3-16

Limnological characteristics, eutrophication and cyanobacterial dominance in three Ugandan national park shallow lakes

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Keywords: lake ecosystem functions; water quality; nutrient dynamics; eutrophication and harmful algal bloom

ABSTRACT

Limnological studies that started in Uganda in the second half of the twentieth century, illustrates that water quality remains a major driver in lake ecosystem functions in the tropics. As it advances, interrelation and combination of physical, chemical and biological parameters in East Africa lakes started. The works centred on Lake Albert then Victoria shared between Kenya, Tanzania and Uganda. Uganda astride the equator is 18% covered by other lakes, rivers and wetlands besides Albert and Victoria. Three of these major lakes are Edward, George and Kyoga plus many crater lakes, small lakes and rivers. Among the five major lakes, Lake George was intensively studied in 1970 unlike lakes Edward and Mburo despite their equal water resources socio-economic development and value in supporting wildlife and conservation. We assessed the status of Lakes George; Mburo and Edward describing their physico-chemical, biological and environmental variables using standard methods from May 2007 to April 2008. In conclusion, the factors that have driven changes in the other lakes: high nutrient concentration; high phytoplankton biomass dominated by harmful algal bloom are discussed. Four decades later Lake George limnological conditions remained stable providing an insight of alternative states of tropical shallow lakes.

1. INTRODUCTION

Unlike in the temperate, most limnological studies in the tropics were made in the second half of twentieth century. In Uganda, early studies were in the 1920 (1). Work before 1925 as summarise by (2) were short-term expeditions with mainly taxonomic, faunistic and floristic approach. The expeditions that followed forty-five years later included two prolonged and more quantitative studies (3). Later, studies in East Africa by, (4) opened the interrelation of physical, chemical and biological parameters, and paved way to the quantitative studies on phytoplankton (5).

These early studies gave valuable insight used later to show the impact of human development as the major cause of nutrient loading in Lake Victoria. Apart from Victoria, Uganda have nearly 18% of its total area covered by other lakes, rivers and wetlands (6). Four of these major lakes are Edward, George, Albert and Kyoga plus many small lakes and rivers. Much as the three lakes do not make a significant contribution to the global surface area, their aesthetic value supports wildlife that attracts tourist. They are also important to the local communities as source of water supply for domestic use and livestock. Wetlands surrounding these lakes are all gazetted as Ramsar sites because of the high biodiversity they support, therefore high conservation status.

Previous studies of 1967 to 1968 in L. George describe it as a lake that experiences constant climate with incidence radiation although irregularly intercepted by cloud, varies within only ±13% of the mean. The potential effect of the two usual dry seasons (June to July and December to February) towards controlling changes in nutrient loading is offset by mountains in the catchment whose high runoff allows a continuous flow to the lake. By that time, a dense permanent phytoplankton population measured up to a concentration of 250 µg chlorophyll-a L^{-1} with the major component of mainly three blue-green algae comprising of *Anabaenopsis* species, *Aphanocapsa* species and *Microcystis* species (7).

It is since then known that Lake George is not a recently polluted lake, but has had a naturally large crop of blue-green algae presumably for a long-time (8). This would add more valuable insight if the current condition is documented to compare with the development over the past years. A number of the cyanobacterial species recorded earlier has been shown to produce toxic substances now. The genus *Microcystis* species is well described to produce the hepatotoxic microcystins and local microcystin concentrations determined previously (9). However, species occurring in Lake George might also include additional cyanotoxin producers such as *Cylindrospermopsis raciborskii*. Thus a more detailed analysis of phytoplankton composition is required to monitor potential harmful effects of these cyanobacteria to the aquatic, human and wild lives. Since the lakes have enabled potential rural development as stated above, we aimed to re-assess the current status of Lake George (Kahendero) for service to the community. In parallel we also sampled Edward (Katwe) and Mburo for physico-chemical and phytoplankton community composition during one year from May 2007 to April 2008.

2. METHOD

Three inshore sites were chosen one for each lake. Kahendero (0º03.004'N, 30º03.439'E) with a mean depth of 1.8 m. Katwe (0º09.198'S, 29º53.056'E) with mean depth of 3.2 m. Lake Mburo (0º38.513'S, 30º56.869'E) with a mean depth of 2.8 m.

Physical and chemical characteristics

In-situ parameters (pH, dissolved oxygen, temperature, and conductivity) were measured using a Hach Lange HQ 40d multiprobe monthly from May 2007 to April 2008.

Dissolved nutrients: soluble reactive phosphorus (SRP), soluble reactive silica (SRSi), nitrate (NO_3-N), nitrite (NO_2-N) and ammonia (NH_4-N) using (10). Total phosphorus (TP) was determined as SRP after persulphate digestion of unfiltered sample. Total nitrogen (TN) analysis from the unfiltered sample was as described in (10).

Phytoplankton abundance and community distribution

Algae were counted by the inverted microscope from samples fixed with Lugol solution as described in (11) and identified with the help of standard literature (12 and 13).

3. RESULTS

In-situ measurement

Monthly measurement taken from May 2007 to April 2008 with n = 12 showed the following temperature in Lake George 24.3 - 29.3ºC; Lake Edward had 25.4 - 29.0ºC and a colder Lake Mburo ranging from 22.4 - 26.2ºC. pH were all above 7.0 ranging from 9.8 - 11.0 in George, 9.7 - 10.2 in Edward and 7.5 - 9.5 in Lake Mburo. Compared with the available data of 1967-1968 only from Lake George and Lake Edward, the 2007 to 2008 measurements encompass the historical data. The two lakes (Edward and George) were more alkaline.

Nutrient measurement

The nutrient measurements were all high (Fig. 1) but within the same range forty years ago. No significance difference between wet and dry season in almost all measurement. Even with SRSi that showed a slight variation within some few months in Kahendero the difference was not statistically significant (P = 0.163, Kruskal Wallis One-way ANOVA). TP and SRSi used as the main features in defining the phytoplankton community and abundance in the lakes showed no statistical significance difference either (P = 0.689 and P = 0.076 respectively, Kruskal Wallis One-Way ANOVA on Ranks) among the three lakes.

Phytoplankton community and abundance

Chlorophyll a was high in the ranges of 30-177 μg L^{-1} and Kahendero showed a six fold increase from the dry month (June 2007) to the wet month (August 2008). Katwe and L. Mburo had intermediate concentration with less variation within months.

Four classes of phytoplankton were constantly present and identified as Bacillarophyceae, Chlorophyceae, Cryptophyceae and Cyanoprokaryota.

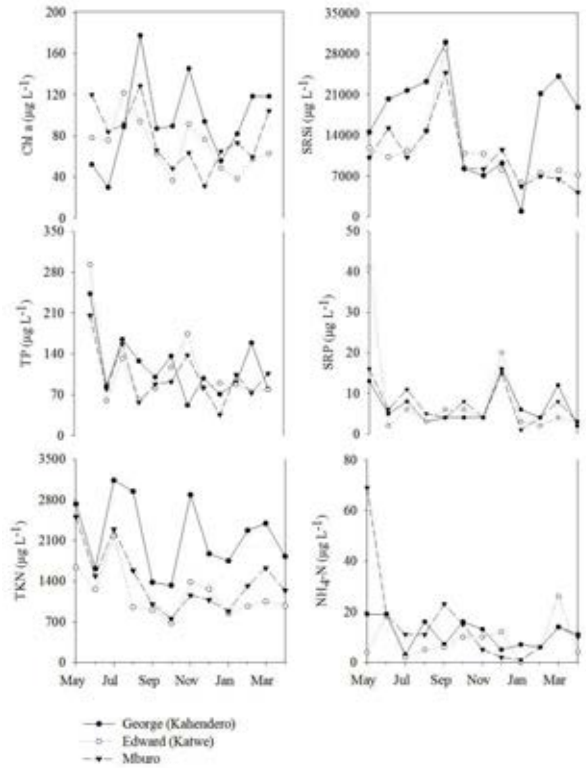

Fig. 1 Physical, chemical and biological conditions of Lakes Edward, George and Mburo May 2007 to April 2008. Vertical axes are different for each particular parameter

Biovolume was higher in Kahendero (93-432 mm^3 L^{-1}) followed by Katwe (35-228 mm^3 L^{-1}) and least in L. Mburo (40-83 mm^3 L^{-1}). Kahendero had a twofold increase from the dry month (June 2007) to the wet month (August 2008). Biovolume dropped further in January 2008, the driest month during the sampling period. Katwe and L. Mburo had stable intermittent biovolume with Katwe showing slight decrease in January 2008. There was a statistical significance differences (P = <0.001, Kruskal Wallis One-Way ANOVA on Ranks) among the sites with Kahendero ranking first.

4. DISCUSSION

In-situ measurements in Lakes: Edward, George and Mburo showed lowlight transparency because of the shallow lakes condition therefore ease of mixing as one condition that was report in (14). Apart from wind mixing, the animals that come to drink, bath and those like the hippopotami that partially leave in stirs the bottom and suspend the sediment therefore lowering the light penetration. Low transparency was also because of the high standing biomass of the phytoplankton. All these were the major internal factor with less influence from the human activities around the area. Because of the high standing crops of phytoplankton in Lake George and Edward, high algal production within led to the higher pH values in some months reaching over 10. These values were occasionally above the 1967 to 1968 measurements (7).

TP and TN concentrations throughout the study period within the three sites did not change much. The climatic condition depicted in the temperature variation of 24.3-29.3ºC in Lake George did not correlate with the change in the nutrient concentration. A similar observation was made by (15) in that, the lake has a fairly constant environmental conditions. Forty years ago Lake George TP concentration was equally higher at 250 μgL^{-1} (7) falling at the far right-hand side of the alternative states in shallow lakes. Lake George in 2008 mean concentration of 117±15.2 μgL^{-1}, n = 12 although slightly lower than the 1968 measurement, is at the same region of alternative state preserving its original natural pristine condition. This system agrees with the finding that they do conserve nutrients and store organic matters while others that have been disturbed by humans for agricultural purposes, industries, domestic sewage lacks conservation mechanisms leaking nutrient into the streams and other water bodies (15). Lake Edward with TP concentration of 111.0±65.9 μgL^{-1}, n = 12 and Lake Mburo with TP concentration of 102.0±13.3 μgL^{-1}, n = 12 are also documented. The variations were also insignificant despite the marked seasonal temperature and rainfall variation. This however could not be compared with earlier published data as they were lacking. The study fills in the gap for future references and increasing knowledge of shallow lakes in Uganda to the wider scientific community.

Coupled with the TP, the TN concentration and other nutrients (SRSi, SRP, NH_4-N, NO_2-N and NO_3-N) were documented (Fig. 1). It was noted; that flow of water to the lake increased when it rain however the relative proportions of the solutes and their total concentrations in the lake did not change much throughout the year. It is in a mark contrast to the equivalent productive temperate lakes (14). The explanation why Lake George environment remained in equilibrium forty years goes back to the earlier finding. The enormous amount of organic material present in the mud and the high flow rates during the rainy season supplies the lake constantly with high nutrient contents therefore upholding it's productive.

Phytoplankton community and abundance

The historic work of 1967-1968 in Lake George documented a permanent phytoplankton population density of 250 μgL^{-1} chlorophyll-a described as pea-green "soup" (7). (2) portrayed the same algal community as remarkably stable and uniform through the years, 1967-1968 and 1969-1970. Forty years later, chlorophyll-a remained high ranging from 30-177 μgL^{-1} with slight annual variation. Lake Edward and Mburo probably studied earlier but not documented showed intermittent chlorophyll-a concentration. The biovolume was contributed majorly by Cyanobacteria. Lake Edward inflow is beginning influenced by the community around Katwe settlement and Mweya Lodge while Mburo receives greater inflow from the Rinzi River with degraded catchment area of Mbarara Town.

5. CONCLUSION

The factors that have driven changes in other lakes: high nutrient concentration and phytoplankton biomass were recorded in Lakes Edward and Mburo describing them as hyper eutrophic. Lake George had its peculiar high nutrient that is hyper eutrophic also with high biomass of blue green algae but remained stable for the last four decades providing an insight of alternative states of tropical shallow lakes that can be applied in ecosystem management. This information provides valuable inputs into compilation of historical physical and chemical trends in three shallow lakes for the water managers, conservationist and policymaker.

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O3-17

Properties of cyanobactericidal bacteria and growth inhibiting bacteria associated with waterweeds against *Dolichospermum crassum* (Cyanophyceae) causing musty odour problem in drinking water

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Keywords: Musty odor, Cyanobactericidal bacteria, *Dolichospermum crassum*, Waterweed, *Potamogeton malayanus*

ABSTRACT

The population dynamics of effective bacteria (cyanobactericidal bacteria and growth inhibiting bacteria) against the nuisance cyanobacterium *Dolichospermum crassum* were investigated at two habitats, the surface water of a reservoir and the waterweed zone (containing *Potamogeton malayanus* Miq.) of Lake Biwa. The number of effective bacteria associated with *P. malayanus* in the lake water in the waterweed zone greatly exceeded the number in the reservoir where algal blooms frequently occur. Trichomes of *D. crassum* were rapidly destroyed by effective bacteria when they were co-incubated with a biofilm from *P. malayanus* or water from the waterweed zone of Lake Biwa. The effects of other predators and chemicals were negligible, and it is concluded that waterweed beds play a significant role in preventing *D. crassum* blooms as providers of effective bacteria. Possible control of *D. crassum* blooms was discussed in relation to effective bacteria as feasible prevention strategies for the nuisance cyanobacterial blooms in water environments.

1. INTRODUCTION

Musty odor in drinking water supplies is a worldwide problem. In Japan, the odor compounds geosmin and 2-methylisoborneol are included in the quality standards for drinking water (less than 10 ng/L), and water suppliers struggle to provide good-tasting drinking water. The Cyanophyceae species *Dolichospermum crassum* (Lemmermann) Wacklin, Hoffmann et Komárek (syn.: *Anabaena crassa* [Lemmermann] Komárková-Legnová et Cronberg) is the major producer of geosmin in eutrophic lakes in temperate areas of the world. Kobe City, Japan, has been suffering from musty odor in water caused by geosmin, which is mainly produced by *D. crassum* since the mid-1990s. Chemicals such as copper sulfide have been widely used to terminate these algal blooms. However, this is not a fundamental solution strategy.

Several types of bacteria have been reported to show algicidal activity against harmful plankton in marine coastal systems (Imai et al. 1993, Harvey et al. 2016), and eutrophic lakes and ponds (Li et al. 2015). These bacteria are found at high density in biofilms on seaweeds (Imai et al. 2006) and seagrasses (Imai and Yamaguchi, 2012). Therefore, seaweeds and seagrasses are attracting attention as important players not only in environmental remediation, but also as sources of effective bacteria in water environments. However, there are no reports on the ecology of bacteria with cyanobactericidal activity against *D. crassum* in fresh water. We previously reported the isolation and characteristics of bacteria possessing cyanobactericidal activity against *D. crassum* from the Karasuhara Reservoir (Shimizu et al. 2017). Here, we monitored the seasonal dynamics of effective bacteria in the reservoir. Then, we compared cyanobactericidal populations in this reservoir and in the waterweed zone of a lake. We verified the effectiveness of these bacteria inhabiting on the waterweed for controlling the growth of *D. crassum*.

2. METHOD

Surface water samples were taken from the Karasuhara Reservoir, which is a water source for Kobe City, every month from May 2013 to October 2014. The seasonal dynamics in the populations of effective bacteria against *D. crassum* were monitored with algicidal assays in which isolated heterotrophic bacteria were co-incubated with an axenic culture of *D. crassum*. Then, the densities of effective bacteria in the waterweed zone (containing *Potamogeton malayanus* Miq.) at Yanagasaki of Lake Biwa were counted for comparison.

A small piece of *P. malayanus* or lake water in the waterweed zone was inoculated into a culture of *D. crassum,* and the change in the *D. crassum* populations were monitored during incubation.

3. RESULTS

In the Karasuhara Reservoir, cyanobacteria dominated most of the year, and algal blooms occurred during summer. *D. crassum* increased up to 1.5×10^3 cells mL^{-1} in 2013, and 1.1×10^3 cells mL^{-1} in 2014. The number of effective bacteria increased in summer and autumn; however, their numbers were relatively low (7.0×10^0 cfu mL^{-1}–3.4×10^2 cfu mL^{-1}) throughout the experimental period (**Fig.1**). In contrast, the number of effective bacteria in the waterweed zone of Lake Biwa was much higher (3.1×10^3 cfu mL^{-1}) than that in the Karasuhara Reservoir, and they accounted for 54% of the total heterotrophic bacteria. In the *P. malayanus* biofilm, the number of effective bacteria was 6.4×10^6 cfu g^{-1} -wet weight. Trichomes of *D. crassum* were rapidly destroyed by attached bacteria when inoculated with a piece of *P. malayanus* or lake water from the waterweed zone. The effects of viruses or chemicals were negligible.

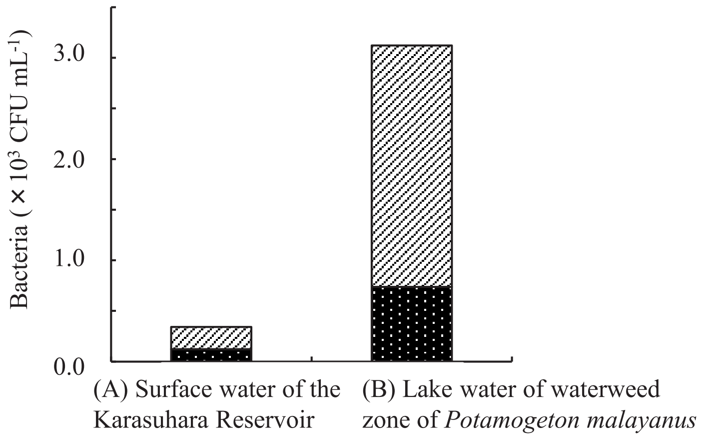

Fig.1 Comparison for densities of the effective bacteria (sum of cyanobactericidal bacteria and growth inhibiting bacteria) in surface water of the Karasuhara Reservoir and waterweed zone of *Potamogeton malayanus* in Lake Biwa.

A, Maximum density of effective bacteria in the surface water of the Karasuhara Reservoir during the monitoring from May 2013 to October 2014. The water sample was collected on 3 September 2013.

B, Density of effective bacteria in lake water collected from waterweed zone of *P. malayanus* at Yanagasaki in Lake Biwa on 3 August 2017.

▩ Cyanobactericidal bacteria ▨ Growth inhibiting bacteria

4. DISCUSSION

There was no waterweed in the Karasuhara Reservoir, and densities of cyanobactericidal bacteria and growth inhibiting bacteria were very low. Therefore, the absence of water plants probably enhanced the growth of algae such as *D. crassum*. On the other hand, waterweed beds served as sources for effective bacteria. Suspended biofilm released from *P. malayanus* were abundant in waterweed zone, and it means effective bacteria from waterweeds prevent occurrences of cyanobacterial blooms in freshwater environments. Similar results were reported on toxic *Microcystis aeruginosa* with the water plant *Trapa japonica* (Miyashita et al. 2018). The musty odor remains a serious problem for drinking water suppliers in the world. Effective bacteria associated with waterweeds will be the clue for solving this problem.

5. CONCLUSION

Densities of cyanobactericidal bacteria and growth inhibiting bacteria associated with *P. malayanus* in the lake water in the waterweed zone of Lake Biwa were significantly higher than the densities in the Karasuhara Reservoir where cyanobacterial blooms frequently occur. It is hence concluded that waterweed beds are the key providers of cyanobactericidal bacteria and growth inhibiting bacteria for preventing occurrences of nuisance cyanobacterial blooms in fresh water environments.

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O3-18

"Ecosystem health assessment of Powai Lake, Mumbai, India"

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Keyword: Powai lake, Water Quality, Eutrophication processes, Conservation

ABSTRACT

Powai lake is an important ecological landmark on the map of megacity with more than 2 billion population of Mumbai that provides the citizens an opportunity for some recreation and natural ambience. The lake has an unique location with reasonably well protected catchment having Indian Institute of Technology and Sanjay Gandhi National Park. In the past two decades, the lake has suffered significant environmental injury in terms of siltation, weed growth, blue green algal blooms and deteriorated water quality. The concomitant urban activities at the bank are increasing rapidly with more potential for environmental impact.

Powai Lake is one of the best studied freshwater ecosystems in this region and a good record of its water quality over a period of time is available. Relatively higher values of dissolved solids, nitrates and phosphates as well as COD and BOD and primary productivity along with significant decrease in transparency in Powai lake indicates hyper eutrophic conditions. This is further corroborated with symptoms such as foul odors, prolific growth of water hyacinth (*Eichornia crassipus*) and blooms of blue green algae (*Microcystis sp.*) with recurrence of mass mortality of fish species.If appropriate measures are taken, the lake can be revived for future sustenance of the lake itself, supporting ecosystem and for the benefit of the lake dependent community as a whole.

1. INTRODUCTION

Urban lakes are very often man-made ecosystems and in several cases they result from excavation activities to provide building material for residential development, road system and walkways. In some cases they come from the enlargement of smaller water bodies to provide recreational activities (angling, swimming, and boating). The small and shallow aquatic ecosystems are more sensitive to water pollution and eutrophication processes. The high population density around urban lakes makes them vulnerable to release of sewage, solid waste dumping, reclamation and various other anthropogenic activities including improper beautification. Due to these, the lakes are getting polluted and are losing their utility. It has become very much essential to come together, discuss different issues about the urban lakes, exchange ideas so that we can effectively plan for rejuvenation and restoration of the urban lakes.

The water quality and conservation aspects of five water bodies in and around Hyderabad, Andhra Pradesh are discussed by Kodarkar, M.S. (1995). In the last two decades it has become a recurrent phenomenon in water bodies particularly in urban areas and linked to environmental degradation due to unprecedented urbanization and industrialization. (Kodarkar, 1995). Extensive limnological work of Powai Lake was carried out by a number of workers (Thakhare, 1969; Bhagat, 1977; Singh Kohili M.P., 1991).

Powai Lake is situated in metropolitan city of Mumbai, the financial capital of India, and has total water spread area of 210 hectors. It is a man-made impoundment built in 1891. Powai lake (19º07,862'N and 72º53,153'E) situated 55 meters above the mean sea level (msl) is known as 'Anglers Paradise'. The lake has an unique location with reasonably well protected catchment having Indian Institute of Technology and Sanjay Gandhi National Park. In the past two decades, the lake has suffered significant environmental injury in terms of siltation, weed growth, blue green algal blooms and deteriorated water quality. The concomitant urban activities at the bank are increasing rapidly with more potential for environmental impact.

Nauashad Ali Sarovar Samvardhini (NASS) is a body constituted for the conservation of urban lakes in Mumbai base on the Sarovar Samvardhini concept. NASS initiated its field activities at Powai Lake since February 2008. A field station dedicated to the fond memory of Late DR M.S. Kodarkar, an International Expert on Lake Management and former Secretary, Indian Association of Aquatic Biologist (IAAB) was established on 8th September, 2012. Dr M.S. Kodarkar Field Station provides facilities for field work to the students, researchers, NGO and citizens interested in the environmental issues of Powai lake apart from sharing literature on environmental aspects of lakes and their conservation. Museum on flora and fauna of Powai lake is proposed to be established in future.

Table 1 Profile of the lake (physical):

Particular	Powai lake
Location	North-eastern suburb of Mumbai
Year of Impoundment	1891
Purpose	Drinking water
Constructed by	Mumbai Municipal Corporation
Lakes Types	Fresh water reservoir
Geographical features	19°07,862'N 72°53,153'E
Water spread area (Wet season)	2.1 sq.km
Maximum depth	6.1 meter
Source of water	Rain Water
Main use of water	Recreation and fishing

2. COLLECTION AND ANALYSIS OF SAMPLES

Sampling was carried out on a monthly from 03 stations of each lake, usually between 09.00 and 10.00 hr. Sub-surface (0.3 m) water and plankton samples were collected from May, 2016 to December, 2017. Surface water sampling was done using 05 liter polythene cans. The can was washed in ambient water before sampling. Care was taken to preventing entry of air bubbles. Standard methodology as per APHA (1981) has been used for sample collection, physicochemical and biological analysis of lake water.

Table 2. Average values of Water quality of Powai lake

Sr. No.	Parameters	Unit	Average value
1	Transparency	cm	27.6 $\pm$ 0.98
2	Dissolved Solids	mg/l	257.0 $\pm$ 116.2
3	pH	…	7.4 $\pm$ 0.86
4	Total Hardness	mg/l	128.0 $\pm$ 18.4
5	Total Chlorides	mg/l	42.8 $\pm$ 8.4
6	Dissolved Oxygen	mg/l	5.1 $\pm$ 0.46
7	Total Alkalinity	mg/l	146.8 $\pm$ 48
8	Phosphate	mg/l	0.28 $\pm$ 0.24
9	Calcium	mg/l	34.8 $\pm$ 6.14
10	Magnesium	mg/l	19.36 $\pm$ 4.60
11	Sulphate	mg/l	11.46 $\pm$ 18.84
12	Nitrates Nitrogen	mg/l	1.34 $\pm$ 0.56
13	BOD (5-days at 20°C)	mg/l	17.8 $\pm$ 2.56
14	COD	mg/l	113 $\pm$ 4.16

3. FINDINGS AND ARGUMENT

Powai Lake is one of the best studied freshwater ecosystems in this area and a good record of its water quality over a period of time is available. Water quality assessment of the lake water from five different locations revealed that the Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) as well as Dissolved Solids were highest in the northern part followed by Ganapati Immersion Point of the lake. A relatively higher value of dissolved solids, nitrates and phosphates as well as COD and BOD and primary productivity along with significant decrease in transparency in Powai lake indicates hyper eutrophic conditions. This is further corroborated with symptoms such as foul odors, prolific growth of water hyacinth (*Eichornia crassipus*) and blooms of blue green algae (*Microcystis sp.)*.The sewage entering the lake is rich in pollutants like nitrates and phosphates that lead to algal bloom thus depleting the oxygen levels of the water causing mass death of fishes.

4. AWARENESS

Sarovar Samvardhini has invited people by organizing educational or recreational events. Sarovar Samvardhini has connected local environmental NGOs, local governments and residents efficiently and its staff members work hard to keep their momentum in activities.

There is no more effective, longer-term and preventative approach towards protecting the lakes than teaching children to value the very resources that they will need in the future. Children, who are inspired at an early age, will take small, but continual actions that will make the world a better place for the environment and the people. The children's enthusiasm in doing their voluntary work can even sometimes put an adult's lethargy and apathy to shame.

5. WAY AHEAD

1. Fountains and aeration systems: Introduction of fountains and aeration systems in the lake can have beneficial effects on the lake water quality.
2. Traditional use: The lake is also being used as immersion site for Ganesh idol and other rituals and suitable measures will have to be adapted to accommodate these demands.

3. Powai lake conservation and management society (Sarovar Samvardhini): Powai lake Sarovar Samvardhini will be platform for all the stake holders

including neighborhood communities for discussing the issue of sustainable management of Powai lake ecosystem.

4. Annual lake festival: To raise lake environmental awareness Powai lake festival should be arranged annually.

5. Educating and creating awareness about limited nature of fresh water and need for protection of lakes among the common man goes a long way in protection of lakes.

6. Educating children about water-related issues is a beneficial long-term measure for achieving sustainable lake use. It is necessary to educate use of free P detergents and also pre treatment of domestic wastes before releasing then in water bodies.

7. Propagation of World Lake Vision (WLV) through training programmes and other activities can be a very effective measure to implement Integrated Lake Basin Management (ILBM).

6. CONCLUSION

Powai Lake is polluted mainly by sewage disposal, growth, death and decay of aquatic weeds, and blooms in the lake. Regular cleaning of the macrophytes, enhancing public awareness, scavenging of polluted sediments, proper regulatory measures for anthropogenic waste disposal and strict measures to prevent further encroachment to the catchment area are needed for the restoration of Powai Lake. To generate public interest and involvement in the lake's conservation, there is a need of bringing together diverse groups of stake holders including NGOs, Civic body, Fishermen, Angler’s Association and other organized sections of the society.

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