Effect of hydrological changes on algal blooming in the reservoir and the required modification for treatments.

T. Asaeda[1*], M. Maniruzzaman[2] and M. H. Rashid[2]

[1]Institute for Environmental Science & Technology, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama, **Japan**.
[2]Department of Environmental Science, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama, **Japan**.
*Corresponding author

The severe incidences of *Microcystis* blooming in 1980s of the Sagami and Tsukui reservoirs, located in Sagami river, Japan were effectively controlled by the installation of 8 and 5 bubbling circulation systems, respectively. However, the blooming had started again in those reservoirs. It was found that those algal blooming occurred due to the formation of strong stratification following a temperature gradient between upper and lower water levels of those reservoirs. In recent years, algal blooming re-appeared due to the rise in temperature of the spring inflow. Another reservoir namely the Sensui lake, located at the tributary of Takahashi river in the western part of Japan experienced severe droughts in winter between 2002 and 2003 and between 2008 and 2009. After the drought, *Microcystis* declined while *Anabaena* increased at the deeper zone. It appeared that the improved light condition at the deeper sediment surface might provoke the germination of *Anabaena*. These results indicate that snow fall reduction due to the global warming increased the inflow temperature in the reservoir. Thus, there is a possibility that the present destratification systems are not effective enough to suppress the blooming. On the other hand, the exposure of the bottom sediment can prevent algal blooming by changing the species composition. The artificial drawdown of the water level and the exposure of the bottom sediment for twenty days in early spring in Watarase reservoir, Japan, delayed the *Phormidium* cell density peaks to late summer and the 2-MIB production rate also declined.

Algal blooming in the reservoir is mainly attributed to the excessive nutrient load (Asaeda and Van Bon, 1997; Glibert and Burkholder, 2006; Moncheva et al., 2001; Paerl, 1997). However, hydrological regimes also have substantial effects on the algal biomass and composition of the blooming in a reservoir (Billen et al., 1994; Cloern, 1996; Lung and Paerl, 1988). Hydrological conditions in every corners of the world have been changing gradually in recent years due to the global warming (Loaiciga et al., 1996; Nijssen et al., 2001; Rosenberg et al., 1999). In some cases, changes are so drastic that the existing natural mechanisms to reduce algal blooming have failed (Paul, 2008). At the same time, hydrological conditions are expected to change further in future. Under these conditions, it is obvious that the previous system will not work sufficiently in future. Therefore, some modification is required in the present treatment system to cope with the future hydrological changes. Treatment systems are considered to change the reservoir conditions to reduce algal biomass under certain hydrological regime. This article indicates some examples of effects of change in hydrological conditions on the algal bloom of reservoirs, and an example to apply an artificial treatment of water level for the treatment of reservoir.

MATERIALS AND METHODS

Investigation was caring out from 1997 to 2005 on Sagami, Tsukui, Sensui and Watarase reservoir in Japan to find out the

effects of hydrological changes on algal blooming. Sagami and Tsukui reservoirs are consecutively located from up to downstream, respectively, at the midstream of the Sagami River, Kanagawa, Japan. The Sensui Lake is a reservoir located at the tributary of the Takahashi River in the western part of Japan.

Watarase reservoir is located at the central part of Kanto plain, 50km north of Tokyo ($36^o13'5"N$, $139^o40'31"E$). The reservoir was completed in 1989 for the purpose of flood protection and water supply for the domestic use. The reservoir is $4.5km^2$ and total the total volume is 26.4 mil.m^3, which is however, divided into three nearly same size parts connected by small channels.

In each year, water level was measured and around the center of the reservoir water temperature was measured in situ, then 2 liters of water was sampled near the water surface. Immediately in the laboratory, phytoplankton species composition (cell numbers) was analyzed under microscope (APHA, 1996) and total nitrogen and total phosphorus was analyzed by spectrophotometric method (APHA, 1996). Then, 2-MIB and geosmin concentrations were analyzed by gas chromatography (Shimadzu GCMS-QP2010) as the method describe by Sugiura et al. (1994). Gas chromatographic analysis was done with an instrument equipped with a flame ionization detector and a glass column (3mm×2m), containing 10% SE-30. Nitrogen was use as a car-rier gas at a flow rate of 30 ml min^{-1}. The column and injection temperatures were 150 °C and 200 C respectively. A sample of 100 ml plus 18 g of NaCl was taken in a 125-ml serum bottle, which was then sealed with an aluminum stopper. The bottle was shaken vigorously for 1 min, and kept at 70 C in a hot water bath for 1 h. Then 2 ml of the gas phase was collected by a gas-tight micro-syringe and injected into gas chromatography.

RESULTS AND DISCUSSION
Effects of the global warming on algal blooming
An investigation on the vertical temperature distribution in the reservoir before the operation of bubbling systems indicated that a high temperature gradient was developed between the upper and the lower layers due to the formation of strong stratification. However, after the installation of bubbling system, it was less than 3°C and thus the blooming was suppressed. Figure 1 and Figures 2 show the effects of destratification process and temperature difference on *Microcystis* density, respectively. Cyanobacteria often favor warm water temperatures (Briand et al., 2004; Paerl et al., 1985; Robarts and Zohary, 1987). Global warming could provide *C. raciborskii* with better environmental conditions for optimal growth, which occurs at temperatures approximately 30^oC (Briand et al., 2004).

In 1980's, the Sagami reservoir was severely affected by *Microcystis* blooming up to 2.5×10^6 cells/ml. As a control measure, 8 bubbling circulation systems were installed and thus the algal blooming was suppressed, though the downstream Tsukui reservoir had algal blooming up to 8×10^5 cells/ml in return. Then 5 bubbling circulation systems were installed in Tsukui reservoir which resulted in almost no blooming thereafter. After nine years, however, the blooming had started again with algal biomass of 1×10^6 cells/ml and 3×10^5 cells/ml in the Sagami and Tsukui reservoir, respectively.

It is reported that in subtropical estuaries the cyanobacteria have been shown to be dominant in the warmer months (Murrell and Lores, 2004). In recent years, after algal blooming had resumed, spring inflow temperature is higher than before likely due to the smaller snow fall in winter. This event has resulted in rapid melting of snow. Thus high temperature gradient is again created unless there is no large flood. It was found that the present operating duration of bubbling systems is not sufficient to destratify the reservoir.

Effects of drawdown of the water level on algal blooming
Water level regulation promotes the growth of algae (Burns and Walker, 2000). The Sensui reservoir had been suffering from stale odor generated by *Anabaena* spp. for more than 9 years. *Microcystis* spp. is another dominant cyanobacterium in that lake. There were severe droughts in winters between 2002 and 2003, and between 2008 and 2009 in that area. After the drought, cyanobacterial biomass declined (Figure 3). The density of cysts on the bottom surface was highly affected by drought (Figure 4). The density of *Microcystis* decreased remarkably after the drought. While the density of *Anabaena* on the surface, which was high only at shallow

Figure 1. Density of *Microcystis aeruginosa* of Sagami and Tsukui Reservoirs in response to the destratification operation.
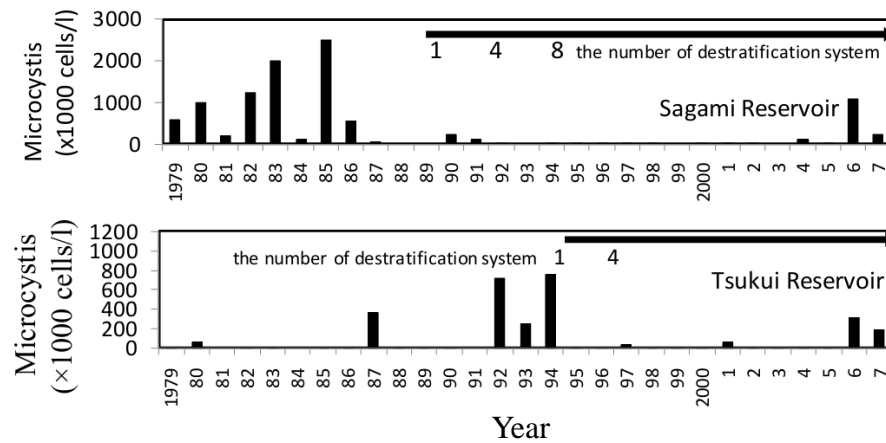

Figure 2. *Microcystis* density vs. temperature difference between 0.5m deep and 10 meter deep.
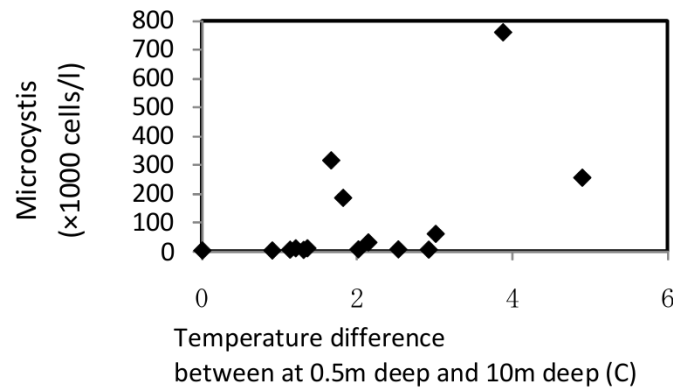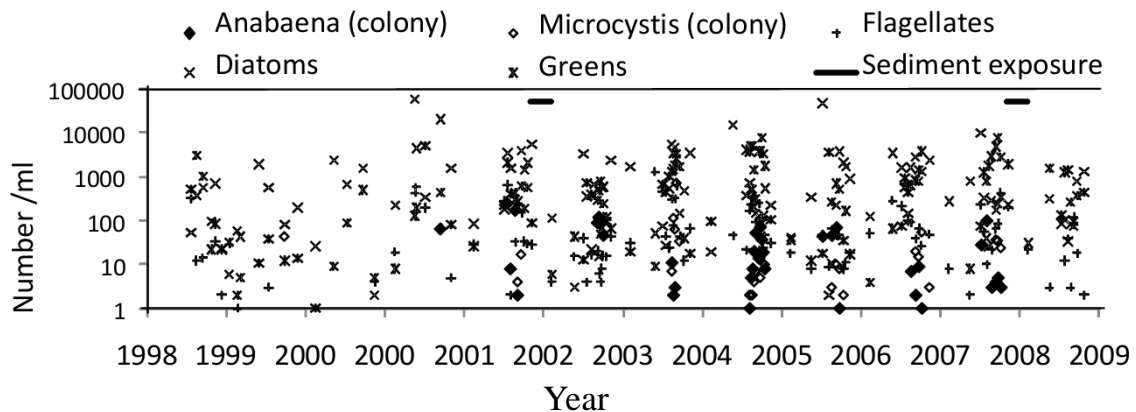

Figure 3. The relation between the drawdown and algal blooming in Sensui Lake

area before the drought, substantially increased at deeper area. It was indicated that *Microcystis* does not have tolerance to the desiccation of the bottom sediment, however, *Anabaena* increased at the deeper zone of the reservoir after the drought in some occasion, due to the improved light condition at the deeper sediment surface.

These results indicate that the drawdown of water and the exposure of the bottom sediment may have a high impact of *Phormidium* density and resulting the production rate of 2-MIB. It is obvious that the drawdown delays the peak of *Phormidium* density. The reason has not been elucidated yet. However, simulation of the growth rate can provide reasonable periods to grow up to the reference density if starting after re-filling water. It is clear that if *Phormidium* density peaks delay the production rate of 2-MIB decreases. The underlying mechanisms are still unclear. However, as there are several documents reporting that some species produce 2-MIB (Sugiura et al., 1994; Sugiura et al., 1986; Yagi et al., 1985) and some do not (Marquardt and Palinska, 2007), thus one possibility is that they are mixed cultures of several species and the composition might be changed by the drought.

Hydrological Treatment for Controlling Cyanobacterial Blooming

The phytoplankton abundance is controlled in the river by the discharge pattern (Descy, 1993; Huff, 1986; Lange, 1993; Reynolds, 1988; Reynolds, 1995). Watarase reservoir has a flat bottom with slight depressions except for the side bank, and the deepest point of the reservoir was approximately Y.P.8.0m. The inundated area increased up to the water level of Y.P.8.8m, such as 80% at Y.P.8.3m. However, at the high water level, the entire area is essentially inundated. The water level is raised to Y.P.11.5m from the middle of June to the middle of October for the purpose of flood protection, while it is kept at the normal level of 15m Y.P. during winter.

Immediately after the construction, supplied water in the reservoir has been suffering from stale odor (mainly 2-MIB di-methylisoborneol) (Wood et al., 2001) in spring to summer produced by Cyanobacteria, *Phormidium* spp (Sugiura et al., 1998). From 1997 onwards, water level was regulated for approximately one month in early spring in different manners, to investigate its effects on the Cyanobacterial blooming. The water level was kept at the high level during the period in 1998 and 1999, and therefore whole area was inundated. From 2000 to 2003, the water level was reduced down to Y.P.9.0m for different periods; one month in 2000, 40 days in 2001 and 2003, and two weeks in 2002. However, more than 80% area was still inundated during the period. In 1997, the water level was reduced down to Y.P.8.5m. Then in 2004 and 2005, it was further reduced to Y.P.8.3m, for three weeks. Therefore about 60% and 80% of the bottom was exposed in these years, respectively. After the reduction of the water level for the period, water was introduced from the nearby river to recover the water level. The exchange rate of water in the treatment was 97% when the water level was reduced to Y.P.8.3m, while 70% when the water level was remained at Y.P. 8.5m and only 35% at Y.P.9.0m.

Figure 5 indicates TM and TP variation in the experimental periods. There was distinct annual variation trend, such as high in spring and low in autumn, however, there was no systematic long-term trend in the period.

**Variation of Algal cell density and 2-MIB concentration with water level management**

After the construction of the reservoir, the cell density of *Phormidium* had been 20000 to 40000 cells/ml at maximum in May after the dominance of about 10000 to 40000 cells/ml of Diatoms. From June onwards, Cyanobacterial density often had enhanced more than 30000 cells/ml. Since 1997, *Phormidium* cell density has been exclusively dominant from spring.

Figure 6 presents the temporal distribution of *Phormidium* peaks in the Watarase reservoir. Without the reduction of the water level, in 1998 and 2002, the cell density of *Phormidium* enhanced to more than 70000 cells/ml in the beginning of May and June. In 1999, 2000, 2001, and 2003, in response to the reduction of the water level without exposure of much bottom area, the density of *Phormidium* varied in different manners. In 1999, *Phormidium*, a number up to 200000 cells/ml in May, suddenly increased and fluctuated up to more than 300000 and 400000 cells/ml from July to September. In 2000, after recovering water level in April, the density enhanced up to more than 300000
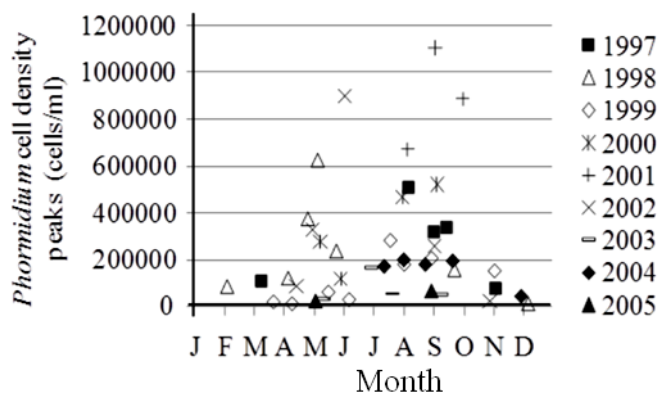
Figure 4 Density of algal cells including cysts on the bottom surface in relation to the water levels at drought.
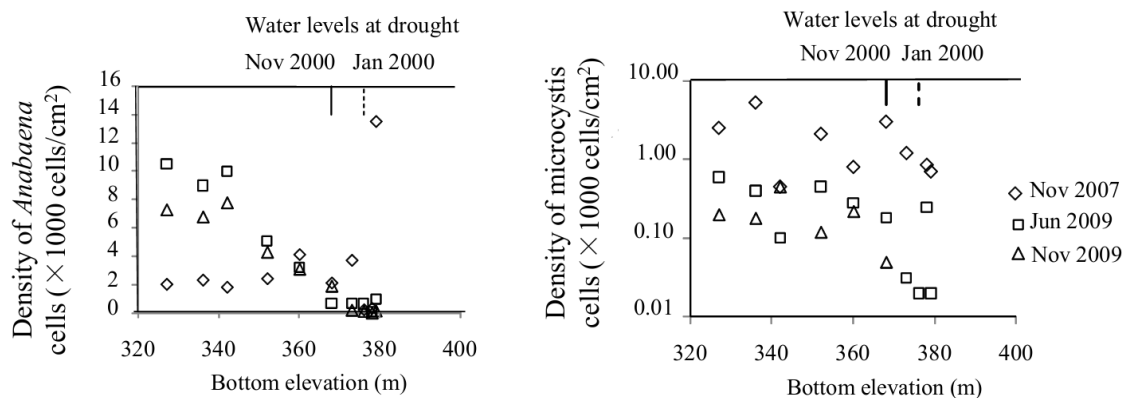
Figure 5. The variation of TN and TP during the experimental time.
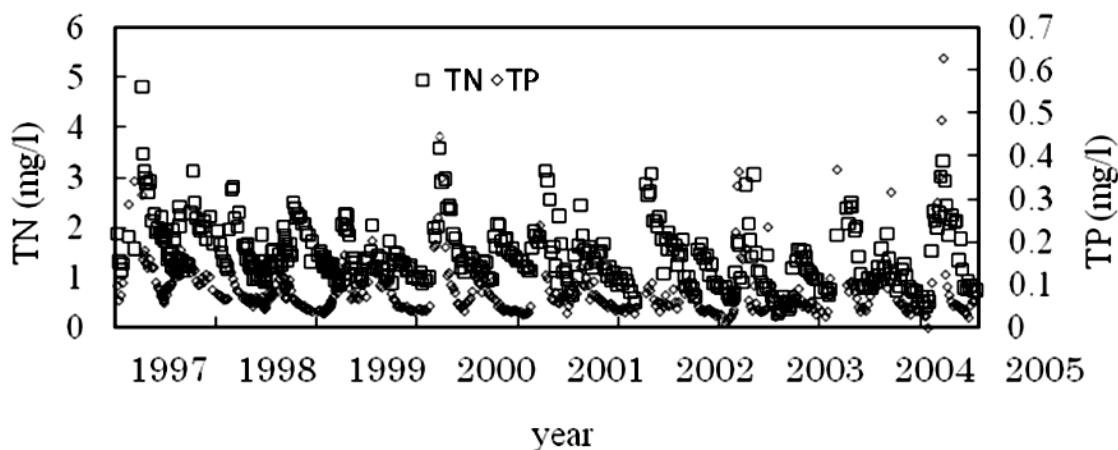
Figure 6. The density peaks of *Phormidium* cells at each year. Year shown by filled marks indicates those with high reduction of the water surface, followed by open marks.

cells/ml, which, once declined in June, again peaked in the beginning of August and September up to 500000 and 600000 cells/ml, respectively. In 2001, the density of *Phormidium* were relatively low until June, however, markedly enhanced up to 700000 cells/ml in the end of July and 1100000 cells/ml in the beginning of September, then continued high until October. In 2003, although low before March, cell density markedly increased with the introduction of river water and peaked 50000 cells/ml in May and 166000 cells/ml in the beginning of July, then continuing high value until September. In 1997, when 60% of the bottom was dried in the end of March, cell density did not enhance until the end of June although once high value was observed in the middle of May. In 2004, 80% of the bottom was dried in the end of March, and then cell density maintained the value in February and March until June, and then markedly increased up to nearly 200000 cells/liter. *Phormidium* cell density was in the range of 10 to 100cells/ml in the river water, when it was introduced in the reservoir to recover the water level. These densities were negligibly small compared with the density in the reservoir, however, the river water with its low temperature spread along the reservoir bottom, maintained the stable stratification of the reservoir. Therefore, the cell density of the epilimnetic water did not change much by the introduction of the river water.

The concentration of 2-MIB was more than 20 times higher than geosmin, except for 1999, in which geosmin concentration became as high as 300ng/liter in the beginning of March, thereafter however, 2MIB dominated. The variation of 2-MIB concentration of reservoir water is presented in Figure 7. Unlikely the variation of cell density of *Phormidium*, which is relatively continuous, 2-MIB concentration showed spiky peaks. A spiky major peak is seen once in a year before July, except for 1997, 1999 and 2000. In 1997, the peak value of 2-MIB was very low, 100ng/liter, and relatively late (in the middle of August). In 1999 and 2000, more than half of the peak concentration continued nearly two months for 2-MIB, thereafter the concentration became almost zero. Although the trends were different, the peak concentration of 2-MIB nearly corresponds to one of peaks in *Phormidium* cell density.

Almost no decline of the cell densities with introducing river water implies the prolonged stay of algal cells in the epilimnion, with continuous photosynthesis. Therefore, the dilution with river water did not work efficiently to reduce cell density. The decline of water level and bottom drying may have some effects on the succeeding cell density variation. Since the cell density before the treatment differed by years, the period to exceed some reference values is considered. Figure 8 shows days from April 1st until the cell density exceeds 10000 cells/ml and 100000 cells/ml with respect to the drying index, defined by the product of dried area and the period. Almost similar trends were obtained for the relationship between two reference cell densities, such that it took longer period with the larger index. Figure 9 indicates the ratio between 2-MIB concentration and cell density of *Phormidium* peaks, which indicates the production of 2-MIB by particular amount of cells. It is obvious that the production rate is high if cell density peaks before June, while it substantially decreases corresponding to the density peaks after July.

Conclusions

The change in metrology and hydrology due to the global worming has a lot of impacts on the algal blooming in reservoirs. There is a possibility that present destratification system, which has been the major treatment system in Japanese reservoirs, may no longer be capable of decreasing algal biomass under the warm temperature. In the case of Sagami and Tsukui reservoirs, the major cause of algal blooming reappearance is most likely the reduction of snow melt in the upstream of Sagami river. Similar conditions are expected in many reservoirs, as most of reservoirs are located in mountainous areas. Intensive drought is also expected to be associated with global warming. Though cannot say at the moment whether severe drought in Sensui reservoir is a result of global warming, however, the frequency of drought incidence is in increasing trend. Since cyanobacterial cysts are not tolerant to the desiccation of sediment compared with other algae, such as diatoms and greens, the exposure of the bottom sediment has substantial effects on its blooming. The reduction of cyanobacteria after the artificial draw down of water is also reported in Miharu Reservoir, and Ushigafuchi at the Imperial Palace in Tokyo.
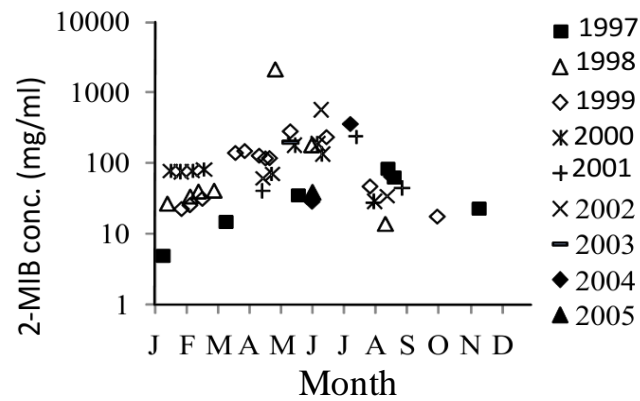
Figure 7 Peaks of 2-MIB concentration

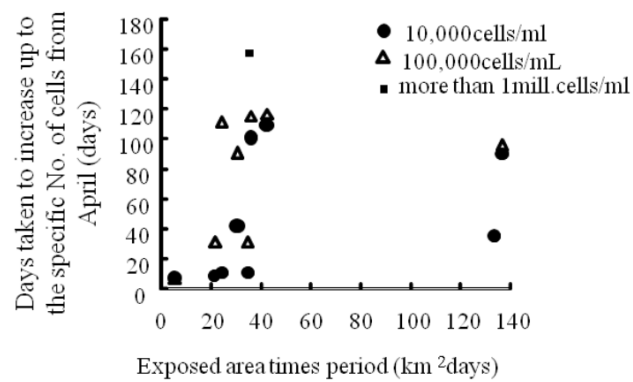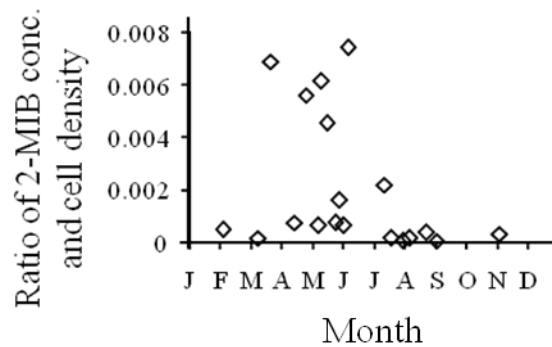**Figure 8 The days taken to increase up to the specific cell density vs drying index**

Figure 9 The ratio between 2-MIB concentration and *Phormidium* cell density

Drawdown of water, called *Kaihori*, is the traditional management system of Japanese ponds, although the reason is unknown. However, it is probable that clean water was maintained by the drawdown. Likewise, there is a high potentiality of applying the bed-

47

drying method in the reduction of cyanobacterial blooming.

REFERENCES

APHA, 1996. Standard methods for the examination of water and wastewater : 19th edition supplement.American Public Health Association, Washington, DC, pp: ix- 43.

Asaeda T and Van Bon T, 1997. Modelling the effects of macrophytes on algal blooming in eutrophic shallow lakes. Ecol. Mod. 104: 261-287.

Billen G, Garnier J and Hanset P, 1994. Modelling phytoplankton development in whole drainage networks: the RIVERSTRAHLER Model applied to the Seine river system. Hydrobiologia. 289: 119-137.

Briand J-F, Leboulanger C, Humbert J-F, Bernard C and Dufour P, 2004. *Cylindrospermopsis raciborskii* (cyanobacteria) invasion at mid-latitudes: selection, wide physiological tolerance, orglobal warming. J. Phycol. 40: 231-238.

Burns A and Walker KF, 2000. Effects of water level regulation on algal biofilms in the River Murray, South Australia. Regul. Rivers: Res. Manage. 16: 433-444.

Cloern JE, 1996. Phytoplankton bloom dynamics in coastal ecosystems: A review with some general lessons from sustained investigation of San Francisco Bay, California. Rev. Geophys. 34: 127-168.

Descy JP, 1993. Ecology of the phytoplankton of the River Moselle: effects of disturbances on community structure and diversity. Hydrobiologia. 249: 111-116.

Glibert PM and Burkholder JM, 2006. The Complex Relationships Between Increases in Fertilization of the Earth, Coastal Eutrophication and Proliferation of Harmful Algal Bloom. Ecological Studies. 189: 341-354.

Huff DR, 1986. Phytoplankton communities in navigation pool no. 7 of the Upper Mississippi River. Hydrobiologia. 136: 47-56.

Lange TR, 1993. Community dynamics of phytoplankton in a typical navigation pool in the Upper Mississippi River. J. Iowa Acad. Sci. 100: 21-27.

Loaiciga HA, Valdes JB, Vogel R, Garvey J and Schwarz H, 1996. Global warming and the hydrologic cycle. J. Hydrol. 174: 83-127.

Lung W-S and Paerl HW, 1988. Modeling blue-green algal blooms in the lower neuse river. Water Res. 22: 895-905.

Marquardt J and Palinska K, 2007. Genotypic and phenotypic diversity of cyanobacteria assigned to the genus *Phormidium* (Oscillatoriales) from different habitats and eographical sites. Arch. Microbiol. 187: 397-413.

Moncheva S, Gotsis-Skretas O, Pagou K and Krastev A, 2001. Phytoplankton Blooms in Black Sea and Mediterranean Coastal Ecosystems Subjected to Anthropogenic Eutrophication: Similarities and Differences. Estuar. Coast.Shelf Sci. 53: 281-295.

Murrell MC and Lores EM, 2004. Phytoplankton and zooplankton seasonal dynamics in a subtropical estuary: importance of cyanobacteria. J. Plankton Res. 26: 371-382.

Nijssen B, O'Donnell G, Hamlet A and Lettenmaier D, 2001. Hydrologic Sensitivity of Global Rivers to Climate Change. Clim. Change. 50: 143-175.

Paerl H, 1997. Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and groundwater as "new" nitrogen and other nutrient sources. Limnol. Oceanogr. 42: 1154-1165.

Paerl HW, Bland PT, Bowles ND and Haibach ME, 1985. Adaptation to High-Intensity, Low-Wavelength Light among Surface Blooms of the Cyanobacterium Microcystis aeruginosa. Appl. Environ. Microbiol. 49: 1046-1052.

Paul VJ, 2008. Global warming and cyanobacterial harmful algal blooms In: Hudnell HK (ed.), Global warming and cyanobacterial harmful algal blooms Springer New York,pp: 239-257.

Reynolds CS, 1988. Potamoplankton: paradigms, paradoxes and prognosis. In: Round FE (ed.), Potamoplankton: paradigms, paradoxes and prognosis. Biopress,Bristol, pp: 285–311.

Reynolds CS, 1995. River plankton: the paradigm regained. In: Harper DM, Ferguson AJD (eds.), River plankton: the paradigm regained. Wiley,New York, pp: 161–174.

Robarts RD and Zohary T, 1987. Temperature effects on photosynthetic capacity, respiration, and growth rates of bloom-forming cyanobacteria. N. Z. J. Mar.

Freshwat. Res. 21: 391-399.

Rosenberg NJ, Epstein DJ, Wang D, Vail L, Srinivasan R and Arnold JG, 1999. Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region. Clim.Change. 42: 677-692.

Sugiura N, Inamori Y, Hosaka Y, Sudo R and Takahashi G, 1994. Algae enhancing musty odor production by actinomycetes in Lake Kasumigaura. Hydrobiologia. 288: 57-64.

Sugiura N, Iwami N, Inamori Y, Nishimura O and Sudo R, 1998. Significance of attached cyanobacteria relevant to the occurrence of musty odor in Lake Kasumigaura. Water Res. 32: 3549-3554.

Sugiura N, Yagi O and Sudo R, 1986. Musty odor from blue- green alga, Phormidium tenue in Lake Kasumigaura. Envir.Technol. Lett. 7: 77-86.

Wood S, Williams ST and White WR, 2001. Microbes as a source of earthy flavors in potable water –a review. International Biodeterioration. 48: 26-40.

Yagi O, Sugiura N and Sudo R, 1985. Chemical and Biological Factors on the Musty Odor Occurrence in Lake Kasumigaura. J. Jpn. Limnol. 46: 32-40.

.