DISTINCTIVE FLUCTUATION IN WATER QUALITY AND PLANKTON IN THE CENTER OF LAKE KASUMIGAURA, JAPAN SINCE 2001

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ABSTRACT

Lake Kasumigaura is a wide and shallow maritime lagoon lake in which the water is artificially desalinated to be utilized effectively for tap water, irrigation water and industrial water. The water is highly eutrophicated and its improvement has been an urgent matter for some time. We have scientifically monitored the water quality and plankton periodically at six monitoring points since 2001 in citizen activities. We experienced outbreaks of Bosmina, high transparency in early summer and a massive microcystis bloom in midsummer, 2011 after the Great East Japan Earthquake and the subsequent radioactive cesium pollution from the accident in the Fukushima nuclear power plant in March. We propose that the outbreak of Bosmina grazing diatoms and green algae in early summer caused the increment of transparency, resulting in a massive proliferation of microcystis in midsummer. However the causalities from this abrupt outbreak of Bosmina are uncertain. It was observed that water fleas including Daphnia and Cyclops became scarce during the white turbidity period, 2002~2006. White turbidity in the lake water inhibits the photosynthesis by phytoplankton, resulting in a decrement in primary production, including the population of zooplankton and the fishery catch. While COD values also decreased, the inorganic nitrogen and phosphorus values were relatively high during the white turbidity period. Since 2012, a restoration of transparency has brought about relatively high COD values probably because of the proliferation of phytoplankton. Through these experiences we have learned the importance of transparency for the productivity and health of our lake ecosystem.

INTRODUCTION

Lake Kasumigaura is a maritime lagoon lake located in Ibaraki Prefecture near to Tokyo in the Kanto plain, Japan. It is a typical wide and shallow lake (max.depth: 7m, mean depth:4m, surface area:220km^2, volume:0.85 billion m^3, mean chloride ion:40mg/l, electro-conductivity: 260 μ S/cm, mean transparency:70~80cm). It has 2157 km^2 of catchment area and 56 inflowing rivers. The water quality has deteriorated due to rapid eutrophication and desalination. Desalinated water due to the construction of a sea water barrier (Hitachigawa Water Gate, 1963), now provides a vital water resource utilized as agricultural irrigation water, industrial water and drinking water for the Ibaraki Prefecture and the Tokyo metropolitan area. At the same time, the littoral zone is mostly reclaimed and a concrete dyke is constructed along most of the shore line. The lake has been completely enclosed by a dyke. Lake water has been managed over the last four decades by the national and prefectural government. The water quality has remained at the eutrophicated level. Recent values in water quality are approximately 7~8mg/l in Chemical Oxygen Demand i.e.COD ($KMnO_4$), 0.1mg/l in total phosphorus, 1.0mg/l in total nitrogen. Water quality improvement is one of the important matters to be addressed not only by local residents using the lake water as tap water, irrigation water and industrial water but also by the local or national government and the people who live in the Tokyo Metropolitan area.

The problem is that once the water quality deteriorates in a big lake, improvement becomes a very difficult issue. Many countermeasures and a large budget have been utilized on this based on statutes against eutrophication or pollution of the lake. We, in citizen activities, have been continuing the water quality monitoring by ship since 2001. During this monitoring, we have experienced several interesting phenomena and events concerning the water quality of the lake and learned some lessons for the appropriate management of such a wide and shallow lake located in a plain.

METHODS

During 2001-2015, the monitoring was carried out monthly (2001-2009) or bimonthly (2010-2015) from an investigation ship scheduled from 10:00 a.m. to 4:00 p.m. at six monitoring points positioned by Global Positioning System as follows: Okijyuku-offshore (36° 03′ 00″ N,140° 15′ 23″ E), Ushiwata-offshore (36° 02′ 34″ N、 140° 19′ 30 ″ E), Edosaki inlet (35° 59′ 13″ N,140° 22′ 07″ E), Tennouzaki-offshore (35° 58′ 37″ N、 140° 27′ 57″ E), Mitsumata-Lake Center (36° 00′ 48″ N、 140° 25′ 12″ E), Takahama Inlet (36° 07′ 22″ N、 140° 22′ 28″ E).

At each monitoring point, we measured the water temperature, dissolved oxygen, pH, transparency and electric conductivity of the surface water (30 cm depth). At the same time we recorded the color of the water. A plankton net (NXX13, made by RIGO CO., LTD Cat. No. 5513) was pulled up 5 meters vertically at each point to collect zooplankton. Zooplankton specimens were fixed with 5% formalin or 10% ethanol immediately after collecting. For the phytoplankton count, the surface water was sampled and examined under the microscope. The water samples were brought in a cooling carrier box to the laboratory and the suspended solids (until 2009), chloride ions and chemical oxygen demand (COD) were measured along with the inorganic nitrogen (ammonium nitrogen, nitrite nitrogen, nitrate nitrogen) and phosphate phosphorus, on a HACK colorimeter DR/890.

RESULTS AND DISCUSSIONS

During the white turbid water period (2002-2006), the transparency of the lake water was significantly low, showing about 80 cm even in the lake center. The mean transparency of 6 monitoring points was seen to be 50-60 cm in the worst period (Fig.1). During the same period, the numbers of Diatoms and Green algae were all low (Fig. 2, 3). Just after the end of the white turbid water, Planktothrix or fibrous Blue-green algae proliferated temporarily for several years (2007-2010) as shown in Fig.4. The levels of phosphate phosphorus and inorganic nitrogen were significantly high during the white turbid water period (Fig.5,6). Additionally, the COD values were relatively high for the same period (Fig. 7).

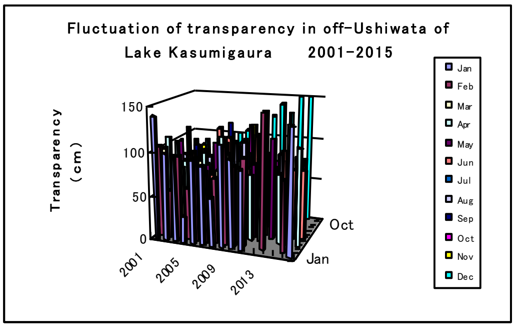
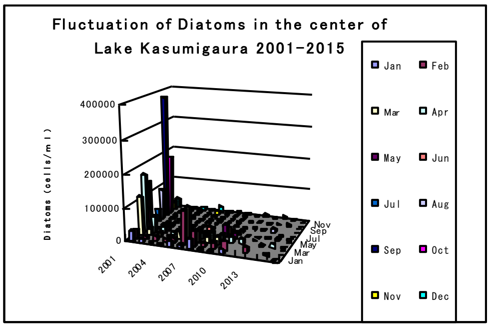


Fig.1



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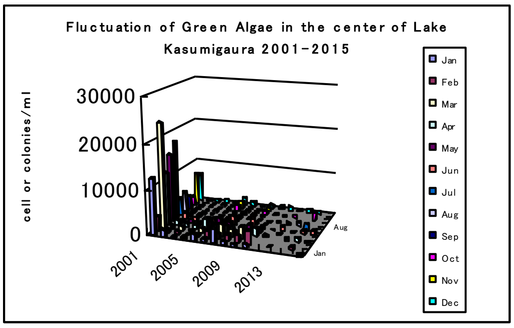

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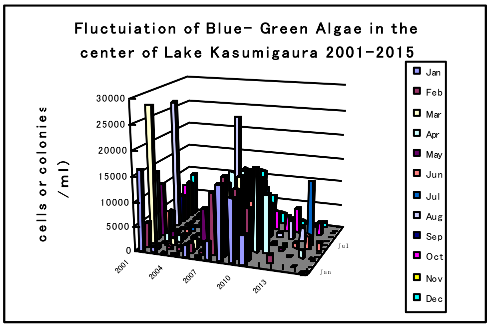

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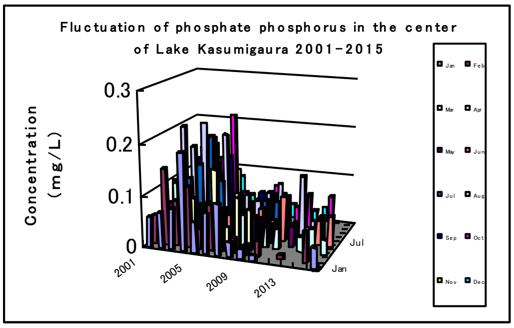

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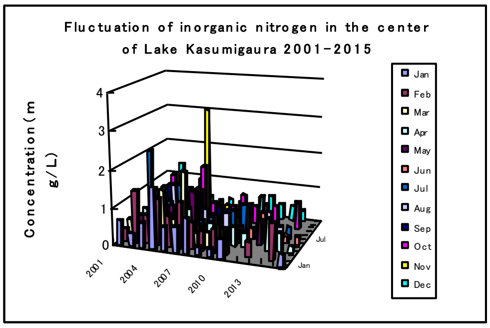
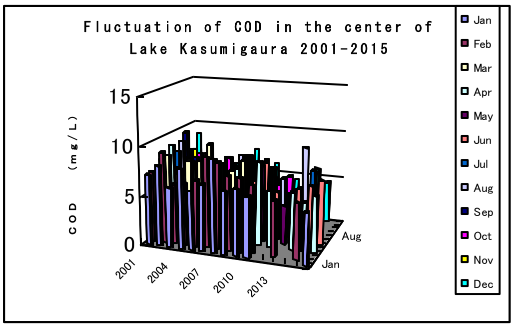


Fig.6

Zooplankton fauna in the lake center fluctuated distinctively during 2001-2015. An outbreak of *Bosmina* occurred in June 2011 (Fig.8) just after radioactive cesium pollution, suggesting activation of dormant eggs in the mud of the lake bottom. The supposed cause of this abrupt increment of *Bosmina* is discussed later. The *Daphnia* number increased in 2008 and 2012 (Fig. 9). The number of *Diaphanosoma* increased mainly in the summer of every year (Fig. 10). Copepodas were observed from spring to autumn through the monitoring period including the white turbid water period (Fig. 11). Rotifers proliferated after the end of the white turbid water (Fig. 12).



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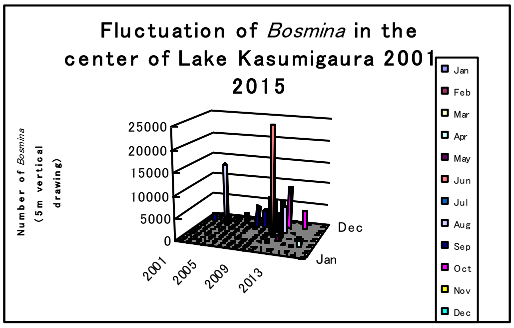

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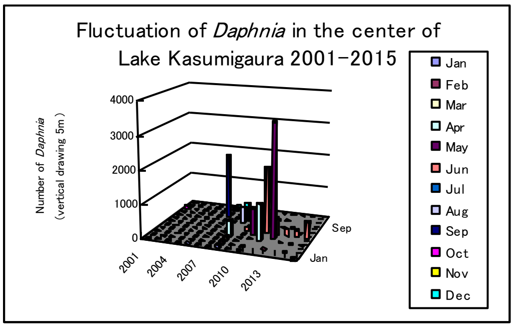

Fig.9

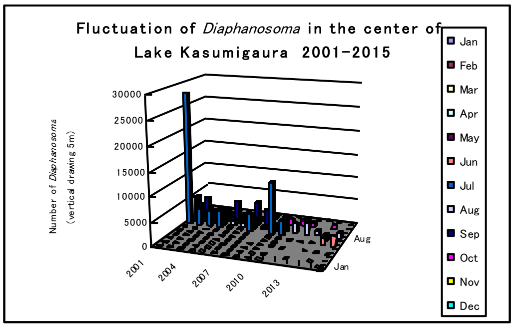

Fig.10

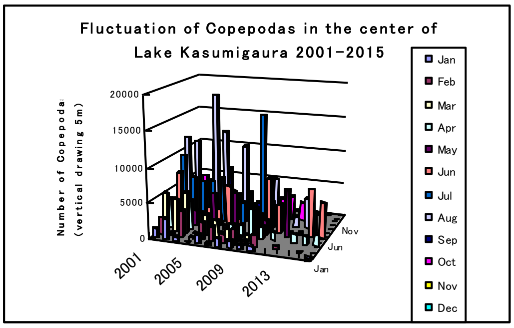

Fig.11

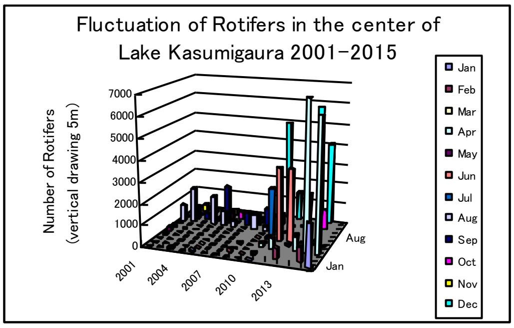

Fig.12

Lake Kasumigaura is the wide but shallow. Therefore, the transparency is always relatively low in comparison with a deep water lake due to three factors at least , i.e. the re-suspension of bottom sludge during high waves induced by strong winds, inflow of turbid water from the rivers during torrential rain in the catchment area and high proliferation of phytoplankton induced by lake water eutrophication. Five decades ago, the mean transparency of Lake Kasumigaura was still about 150 cm. In those days, there were many bathing beaches on the sandy shores. Afterwards, the transparencies were reduced to about 60~80 cm due to the progress of eutrophication of the lake water. During the white turbid water period (2002-2006), the worst transparency was 40~50 cm at the Ushiwata-offshore monitoring point and some other points. The primary productivity of the lake water was seen to be also worst in such periods due to the inhibition of phytoplankton proliferation accompanying the low light intensity.

Moreover the COD values in the lake water from the 6 monitoring points were relatively low during same period. Infection of Koi (Carp) Herpes Virus and the resulting massive death of cultured carp occurred in the worst period (2003), suggesting some relationship with the white turbid water. In addition, some researchers pointed out the influence from large scale dredging by the Ministry of Construction aiming at a decrement in the release of nitrogen and phosphorus from the lake bottom for improvement of the lake water quality. However, the exact reason why the terrible white turbid water occurred is uncertain in spite of the some earnest research projects [1)2)3)] Fortunately, transparency has gradually improved with the replacement of lake water due to high precipitation in the catchment area in the rainy or typhoon seasons (2004, 2010). Nowadays the mean transparency is improved to 80-100 cm in the lake center. The proliferation of phytoplankton and zooplankton has been altering seasonally in recent years. Additionally the fishery catch of Pond Smelt and Icefish which are the main fishery products in Lake Kasumigaura is recovering to the former level before the white turbid water period suggesting rehabilitation of the food web, material circulation and the lake ecosystem.

Outbreaks of *Bosmina* in June and water bloom in August 2011 proved difficult problems. It is probable that the dormant eggs of *Bosmina* were activated and hatched by some stimuli, possibly radioactive cesium pollution in the lake bottom, the fall of water level (about 10~20cm below from the average level) due to dyke damage, accompanying ultraviolet rays radiation, and the strong tremors from the Great East Japan Earthquake. In addition, the transparency of the lake water transitory rose to about 200-250 cm probably due to the decreasing phytoplankton grazed by *Bosmina*. Radioactive cesium pollution after the accident of Fukushima Nuclear Power Plant caused by Great Earthquake or Tsunami, prevailed in the catchment area of Lake Kasumigaura. Radioactive air containing cesium released from the Nuclear Power Plant fall out, polluted the Lake Kasumigaura and its watershed. Fortunately the lake is located about 150km far from the Fukushima and the radioactive levels of polluted soil in the catchment area, bottom sludge, lake water and aquatic organisms, were relatively low. The radioactive level of the bottom sludge temporarily rose just after the accident. Afterwards, the level gradually decreased (Fig.13). At present, the levels of radioactivity in the lake water, bottom sludge, fishery catch and the soil in the catchment area are all well below the standard for safety levels designated by the Environment Ministry. We are able to drink the tap water originating from the lake water and to eat the fishery products safely. The mystery of the abrupt outbreak of *Bosmina however* has remained elusive.

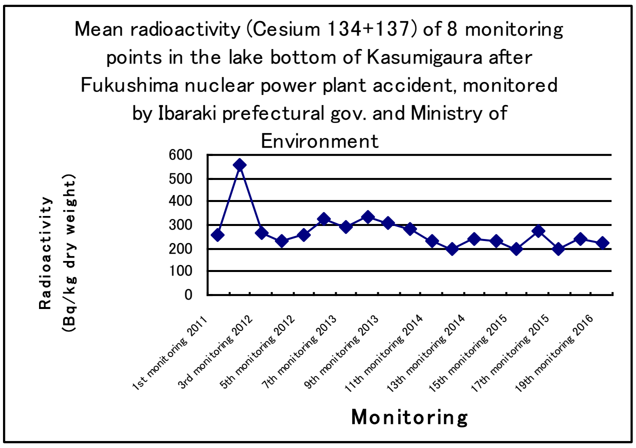

Fig. 13

Likewise, the partial outbreak of water bloom in the summer of the year when the Great East Japan Earthquake occurred, remains another mystery. We guess that with temporal high transparency induced by the outbreak of herbivorous zooplankton, *Bosmina* brought about sufficient light intensity for the proliferation of *Microcystis* of blue-green algae. This accumulated on the surface of the water in the port of Tsuchiura, the lakeside city, released a hazardous rotten smell, and forced the residents to react by calling for the countermeasures from the administration.

Other important events have occurred since 2001. They are as follows; tide gate and dykes suffered damage from the Great East Japan Earthquake and their repairs took time to complete (2013); wave breaker installment as an urgent measure for vegetation conservation were performed (2001-2004); dredging gravel as aggregate was ended by several private companies (2013); Smelt resource management by the fishery department of Ibaraki Prefectural Office began (since 2006); the fishery catch of Smelt recovered (since 2009); decrease in COD, attained its target value in the Prefectural plan for conservation of the lake water quality (2013); partial sandy shore development by the Ministry of Construction and the Water Resources Development Public Corporation (since about 2010).

These events were performed mostly independent of each other to pursue beneficial good effects for the lake water or the lake ecosystem through various business agencies or administrations. Of these, the restoration of the fishery catch of Smelt and partial improvements in water quality like the slight decrement of COD values and a certain recovery of transparency were somewhat auspicious, but the effects of the other measures are still uncertain and will need some time to evaluate.

During the white turbid water period, the proliferation of blue- green algae, diatoms and green algae were inhibited. After the end of the white turbid water period, diatoms were dominant in spring and fibrous blue–green algae were dominant from spring to autumn respectively. Sadly, afterwards, phytoplankton became relatively scarce. The number of phytoplankton at present seems to be inhibited by the outbreak of herbivorous zooplankton, *Bosmina*, *Daphnia*, *Diaphanosoma* and Rotifers, resulting in a slight decrement of COD values in the lake water.

Rotifers also proliferate and have been dominant especially from early spring to early summer since 2012. The outbreak of Rotifers is another interesting factor in evaluating the recent ecosystem of Lake Kasumigaura. There seems to be some relationship between the outbreak of Rotifers and the decrement of phytoplankton caused by grazing, resulting in a decrement of organic substance including phytoplanktons. Promising ideas to solve the reason for the tendency of decrease in the COD values of the lake water in recent years are as follows. Herbivorous zooplanktons proliferate satisfactorily and graze on phytoplankton, resulting in low COD values. Herbivorous zooplanktons are a good food source for Smelt. In particular, Rotifers are initial food for the fry or juvenile Smelt after hatching. Smelt become to predate medium sized zooplanktons like *Bosmina* and large-sized zooplanktons *Daphnia* or *Diaphanosoma* during their growth in the lake water. Smelt are the main fish catch for the fishermen of Lake Kasumigaura. Caught Smelt are the base for Tsukudani, a popular local side-dish specialty made by simmering the fish with sweetened dense soy sauce. A good fish-catch means the removal of the nitrogen and phosphorus through the fish from the lake water to ensure smooth material circulation and improvement of the water quality. In recent years, the Smelt catch in Lake Kasumigaura is over 400 tons per year, while this was only about 50 tons in the peak year of the white-turbid water. The fishing industry in the lake proves to be a good criterion for evaluating the ecosystem.

Other phenomena concerning the water quality were as follows: The levels of PO_4-P have tended to decrease along with the levels of inorganic nitrogen while levels of NH_3-N have tended to increase, all since around 2009. According to the monthly research performed by Ibaraki Prefectural Government, the annual mean levels of total nitrogen in the lake water of Kasumigaura has remained roughly the same in recent years. The total phosphorus level in the lake water however has increased annually. The reason why the total phosphorus level increased in the Lake water remains uncertain despite eager research by scientists. Analyses of inorganic nitrogen and phosphate phosphorus levels are very important but do not explain the fluctuation of the current water quality, fauna and flora of plankton including the fish-catch.

Probable macro-views about the load influencing the water quality, ecosystem including plankton and fish are as follows; Increase in precipitation in the catchment area results in shortening the retention time in the lake water. Water qualities of the inflowing river have improved in recent years. Successful measures against household wastewater including the gradual installation rate of sewage system rise and combined septic tank and so on , have been more effective, resulting in a tendency of decrement of the load from the catchment area.

CONCLUSIONS

During white turbid water period, 2002-2006, in Lake Kasumigaura, the photosynthesis and the proliferation of phytoplankton were inhibited. After the white turbid water period, diatoms were dominant in spring and fibrous blue-green algae including the *microsystis* bloom were dominant from spring to autumn, suggesting the importance of transparency for the productivity and healthy of lake ecosystem.

But afterwards, the number of phytoplankton was relatively few until now. The number of phytoplankton at present seems to be regulated by the herbivorous zooplankton, Rotifer or Daphnia. Herbivorous zooplanktons proliferate satisfactorily and graze on the phytoplankton, resulting in low COD and offering the initial food for the Smelt fry. This has brought about a relative good transparency and a proliferation of Smelt and smooth material circulation with removing the nitrogen and phosphorus through the fish catch. The exact causality of the abrupt outbreak of *Bosmina* and *Daphnia* in summer 2011 was uncertain because to reproduce the experiment is not practical.

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