LAKE EUTROPHICATION MODEL BASED ON THE IMPACT OF THE ZOOPLANKTON COMMUNITY ON PHYTOPLANKTON SUCCESSION

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ABSTRACT

To estimate the long-term effects of ecosystem-manipulating lake restoration methods such as biomanipulation, we need a numerical model which can predict the succession of plankton community with sufficient accuracy. An accurate numerical model can be prepared based on an accurate data background. In this sense, two series of mesocosm (outdoor open-air pond) experiments that mimicked conditions in shallow and eutrophic water ecosystem were performed to clarify the effects of the zooplankton community on phytoplankton succession quantitatively. The experiments were carried out in both summer and winter periods. The results revealed that three types of zooplankton, namely rotifers, copepods, and cladocerans, have different effects on phytoplankton succession. Rotifers did not graze blue-green algae. Cladocerans suppress the growth of phytoplankton even for some blue-green algae effectively by their predation. The results of these experiments suggest that the amount of crustaceans, i.e., copepods and cladocerans, should be increased for the successful enforcement of biomanipulation. A model based on these quantitative outcomes, and its prediction of a biomanipulation for an eutrophic shallow lake is also mentioned.

KEYWORDS
lake ecosystem model, mesocosm, biomanipulation

INTRODUCTION

People have always needed clear and safe water. Lakes supply most of the water for human communities, so this desire appears in the growing concern with the purification of lakes. In most cases, lake purification is equivalent to the prevention of lake eutrophication and consequent algal-bloom, which can cause many problems in water use. Interest in the "biomanipulation" that utilizes zooplankton as algal predators to effect the sustainable purification of lakes has been growing (Wright and Shapiro 1984; Hosper 1989; Shapiro 1990; Perrow et al. 1997; Hosper and Meijer 1999). In biomanipulation, the zooplankton-eating fish (planktivorous fish, e.g., bream) was removed to keep the high biomass of zooplankton, or fish-eating fish (piscivorous fish, e.g., pike)
was introduced to keep the low biomass of planktivorous fish.

Some biomanipulation trials have resulted in clear water (e.g., Driessen et al 1993; Meijer et al 1994), while in other cases the suppression of algal growth was not observed (e.g., Pekkarinen 1990; Van Donk et al. 1990; Van der Vlugt et al. 1992; Bratil 1994). Moreover, the long-term stability of biomanipulation remains questionable (Shapiro, 1990). The lake ecological model is one of the most powerful tools to predict the long-term effects of biomanipulation. Studies have tried to predict the effects of biomanipulation on the basis of lake ecological model calculations (e.g., Janse et al.,1992; Scheffer,1989,1991). These calculations outlined some features of biomanipulation's stability. However, the rate process parameters of these models, especially for the dynamics of zooplankton and fish, were estimated on the basis of a limited amount of data. The problem that we have to consider next is to estimate these model parameters more accurately.

It is obvious that the succession of phytoplankton is strongly affected by the zooplankton species that exist in the habitat, and this effect is defined by the food preference of the zooplankton. For successful modeling of the lake ecosystem, the impact of zooplankton on phytoplankton succession should be clarified. The semi-large scale experiments (so called mesocosm experiments) are suitable for estimating the intra-species relationship because they show a lower variability of observation data than that of actual lakes and are more similar to the actual lakes than are the laboratory scale experiments.

In this paper, we describe the results of our mesocosm observations especially focused on the impact of zooplankton on algal succession, and dominant material flow in water body estimated from the results. Furthermore, an application of our eutrophication model for an eutrophic lake (Lake Balaton, Hungary) is also outlined.

**MATERIALS AND METHODS**

The mesocosm experiments were carried out using four open-air circular ponds (4.0 m in diameter, 0.85 m in depth; Ponds #1 ~ #4) located in Shida County, Shizuoka, Japan. A vertical sectional view of one of the ponds is found in Fig. 1. To prevent the water temperature from rising to undesirable levels, all ponds were covered with shading nets, which cut off 70% of sunlight. Highly eutrophic sediment (total nitrogen (T-N): 3.1-3.9 mg·g⁻¹-sediment, total phosphorus (T-P): 6.2-9.4 mg·g⁻¹-sediment) and well water were introduced to the four ponds. After five months of pre-observation, we used these ponds as experimental mesocosms.

Experimental observations were carried out in summer (June 11, 1997 ~ Oct. 13, 1997), and in winter (Nov. 4, 1997 ~ Jan. 12, 1998). At the start of the summer experiment, 60 g-wet·m⁻³ of crucian carp (Carassius sp., body length: 8-10 cm, body weight: 15-30 g-wet) were stocked as planktivorous fish in Ponds #1 and #3. During the experimental period, no water was supplied except rainfall. The water temperature and irradiance of these two experiments are given in Fig. 2. A little amount of macrophytes was founded on June 9, 1997, in Ponds #3 and #4. The species of macrophytes were Hydrocaryaceae in Pond #3 and Hydrocaryaceae and Lemnaceae in Pond #4. During the pre-observation period, these ponds were rendered stable as regards the lack of inorganic
nitrogen. Observations were thus initiated by loading inorganic nitrogen (ammonium sulfate) into the ponds. The loading was performed in pulses (rise 0.56 mgN·L⁻¹ in a load) every few days.

The sampling methods and its analysis were described in our previous paper (Suzuki et al., 2000). The water temperature was continuously measured in situ using a maximum-minimum thermometer (Digi MIII, NIHON KEIRYOKI KOGYO, Japan). The observed daylight time at the Omaezaki weather station (about 20 km away from the pond) was utilized for calculating the daylight fraction. The latitude of the observation site (34°47') was used to calculate the daily irradiance. These calculations were done according to Stewart (1975), Groden (1977), and Jayaweera and Asaeda (1996).

RESULTS AND DISCUSSION

The observation results of the summer experiments are depicted in Fig. 3. Rapid growth of green algae was observed immediately after the start of inorganic nitrogen loading in each pond. The dominant species of green algae were Ankistrodesmus, Scenedesmus, and/or Crucigenia. Three types of blue-green algae were observed, namely, Microcystis, Phormidium, and Merismopedia. The prompt growth of rotifers was observed in the ponds without macrophytes (#1 and #2) followed by the growth of green algae. The dominant species of rotifers were...
Trichocerca, Brachionus, Keratella, and Asplanchna. A decrease in rotifers was observed in Pond #1, probably the result of fish predation, while the zooplankton was dominated by rotifers in Pond #2, in which the crucian carp had not been stocked. In this pond, Microcystis dominates the phytoplankton. In Pond #3 and #4, a temporal growth of Microcystis and Phormidium was observed, respectively. However, these species was eliminated after that, and the phytoplankton was dominated by green algae. In both ponds, large amount of cladoceran (Daphnia sp.) was observed.

On the whole, some important relations between phytoplankton and zooplankton were clarified. The biomass of rotifers was correlated with Microcystis. On the other hand, the biomass of Daphnia, which is abundant especially in Pond #4, was negatively correlated with Microcystis and Phormidium. Considering some literature (e.g., Matveev et al., 1994; Hlawa and Heerkloss 1994), it was concluded that the Daphnia seems to graze not only green algae but also Microcystis and Phormidium. While, rotatoria seems not to graze Microcystis and Phormidium. This was due to its size. In fact, the large size of blue-green algae was not grazed by Daphnia. However, the large colonies of Microcystis were not observed in these experiments, and the filamentous of Phormidium in this study seemed to be small enough to be grazed by Daphnia.

The observation results of the winter experiment are depicted in Fig. 4. The difference of the phytoplankton succession among each pond was more obvious than that in the summer experiment. In Pond #1, a relatively high biomass of phytoplankton dominated by green algae was observed. The biomass of phytoplankton in Pond #2 was also high, however, it was dominated by Phormidium. The growth of phytoplankton in Pond #4 was completely suppressed. The large number of Daphnia was observed in Pond #4, indicating that the strong suppression of phytoplankton growth in this pond might have been caused by high grazing pressure of Daphnia. Almost only rotifers were grew in Pond #2, in which the domination of Phormidium was observed. These results consistent with the correlation observed in the summer experiment. Furthermore, the temporary growth of Microcystis was observed in Ponds #1 and #2, however, it was eliminated gradually, probably as a response to low water temperature (Fig. 2).

In the winter experiment, the water temperature was low and the true growth rate of phytoplankton was slow. As a result, the grazing rate of zooplankton became a dominant factor to determine an apparent growth rate of phytoplankton. That is why we can observe the impact of zooplankton community on phytoplankton succession was more obvious in the winter experiment than in the
summer experiment. On the other hand, the selectivity of copepods on their food was not clarified in this experiment.

**NUMERICAL MODEL**

Differences of the characteristics of predation in zooplankton were found in the experiments described above. From these results, it is clear that the functional aspects of zooplankton communities are different based on which species is dominant. Coupled with some literature (e.g., Matveev et al., 1994; Price, 1988; DeMott 1989,1990; Vanderploeg 1990; Burns and Hegarty, 1994) we concluded that the structure of model depicted in Fig. 5 can describes the impact of zooplankton on algal succession sufficiently.

![Fig. 5](image.png)

**Fig. 5** Flow scheme of the model. Arrows with solid line mean the flow of carbon, nitrogen and phosphorus. Material or organism which was depicted in square with solid line means the state variable in the model. And material or organism depicted in square with dashed line was not considered as variable in the model.

On the other hand, each state variable (box) described in Fig. 5 consists many species and growth stages of organisms. Therefore, the kinetic parameters of them have a certain ranges of statistical variations. Considering this feature, the parameters should be determined not as a certain values but as a values with ranges. The set membership approach is one of the most feasible methods to determine such parameter sets. The detail description of this method was found in our previous work (Sagehashi et al., 2000).
One example that shows the effectiveness of such lake model for the prediction of the long-term effect of biomanipulation is the application for the Keszthely Basin, Lake Balaton (Hungary). Figures 6 and 7 shows the model structure and the calculation results. Note that the calculation results have some bands. As mentioned above, the calibrated parameters based on actual observation data have some statistical ranges. Therefore, we performed ten times of model calculation with random sampling of the parameters within the calibrated ranges. The lines depicted in Fig. 7 are thus the average and standard variation of the calculations. From this figure, the effective algal growth suppression, especially blue-green algae, by biomanipulation (90% removal of planktivorous fish) will take place within first 2 years. However, the algal growth become initial states after 10 years. This means that only once biomanipulation is not sufficient for the long-term stabilized lake restoration. It needs at least every two years removal of planktivorous fish. More information about this modelling is shown in our previous paper (Sagehashi et al., 2001)

As mentioned, the numerical model that includes the impact of zooplankton community on phytoplankton succession is a powerful tool to predict the long-term effect of lake ecosystem manipulating restoration method such as biomanipulation. The concern with the symbiosis of human beings and nature has been growing, therefore, such restoration methods play more important role in conservation of lake ecosystem. It is also true that the dynamics concerned with fish were not sufficient. In future works, the clarification of fish behavior with high accuracy using mesocosms or such controllable experimental apparatuses will be desired.

Fig. 6 Schematic diagram of the Keszthely Basin model

Fig. 7 Fate prediction of the ecosystem in the Keszthely Basin after 90% removal of bream. Thick lines: average calculations; thin lines: average±SD (n =10).
CONCLUSION

The characteristics of three types of zooplankton communities, i.e., rotifers, copepods, and cladocerans, were revealed on the basis of mesocosm experiments. The rotifers select against blue-green algae (*Microcystis* and *Phormidium*). Cladocerans (*Daphnia*) suppress the growth of algae including small size *Microcystis* and *Phormidium* strongly by their predation. These results suggested that the biomass of cladocerans should be increased for successful biomanipulation. On the basis of these results, a material flow structure required for the lake numerical model used for the prediction of ecosystem manipulating restoration methods (e.g. biomanipulation) was proposed.

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