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Note

Introduction of Water Quality Management in Korean Pond Ecosystems

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This study was conducted from July to December 2004, in order to find measures to improve the water quality and the function of pond ecosystems which are often negatively affected by phytoplankton and suspended particle matters. Most of the time, the management of ponds in Korea does not consider the ecological concepts such as self-purification and nutrient recycling. Instead, conventional methods depend on other factors such as fish farming and the function of fountains and waterfalls. Sustainability of pond ecosystems must be studied with the highest emphasis given to water quality. Water discharges of inflow and outflow as well as balance adjustment for different factors must be thoroughly studied. There is a great need for studies on sustainability because it can be realized through the horizontal or vertical balances of an ecosystem. Our current research offers useful information to the academia and public on maintaining sustainability in terms of structure and function of the pond.

Key words : pond ecosystem, water quality, pollution, phytoplankton, suspended particle

A pond can be seen as a small conventional semi-enclosed water body made artificially like a reservoir or a lake. It is usually relatively easy to manage due to its small size. Ponds are used for environment-friendly landscaping and water purification throughout the world (McComas, 2003). The size varies both in area and volume based on an available land and constructive purposes. Pond ecosystems are highly regarded for efficient use of space and appearance, yet water quality management is difficult to do by the persistent algal problems. In order to resolve the problems, various water treatment methods have been applied in preceding studies, but the fundamental solution was not suggest. Most ponds have a rather simple ecosystem structure that maintains a balanced biota, and water quality management becomes more difficult with increasing the retention time and internal pollution. The current research investigated the water quality control in major ponds in Korea and assessed problems especially in Sukungji Pond. It also aimed to induce water quality control and limit the algae growth by adjusting the ecosystem with organic relations.

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A situation of management technique of pond ecosystem

Subjects of the pond management technique survey were randomly selected based on the spatial size and the purpose regardless of geographical location. The study was made first-hand at selected sites. A total of 30 ponds-4 in government office sites, 5 in expressway rest stops, 4 in parks or temples, 2 in army bases, 2 in university campuses, and 3 in golf courses, as well as 2 city lakes, 2 artificial wetlands, and 5 others (including artificial undercurrent fields)-were designated as research targets. Pond conditions were recorded based on statements by on-site managers and investigators' observance.

Morphology and structure of Sukungji

Sukungji is a typical artificial small pond that was completed in August 1987. The width, length, and depth of the pond were measured on-site using a tape line in order to draw out the form and structure. The pond was studied every 1 m and 2 m of the width and length, respectively, while the depth was measured every 0.5 m from the edge to the center of the pond. Information on major sections of and devices installed on the pond was recorded in detail using a digital camera.

Basic water environment survey

Diminishing clarity from excessive freshwater algae growth is the main source of water quality deterioration in Sukungji. Water temperature, turbidity, clarity, and the volume of algae organisms were featured in this research. The survey was run 7 times between August and November, 2004. On-site water quality survey and sample collection was done in 1 central part and 2 edge parts of the pond. The sample analysis was run by mixing samples collected separately from the 3 parts. All samples were immediately pre-processed upon collecting and moved to the laboratory in an icebox.

Water temperature and clarity were measured using thermometers (Hg) and Secchi discs (Wetzel and Liken, 1991; APHA, 1995). Turbidity was measured twice using a HACH 2100N meter at the laboratory, and the average value was calculated. Chlorophyll-*a* contents were used to determine the volume of algae organisms, and the sample was filtered through GF/F paper and 90% ethanol was applied as an extract solvent (Nusch, 1980).

Ecological environment survey of Sukungji pond

The ecological environment of Sukungji was studied through the pond biota to assess its function and structure. Phytoplankton and periphyton as producers and zooplankton and fish as consumers were put at the center of this research. Flora around the water was also studied.

Biological experiment against water quality improvement

Freshwater bivalves were used in the water quality improvement research. Bivalves were collected from Somjin River downstream, and they were adapted to the pond environment using the pond water for 2-3 days before the final move. They were cleaned daily to get rid of discharge and the oxygen shortage problem while being provided with oxygen through an aerator. Dead bodies that failed to adapt to the change in environment were immediately removed to minimize the effect on other organisms. Indoor experiments and on-site experiments using an enclosure ($w \times l \times d = 0.94 \times 0.67 \times 0.34$ m) were run as a part of the water quality improvement research.

The situation of pond ecosystem management

Ponds are created in various places, and they can be classified as relatively small ecosystems in environmental terms. Their purposes are many in number and great in significance, yet little work has been done that highlighted structure and functions of ponds. As a result, most ponds are faced with severe turbidity and excessive algae inhabitation (Table 1).

Techniques for pond ecosystem management included fountains, waterfalls, and water mills that can provide both visual aesthetic value and oxygen supply. Fish and aquatic plants were also used for that end. Circulating devices were introduced to minimize stalling of the water. Some ponds even had water purification systems running. The shallower a pond (with depth between 5 and 10 m) was, the clearer the water layer was, while a thick biota of periphyton was formed at the bottom. Clarity was significantly diminished

Table 1. Introduction of water quality management in major pond ecosystems in Korean inland.

Stations	Numbers	Fall	Fish	Circulator	Clarifier	Turbidity sources	
						Water	Bottom
Government office	4	●	●	(●)	(●)	Turbid	Periphyton
Highway	5	●	●	(●)	–	Clean	Periphyton
Park and temple	4	–	(●)	–	(●)	Very turbid	Phytoplankton
Army	2	●	●	–	–	Very turbid	Phytoplankton
University	2	●	●	–	(●)	Very turbid	Phytoplankton
Golf club	3	●	(●)	●	●	Clean	Periphyton
City lake	2	●	●	–	(●)	–	Phytoplankton
Constucted wetland	2	–	●	(●)	–	Turbid	Complex
Others	5	–	●	–	–	Turbid	Complex
This study	1	●	●	●	–	Turbid	–
Total	30	7	8 (2)	2 (3)	1 (4)	–	–

(●): rare or less.

in ponds with depth of 10 m or more. Ponds with fountains and fishes exhibited higher turbidity with a greater concentration of phytoplankton and suspended particles. Clear ponds were generally shallow with a limited use of fountains and fishes; an appropriate holding capacity was naturally controlled in these ponds with water purifying devices. Nevertheless, even though the water layer seemed clear, algae protonema was concentrated in the bottom impairing the aesthetic value of the ponds. Existence of environment factors such as fountains, waterfalls, and fish that create movement of the water body greatly affected the water quality.

Morphological analysis of pond

Sukungji Pond is designed to look similar to the Korean Peninsula or a straw hat. There are water channels on each side of the pond and a round fountain faucet made of stainless steel in the center. The waterfall is located in the back right-hand corner. Groundwater and tap water flow into the pond through water channels and the waterfall. Water drains through a pipe at the end of the left water channel or is pumped to an external overflow.

The floor of the pond is finished with cement, and the edge is made in a step-form with rocks. The circumference of the pond is 107.8 m, and the width ranges from 2.9 to 13.0 m. The depth measured at the outer edge of the pond ranges between 0.74 and 0.85 m with an average of 0.79 m. The central part of the pond features a greater depth, which recorded the highest of 1.8 m where the fountain is located. The most drastic depth difference is 0.8-1.5 m away from the fountain where the floor has the sharpest angle.

Linear or circular stone piles were prepared inside the pond as ecological structures that provide fish with spawning grounds and/or resting spaces. Thick layers of periphyton biofilm had formed on the surface of these stone piles as well as or the rocks around the edge, providing fishes with abundant source of food.

Analysis of structure and function of pond ecosystem

Analysis of the ecological structure and function at Sukungji has much significance for the goal of water quality improvement. Biota within Sukungji were rather simple. Phytoplankton, periphyton, and fish could ge observed with the bare eyes. Zooplankton and invertebrates as the primary consumer were nearly extinct due to predation by fish (Table 2). Lack of organisms that connect producers with secondary consumers poses an abnormality in the pond's ecological function. Fish directly consume phytoplankton unless artificial feeds are applied, yet the pond housed mostly polyphagous carps that exhibited a general preference for animal food. It was decided that biological adjustment of the food chain using phytoplankton and periphyton would be ineffective, calling rather for introduction of shellfish organisms that consume phytoplankton.

Basic water quality of Sukungji pond

The water temperature in Sukungji ranged

Table 2. Species composition and individuals of fish fauna in the Sukungji pond.

Pond name	Fish fauna	Species	Abundance	Remark
Sukungji	*Cyprinus carpio linne* *Cyprinus carpio nude* *Carassius auratus* *Misgurnus mizolepis*	5	110	Dominant fish

Table 3. Mean values of major water quality in Sukungji pond from August to November 2004 (N=7).

Factors	Mean	Maximum	Minimum
Water temperature (°C)	19.0	27.5	10.4
Transparency (m)	0.7	1.0	0.4
Turbidity (NTU)	35.9	42.3	29.4
Chlorophyll-*a* (μg chl-*a* L^{-1})	62.4	78.6	46.2

between 10.4 and 27.5°C with an average of 19.0°C (Table 3). The average clarity was 0.7 m, ranging from 0.4 to 1.0 m, and the average turbidity was 35.9 NTU, ranging in the 29.4-42.3 NTU. The volume of algae organisms was measured at 46.2-78.6 μg chl-*a* L^{-1} with an average of 62.4 μg chl-*a* L^{-1}, indicating a 20 times growth from 3.0 μg chl-*a* L^{-1} at the time of water change. Increase of chl-*a* content created a pattern similar to the growth curve in indoor farming. There was little change for the first 3 days after the water change at 5.0 μg chl-*a* L^{-1}, whereas the figure drastically skyrocketed on the 6th and 7th day to reach 12.0 μg chl-*a* L^{-1}. In just 2 weeks, the measure exceeded 45.0 μg chl-*a* L^{-1}. At this time, the water clarity was significantly diminished and exhibited traits of typical algae-based water pollution.

The effect analysis of water quality improvement

Indoor experiments were run on eutrophic samples from Sukungji to test water purification capacity of bivalves (*Corbicula leana*). Sukungji housed water with a high content of algae organisms and severe turbidity. A clear decrease in both phytoplankton volume and concentration based on the feed by bivalves was observed. Test samples with a bivalve concentration of 1/1 L housed an average drop of phytoplankton and bio-particle volume by 90.2% and 94.3%, respectively, in comparison to the control sample without a bivalve addition (Ten Winkel and Davids, 1982), indicating that most planktons were of an appropriate size to feed the bivalves. The on-site experiment with bivalve addition at Sukungji resulted in an average drop of phytoplankton and bio-particle volume by 44.7% and 43.0%, respectively.

In terms of phytoplankton composition, more substantial change in green algae (70%) and diatoms (57%) was observed than in blue-green algae (44.0%) and flagellates (31%) to demonstrate the bivalve's preference for certain types of algae organisms. The rate of decrease in phytoplankton cell concentration based on the bivalve feed marked 0.38-1.64 day^{-1}. The filtration rate as calculated in consideration of bivalve organic content and number was 0.7 mL mg^{-1} AFDW hr^{-1} and 1.2 L $mussel^{-1}$ day^{-1}, respectively.

It is a challenging task to artificially control environmental and physical traits of the designated body of water when trying out the pond water quality improvement using bivalves. As a result, on-site verification of varying sizes and types must be run prior to the actual application. In this research, the water quality improvement effect of bivalve filtration was confirmed through indoor experiments, and then on-site feasibility and efficiency were tested through outdoor experiments of an enclosed scale.

The bivalve feed effect was clearly observed in both clarity and chl-*a* concentration. Two days after the bivalve introduction, the clarity increased from 0.48 m to 1.2 m while the chl-*a* concentration decreased from 74.3 μg L^{-1} to 28.7 μg L^{-1}. However, no further decrease in chl-*a* was detected after that, and even a gradual increase followed until the 7th day. Such a result led to a conclusion that the bivalve introduction could be compared to the water surface area, that effect from other environment factors outrun the bivalves' purification work, or that the bivalves' water purification capacity had reached its limit.

Bivalves have a superb ability to filter out particulate matter, and there have been many studies in regard to their use as biological purifiers for eutropic water. It has been found out that

Table 4. Comparison of water quality and maintenance component in Sukungji and Golf course pond.

Factor	This study (Sukungji)	Golf course	Remark
Pond capacity ($\times 10^3$ m^3)	0.25	25.0	
Ecosystem structure	Fish	Periphyton	
Trophic state by chl-*a* (μg L^{-1})	Eutrophic (46-79)	Mesotrophic (5-12)	
Waterfall	Medium (fixation)	Small (mobile)	Daily operation time is 12 hrs in the Sukungji
Circulation	Fountain, fall	Rresupply after the treatment	Daily operation time is 12 hrs in the Sukungji
Clarifier	None	Present (closed sedimentation pond)	DAF (mobile)
Treatment chemicals	None	Emergency	Non-toxic chemicals

bivalves take different feeding habits by types. For example, *Dreissena Polymorpha* practices selective diet habits, and *Corbicula leana* used in this study practices non-discriminative diet habit (Lauritsen, 1986; Way *et al*., 1990; Hwang *et al*., 2001). Environment factors that positively affect the bivalves' feeding capacity include relatively low water temperature (10-20°C) and water mobility (Walz, 1978; Reeders and Vaate, 1990; Fanslow *et al*., 1995). Algal composition and volume along with bivalve concentration are also closely related to the bivalves' feeding capacity (Winkel and Davids, 1982; Sprung and Rose, 1988). When blue-green algae bloom, the filtration capacity of *Corbicula leana* is lowered, while it exhibits a superior filtration capacity in a quasi-eutropic or oligotripic environment than in an eutropic environment (Hwang *et al*., 2001). In short, small bivalve concentration in comparison to phytoplankton content is likely to undermine the degree of phytoplankton decrease and water quality improvement by bivalves (Dame, 1996; Strayer *et al*., 1999). Water quality improvement after the introduction of 1,000 bivalves m^{-2} coincided with a significant change in the downstream with high unionids concentration (350 bivalves m^{-2}) (Walker and Walz, 1998).

Diagnosis and problems of pond ecosystem

It was confirmed that ponds in general constitute very simple ecosystems. Survey of major ponds in Korea showed that the bigger and older a pond is, it is likely that the water pollution in clarity was more severe. Aggressive maintenance had a positive effect on pond water quality. Old ponds usually suffered from deteriorated water quality and base sedimentation.

The water quality of Sukungji was rated as medium in comparison to other ponds. However, pollution based on appearance and water quality standard was rather severe. Continuously deteriorating water quality in Sukungji was heavily influenced by physical factors (Table 4). Reasons why phytoplankton and freshwater algae such as attached algae thrived and why there was a high concentration of suspended particles included the following. First, the enclosed space of a pond did not allow active inflow and outflow of water to result in excessive autogenous organic compounds that are trapped inside the body of water. Second, the fountain faucet is located 1.4 m under the surface to continuously re-supply biological and non-biological particles to the surface. Sugungji takes a form with an increasing depth towards the center where particle matters are accumulated. The suspended particle concentration was 3.3 times higher in the lower layer than in the surface level of the water near the fountain with a visible difference in particle sizes as well. Third, high concentration of fish and their movements created disturbances in the water, stirring up the sedimentation and removing the algae layer from the pond sides directly and indirectly. There also was a need to limit the fish feed input. Fourth, the waterfall facilitated detachment of algae from rocks that continued growth in the water layer. Such a fact was verified from the microscopic observation of suspended algae. Fifth, there was a need for regular freshwater supply while heightening the surface water circulation function towards controlling the internally generated organic compound content. Tap water, ground water, and processed water can be used, and the final decision should be made based on effectiveness and efficiency. In conclusion, there was a limit to water processing method and biological control capacity in an environment of prolonged problems. Elimination of pollutants can have a more significant effect toward that end.

Maintenance methods of sustainable pond ecosystem

There are many techniques and methods in both engineering and ecological terms to improve the pond water quality and function. Bivalves are one example of ecological improvement methods used in biological restoration. Energy and capital intensive and large scale technical remedies may not be an appropriate approach to disturbance or destruction of ecosystem because it takes little consideration for circulating nature of earthly matters. Study of engineering methods with fundamental limitation in accommodating ecosystems promotes ecologically dependent values among different organisms within a natural ecosystem. It fosters sustainability of ecosystems and symbiosis between nature and humans.

The current study indicated that there were many internal problems to be taken into consideration in applying ecological techniques to improve pond water quality. Elimination of pollutant sources was necessary for the ultimate ecological restoration. Ecosystems in ponds are highly dependent on freshwater algae and fish, and an impaired ecosystem with little capacity to conduct matter circulation led to a halt in the natural purification process. The artificial and physical impact on such phenomena can result in chronic problems by heightening the degree and cycle of pollution.

Consequently, the level of internally generated organic compounds must be taken into consideration to eliminate potential stimulants while maintaining sustainable ecosystems. It was found that physical or biological factors rather than chemical factors played the dominant role in water quality deterioration (Fig. 1). The key remedy would be to control the supply of unprocessed water with high turbidity from the fountain faucets while minimizing the fish concentration in the body of water.

Upward adjustment of the fountain faucet or installment of temporary filter to prevent resuspension of particles would be able to improve

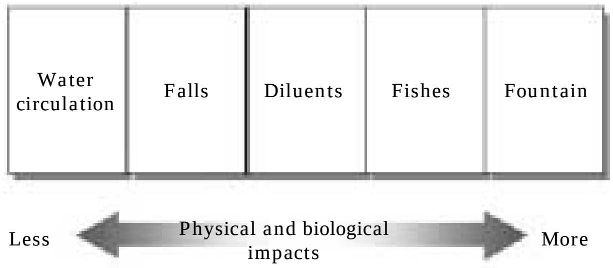

Fig. 1. Comparison of the impact factors for the deterioration of water quality in the pond ecosystem.

the water quality in terms of turbidity at Sukungji. There arises a small inconvenience of artificially processing accumulated by-products, yet it is a necessary process to tackle the worsening water quality problem. Provision of autonomous control devices to the ecosystem in consideration of the food chain relation will be particularly helpful. The need for concentration adjustment and matter circulation inducement through regular organism surveys cannot be undermined.

The sustainability of the pond ecosystem must be studied with the greatest emphasis given on the water quality. Water inflow and outflow as well as balance adjustment for different factors must be thoroughly studied. There is a great need for studies of sustainability because it can be realized when horizontal or vertical balance of a kingdom. This research will able to offer academia and the public much information to maintain sustainability in terms of pond's structure and function.

Lastly, the ideal pond ecosystem must exhibit a harmonious form with a commendable composition of different environmental factors. Composition can be made biologically, yet a complex ecosystem structure will pose great challenges in terms of maintenance and management.

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<국문적요>

국내 연못생태계의 수질관리

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본 연구는 식물플랑크톤과 입자성 부유물질에 의해 수질문제를 야기하는 연못의 수질개선과 생태계의 기능 향상을 위해 2004년 7월부터 12월까지 수행되었다. 국내에서 대다수 연못의 관리는 자정작용과 물질순환의 생태학적 개념을 고려하지 않고 있었다. 다른 요인보다도 분수, 폭포 및 어류 생물 사육에 의존되었고, 이러한 요인의 유무에 따라 수질 차이가 매우 큰 것으로 파악되었다. 연못 생태계 유지의 지속 가능성은 수질이 최우선으로 고려되는 기반이 제공되어야 한다. 물의 유입량과 유출량의 적절성과 함께 각 요소간 비율의 평형 조절이 무엇보다도 중요하다. 지속 가능성은 하나의 계에서 수평 또는 수직적 균형을 이룰 때 실현될 수 있기 때문에 이에 대한 연구 결과가 반드시 필요하다. 본 연구 결과에서 연못의 구조와 기능적 문제점이 도출된 데 대해 이러한 지속 가능성을 유지하는데 가치 있는 유용성을 제공하게 되었다.