Water Science and Engineering, 2011, 4(1): 92-100
doi:10.3882/j.issn.1674-2370.2011.01.009

http://www.waterjournal.cn
e-mail: wse2008@vip.163.com

Impact of pond and fence aquaculture on reservoir environment

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Abstract: With the rapid development of aquaculture in lakes and reservoirs, its negative effects on water quality and aquatic organisms are clearly emerging. Toward a better understanding of these effects, chemical and biological monitoring was conducted in the Fangbian Reservoir to study the relationship between aquaculture and eutrophication. As a domestic water supply source, this reservoir has reached the mesotrophic level. The concentrations of total nitrogen (TN) and total phosphorus (TP) in the Fangbian Reservoir have frequently exceeded the prescriptive level according to the *Environmental Quality Standards for Surface Water* (GB3838-2002). Pond and fence aquaculture feeding is the main cause of high levels of nitrogen and phosphorus, accounting for nearly half of the total pollution, and causing the reservoir environmental capacity to be exceeded. The amounts of nitrogen and phosphorus that went directly to the reservoir through the residual bait and fish droppings in fence aquaculture were 42 768 kg per year and 10 856 kg per year respectively, from 2007 to 2009. About 2 913 kg of nitrogen and 450 kg of phosphorus were imported to the reservoir through the exchange of water from the culturing ponds at the same time. Therefore, controlling the aquaculture scale and promoting eco-aquaculture are key measures for lessening the eutrophication degree and improving the water quality.

Key words: *reservoir environment; fence aquaculture; pond aquaculture; bait; eutrophication; nitrogen and phosphorus*

1 Introduction

Lakes and reservoirs are important water supply sources, and also culture farms of aquatic products such as fish, shrimp, and crab (Sun et al. 1999). In recent years, the rapid development of aquaculture in lakes and reservoirs has made the aquatic environment increasingly worse (McDaniel et al. 2005). Although aquaculture is part of the comprehensive utilization of lakes and reservoirs, intensive aquaculture with high density and substantial bait is bound to influence the levels of nutrients, increasing the pollution load in water and sediment, and ultimately leading to eutrophication (Simões et al. 2008; Garner 2008).

There are primarily two types of freshwater aquaculture in China. One is fence aquaculture and the other is pond aquaculture near lakes and reservoirs. Fence aquaculture is

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Received May 10, 2010; accepted Oct. 14, 2010

also known as cage aquaculture. It is an intensive farming mode with a high density of fish in captivity in natural aquatic environments such as lakes, rivers, and reservoirs (Chen and Zheng 2005). In the process of breeding, substantial exogenous bait is put in the water, and the residual bait and fish droppings lead to the accumulation of nitrogen and phosphorus, which result in nutrient enrichment of water and sediment (Tang et al. 2003; Qi et al. 2006). Pond aquaculture is also intensive, and nutrients enrich the medium more rapidly because of the low water exchange rate. The silt deposits of the ponds become thicken with the accumulation of residual bait and aquatic creature excreta (Buykcapar and Alp 2006). The polluted water from the pond is discharged into the adjacent lakes and reservoirs and fresh water is pumped in. This increases the pollution degree of lakes and reservoirs (Milstein 1993; Scharf 2007; Salami et al. 2008).

In order to verify the adverse effects of pond and fence aquaculture on the reservoir environment, chemical and biological monitoring were conducted in the Fangbian Reservoir to study the relationship between aquaculture and eutrophication, which is a positive step toward the key goal of strengthening ecological environmental monitoring throughout China for the Twelfth Five-Year Plan for water conservancy industry.

2 Water quality and pollution sources of study area

2.1 Variation of water quality

The Fangbian Reservoir is located in the upper reaches of the Qinhuaihe River in Nanjing, in Jiangsu Province, China. It is a medium-size reservoir with a catchment area of 77.1 km^2 and a total storage capacity of 5.07×10^7 m^3. The Fangbian Reservoir is the domestic water supply source for the city of Lishui and the town of Dongping and also provides the functions of flood control, irrigation, aquaculture, and tourism. According to the functional division of water, the water quality of the Fangbian Reservoir should meet grade Ⅱ of the *Environmental Quality Standards for Surface Water* (GB3838-2002) with a total nitrogen (TN) concentration of 0.5 mg/L and a total phosphorus (TP) concentration of 0.025 mg/L. However, the TN and TP concentrations exceeded the standard frequently from 2007 to 2009.

The TN concentrations were 0.65 mg/L on average in 2007 with a range from 0.30 mg/L to 0.96 mg/L, and 0.96 mg/L on average in 2008 with a range from 0.61 mg/L to 1.63 mg/L (Fig 1). Compared with the standard concentration of TN (grade Ⅱ of the *Environmental Quality Standards for Surface Water* (GB3838-2002)), the reservoir was polluted all the time except in June and November of 2007 and in February of 2009. Moreover, the TN concentrations in summer were higher than those in winter and the highest values in 2007 and 2008 both appeared in July. The TP concentrations were 0.02 mg/L on average with a range from 0.01 mg/L to 0.03 mg/L in 2007, almost meeting the standard, and 0.05 mg/L in 2008 with a range from 0.01 mg/L to 0.11 mg/L (Fig. 2). In comparison with the year 2007, the pollution levels of TP rose in 2008 and in the first four months of 2009. The Fangbian Reservoir reached the mesotrophic level, and blue-green algae appeared in some parts of the water in the summer (Painting et al. 2007).

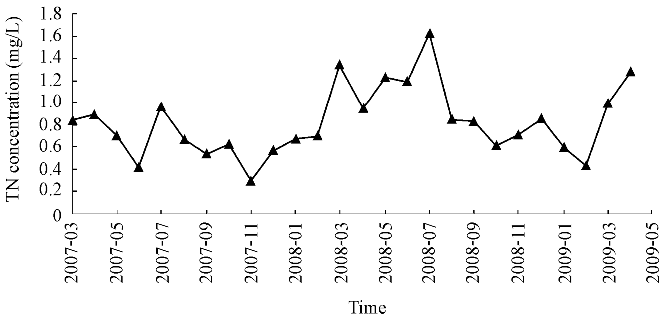

Fig. 1 Temporal variation of TN concentration in Fangbian Reservoir from March 2007 to April 2009

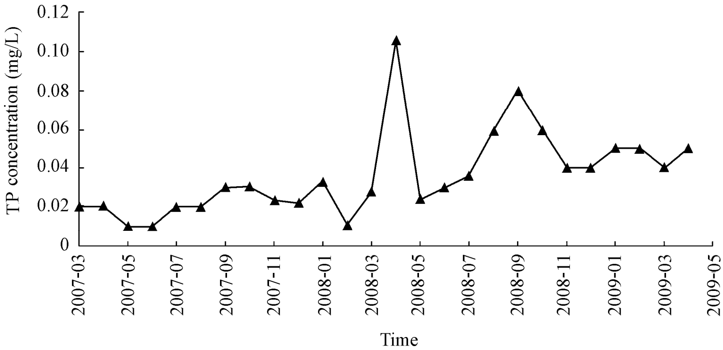

Fig. 2 Temporal variation of TP concentration in Fangbian Reservoir from March 2007 to April 2009

2.2 Analysis of pollution discharged into reservoir

The Fangbian Reservoir is located in a hilly and mountainous area. Reservoir pollutants such as nitrogen and phosphorus come from non-point sources as there are no cities or industrial enterprises around the reservoir. Non-point source pollution is caused by the use of fertilizer, domestic sewage from rural villages, livestock cultivation, and aquaculture. In addition to the aquaculture pollutants discharged directly into the reservoir, the other pollutants from the watershed flow into the reservoir through the tributaries.

2.2.1 Pollution from aquaculture

There are two kinds of aquaculture: pond aquaculture and fence aquaculture.

(1) Pond aquaculture: There are 0.19 km^2 of intensive ponds with an average depth of 3.5 m around the Fangbian Reservoir, including 0.08 km^2 of fish ponds for the mixed breeding of silver carp, variegated carp, herring, grass carp, and 0.11 km^2 for pearl mussel. About 2.25$\times$ 10^6 kg/km^2 of bait was put into the fish ponds according to a goal of 9 $\times$ 10^5 kg/km^2 of annual yield of fish from 2007 to 2009. 6 072 kg of nitrogen and 1 725 kg of phosphorus were imported to the fish ponds each year by the bait, accounting for 3.52% and 1% of the bait content, respectively.

Pearl mussel farming requires plankton-rich and eutrophic water. Aquaculturists put fertilizer to the mussel ponds to increase nutrition and the amount of bacteria and phytoplankton in the water in order to meet requirements of pearl oyster breeding. To improve the water fertility, about 1.125×10^6 kg/km^2 of fermented poultry manure with 1.6% of nitrogen and 0.4% of phosphorus was put into the pearl mussel ponds. This shows that 2 040 kg of nitrogen and 510 kg of phosphorus were imported to the pearl mussel ponds every year by poultry manure.

The water quality for fishery aquaculture needs to meet grade III of the *Environmental Quality Standards for Surface Water* (GB3838-2002). However, the concentrations of TN in fish and pearl mussel ponds monitored in August 2008 reached 2.09 mg/L and 2.53 mg/L, respectively, while the concentrations of TP were 0.28 mg/L and 0.42 mg/L, respectively, all being inferior to grade V water.

According to a survey, a depth of 20 cm to 30 cm (a mean of 25 cm) of water in ponds needs to be changed at 7-day intervals during the growing seasons of summer and autumn. It follows that 2 913 kg of nitrogen and 450 kg of phosphorus were exported annually from 2007 to 2009 to the Fangbian Reservoir by water exchange.

(2) Fence aquaculture: There are seven fenced farming regions in the Fangbian Reservoir for the cultivation of silver carp, bighead carp, herring, grass carp, covering an area of 1.33 km^2. About 1.125×10^6 kg/km^2 of bait with 3.52% of nitrogen and 1% of phosphorus was put in the reservoir each year from 2007 to 2009. In the feeding process, about 10% to 20% of the bait could not be assimilated, and went directly into the water. For the ingested bait, about 20% to 25% of nitrogen and 25% to 40% of phosphorus were used for growth, and 75% to 80% of nitrogen and 60% to 75% of phosphorus were discharged into the aquatic environment in the form of excreta and metabolites (Yuan and Cui 2003; Liu et al. 1997; Yaro et al. 2005).

It is calculated that 427 68 kg per year of nitrogen and 10 856 kg per year of phosphorus were imported to the Fangbian Reservoir from 2007 to 2009 by bait remnants and fish excreta in fence cultivation (shown in Table 1).

Table 1 Imported amounts of nitrogen and phosphorus from fence and pond cultivation

Aquaculture type		Aquaculture area (km^2)	Bait amount (10^6 kg/km^2)	Pollutant load		Pollutant amount imported to reservoir	
				Nitrogen (kg/year)	Phosphorus (kg/year)	Nitrogen (kg/year)	Phosphorus (kg/year)
Pond	Pearl mussel	0.11	1.125	2 040	510	2 913	450
	Fish	0.08	2.250	6 072	1 725		
Fence		1.33	1.125	42 768	10 856	42 768	10 856
Total		1.52				45 681	11 306

This shows that the application of exogenous bait has increased fishing productivity and aquaculturists' economic benefits, but the economic profit is based on sacrifice of the aquatic environment for the cost. An annual increase of 45 681 kg of nitrogen and 11 306 kg of phosphorus was loaded into the Fangbian Reservoir due to pond and fence aquaculture.

2.2.2 Amount of pollutants

The pollutants from other sources including agricultural fertilizer, domestic sewage, livestock cultivation, and soil erosion were calculated due to the related loss rates and are listed in Table 2. The amounts of nitrogen and phosphorus discharged into the reservoir were respectively 103 604 kg and 19 909 kg each year. Nitrogen and phosphorus from aquaculture respectively accounted for 44.09% and 56.79% of the total pollution, and were one of the main pollution sources.

Table 2 Amount of nitrogen and phosphorus discharged from different pollution sources into Fangbian Reservoir

Pollutant	Nitrogen (kg/year)	Nitrogen percentage (%)	Phosphorus (kg/year)	Phosphorus percentage (%)
Fertilizer	48 647	46.95	6 355	31.92
Domestic sewage	3 506	3.39	772	3.88
Livestock cultivation	5 120	4.94	1 101	5.53
Soil erosion	650	0.63	375	1.88
Aquaculture	45 681	44.09	11 306	56.79
Total	103 604	100.00	19 909	100.00

2.3 Water environmental capacity

Due to its long detention time and relatively stable state, the reservoir can be viewed as a uniformly mixed water body. The water environmental capacity of TN and TP were calculated with the model proposed by the International Organization for Economic Cooperation and Development (OECD), and the formulas are as follows:

$$L = q_{\mathrm{s}} C_{\mathrm{s}} \left[1 + 2.27 \left(\frac{V}{Q_{\mathrm{out}}} \right)^{0.586} \right] \tag{1}$$

$$q_{\mathrm{s}} = \frac{Q_{\mathrm{in}}}{A} \tag{2}$$

$$W = 0.001LA \tag{3}$$

where L is the allowable load of the quantity of nitrogen or phosphorus per square meter per year in reservoirs (g/m^2); q_{s} is the discharge per square meter per year in reservoirs (m); C_{s} is the TN and TP standard of the surface water environmental quality (mg/L); V refers to the volume of reservoirs (m^3); Q_{out} is the outflow per year from reservoirs (m^3) while Q_{in} is the inflow per year (m^3); A is the area of the reservoir (m^2); and W is the water environmental capacity of TN or TP per year (kg).

According to relevant data, when the water quality of the reservoir can be maintained at grade II of the *Environmental Quality Standards for Surface Water* (GB3838-2002), the water environmental capacities of TN and TP in the reservoir was 49 775 kg per year and 2 489 kg per year, respectively.

With the same conditions of pollutant discharge, the amount of nitrogen discharged into the reservoir is 2.3 times higher than the environmental capacity, while that of phosphorus is 9.6 times higher. Furthermore, nearly half of the pollution is from aquaculture, exceeding the reservoir environmental capacity, which means that aquaculture is the main reason for making the reservoir polluted and upsetting the ecological balance.

3 Impact of aquaculture on reservoir environment

3.1 Impact on water quality

There are three main tributaries to the Fangbian Reservoir: the Shijiawa River, Qinglong River, and Yangxiang River. The water quality in the three tributary mouths was monitored in 2008. The results showed that the TN concentrations in the three river mouths varied from 0.51 mg/L to 0.69 mg/L, lower than those in the reservoir. The TP concentrations varied from 0.032 mg/L to 0.054 mg/L in the river mouths, frequently lower than those in the reservoir. This means that nitrogen and phosphorus in the Fangbian Reservoir are not from the three tributaries, but from the fence and pond aquaculture. The impact of aquaculture on water quality can be described in four components.

3.1.1 Residual bait and metabolites

A notable characteristic of fence and pond aquaculture is the casting of artificial bait rich in nitrogen and phosphorus to satisfy the demand of the intensive aquaculture of fish for food. The nutrients in the bait are the main factor causing water quality deterioration. According to the calculation results above, an annual increase of 45 681 kg of nitrogen and 11 306 kg of phosphorus was loaded in the Fangbian Reservoir from 2007 to 2009 due to the pond and fence aquaculture. Therefore, nitrogenous and phosphoric contamination caused by the fence and pond aquaculture significantly affects the reservoir water quality.

3.1.2 Organic pharmaceuticals

In the process of aquaculture, organic pharmaceuticals such as disinfectants, antibiotics, various hormones, and vaccines are inevitably used. Some are applied directly to the water and others are added to the bait. In the end, these pollutants are all discharged into the water. When the concentrations of pollutants reach a certain level, they cause serious water pollution.

3.1.3 Decrease of dissolved oxygen

Under the combined effects of residual bait, excreta, metabolites, and organisms, too much organic matter decomposition consumes a lot of dissolved oxygen in the water, coupled with a dramatic increasing consumption of biological oxygen demand from high-density aquaculture, which leads to the reduction of dissolved oxygen in the reservoir.

3.1.4 Increase of pollutants in sediments

As a result, phosphoric compounds often exist in insoluble states, most of which, produced by aquaculture, are deposited in the sediment. Some will be released again into the water due to biological decomposition or reuse, and most remain in the sediment as a long-term pollution source (Zeng and Li 2006).

3.2 Impact on aquatic ecosystem

Fish cultured in the Fangbian Reservoir can be divided into three general categories, and different categories have different influences on the aquatic ecosystem.

Filter-feeding fish, such as *Hypophthalmichthys molitrix* and *Aristichthys nobilis*, can directly leach zooplankton, large phytoplankton, or tiny phytoplankton with gill rakers. When herbivorous zooplankton is inhibited by filter-feeding fish, phytoplankton, especially small species, increase, leading to the reduction in number or biomass of large phytoplankton in proportion to total phytoplankton. Coupled with strong reproductive capacity, the biomass of small phytoplankton tends to increase, and sometimes the total biomass of phytoplankton also rises. Moreover, in the process of filter-feeding fish leaching phytoplankton, some nutrients are excreted in the chemical form directly absorbed by phytoplankton, which accelerates the release of nutrients in water (Pogozhev and Gerasimova 2001). Thus, high-density filter-feeding fish can result in the decrease of herbivorous zooplankton biomass and an increase in phytoplankton biomass, chlorophyll concentration, and primary productivity, playing an important role in promoting eutrophication in reservoirs.

Herbivorous fish, such as *Ctenopharyngodon idellu*, are typically large aquatic plant feeding fish. Large aquatic plants have important functions in the structure of the aquatic ecosystem. First, large aquatic plants and phytoplankton are the main primary producers in ecosystems. They are in competition for sunlight, nutrients, and space, and mutually inhibit each other. Second, large aquatic plants are the habitat and the feeding and spawning places for zoobenthos. With their reduction, some types of macroinvertebrates decrease in number as well. Third, large aquatic plants can absorb nutrients and degrade harmful substances, which is a means of purifying water (McLachlan 1969). Therefore, when food intake of herbivorous fish is much more than the regenerated yield of large aquatic plants, some aquatic plant species decrease and even go extinct, leading to the poor self-purification capacity of the reservoir, and causing nitrogen, phosphorus, and other nutrients fixed by large aquatic plants to be re-released to the water, which accelerates water quality deterioration.

Because of the uneven vertical distribution of nutrients in a reservoir, the growth of plankton communities is usually restricted. The third type of fish, omnivorous or moderately carnivorous fish such as *Cyprinus carpio*, can contribute to the mixture of the photosynthesis and decomposition layers, supplementing the nutrients at the bottom. Meanwhile, the activities of fish (such as foraging) stir sediments and make the sediment-water interface active, causing re-suspension of nutrients in sediments and release to the water at last (Lazzaro et al. 2003; Beklioglu et al. 2003; Kairesalo et al. 1999). Digestive activity of the fish release nutrients directly into the water, causing nitrogen and phosphorus content to increase.

4 Pollution prevention and control measures

4.1 Strengthening management of intensive ponds

Daily bait feeding amounts are determined on the basis of nutrient demand in different growth stages of the fish and pearl mussels in the intensive ponds to avoid the dissolving of excess material in water, which causes water pollution. Also, the outflow water from the ponds may be introduced to irrigate the nearby fields in order to avoid direct discharge into the reservoir.

4.2 Reducing fence aquaculture

Reduction of fish production by fence aquaculture and strict control of the feeding amount are the main methods of minimizing the pollutants. The natural breeding is a good choice to make full use of plankton bait and organic debris in the reservoir. Silver carp and bighead carp are filter-feeding fish, and can improve the reservoir water quality by capturing phytoplankton and zooplankton in the case of no exogenous feeding bait. The natural breeding of fish can reduce a large amount of the feed cost, and generate green products.

4.3 Promoting ecological cultivation

Farming structures need to be optimized to enhance the self-purifying capability and to improve water quality. The optimization methods are to control the fish community by stocking filter-feeding and carnivorous fish, as well as to reduce zooplankton and omnivorous fish in the reservoir to reduce or eliminate the adverse effects of aquaculture on the aquatic environment and to enhance the culture capacity. Advanced aquatic plants are chosen for planting around the fence to absorb the excess nutrients and reduce aquatic environmental pollution.

5 Conclusions

Through the analysis and calculation of monitoring data from the Fangbian Reservoir, potential relationships between aquaculture and eutrophication were found, which would be applied in most lakes and reservoirs of China.

(1) Of all the pollution sources, aquaculture is one of the main reasons for the high level of nutrients. Nitrogen and phosphorus discharged into the Fangbian Reservoir were 103 604 kg and 19 909 kg each year from 2007 to 2009, respectively, exceeding the reservoir environmental capacity. Those from aquaculture account for 44.09% and 56.79% of the total pollutants, meaning that casting bait for aquaculture pollutes the reservoir and upsets the ecological balance.

(2) Aquaculture accelerates eutrophication in lakes and reservoirs due to its adverse effects on water quality and the ecosystem. Substantial amounts of exogenous bait used in the process of breeding cause 75% to 80% of nitrogen and 60% to 75% of phosphorus to be discharged into the aquatic environment in the forms of excreta and metabolites, which consume dissolved oxygen and result in the nutrient enrichment of water and sediment. Meanwhile, the large quantity of fish cultured destroys the original ecological balance. Increase in phytoplankton biomass, chlorophyll concentration, and primary productivity promote the process of eutrophication in reservoirs.

(3) In order to protect lake and reservoir environments, certain prevention and control measures should be taken, such as strengthening management of the intensive ponds, reducing fish production by fence aquaculture, and promoting ecological cultivation.

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