Ecological engineering for traditional Chinese agriculture—A case study of Beitang

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A R T I C L E   I N F O

Article history:
Received 23 September 2013
Received in revised form 24 June 2014
Accepted 24 June 2014
Available online 13 August 2014

Keywords:
Beitang
Evolution processes
Ecosystem services
Ecological engineering

A B S T R A C T

Beitang is an ecologically engineered constructed wetland dominated by human activities and is composed of paddy fields, ponds, ditches, courtyards and other related ecological infrastructure with the functions of agricultural production, hydrological regulation, environmental cleanup and ecological agricultural regulation. The history of Beitang extends back more than 2500 years in China, and it plays a very important role in China's agricultural development. This paper first reviews the history of the development of Beitang; then according to the historical structural features of Beitang, it summarizes Beitang as a pond–ditch–courtyard–farmland ecological engineering composed of constructed breakwaters, sluice gates, and water intakes; courtyards; and farmland and irrigation ditches with the functions of water collection, storage and conveyance. Under different terrain conditions, Beitangs exhibit different characteristics. For example, in flat areas featuring a larger pond capacity, longer shoreline and larger area of farmland, a Beitang can serve more rural areas; in hilly areas featuring a smaller pond capacity and smaller area of farmland, ditches serve as a very important structural unit that can connect ponds for water volume regulation between ponds, increase the irrigated area, and achieve gravity irrigation to as great an extent as possible. Moreover, the paper analyzes the hydrological, nutrient cycling and biological processes as well as other ecological processes associated with this type of pond–ditch–courtyard–farmland-system. The paper also proposes five ecosystem services of Beitang: hydrological regulation, ecological purification, soil and water conservation, production functions and biological diversity protection. Finally, the paper analyzes the reasons for the degradation of Beitang over the past 30 years from the perspectives of institutions, management, concepts and technology, and proposes corresponding countermeasures to protect and restore Beitang.

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1. Introduction

The distribution of precipitation in China is regionally and temporally heterogeneous and varies interannually (Deng et al., 2006). At present, China’s agricultural water accounts for 74.3% of the total use of water resources (Su, 2000), and the country faces certain water shortages, constraining the development of agriculture. Over the long-term process of agricultural development, China has regulated the distribution of water resources through the construction of a large number of water conservation projects to meet the demand for agricultural water.

Beitang, a traditional water conservation project, played a very important role in ancient China’s agricultural irrigation. Beitang appeared early in Anhui, and then with the southwards movement of agriculture, the construction of Beitang also drove agricultural development in Jiangsu, Zhejiang and southwestern China. In modern times, with the advancement of technology and the construction of more and more reservoirs, the role of Beitang in irrigation has gradually weakened, and they have been increasingly neglected. Areas that were once Beitang have been occupied by farmland. However, Beitang cannot be replaced by other water conservation projects due to their short irrigation distance, high water delivery efficiency and other advantages.

At present, there are varying degrees of water pollution in most rivers and lakes in China (Wang et al., 2008; Xia et al., 2011). Agricultural nonpoint-source pollution is an important factor for water pollution (Sun et al., 2012; Zhu and Pu, 2004). Given the extensive...
primitive farming methods in China, massive amounts of nitrogen and phosphorus enter the ground and surface water bodies, resulting in eutrophication and an inhospitable environment for the survival of aquatic life (He et al., 1998; Ongley et al., 2010). Studies have found (Mao et al., 2006) that Beitang has a significant impact on the production and migration processes of nonpoint source pollutants. With its stable retention characteristics, Beitang can effectively reduce the output of watershed nonpoint source pollutants.

Beitang is an ecological engineering dominated by human activities and composed of farmland, ponds, ditches, courtyards and other related ecological infrastructure with the functions of agricultural production, hydrological regulation, environmental cleanup and ecological agricultural regulation. Beitangs are primarily distributed south of the Yellow River and are of high significance for maintaining the sustainable development of China’s 2500-year-old agriculture.

2. Historical evolution of Beitang

Beitang was recorded as early as in Part Two of Discourses of Zhou, Chime-bells’ Temperament Recorded in Discourses of States in the Qin Dynasty (21st century BC–221 BC), which noted that “Beitang can store plenty of water”. Ancient Chinese constructed water storage projects were known as Bei, ponds or pools, which were ecologically engineered for water impoundment and constructed on top of natural swamps by means of artificial enclosures. Although their main purpose was water impoundment and storage, these also provided flood and waterlogging protection, production, life, ecology, landscape and other benefits (Yu, 2006). China’s oldest water storage project, Shao Bei, was constructed under the reign of King Zhuang of Chu State during the Spring and Autumn Period (613–591 BC) and was a large-scale water conservation project whose construction had been presided over by Sun Shuao, Prime Minister of Chu State. It is the earliest large embankment irrigation project in China. History books recorded that “Bei has five outlets to collect water from upstream and discharge floods”. With a diameter of approximately 50 km and circumference of 150 km, Shao Bei still irrigates 2700 km² of fields between Pi River and Fei River in the south of Shou County, Anhui Province.

During the agrarian age since Shang Yang’s Reform, the rulers of various periods adopted policies to “emphasize agriculture and restrain commerce”; and thus, irrigation techniques soon developed, and Beitang technology soon flourished. Beitang entered its prime during the Han Dynasty (206 BC–220 AD). For instance, when Beitang peaked in Runan in the Han Dynasty, their water storage capacity reached 150 million m³, far more than the total capacity of all water storage projects in the Zhumadian region in the 1970s.

From the Western Jin Dynasty to the Sui and Tang Dynasties, for political reasons and due to warfare, Beitang gradually began to decline. Despite its slight recovery in the Sui and Tang Dynasties, the scale of Beitangs at that time was far smaller than during the Eastern and Western Han Dynasties (Xu, 1994). In the Qing Dynasty, though water conservation benefits were rarely recorded in historical files, some records still state that Beitang improved the agricultural environment in mountainous regions in Guangzhou and raised the value of the land (Wu, 2011). After the foundation of China P.R., small-scale water conservation projects were vigorously developed, and Beitang construction flourished everywhere. According to statistics in the 1950s, there were 8.3 million Beitangs nationwide with a total irrigated area of 13 million ha, accounting for approximately 39% of the total irrigated area in China. According to statistics in 1980, there were 6.31 million Beitangs, a decrease of 25% compared to the number in 1958. In the 1990s, the number of Beitangs declined sharply due to flood damage and sludge. In Changsha City, for example, more than 2/3 of the ponds fell into disrepair. The overall trend of Beitang has been toward degradation, but Beitang has still been retained in the Yangtze River and Huaihe River Basin region due to the production needs in the rural areas of China.

In the Warring States, Qin and Han Dynasties, most of the Beitang projects were located in the Huaihe River, Hanjiang River Basin, the middle and lower reaches of the Yangtze River and other places. More than 60% of the nearly 200 Beitang projects constructed in the Han Dynasty recorded in Commentary on the Waterways Classic were located in the Yangtze River and Huaihe River Basin region (Hui and Huang, 2007). With the southward development of farming, construction of Beitang extended rapidly from Hanzhong, Nanyang, Runan and other places to the middle and lower reaches of the Yangtze River and regions in the south of the Yangtze River reaching areas on the border of Yunnan. At that time, the majority of Beitangs were small-scale. The Beitang-Paddy Field Model appears in tombs in the south from the Eastern and Western Han Dynasties, and such tombs have been unearthed in Hunan, Hubei, Guangdong, Guangxi, Sichuan, Yunnan, Shanxi and other places. Many Beitangs were also distributed in Taiwan. In the Taoyuan irrigation area, more than 8000 ponds were connected by rivers and ditches, forming an intricate irrigation system with an irrigated area of up to 2.12 million ha². Table 1 shows the known numbers of Beitang built from 206 BC to 2010 AD. From this perspective, Beitang has been applied in more than half the total area of China and plays a very important role in China’s agricultural development.

After continuous adaptation to agricultural production over thousands of years, Beitang has taken the form of a unique, scientific, agriculture-cycling, ecologically engineered constructed wetland under the combined effects of social and economic factors through a series of evolutions. Beitang is a typical natural–economic–social complex system which has great economic, ecological and social benefits.

3. Beitang structure

3.1. Overall structure

Agricultural development in ancient China originated approximately ten thousand years ago. China’s climatic characteristics led to uneven rainfall. To enable the spatial and temporal distribution of water resources to match the demand for food crops, a Beitang-based agricultural production model gradually took shape in the rural areas in the south of the Yellow River. Beitang is a pond–ditch–courtyard–farmland ecological engineering system composed of constructed breakwaters, sluice gates and water intakes; courtyards; farmland and irrigation ditches with the functions of water collection, storage and conveyance (structure shown...
Fig. 1. Diagram of Beitang.

Fig. 2. Lianhu Lake in Danyang (typical historical Beitang).
in Fig. 1). In ancient times, according to the characteristics of the region, Beitangs could be roughly divided into two categories. One was the plain Beitangs, such as Shao Bei in Huainan, HongxiBei in Runan, LiumenBei in Nanyang, Jianhu Lake in Shaoting and Lianhu Lake in Danyang, constructed in the early years (Fig. 2, excerpted from Lianhu Lake Annuals by Li Shixiu in Qing Dynasty). In flat areas featuring a longer dam shoreline, larger storage capacity and larger area of farmland, Beitang could serve more rural areas. Taking Shao Bei in Huainan as an example (605 BC), historical records show that the structure's original area was “60 km in circumference”, and the Bei was said to be able to irrigate 667 km² or 330 km² of farmland. After restoration, the pond now has a dam shoreline of approximately 24 km, covering an area of over 40 km², with a water storage capacity of nearly one hundred million km³ to irrigate nearly 300 km² of farmland. The other category is Beitangs in hilly areas, such as MarenBei in Biyang, Henan, Chengong Pond in Yangzhou and Chishanhua Lake in Jurong, Jiangsu. Beitangs in hilly areas have a relatively smaller capacity and irrigated area. Therefore, ditches are a very important structural unit that can connect Beitangs for water volume regulation between ponds, increase the total irrigated area and achieve gravity irrigation to as great an extent as possible. Taking Chengong Pond in Yangzhou as an example, Volume 7 of LongqingYizheng County Annals states that “Chengong Pond has a circumference of 45,000 m and can impound 36 streams of water.” Chengong Pond can retain and regulate mountain floods, keeping mountain floods in check and serving over 67 km² of farmland.

3.2. Supporting facilities

In the process of Beitang development, the corresponding supporting facilities have also gradually improved, including gates, ditches, waterwheels, dams, etc. Gates are primarily used to control the water level with water retaining and draining functions. Ditches are water delivery facilities, which can increase the irrigated area by connecting Beitangs. Baiqi Ditch, through large-scale renovation and extension, has increased the irrigated area from 47 km² to 400 km². Waterwheels can be driven by hand, foot, cattle, water or wind. The use of waterwheels has increased water harvesting efficiency, especially in low-lying areas with dense water networks. Dams, as water-retaining structures, can be classified into earth dams, rock dams and mixed dams (grass-earth dam) according to the building materials. Ancient people proposed requirements for the cross-section of earth dams long ago in practice. Guanzi’s Thought on Appraising the Terrain proposed that a dam’s cross-section should be trapezoidal in shape “with a smaller upper part and larger lower part”. Records of Examination of Craftsman–Craftsman also stated that the slope must be 1:1.5 to 2:1. The Wu Pond constructed in Shaoting during the Spring and Autumn Period (Fig. 3, excerpted from Chinese Historical Geography).

3.3. Key parameters

Beitang rate refers to the ratio between the pond and paddy fields, which is an important characteristic of Beitang. Chen Fu proposed in his Book on Agriculture that "1300 to 2000 m² out of approximately 6666 m² of farmland needs to be used for water storage", which means that the area of ponds accounts for approximately 20–30% of the farmland area. Chen Fu noted that the irrigation of paddy fields in hilly and high-lying areas requires higher water consumption. The Huainanzi—Shuolin Discourse on Forests written during the Western Han Dynasty stated that “1 ha of ponds can irrigate 4 ha of farmland, but 0.01 ha of ponds is insufficient to irrigate 0.04 ha of farmland due to size differences”. Liang Yin, writing in the Yuan Dynasty, stated that “If 1 m² of 10 m² of farmland is used as a pond for irrigation, the remaining 9 m² of farmland will not suffer drought”. Yu Ru in the Ming Dynasty believed that the proportion of 10% was too low, and advocated that “even if rice crops are growing well, they should be irrigated for 120 days; if only 1 m² of 5 m² is used as ditches for water retention, the water is only enough to ease droughts by half”. In other words, a water retention area of 20% of a given agricultural area can roughly guarantee the water required for irrigation of paddy fields without rainfall for 50 days. A previous study (Mao et al., 2002) focused on the relationship between pond area and rainfall frequency and found that when the rainfall frequency was 10% and retention rate was 90%, the pond area accounted for approximately 26.7% of the watershed area; when the rainfall frequency was 40% and retention rates were 90%, 80% and 50%, the pond areas accounted for 7%, 6% and 4% of the watershed area, respectively, close to the reality, where the actual pond area in the basin accounted for approximately 10% of the total watershed area.

4. Ecological processes

Beitang is a complex social–economic–natural ecosystem. With human involvement, it makes use of the ecological principles of biological symbiosis, energy multi-level transmission and material recycling and regeneration to promote the control of pollutants and achieve the goals of water resource regulation and storage, environmental improvement and productivity enhancement, benefiting both humans and nature. The complex pond–ditch–courtyard–farmland landscape structure in rural areas includes aquatic and, terrestrial ecosystems, as well as a land–lake ecotone. Rural Beitang ecological engineering structures can effectively collect rainfall runoff and farmland drainage, change the spatial and temporal distribution of rainfall, improve crop yields, and also effectively control the migration of nutrients in rural areas and alter the pathways and forms of nutrient migration.
5.1. Hydrological regulation

Beitang changes the spatial and temporal distribution of water volume and runoff in the entire basin (Mao et al., 2003). When rainfall occurs, net rainfall generated after losses due to the retention by courtyards and farmland, depression filling, infiltration, evaporation and other processes, and forms surface runoff on the ground flowing into the pond. The underground portion of such runoff will replenish water shortages in the soil, and part of that becomes underground runoff. When the volume of runoff is less than the remaining capacity of the pond, the runoff will be completely retained by the pond; if it is greater than the remaining capacity, the runoff will flow into the downstream river channels. Beitang increases natural regulation and storage capacities, and changes in the runoff coefficient lead to corresponding changes in the water flow production and convergence processes. Beitang’s interception of stormwater runoff leads to prolonged flood discharge. When the appearance of a flood peak in surrounding rivers in a rural area is delayed, rainwater runoff, peak flow and total flood volume will become smaller, and the flood hydrograph will be flatter than in rural areas without Beitang.

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4.2. Nutrient cycling processes

In the presence of rainfall and human and livestock activities, nutrients are present in the water, soil and sediment and migrate and mutually convert between different systems. During rainfall runoff, nutrients enter Beitang from the courtyards and farmland through ditches along with water, then precipitate from the water. Beitang degrades some of the nutrients through uptake by plants, animals and microorganisms and transports a portion of the nutrients back to farmland through irrigation and sediment fertilization. Ditches also retain and adsorb a portion of the nutrients during migration, and farmlands absorb and adsorb some of the nutrients through crop growth and filtration though farmland soil, respectively; finally, the remaining nutrients go back into the Beitang to achieve the recycling of nutrients in the system.

4.3. Biological processes

In the courtyard, the manure produced by the production of live stock is thrown into Beitang to feed fish; part of the manure can be eaten by the fish directly, whereas part is decomposed by aquatic organisms to generate nutrients, promote phytoplankton growth and generate oxygen through photosynthesis, and increase zoo-plankton reproduction, thereby satisfying the food requirements of various fish. In the farmland, crops are produced through fertilization of the soil with pond sludge. After harvest, some of the straw is returned to the farmland to improve soil structure, cultivate soil fertility and increase crop yields; some of the straw can also be used as feed for livestock and then become manure for the fields, thereby reducing the demand of livestock for food and also improving soil fertility (Fu and Shen, 2007). Rural Beitang ecological engineering can produce chickens, ducks, fish, cattle and sheep by adopting the mode of storing water in ponds, fertilizing soil with pond sludge, feeding livestock with straw and feeding fish with poultry manure through the circulation of materials and energy among straw, poultry manure and pond sludge.

5. Beitang ecological services

5.1. Hydrological regulation

Beitang plays important roles in regulating and storing flood peaks, storing water, regulating river runoff, recharging groundwater and maintaining the regional water balance. Through regulation by Beitang, rainfall runoff can be stored, thereby avoiding floods and ensuring a stable water supply. A study of the Liucha River Basin showed that the water storage capacity of the Beitang ecological projects in the Liucha River Basin was 61.72 million m³, which could effectively regulate the temporal and spatial distribution of water resources in the basin in years of different hydrological conditions and meet the needs for crop growth. A quantitative study of crop water requirements and rainfall runoff showed that Beitangs could effectively retain rainfall runoff to make up for water shortages in the basin by taking advantage of their huge storage capacity, reducing water shortages from 320 mm to 40 mm in average years, from 333 mm to 138 mm in wet years, and from 280 mm to 41 mm in dry years.

The ecological functions of Beitang are also reflected in its role in weakening flood peaks and relieving pressure on downstream river floods. A simulation of the rainfall runoff on July 10, 1991 showed that for 100-year rainfall with a daily rainfall intensity of 141 mm, the runoff peak was reduced from 2.5 to 0.3 m³/s. The Beitangs in the Laodaohe River Basin, Changsha, if operating well, can reduce the Laodaohe flood level by 0.86 m, roughly equivalent to reducing the 100-year floodplain to below the 50-year floodplain.

5.2. Ecological cleanup

Beitang is a unique soil–plant–microorganism–animal ecosystem often composed of soil and aquatic plants, with strong capabilities to degrade and transform pollutants. Through the integrated physical–chemical–biological effects of the ecosystem, Beitang achieves efficient decomposition and purification of pollutants through filtration, adsorption, precipitation and absorption by plants and microbial degradation.

5.2.1. Plant absorption and interception

The aquatic plants in the pond system play a very important role in the control of agricultural non-point source pollution. Plants can remove pollutants both by absorption, as N and P are plant nutrients and can be absorbed by plants directly, and by transporting oxygen through their stems to create an aerobic environment in the root zone, enabling the microbial degradation of pollutants. Moreover, plants can retain a portion of pollutants through physical action. Han and Sun (2007) found a total of approximately eight types of aquatic vegetation in a survey of the Beitang system in small Liuchahe River basins, including emergent plants, floating plants and submerged plants. The study showed that the area of aquatic vegetation only accounted for 1.2% of the area of the Beitang system, and the retention rates of nitrogen and phosphorus non-point source pollution loads by aquatic vegetation were 12.0% and 6.7%, respectively. A study by Zheng and Wang (2009) proved emergent plants effective in the removal of N and P. Ditches can also retain and remove N and P, as N and P migrate through the ditches and are retained by the plants in the ditches during the migration and transformation processes, which ultimately reduces the pollution load into the water body.

5.2.2. Microbial degradation

The microbes in Beitang system provide adequate decomposition for the treatment of sewage and also play a very important role in the treatment of pollutants. Plant roots transport oxygen to the root zone and form an aerobic zone at the root surface, where organic matter can be decomposed by aerobic microorganisms into carbon dioxide (CO₂) and water and ammonia can be nitrified by nitrifying bacteria; the concentration of oxygen in areas further away from the root surface is reduced, but nitrification still occurs. Organic matter is decomposed primarily by denitrifying bacteria,
and nitrogen substances are released into the atmosphere in the form of nitrogen. In the reduced-state area of the root zone, organic matter is decomposed into carbon dioxide and methane by means of anaerobic fermentation and released into the atmosphere (Liang and Hu, 2003). Liang et al. (2002) found that bacteria, fungi and the number of actinomycetes in the matrix are significantly correlated with the Kjeldahl nitrogen (KN) removal rate. The correlation between the number of bacteria and the chemical oxygen demand (COD) removal rate was highly significant; the number of fungi and the COD removal rate were also significantly correlated.

5.2.3. Sediment adsorption

Sediment, as the matrix and carrier of the Beitang system, provides carriers and nutrients for the growth of microorganisms and aquatic plants (Zhang et al., 2012). Sediment in the Beitang system is composed of soil from farmland, naturally formed sediment and other components. Abundant aerobic, anaerobic and facultative microorganisms exist in the sediment, which can all remove organic matter and nitrogen. The sediment has strong adsorption and nitrification effects on ammonia, and the maximum adsorption and nitrification capacities reach approximately 1.3 and 0.15 mg/g (Xu et al., 2007). The sediment also has the ability to remove phosphorus, as it is rich in organic matter with good aggregate structure and strong adsorption, conducive to the adsorption and degradation of phosphorus-containing pollutants; soluble inorganic phosphate can easily undergo adsorption and precipitation reactions with $\text{Al}^{3+}$ and $\text{Fe}^{3+}$ in the sediment to generate low-solubility iron phosphate or aluminum phosphate. The sediment can also remove organic matter (Jiang et al., 2004a). It was found, in an analysis of the spatial and temporal distribution patterns of the concentration of organic matter in ditch wetland water and sediment, in reed and zizania grass wetlands, the organic matter content in the sediment remained high at depths greater than 40 cm, approximately three times the content in farmland soil at the same depth, suggesting that the sediment had a significant accumulation of organic matter. Sediments in Beitang should be regularly dredged and used as farmland fertilizer so that nutrients can be returned to the farmland, rendering them harmless and useful.

5.3. Soil and water conservation

Beitang can improve the role of fields in soil and water conservation, and this role is even more significant in hilly areas. The irrigation of sandy soil, coupled with appropriate farming systems, can improve soil quality. Beitang can impound large amounts of sediment, reduce the flooding flow rate, decrease reservoir sedimentation and extend the service life of reservoirs. Due to the absence of upstream Beitangs, the annual deposition volume of the Yejiao Liberation Reservoir is 800–1000 t, whereas the annual deposition volume of the Sumigou Dadingzi Reservoir is only 600–500 t owing to the presence of upstream systems.

5.4. Biodiversity conservation

Biodiversity refers to the variety and variability of living organisms and the ecological complexes on which their survival relies, including three levels—genetic diversity, species diversity, and ecosystem and landscape diversity. Beitang supports a high degree of biodiversity. Approximately eight types of aquatic vegetation have been found in the Beitang system in the small Luichae River basins, including emergent, floating and submerged plants. Beitang provides necessary habitat, migration, wintering and breeding grounds for waterfowl and also increases the diversity of landscape patterns and landscape patches.

5.5. Production functions

Rural domestic sewage, livestock manure and farmland nutrients flow into Beitangs along with stormwater runoff, and the Beitang retains a portion of the water and nutrients. During the irrigation season, water and nutrients in the water and sediment flow from the Beitang into farmlands through ditches, which is of very important significance for meeting the needs of crops for both water and nutrients, increasing food production, reducing fertilizer use, improving soil fertility and enhancing productivity in rural areas. Beitang can provide a wealth of animal and plant products, such as lotus, fish, shrimp, shellfish, algae and other food; the reeds in Beitang can be used as an important raw material for paper. Anyang City has used abandoned Beitangs as fish nurseries. After years of trials, the fish production amounted to 2.2–2.6 kg/m² and the output value reached 13.4–13.7 Yuan/m².

6. Prospects

Beitang is not only an ecological engineering structure but also a hydraulic engineering structure that provides irrigation, cultural and transportation functions along with the other ecosystem services mentioned earlier. Taking Lianghu Lake as an example, from the late Western Jin Dynasty to the Tang Dynasty, its major function was irrigation, which later switched to transportation. Beitang also has a very important cultural function in terms of Chinese heritage. The construction of Shao Bei, one of the most important ecological engineering structures, was directed by Sun Shuao. To commemorate Sun Shuao, the people built Sungong temple. Ancient monuments in the temple, with valuable information on the water conservation history of Shao Bei, have high and appreciating value as well as calligraphy art.

Beitang played an important role in the development of agriculture in ancient China. It has experienced trends from flourishing to gradual degradation. The historical causes of Beitang degradation include digging for warfare, opening up wastelands for tax increases, opening up farmland by royalties, blockage-induced shrinkage and other factors. In the Three Kingdoms, Cao, Wei and Wu competed for the region in the south of Huaihe River and discharged the water in Juebei to restrain the other parties, which was one example of Beitang abandonment due to warfare (Huang, 2001). In the last 30 years, there have been other causes of Beitang degradation. First, to pursue higher food production, Beitang have been gradually filled to serve as farmlands. Population growth has led to an increasing demand for food. To create more farmland, some ponds have been converted into farmland because of a lack of understanding of the value of Beitang. According to statistics, from 1960 to 2011, China's population nearly doubled. The number of Beitang was 803,000 in the late 1960s, whereas in 1980, the total was only 680,000 in Yangtze-Huaihe area (Jin et al., 2013). As result, the capacity of Beitang was reduced by 100 million m³. The number of Beitang had increased to some degree until recently. Furthermore, in the early 1980s, China began to implement the contracting of production to individual households, which increased the enthusiasm for production in rural areas. Second, conceptually, reservoir-based centralized irrigation has gradually drawn more and more attention with the construction of a large number of reservoirs, whereas the pond–ditch–courtyard–farmland mode of decentralized irrigation was gradually neglected. Since 1949, the government has constructed more than 86,000 reservoirs, which has truncated the water supply to Beitang and led
to a decrease in the number of Beitangs. Taking Lianhu Lake as an example, after years of neglect and silting up, the Beitang gradually degenerated and disappeared. Studies have shown that 62% of the ponds were abandoned due to the neglect of management (Jiang et al., 2004b). Third, as for management, China does not have any dedicated department for the management of Beitang. Finally, agricultural nonpoint-source pollution has also contributed to the degradation of Beitang. Excessive inputs of nitrogen, phosphorus and heavy metals from agricultural fertilizer and pesticide have resulted in damage to the biome, imbalances of material and energy flow, and reductions in ecosystem services.

A major characteristic of modern agriculture is the extensive use of chemical fertilizers and pesticides, and rural non-point-source pollution causes the eutrophication of water bodies. For the control of agricultural non-point-source pollution, natural cleanup and decentralized handling should be used to as great an extent as possible. At present, Beitang systems as an ecological engineering structure feature low handling efficiency and unreasonable planning and cannot fully adapt to the development of modern agriculture. Therefore, in the future, decisions about Beitangs should consider the following recommendations:

(1) Direct the Ministry of Water Resources, in cooperation with the Ministry of Environmental Protection, to manage, supervise and standardize the construction, operation, maintenance of Beitangs and the timely treatment of dangerous Beitangs. They would also be responsible for the proposal of relevant laws and regulations about Beitang protection and utilization, such as “Beitang Safety Management Provisions”, “Beitang Registration Measures”, and “Plan for Beitang Protection”.

(2) Establish a comprehensive monitoring system for Beitangs, including meteorological, hydrological, water quality, aquatic life and soil indicators. Meteorological indicators include temperature, humidity, rainfall, evaporation, etc. Hydrological indicators include water table, annual runoff, water temperature, etc. Water quality indicators include pH, total suspended solids, dissolved oxygen, total nitrogen, total phosphorus, etc. Aquatic life indicators include aquatic plants, aquatic animals, microorganism, etc. Soil indicators include soil type, soil moisture, pH, organic matter, the concentration of each element, etc.

Acknowledgements

This research was financially supported by the National Natural Science Foundation of China (General Program, No. 71273254). We also express our gratitude to the reviewers and editors for their comments on the manuscript.

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