A Case Study on Sustainable Development of Dianchi Lake Wetland

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Abstract This paper begins from the discussion on the definition of urban wetland and then depicts the current situation and problems associated specifically with Chinese urban wetlands. The case study of the Dianchi Lake wetland is introduced to illustrate a successful example of Chinese systematic urban wetland conservation and development. From wetland plants guidance and water quality controls, increasing the self-purifying ability to construction guidance and controls, the paper provides a comprehensive process of urban wetland management. From the case study, this paper discusses the successful experience of wetland conservation and development as well, providing a strong guideline for corresponding cases across China and the world.

Keywords Urban wetland · Conservation and development · China

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1 Introduction

Urban wetland is a new conception which has only undergone systematic research since the end of 1990s. Although there has been no formal definition of urban wetland to date, Yu (2001), Yang (2002), and Sun et al. (2004) all regard it as a transitional ecosystem between land and water located in urban areas, including coastal and estuarine areas, river banks, shallow lakes, water conservation areas, and natural or artificial ponds. Over the last twenty years, research on conservation and the use of urban wetlands has become increasingly important alongside the increase of worldwide concerns over urban problems such as air pollution, flood risks, and ecology unbalance. Jackson (2003) and Ehrenfeld (2000) reported a key function of wetlands among urban ecosystems as restoring water resource, relieving urban hot island effects and providing space for a wide range of animals and plants. Additionally, Boyer and Polasky (2004) and Nassauer (2004) hypothesized that urban wetlands have significant applicability in environmental control and natural disaster prevention, and treated wetlands as a part of the urban ecological infrastructure. Increasingly, nations are realizing the importance of urban wetlands in the construction of ecological cities, resulting in a new swathe of research projects and organizations focused on wetland protection, restoration, and reconstruction.

China joined the 'Ramsar Convention' in 1992, since when the state forestry administration set up the 'Ramsar Compliance Office' to perform wetland conservation and management. Chinese wetlands now account for approximately 66 million hectares, ca. 10 % of worldwide wetlands, and the highest in Asia. The wetlands in China are quite disparate in nature, from temperate to tropical, coastal to landlocked, and sea level to mountainous.

Urban wetland is much vulnerable to violation and inappropriate development due to its proximity to and inclusion in urban areas. The serious degradation of Chinese urban wetlands in recent years has been exacerbated in the following ways:

Firstly, urban wetland areas have been quickly reduced alongside rapid urbanization. Sediment deposition, lake beach reclamation, garbage disposal, and city construction all contributed to wetland transformation. Many studies have shown that curing revetment of rivers, lakes, and wetlands causes detrimental effects (Booth and Reinelt 1993; Arnold and Gibbons 1996). Chinese urban water curing is very common, with a direct consequence of wetland degradation, reducing the ability of environment adjustment and disaster prevention. Since the 1950 in Beijing, for example, the wetland area declined from 2,568.23 km^2 to only 526.38 km^2 in 2009.

Secondly, pollution of urban wetland significantly worsened. Untreated and slightly treated industrial waste and domestic sewage emissions increased each year continuously reducing the natural wetland capacity of self-purification for water. Increase of urban impervious surface and river channelization reduces the purification function of river ecosystem, making the water quality even worse. According to the 'Report on Water Resources in China' (The Ministry of Water Resources of the People's Republic of China 2004), the national industrial wastewater and urban

sewage emissions increased from 62 to 69.3 billion tons from 2000 to 2004, of which 70–80 % is untreated emissions (Ran 2001; Hong 2003).

The third and the final confounding factor has been a lack of research into the supervision and potential protection of urban wetlands in comparison with wetlands as a whole. To date, research has mainly concentrated on urban sewage treatment and there has been a lack of systematic research on urban wetland protection and development. Simultaneously, there is no monitoring, protection, and development mechanisms at a government level, creating a lack of institutional guarantees for the appropriate utilization of urban wetland (Scholz and Xu 2002; Song et al. 2003).

2 Case Study—The Case of the Dianchi Lake Wetland

Dianchi Lake is the largest freshwater lake on the Yunnan–Guizhou plateau in Southwest China, located in the center of the Yunnan province approximately 5 km from the capital city Kunming. Due to the proximity of Kunming city, the lake area is a popular tourist and vacation destination. The basin area of Dianchi Lake is 2,900 km^2, with a water surface area of 300 km^2, a coastline of 163.2 km, and a water capacity of 15.6×10^9 m^3. The Dianchi wetland is one of the most important urban wetlands in South West China in terms of its rich ecological resources and variety of functions.

Over the past 50 years, the Dianchi Lake has experienced a sequence of degradation, treatment, recovery, and development, analogous to that experienced by many Chinese urban wetlands. This work focuses on the successful, comprehensive conservation and restoration of the Dianchi wetland, which can be used as a basis for the comprehensive management of urban wetlands in general.

2.1 Improvement of the Water Quality

Until the 1970s, the major problem affecting the Dianchi Lake was agricultural pollution. This was superseded by industrial pollution following the late 1970s, all due to the rapid development of industry in surrounding towns. Since then, the water quality has continued to drop rapidly, and degraded the whole ecological system in the surrounding environment.

The specific problems faced by the Dianchi wetland are as follows:

2.1.1 Excessive Land Reclamation on Wetland

Excessive farmland reclamation, changing the natural use, and occupying wetland for urban development directly caused the decline of ecological function of the Dianchi wetland. The destruction activities began from 1950s and massively broke

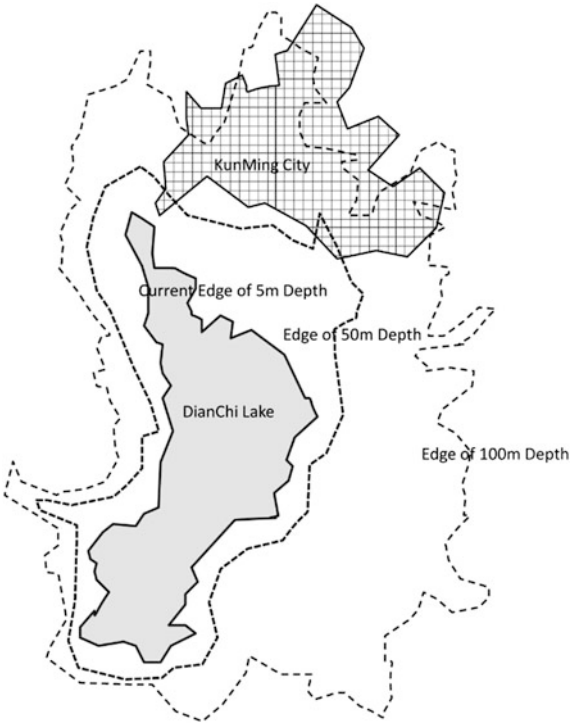

Fig. 1 Map showing the reducing lake area with depth

out after 1990s. On ca. 2000, the lake basins became shallow, water capacity was reduced with many aquatic species, and wildlife habitat sites were destroyed. Then, the water quality deteriorated and outbreak of cyanobacteria was on a massive scale. According to existing research, the purification capability of water depends on the area of the wetlands. Guo and Su (2010) calculated that a lake of 300 km^2 such as Dianchi will need about 2,912–5,814 km^2 wetland to keep its ecology balance. But following the destruction of lakeside, there are only 5,187 ha of natural marshes and only 20,017 ha of aquatic plants remain. The lack of wetland areas not only reduces the purification ability of lake itself, but also seriously influences the surrounding ecological environment.

Based on historical data, the water surface area of the Dianchi Lake is continuously shrinking, and its environmental capacity is also weakening. The Lake was about 1,000 km^2 10,000 years ago, and today, only 300 km^2 remains. Along with the significant reduction in area, the water depth also declined from 100 to 5 m (Fig. 1).

2.1.2 Excessive Destruction of Biological Resources

According to records, aquatic plants in Dianchi Lake were abundant until the 1950s. Vegetation accounted for more than 90 % of the lake, with as many as 100

species of aquatic plants, including 42 submerged species. By the 1970s, there were 46 species of aquatic plants, with a huge reduction in the distribution area from the original 90 to 12.6 %. According to a survey between 1995 and 1997, there remained only 22 species of aquatic plants, with the distribution area rapidly reduced to 1.8 %. Around 2,000, many aquatic plants and wildlife disappeared including Chara, Acuminata, Hydrilla verticillata, Small Carp, and Black Acrossocheilus yunnanensis, and some others reduced drastically (Xiao 2005). The coastal plant zone vanished creating a species imbalance among aquatic plants and causing an outbreak of Cyanobacteria in later years.

2.1.3 Increased Pollution and Water Quality Decline

The pollution to the Dianchi Lake resulting in significant damage mainly comes from the residential sewage of surrounding towns and industrial and agricultural waste water. In 1995, the volume of wastewater discharged into the Dianchi Lake was 1.85×10^8 m^3, among which the total nitrogen was 8,981 ton, total phosphorus was 1,021 ton, and chemical oxygen demand (CODcr) was 41,674 ton. Among the waste, there is 45–58 % of residential sewage and 11–32 % of industrial. In 2000, the wastewater emission had risen to 2.4×10^8 m^3, of which total nitrogen was 14,155 ton, total phosphorus 1,487 ton, and CODcr 62,449 ton. Under normal circumstances, the Dianchi Lake's environmental capacity for nitrogen, phosphorus, and CODcr is about 4,000, 400 and 11,000 ton, respectively. Such high emissions and rapid growth in pollution made the water quality inferior to the index of national quality standards with over 70 % of water areas undergoing eutrophication (Xiao 2005).

2.1.4 The Shortage of Water Resources and the Vicious Cycle of Water Usage

At present, Kunming city on the north shore of the Dianchi Lake covers ca. 180 km^2 with a population of 2 million. The city's expansion not only exacerbated pollution, but also inevitably created a shortage of water resources. The average water resource of Kunming is less than 270 m^3 per person, only equals to 4 % of the world's average rate and 50 % of the UN water standard rate.

To solve the problem of water shortage, in recent years, the local government has constructed a number of utilization facilities within the Dianchi Lake Basin. Eight large and medium-sized reservoirs have been built with a total capacity of 3.4×10^8 m^3, combined with nearly 140 small reservoirs with a total capacity of nearly 1×10^8 m^3. The reservoirs control a 1,651 km^2 runoff area, accounting for 57 % of the basin area. The annual average water supply of the Dianchi Lake Basin is more than 10×10^8 m^3, but according to calculations of surface evaporation and runoff, the actual water resource volume is less than 6×10^8 m^3. That is to say, there

remains a 40 % gap of water needs to be allocated from the outside. This will also instigate negative effects to the ecological environment which in turn will form a vicious cycle.

2.2 Dianchi Wetland Conservation and Restoration

Wetland conservation and restoration includes wetland plants guidance, water quality controls, and increase in the self-purifying ability.

2.2.1 Wetland Plants Guidance

Wetland plants play an important role in Dianchi Lake's ecological environment, with a variety of benefits for recovering wetland functions. So it is emphasized that a wetland plant guide was necessary for Dianchi wetland management. Ornamental plants such as lotus, water lily, hornwort, willow flower, paper grass, Scirpus, Barracuda grass, Canna, water bamboo, and Zhongshan Chinese fir formed a unique wetland landscape. Researchers recommended plants which could thrive in the Dianchi wetland (Chen 2011), and the local authority also published the recommended list of 212 species of plants for the Dianchi Lake Basin (Administration of Kunming Dianchi Lake 2013). Furthermore, during the renovation process of the Dianchi wetland, the authorities put efforts into protecting the native natural plants on the lakeshore and riverside, taking effective measures to implement the growth guide of wetland plants.

Riverside zone vegetation protection and restoration is also an important wetland restoration method. It was recommended to retain the natural shale slope of the rivers without flood discharge usage and to recover the natural curved coastline and gentle slope by planting trees and grass. The floating leaves include Gordon Euryale and grass, while the submerged plants include eel grass, Potamogeton crispus, and Myriophyllum verticillatum, and the floating plants include duckweed and Salvinia natans.

2.2.2 Water Quality Control

One pollution control solution is to build a sewage system surrounding the lake to intercept the discharged waste (Fig. 2). The Dianchi Lake sewage system was divided into four different levels: district sewage, river sewage, rural sewage, and main tube sewage, which all link directly to different disposal stations. The sewage system stopped the polluted water and early rainfall from pouring into the Dianchi Lake. The main sewage canal is about 96 km long and capable of disposing of

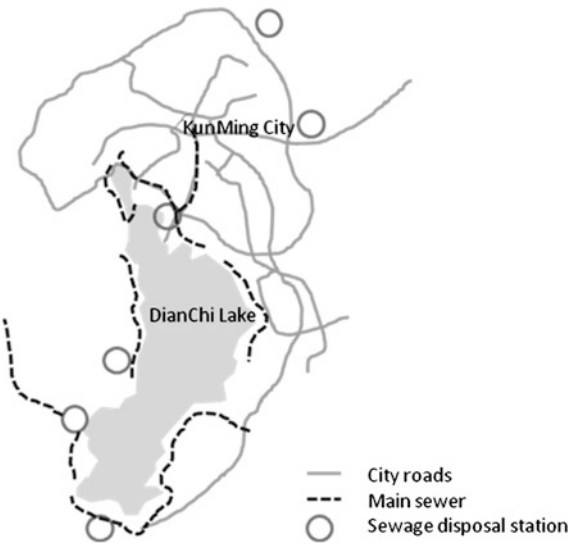

Fig. 2 Main sewage pipes surrounding the Dianchi Lake

172,500 m^3 sewage and 277,500 m^3 of early rainfall per day. The total investment in this system was 5.5 billion RMB (0.8 billion USD), and it was completed by January 2013.

Additionally, several artificial means were used to promote water circulation in order to enhance the water's self-purification ability. One was to pump pure water through plants to various bays. By this means, the water became 'living water' as opposed to 'black water.' An alternative method was to install water-cycling devices into lakes which continuously circulate surface and underlying waters, increasing dissolved oxygen concentrations and avoiding deposition of nutrients. The other method was to set rainwater biological purification canals in east and south shores with rich root plants to absorb suspended solids in intercepted rainfall runoff, before discharge into the lake.

2.2.3 Increase Self-Purifying Ability

To aid the recovery of the lake ecosystem, the authorities dismantled all existing concrete dams, using 1,887.5 m (the normal maximum water elevation) as the scope for ecological restoration. A gentle slope with a tree and shrub belt, an emergent plant belt, and a submerged plant belt was constructed at the land/water interface in order to build a complete ecological system.

According to research, a water flow rate under 0.7 m s^{-1} enhances water interaction with microorganisms and plant substrates for further purification. To reduce the flow rate to this level, the following main three measures were used: Plant species were selected to vary depth and density to form a flow-limiting

barrier; secondly, islands, pools, and beaches were formed, to reduce flow through varying elevation; and thirdly, a circuitous water route was formed to increase the retention time of water in wetlands.

2.3 Construction Guide and Control

Due to the proximity of a large city, the Dianchi wetland not only bears an important ecological function but also accommodates significant leisure and tourism. Therefore, overall planning and control for the future development and construction activities must reflect the natural properties of wetland and follows the principles of feasibility, ecological priority, scarcity, priority, and aesthetics.

2.3.1 Landscape

Due to its proximity to Kunming city, the landscape building around Dianchi Lake was very important. The landscape combined natural and artificial styles for sightseeing and leisure for Kunming's citizens. Thus, at the same time as wetland ecological construction, the authorities must pay attention to combining sewage treatment with natural processes and landscape art, increasing the sustainability of the wetland itself.

2.3.2 Partition and Activity Guidance

The following five partitions and activity controls were dictated by the importance of wetland ecological function:

1. Core wetland conservation area: In this area, all activities were under the strict governance including development, sightseeing, and traffic. Pollution and aquatic breeding control alongside comprehensive management of rural sewage would guarantee the water quality in this area.
2. Ecological buffer area: This area was the buffer zone between conservation and development. Necessary waterflow shelters and wild food supply sites were set up in animal gathering areas, especially for migratory birds, to maintain the open water area and lakeshore grassland and island.
3. Wetland exhibition area: By returning farmland to lakes and reconstruction of wetland vegetation systems to recover wetland ecological function, reduce the water quality pollution by natural wetland purification. At the same time, build wetland landscape and animal habitats.
4. Tourism activity area: This area aimed to provide facilities such as exhibition hall and botanical garden for tourism use. At the same time, opportunities for

close contact between wetlands and tourists were created by water traffic routes, alongside construction of piers, bird-watching facilities, and viewing platforms.
5. Conservative agriculture areas: In this area, the ecological agriculture and fisheries were developed to become a part of experience-based tourism.
6. Tourism service area: Shopping, dining, and entertainment districts for tourism were developed with characteristics of 'Ancient Dianchi' and 'Yunnan' cultures. This area would include an appropriate proportion of residential and resort facilities.

2.3.3 Multi-ring Development

A multi-ring development model was established according to the importance of ecology environment. The inner ring contains the core natural wetland with a complete ecological system (The Primary Grade Conservation Zone according to the 'Dianchi Conservation Regulations of the Yunnan Province') (Yunnan Province Government 2012). The middle ring contains the wetland functional zone for tourism, leisure, exhibitions, new-type rural industry, etc. (The Secondary Grade Conservation Zone Dianchi). The final, outer ring contains the wetland area coordinated with the city construction area (The Tertiary Grade Conservation Zone Dianchi).

Visitors and non-conservation construction activities were forbidden in the Primary and Secondary conservation zones which had great influence on the ecological environment. For development activities in the secondary and tertiary zones to proceed, they must clearly involve 'positive protection' in the form of wetland parks. At the same time, development was guided to reflect the historical and local folk culture, for the purpose of folk culture continuance and educational function.

2.3.4 The Ecological Compensation Mechanism

The wetland ecological compensation mechanism was a coordination mechanism of wetland protection and utilization for stakeholders, comprising of the following two aspects:

The most important was to compensate for the cost of ecological restoration. As the restoration project combined a variety of local authorities like Dianchi Administration Bureau, local communities, and independent firms, the compensation was financed by the provincial government to encourage the ecological restoration. The compensation funds were concentrated on the animal and plant gathering area, important river channels, and main water districts.

The second was to compensate for the local residents for their loss of farmland and chances to do development construction. According to the strict plan, many farmlands would be reclaimed and restored into nature area. Meanwhile, all constructions which do not conform to the ecological protection were determined; thus, the opportunity cost of the residents needs to be compensated.

2.3.5 Establishment of a Dianchi Wetland Conservation and Development Committee

The Dianchi wetland conservation and development committee allows coordination between different administrations and institutions regarding the management of wetland conservation and development. The aims of this body are to do the following:

Integrate existing ecological laws and regulations, and set the lake basin management mechanisms. Formulate unified regulations in Dianchi Lake wetland conservation and restoration by implementation of 'Dianchi Conservation Regulations of the Yunnan Province' and other ecological regulations related to current policy. Expand the management power of the lake basin administrative department and give the corresponding legislative power.

To increase the budget and the ability to use economic means to control and balance the cost between protection and development. To establish collaboration between governmental macroeconomic regulation, democratic consultation, and market-oriented operation with a target of unified management of water resources.

To innovate fiscal and taxation policies, introducing the multi-channel funds into wetland protection and development to overcome the current lack of public investment. Encourage private investment in the ecology via cheap loans, extending maturities, tax returns, accelerated depreciation of fixed assets, and other preferential policies. Meanwhile, to use the ecological capital markets to gather funds, considering the long-term environmental ecological lottery or bonds, or to provide a variety of preferential policies to encourage enterprise to protect the environment.

3 Conclusion

At present, rapid urbanization is occurring in China; this causes urban wetlands to suffer greatly by construction. The natural resources of urban wetlands are decreasing and their ecological function degrading Research concerning China's urban wetland is still in its infancy, exacerbated by a lack of national policy guidance and corresponding management mechanisms for wetland conservation and development. This situation reflects the complexity of Chinese urban wetland management.

From 2010 to 2015, Kunming municipal government plans to invest 42.8 billion RMB (7 billion USD) in the management of the Dianchi Lake wetland. By the end of 2013, the water quality of the Dianchi Lake remained stable with an obvious cessation in the deterioration trend and an improvement in the eutrophic index from severe to moderate. The total phosphorus index of the water dropped by 36.3 %, and the total nitrogen dropped by 34.9 % till 2013. This indicates an obvious improvement in the ecological environment.

The comprehensive management of the Dianchi wetland is typical of multiple cases in China. It covers water area control, water quality improvement, animal and plant guides, pollution control, self-purification control, landscape building,

construction control, capital operation, and many other innovations. These will provide excellent reference for similar urban wetland in China, helping to promote the urban wetland protection and development across China.

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