Application of in-situ restoration combination technique for eutrophic water in Bailuwan Ecological Wetland Park

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Abstract. Bailuwan Ecological Wetland Park with an area of 200 hm², has been the first “National Urban Wetland Park” in Chengdu which is divided into A and B two zones. In zone A, as a window and image representative of the city, 50% recharge water in Daxuanhu Lake comes from Xiaoxuanhu Lake. The water eutrophication was serious with water blooms appeared in Xiaoxuanhu Lake in 2017. In order to repair the eutrophic water body, in-situ ecological restoration combination technology was applied. Thirteen kinds of plants, including submerged water, emergent water and floating leaf together with man-made wetland, submerged macrophyte, ecological floating bed and floating leaf plant were selected to construct as restoration system for Xiaoxuanhu Lake. The results showed that Xiaoxuanhu Lake water quality had improved significantly after restoration. The main physical and chemical indexes were up to the standard of III class of surface water from inferior V in one year’s operation. The annual average concentration of COD\textsubscript{Mn}, TP, TN and NH\textsubscript{3}-N compared with influent decreased 10.4%, 67.7%, 25.1% and 25.6% respectively. The high quality water supply for Daxuanhu Lake was guaranteed in this way. The technique can be used in situ restoration of eutrophic water body in the ecological wetland park and ecological restoration of eutrophic water body in urban rivers and lakes.

1. Introduction
As the “Wet Island” and “Sponge Body” in the city, urban wetland parks (UWPs) were springing up with the continuous improvement of China’s urbanization level, people’s demand for a better life. Twelve batches of fifty-seven national urban wetland parks had been approved and constructed in China [1, 2]. Water eutrophication was a common problem in UWPs because of human activities [2]. A lower degree of landscape change may lead to water quality degradation, and large-scale one may degenerate water quality and damage the aquatic biological community. Thus it will be unable to recover [3].

In China, the improvement and guarantee of water quality of UWPs were mainly realized from four aspects: dredging, sewage interception, water distribution and biological treatment. These remediation technologies can be divided into in-situ and ectopic remediation from the spatial position and mainly in-situ remediation, such as in-situ ecological restoration technology, in-situ bioremediation technology, in-situ fixed chemical restoration and so on. It includes submerged plants [4], constructed wetland [5], ecological floating bed [6], floating plants [7], etc.
Bailuwan Wetland Park (BLWP) had been approved as the first “National Urban Wetland Park” in Chengdu in 2017. A series of large and small landscape lakes as strings of pearls in the park, were inlaid in the ecological belt around the city. In particular, Daxuanhu Lake and Xiaoxuanhu Lake were the images of BLWP endorsement. However, due to the degradation and decomposition of wetland water and plants, the discharge of fish manure, the release of sediment to the overlying water, the entry of tourists’ pollutants and surface runoff lakes water in BLWP were seriously eutrophicated. Water blooms had appeared in Xiaoxuanhu Lake.

In order to repair the eutrophic water body of the wet park, Xiaoxuanhu Lake was selected as the restoration object. Four kinds of in-situ ecological restoration technologies, including artificial wetland, submerged plants, ecological floating bed and floating leaf plant frame, were used to carry out ecological restoration. Thirteen kinds of plants, including submerged water, emergent water and floating leaves, were allocated for ecological restoration, so as to improve the water quality of Xiaoxuanhu Lake, thus providing high-quality supply water for the Daxuanhu Lake.

2. Materials and methods

2.1. Study area
BLWP locates in the Jinjiang ring ecological zone (30°56'-30°57’N, 104°12'-104°14’E) southeast of Chengdu City, Sichuan province. It was divided into two zones A and zone B. Total floor area is 200hm², among which 66.67 hm² is surface water. It is an important part of the overall ecosystem of Jinjiang ring ecological region. It has many functions, such as ecological protection, modern service industry and residence, cultural landscape, infrastructure bearing, urban emergency refuge and so on. Xiaoxuanhu Lake in A zone was selected for ecological restoration.

2.2. Samples and analysis method
Five sampling points were set along the flow direction of Dougou River, and they were Dougou River (1), Xiaoxuanhu Lake (2), Daxianghu Lake (3), Sanjianqiao (4) and Qiyangqiao (5) (Figure 1). Total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH₃-N), permanganate index (CODₘₜₜ), dissolved oxygen (DO) and pH were analyzed according to the methods of monitoring and analysis of water and wastewater (fourth edition) issued by the national environmental protection bureau. The single factor evaluation method was adopted for water quality assessment, and the evaluation standard was carried out according to the corresponding standard of surface water environmental quality standard (GB3838-2002).

![Figure 1. Sampling points in zone A of BLWP.](image)

Note: 1. Dougou River, 2. Xiaoxuanhu lake, 3. Daxianghu lake, 4. Sanjianqiao, 5. Qiyangqiao

2.3. Combination repair technology
The submerged plants, emergent plants and hygrophytes were selected according to the local conditions. Four kinds of in-situ restoration combined technologies of submerged plants (underwater
lawn), constructed wetland, floating leaf plant frame and ecological floating bed were adopted to improve the conditions of microbial growth. Among the in-situ ecological restoration technologies applied, the ecological floating bed technology was a patented one invented by the state. 20m² floating bed was assembled and installed to further improve the quality of make-up water.

2.4. Plant configuration
Thirteen kinds of plants were selected for combination configuration in the restoration of Xiaoxuanhu lake. The types, names, allocating area and density of those plants were listed in Table 1. The floor plan of plant planting and proportion showed in Figure 2 and Figure 3.

| List | Kind | Plant name | planting area /m² | planting density |
|------|------|------------|-------------------|-----------------|
| 1    | Floating leaf plants | Nymphaea L. | 95.2 | 2 plant /m² |
| 2    | Floating leaf plants | Nymphoides peltatum (Gmel.) O. Kuntze | 52.0 | 5 plant /m² |
| 3    | Floating leaf plants | Trapa bispinosa Roxb. | 46.4 | PVC Planting frame |
| 4    | Submerged macrophytes | Vallisneria spinulosa S. Z. Yan | 987.2 | 25 clumps/m² |
| 5    | Submerged macrophytes | Hydrilla verticillata | 200.9 | 20 clumps/m² |
| 6    | Emergent plant | Sagittaria L. | 87.5 | 30 clumps/m² |
| 7    | Emergent plant | Hydrocotyle vulgaris | 47.3 | 18 clumps/m² |
| 8    | Emergent plant | Iris tectorum Maxim. | 39.0 | 20 clumps/m² |
| 9    | Emergent plant | Pontederia cordata L. | 50.9 | 25 clumps/m² |
| 10   | Emergent plant | Thalia dealbata Fraser | 68.6 | 30 clumps/m² |
| 11   | Emergent plant | Scirpus validus Vahl | 39.0 | 30 clumps/m² |
| 12   | Emergent plant (floating bed) | Cannaglauca | 10.0 | 8 clumps/m² |
| 13   | Emergent plant (floating bed) | Iris tectorum Maxim. | 10.0 | 8 clumps/m² |
| 14   | Submerged macrophytes (floating bed) | Myriophyllum L. | 10.0 | 5 plant /m² |

Figure 2. Floor plan of plant planting in Xiaoxuanhu Lake.

Figure 3. Proportion of plant cultivation.

3. Results

3.1. Water quality investigation and evaluation results in zone A
The water quality survey and evaluation results of each sampling point from March to May in 2017 in zone A were listed in Table 2 and Table 3.

The results showed that the source of water from the Dougou river was so poor that the water color was gray and black and there was a large number of bubbles floating on the water surface. The water
body in the BLWP was poor in overall sense, especially in Xiaoxuanhu lake and Daxuanhu lake. There was a large number of algae growing. There were more suspended solid, and water colour was green and dark gray. It can be seen from Table 3 that 65% of TP, TN, NH$_3$-N and COD$_{Mn}$ in zone A did not meet the water quality standard of class V except DO and 20% fell to class V, 10% to class IV and 5% to class III.

The water quality of Daxuanhu Lake and Xiaoxuanhu Lake were worse. 70% of TP, TN, NH$_3$-N and COD$_{Mn}$ did not meet the class V water quality standard, 10% fell to class V and only 10% to class IV. Among them, the indexes of TN, TP, NH$_3$-N in Xiaoxuanhu lake and TN, TP and COD$_{Mn}$ of Daxuanhu Lake were all inferior to class V according to comprehensive evaluation. The main pollutants were TN, TP and COD$_{Mn}$.

Table 2. Statistics of main water quality indicators.

| Sample | TP (mg/L) | TN (mg/L) | NH$_3$-N (mg/L) | COD$_{Mn}$ (mg/L) | Turb (NTU) | pH | TDS (mg/L) | Cond (us/cm) | Tem (℃) | DO (mg/L) |
|--------|-----------|-----------|-----------------|-------------------|------------|----|------------|-------------|---------|-----------|
| 1      | 0.485     | 6.500     | 4.947           | 9.92              | 4.06       | 7.82| 52.10      | 104.30      | 17.00   | 5.6       |
| 2      | 0.417     | 6.756     | 4.167           | 10.04             | 6.70       | 8.10| 24.60      | 49.20       | 17.90   | 7.7       |
| 3      | 0.394     | 5.028     | 1.201           | 35.00             | 24.30      | 9.14| 37.40      | 74.90       | 21.40   | 9.2       |
| 4      | 0.210     | 5.889     | 2.181           | 11.36             | 6.00       | 8.52| 24.30      | 48.70       | 20.10   | 8.6       |
| 5      | 0.169     | 3.000     | 0.942           | 12.56             | 10.00      | 8.40| 48.00      | 96.10       | 19.20   | 8.2       |

Table 3. Results of water quality evaluation.

| Sample | TP       | TN        | NH$_3$-N     | COD$_{Mn}$ | DO |
|--------|----------|-----------|--------------|------------|----|
| 1      | Inferior V | Inferior V | Inferior V   | IV         | II |
| 2      | Inferior V | Inferior V | Inferior V   | V          | I  |
| 3      | Inferior V | Inferior V | Inferior V   | IV         | I  |
| 4      | Inferior V | Inferior V | Inferior V   | V          | I  |
| 5      | V         | Inferior V | III          | V          | I  |

3.2. Effect of ecological restoration

The total area of thirteen kinds of plants in Xiaoaxuanlu lake was 1734m$^2$, of which submerged plants accounted for 68.5%, emergent plants for 19.2%, floating leaf plants for 11.2% and floating bed plants for 1.7%. The planting area and planting density of each plant were listed in Table 1. The comparison of the purification effect before and after the restoration was showed in Figure 4-Figure 7. After the restoration, the water quality in four seasons was significantly improved (P< 0.05). The concentrations of nitrogen, phosphorus and organic pollutants in Xiaoaxuanlu Lake were also obviously lower than before.

![Figure 4. Comparison of TP before and after restoration.](image1)

![Figure 5. Comparison of TN before and after restoration.](image2)
4. Discussions

4.1. Location and function of Xiaoxuanhu Lake

The core area of BLWP with an area of 27000 m² belongs to Daxuanhu Lake. The target water quality requirement needs to meet the standard class III and above (GB3838-2002) for a long time. The main water supply for Daxuanhu Lake comes from Xiaoxuanhu Lake (water area 1600 m²) in the northeast of the tourist center. It was connected with the adjacent Daxuanhu Lake through the culvert (Figure 1). The average water depth of the two lakes was 90 cm at the highest water level and 60 cm at the lowest. Due to the serious leakage of Daxuanhu Lake, the surrounding green landscape irrigation water was also depending on it. The daily supply water for Daxuanhu Lake was 2220 m³ to ensure the basic water balance. Although Xiaoxuanhu Lake is smaller than Daxuanhu Lake, it takes responsibility of more than 50% of the water supply for Daxuanhu Lake. The water quality of Xiaoxuanhu directly affects the water quality and the image of the park.

4.2. Determination of plant species and density

Based on natural rules, In-situ ecological restoration technology aims to restore the balance of water ecosystem and strengthen the self-purification capacity of water body with low costs and no secondary pollution. It emphasizes the purification effect of water quality and creates harmonious landscape effect. It has strong adaptability and shocking resistance, and it was a hot spot and key point in the research of eutrophic water restoration [8,9].

Aquatic plants play an important role in ecological restoration by degrading and transforming organic pollutants in water body through absorption and adsorption of plants. Besides, aquatic plants also provide places and food for the survival and reproduction of other organisms as the main members of aquatic ecosystem. The plant selection is based on the regional status and function, plant adaptability, purification function and ornamental value, so as to adapt to the local climate and strong water purification function of Chengdu. The collocation of cold and warm seasons is taken into account and different varieties are mixed in different areas to configure plants with good landscape effect.

According to the water quality data and the dynamic model of submerged plants, pioneer species and pollution tolerant submerged plants were configured, and then submerged plants, emergent plants and floating leaf plants with good landscape characteristics were planted in Chengdu.

Because of the shallow water depth in Xiaoxuanhu Lake, dwarf Vallisneria angustifolia, which can tolerate the growth of shallow water and have good landscape effect, was selected. Since the Dwarfing submerged plants occupy less space and do not affect the light passing through the water surface, the increase of the number of submerged plants can highlight the effective use of light in the space. The water quality of submerged plants in the treatment of lake and reservoir eutrophication can be improved because of the strong stress resistance caused by longer root growth [10]. Perennial varieties
of aquatic plants were chosen and more than 60% winter low-temperature evergreen varieties were allocated. The selected plants are different on suitable growing water depth. For example, the effective depth of floating plants should be 0.4~0.5 m, the emergent plants should be 0.4 m and the submerged plants should be 0.5~2 m.

4.3. Comparison of repair effect

It can be seen from Figure 4 to Figure 7 (one-year water quality monitoring) that the water quality of Xiaoxuanhu Lake had been significantly improved after in-situ combined technology restoration. The main physical and chemical indexes were improved from inferior V to class III. The annual average purification effect of TP, TN, NH$_3$-N and COD$_{Mn}$ increased by 67.7%, 25.1%, 25.6% and 10.4% than those of Xiaoxuanhu inlet, respectively. The concentration of each index decreased from 0.42 mg/L, 6.76 mg/L, 4.17 mg/L and 10.04 mg/L to 0.13 mg/L, 0.60 mg/L, 0.40 mg/L and 4.70 mg/L after restoration on average. The quality of surface water met class III standard and NH$_3$-N class II for a long time.

On the one hand, the reasons for the remarkable improvement of water quality of Xiaoxuanhu Lake relate to the application of in-situ ecological combination technology. It also due to the enhancement of water environment management in the park during the restoration period. The water quality of Xiaoxuanhu inlet reached class V after 2018 and in this way ensured the application effect of ecological restoration combined technology in Xiaoxuanhu Lake.

For Daxuanhu Lake, Xiaoxuanhu Lake not only provided water supply, but also acted as a front-end reservoir. The high-quality make-up water provided by Xiaoxuanhu Lake ensured the normal operation of the water purification facilities of Daxuanhu Lake and stable long-term maintenance of III Class for the surface water.

5. Conclusions

Xiaoxuanhu Lake is one of the landscape lakes in BLWP of Chengdu. Although it is small in zone A, it provides 50% of the water supply for the representative lake of the park. The water quality of the Xiaoxuanhu Lake directly affected that of the park.

The results shown that Xiaoxuanhu Lake has been greatly improved. The purification rates of COD$_{Mn}$, TP, TN and NH$_3$-N were 10.4%, 67.7%, 25.1% and 25.6%, respectively. The main water quality indexes of the lake can meet the class III standard for a long time after restoration, and ammonia nitrogen also meets the class II.

The combination of submerged plant, constructed wetland, floating leaf plant frame and ecological floating bed can be used in the restoration of eutrophic water body and also provide experience and reference for similar problems in other wetland parks and urban rivers.

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References

[1] Ministry of housing and urban rural development [DB/CD]. http://www.mohurd.gov.cn/
[2] Guo Zi-Liang, Zhang Man-Yin, Cui Li-Juan 2018 Current Status and Trends of Development of National Urban Wetland Parks in China[J] Wetland Science & Management 14(01) 42-46
[3] Zhenhuan Liu, Zhengguo Li, Peng Yang, Yanglin Wang 2013 Threshold value of urban landscape components on water quality degradation [J] Acta Zoologica Sinica 33(02) 586-594
[4] Booth D B, Reinelt L E 1993 Consequences of urbanization on aquatic systems—measured effects, degradation thresholds and corrective strategies *Proceedings. Watershed 93* Alexandria: Tetra Tech.

[5] Hailong Gao, Hanfei Cheng, Maohua Zhan, Bingyu Wang 2018 Research progress and Prospect of submerged macrophyte numerical simulation [J] *Environmental science and technology* 41(08) 59-65

[6] Hao Zhang 2018 Study on the Method of Ecological Restoration and Regeneration of Brown Land: A Case Study of Beijing Yuanbo Lake Constructed Wetland [J] *Modern Horticulture* 24 131-132

[7] Yingjie Wu, Luyao Ma, Chen Chen, Maocang Yan, Xiang Zhang, Xueliang Chai, Qiong Wang, Ying Feng 2018 Purification of cultured seawater and increase of prawn yield by Salicornia crassipes ecological floating bed [J] *Acta environmental engineering* 12(12) 3351-3361

[8] Xie Yue 2011 Study on Field Experiment and Mechanism of Eutrophic Landscape Water Restoration using Plants [D] Xi’an University of Architecture and Technology

[9] Lingling Zeng 2014 The Plant Design of Water Ecological Restoration in Xili Reservoir Pre-reservoir [J] *Pearl River* 35(04) 45-46

[10] Xiao-Pei L, Yin-Jiang Z, Yan L I, et al. 2012 Effects of cycocel on the dwarfing characteristics and physiological indices of Vallisneria natans [J] *Chinese Journal of Ecology* 31(10) 2561-2567