Configuration of Submerged Plants for Plain River Networks Based on Transparency Improvement

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Abstract: The configuration of submerged plants plays an important role in the restoration of river networks. In this study, the Sudong River, a typical plain river network in southern China, was selected for submerged plant configuration research to improve water transparency. Analysis of historical and field research data of Sudong River showed that most of the water was in a state of eutrophication. The main factors affecting transparency were water temperature, ammonia nitrogen, chlorophyll a, total phosphorus, and permanganate index, which were identified through correlation analysis using SPSS. Submerged plants are important for water ecological restoration, and a plant selection evaluation system was constructed to screen six suitable local submerged plants in Suzhou for ecological restoration based on secondary indicators divided into five segments. Each plant was evaluated and scored. Finally, a combination of three submerged plants, Ceratophyllum demersum, Watermifoil, and Foxtail algae, was selected based on their scores. This combination effectively improved the eutrophication status of water and increased water transparency while adhering to the laws of submerged plant succession and facilitating the construction of a stable aquatic ecosystem.

1. Introduction

Transparency is an important indicator in water quality monitoring, which can reflect the light transmission capacity of the water body and intuitively reflect the clarity of the water. It is also a parameter for evaluating the eutrophication level of water bodies [1]. The high and low transparency of water bodies also affects the distribution of submerged plants. The decrease in water transparency can lead to the lack of sunlight for submerged plants, causing their death, and the release of nutrients such as nitrogen and phosphorus enriched in submerged plants into the water body, thereby exacerbating water eutrophication[2]. The study of the spatiotemporal variation of water transparency in rivers and lakes can provide important reference value for water environment and aquatic ecosystem restoration[3]. Domestic and foreign research from the 1970s to the present has shown that transparency is influenced by multiple factors. Suspended particles[4], suspended algae[5], organic matter and other substances change the optical path, reflecting and refracting solar radiation, thereby affecting transparency; the nutrient composition of water such as nitrogen and phosphorus can cause the reproduction of algae in water[6], thereby affecting transparency; environmental factors such as water temperature, wind speed, and flow rate mainly affect the state of the water body, thereby affecting its transparency[7].

Submerged plants play an important role in aquatic ecosystem restoration. In recent years, domestic and foreign scholars have conducted a large amount of research on the use of submerged plants for restoring aquatic ecosystems. Berg et al.[8] found that the cultivation of chara can suppress the re-release of nutrients such as nitrogen and phosphorus in Veluwemmer Lake in the Netherlands, while also increasing lake transparency. Submerged plants have been used for restoration in Trummen Lake in southern Sweden, Lake Boden in Switzerland, and Lake Balaton in Hungary[9], resulting in effective reduction of nitrogen and phosphorus in the water. Although China started its submerged plant restoration efforts slightly later than foreign countries, it has also achieved good results. Wu et al.[10] conducted enclosure experiments in Donghu Lake in Wuhan and restored it by planting nitella, resulting in a reduction of eutrophication level and an increase in transparency. Liu et al.[11] planted submerged plants in Nanhu Lake in Huizhou in 2008, transforming the water from turbid to clear and increasing the transparency from 30cm to 150cm. In 2017, Lu et al.[12] constructed a symbiotic ecosystem consisting of "zooplankton (algal-eating insects)-submerged plants-aquatic animals-microorganisms" in Gucheng Lake in Shijiu Lake, Nanjing, promoting the ecological balance of the lake. In 2022, Wei et al.[13] carried out ecological restoration in Nanhu Lake in Jiaxing, and the main water

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quality indicators have basically reached Class III surface water standards, with water transparencies above 80cm in most parts of the lake.

Against the background of ecological civilization construction, water ecosystem protection and restoration have received increasing attention. Domestic and foreign research on aquatic ecosystem restoration using submerged plants has focused mainly on lakes, with relatively fewer studies on rivers. Sudong River is a typical plain river network located in Suzhou City, with poor water mobility and a tendency towards eutrophication, which poses a high sensory requirement for residents. This study aims to investigate a scheme for the configuration of submerged plants based on improving water transparency in Sudong River, and to provide a reference for the restoration of eutrophic urban rivers in similar plain river network areas.

2 Research Area and Methods

2.1 Overview of Study Area

Sudong River is located in Wuzhong District, Suzhou City, and connects to Taihu Lake and Shihu Lake at both ends, with a total length of 36.2 km and an average water depth of 2.2 m. Sudong River is located in the plain river network area of the Taihu Lake Basin, which is a tributary of the Southern Canal. The climate is subtropical monsoon oceanic, with distinct seasons. The average annual precipitation is around 1100 mm, with an average of 130 rainy days per year.

The areas of the Sudong River mainstream, tributaries, and the surrounding towns of Dongshan, Linhu, Hengjing, and Yuexi have undergone a transformation from rural to urban riverbanks, with the problems of agricultural wastewater, rainwater, and direct discharge into the river.

Sudong River is a flood control channel, and the two ends of the mainstream are controlled by sluice gates. The sluice gates are generally closed except during flood season, resulting in poor water mobility. Most of the riverbank sections are vertical, with restricted connectivity between water and land, and weak self-purification ability of the water body. A national control section, Yuexi Bridge section, is located in the lower reaches of the river, where the water quality indicators comply with Class III surface water standards, as shown in Figure 1.

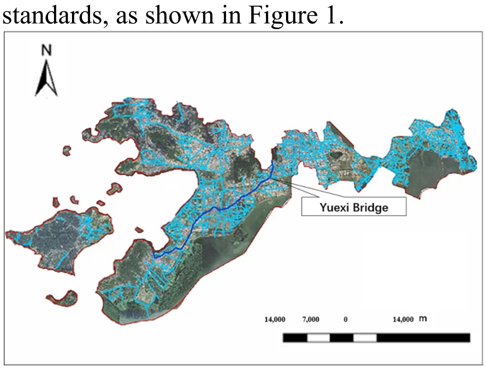

Figure 1. Water system map of Wuzhong District

2.2 Research Methodology

2.2.1 Field Investigation

The data used in this study mainly included: (1) water quality data of the Yuexi Bridge section from 2016 to 2020. (2) Based on factors such as the geographical location of Sudong River, aquatic ecology, and land use type, sampling points were set up from upstream to downstream. In May and July 2021, the research team conducted on-site water quality monitoring at representative sampling points using portable water quality monitors, turbidimeters, and other instruments. The location of the two surveys is shown in Figure 2 and 3, and the second survey locations were adjusted based on the results of the first survey.

Figure 2. Map of Sampling Locations in the First Survey

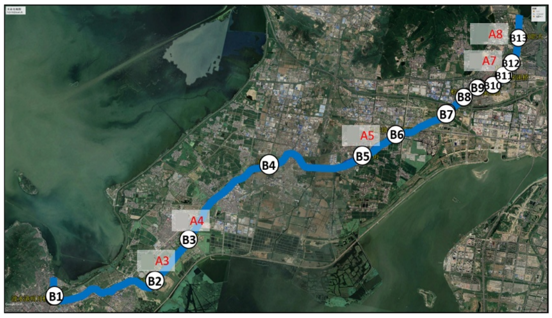

Figure 3. Map of Sampling Locations in the Second Survey

2.2.2 Data Analysis

(1) Comprehensive Nutrient State Index Method

As Sudong River is a closed water body with poor mobility, this study used the Comprehensive Nutrient State Index method to evaluate the eutrophication level of Sudong River at different times and locations. The calculation method of the Comprehensive Nutrient State Index model is as follows:

$$TLI = \sum_{i=1}^{m} W_j TLI_j \tag{1}$$

$$W_j = r_{ij}^2 / \sum_{i=1}^{m} r_{ij}^2 \tag{2}$$

Where: TLI is the Comprehensive Nutrient State Index; W_j is the relevant weight of the nutrient status index of the j parameter; TLI_j is the nutrient status index of the j parameter; r_{ij} is the correlation coefficient between the j parameter and the reference parameter chla; m is the number of evaluation parameters. According to the calculation results of Jin Xiangcan et al. for data from 26 major lakes in China, the correlation coefficients r_{ij} and

r_{ij}^2 between chla and other parameters of Chinese lakes (reservoirs) are shown in Table 1.

Table 1. Correlation between chla and other parameters in Chinese lakes (reservoirs).

Parameter	chla	TP	TN	SD	COD_{Mn}
r_{ij}	1	0.84	0.82	-0.83	0.83
r_{ij}^2	1	0.71	0.67	0.69	0.69

Lake eutrophication status is divided into five grades: oligotrophic (TLI<30), mesotrophic (30≤TLI≤50), mild eutrophication (50<TLI≤60), moderate eutrophication (60<TLI≤70), and severe eutrophication (TLI>70).

(2) "Pearson" Correlation Analysis Method

Using SPSS 26 software, the "Pearson" correlation analysis method was employed to explore the main factors that affect water transparency based on the research data. The Pearson product-moment correlation coefficient is generally used to analyze the relationship between two continuous variables. It is a linear correlation coefficient and its formula is as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2(y_i-\bar{y})^2}} \quad (3)$$

The value range of the correlation coefficient r is -1≤r≤1. When r>0, it indicates a positive correlation; when r<0, it indicates a negative correlation. If |r|=0, there is no linear correlation; if |r|=1, there is perfect linear correlation.

(3) Construction of an Indicator System for Comprehensive Evaluation of Plant Selection

This study combined field surveys, expert consultations, and literature reviews to construct an indicator system for the comprehensive evaluation of plant selection.

① Principles of Indicator System Construction

The principles of constructing an indicator system for the comprehensive evaluation of plant selection include independence, representativeness, feasibility, and simplicity. Independence refers to the clear and relatively independent connotations of the selected plant indicators. The representativeness of the indicators means that the selected plant indicators should have obvious differences and comparability, and can well reflect certain characteristics of the research object. The selection of indicators should conform to objective reality, have stable data sources, and be simple and easy to operate.

② Construction of the Indicator System

The establishment of the indicator system for the comprehensive evaluation of plant selection is a crucial step in selecting submerged plants in the project area. The plant selection should meet four requirements: firstly, it should be able to adapt to the environment of the project area and form a stable community, which provides a good habitat for organisms; secondly, it should be able to purify pollutants in water and improve the quality of the water environment; thirdly, it should take into account the economic benefits of the plants. Therefore, this study constructed the indicator structure system based on three aspects, namely, adaptability, ecological considerations, and economic benefits.

③ Selection of Indicators

According to the above three aspects, seven secondary indicators were established, and the selection of each indicator is shown in Table 2. The primary indicators include "adaptability indicators," "ecological indicators," and "economic indicators." The "adaptability indicators" include two secondary indicators, "adaptation to water depth" and "cold resistance," which reflect the degree to which plants can adapt to water depth and their resistance to cold, respectively. The "ecological indicators" consist of three secondary indicators, including "ammonia nitrogen removal capacity," "total nitrogen removal capacity," and "total phosphorus removal capacity," which measure the ability of submerged plants to remove nutrients from water[14-21]. Lastly, the "economic indicator" relies on the secondary indicator "purchasing and planting cost" to reflect economic considerations.

Table 2. Indicator Selection Table of the Comprehensive Evaluation Indicator System for Plant Selection

Primary Indicators	Adaptability Indicators		Ecological Indicators			Economic Indicators
Secondary Indicators	Appropriate Water Depth	Cold Resistance	Ammonia Nitrogen Removal Capacity	Total Nitrogen Removal Capacity	Total Phosphorus Removal Capacity	Plant Purchase Cost

(4) Determination of Evaluation Factors and Evaluation Levels

As submerged plants need to consider multiple indicators to determine the optimal selection, a rating system is applied to each individual indicator of the plant. Finally, a weighted score is obtained. In the weighting and scoring phase, it was confirmed by the experts that the adaptability indicators account for 50% of the total score, ecological indicators account for 30%, and economic indicators account for 20% of the total score. The evaluation criteria for the corresponding indicators are shown in Table 3, and the corresponding scoring standards are shown in Table 4.

Table 3 Rating evaluation criteria table

Grade	Adaptability Indicators		Ecological Indicators			Economic Indicators
	Appropriate Water Depth	Cold Resistance	Ammonia Nitrogen Removal Capacity	Appropriate Water Depth	Cold Resistance	Ammonia Nitrogen Removal Capacity
Excellent	>2.5m	>0℃	90%	90%	85%	3 rmb/m^2
Good	2-2.5m	>4℃	85%	85%	75%	4 rmb/m^2
Average	1.5-2m	>5℃	80%	80%	70%	5 rmb/m^2
Poor	1-1.5m	>6℃	75%	75%	65%	10rmb/m^2

Inferior	**<1m**	**>8℃**	**70%**	**70%**	**<60%**	**15rmb/m²**

Table 4 Scoring table for grade evaluation standards

Grade	**Excellent**	**Good**	**Average**	**Poor**	**Inferior**
Level Rating	**5**	**4**	**3**	**2**	**1**

(5)Determination of Comprehensive Rating Value

In order to make the final evaluation level more prominent or to avoid the judgment of weights affecting the results and causing the calculation results not to reflect the superiority and inferiority sequence of plants well, the corresponding items of each index are multiplied by their respective values and the products are accumulated to obtain the final comprehensive evaluation score of the scheme. This approach results in a more distinct difference among the obtained results, where the higher the score of the calculated result, the greater the plant's advantage, thus obtaining the optimal plant.

3 Strategies for improving water transparency

3.1 Results of water quality assessment

From 2016 to 2020, the water quality at the Yue Xi Bridge section of Sudong River met the Class III standard on average. The main pollutants exceeding the standard were permanganate index, chemical oxygen demand, five-day biochemical oxygen demand, ammonia nitrogen, and total phosphorus, which exceeded the standard 12 times. In December 2020, ammonia nitrogen was the most serious pollutant, with an exceedance multiple of 2.22 times; followed by chemical oxygen demand in May 2018, with an exceedance multiple of 0.5 times.

In May 2021, the first field survey was conducted, and dissolved oxygen, chemical oxygen demand, total phosphorus, and turbidity were selected for water quality monitoring. All dissolved oxygen contents at the monitoring points met the surface water Class III standard, while all chemical oxygen demands did not meet the standard. The percentage of total phosphorus that met the standard was 62.5%.

In July 2021, the second field survey was conducted, and some adjustments were made to the survey points and water quality monitoring indicators based on the results of the first survey. Five indicators, dissolved oxygen, permanganate index, ammonia nitrogen, total phosphorus, and turbidity, were selected for water quality monitoring. The percentage of dissolved oxygen content that met the surface water Class III standard was 76.9%, the percentage of permanganate index that met the standard was 15.4%, the percentage of ammonia nitrogen that met the standard was 53.8%, and the percentage of total phosphorus that met the standard was 69.2%.

According to historical data and on-site research data, the main pollutants that easily exceeded the standard in Sudong River were chemical oxygen demand, permanganate index, ammonia nitrogen, and total phosphorus. Among them, ammonia nitrogen and total phosphorus were nutrients that easily caused eutrophication of water bodies and led to a decrease in water transparency due to the proliferation of algae.

3.2 Results of eutrophication assessment

Using the comprehensive nutrient status index method, the research sites were evaluated for eutrophication based on the two field surveys. The evaluation results from 2016 to 2017 (Table 5) showed that, except for April and June 2017, the Yue Xi Bridge section was in a state of mild eutrophication throughout the year. The evaluation results from the second field survey in 2021 (Table 6) showed that Sudong River was basically in a eutrophic state, with 53.8% of the sites being moderately eutrophic and 38.4% being mildly eutrophic. Based on the research data and field survey, it can be concluded that Sudong River is basically in a eutrophic state throughout the river, and blue-green algae are prone to outbreaks in summer.

3.3 Analysis of the Influencing Factors of Transparency

The correlation between the transparency of Sudong River and its influencing factors was analyzed using SPSS26, and the factors that have a greater impact on the transparency of Sudong River were identified through correlation analysis.

Based on the analysis of historical data from 2016 to 2017 (Table 5), water temperature was found to be the most significant factor affecting the transparency of the Yuexi Bridge section, with a correlation coefficient of -0.566, showing a negative correlation. As water temperature increased, transparency decreased. Chlorophyll a and total phosphorus were two other main influencing factors.

Table 5 Analysis of the Factors Influencing the Transparency of the Cross Section of Yuexi Bridge from 2016 to 2017

	SD	**Chla**	**v**	**COD_{mn}**	**NH_3-N**	**TP**	**TN**	**Temp**	**DO**
SD	**1**								
Chla	**0.311**	**1**							
v	**-0.168**	**-0.575***	**1**						
COD_{mn}	**-0.042**	**-0.099**	**-0.217**	**1**					

NH_3-N	**0.087**	**0.021**	**-0.485***	**0.207**	**1**				
TP	**-0.295**	**0.055**	**-0.43**	**0.543****	**0.625****	**1**			
TN	**-0.056**	**-0.086**	**-0.041**	**0.123**	**0.643****	**0.455****	**1**		
Temp	**-0.566****	**-0.011**	**0.282**	**0.089**	**-0.305***	**0.044**	**-0.414****	**1**	
DO	**0.281**	**-0.43**	**0.071**	**-0.017**	**-0.164**	**-0.208**	**-0.03**	**-0.503****	**1**

According to the analysis of field research data in the second survey of 2021 (Table 6), ammonia nitrogen was found to be the most significant factor affecting the transparency of Sudong River along the section in 2021, with a correlation coefficient of 0.182. Permanganate index and chlorophyll a were two other main influencing factors.

Table 6 Analysis of the Factors Influencing Transparency of the Sudong River during the Second Survey in 2021

	SD	**Chla**	**COD_{Mn}**	**Temp**	**pH**	**TN**	**TP**	**NH_3-N**	**DO**
SD	**1**								
Chla	**0.127**	**1**							
COD_{Mn}	**-0.144**	**-0.231**	**1**						
Temp	**0.062**	**0.189**	**0.127**	**1**					
pH	**-0.076**	**0.348**	**0.164**	**0.444**	**1**				
TN	**0.042**	**0.558***	**0.017**	**-0.088**	**0.241**	**1**			
TP	**0.072**	**0.41**	**0.451**	**-0.037**	**0.335**	**0.391**	**1**		
NH_3-N	**0.182**	**0.643***	**-0.08**	**0.394**	**0.395**	**0.713****	**0.578***	**1**	
DO	**0.009**	**0.122**	**0.095**	**0.706****	**0.426**	**-0.113**	**-0.209**	**0.063**	**1**

The main factors that affect the transparency of Sudong River are water temperature, ammonia nitrogen, total phosphorus, chlorophyll a, and permanganate index. Therefore, to improve the water transparency of Sudong River, it is necessary to control the nutrient content in the water to inhibit the growth of algae.

3.4 Transparency Improvement Strategies

As analyzed above, the main cause of the decrease in transparency of Sudong River is the excessive nutrients in the water, which leads to excessive growth of phytoplankton and obstructs the transmission of sunlight in the water, resulting in a reduction in water transparency. Therefore, transparency improvement can start from relieving the eutrophication status of the water and reducing the possibility of algal blooms. Traditional physical and chemical methods will greatly damage the existing ecological system in the river and affect the aesthetic of urban rivers. Therefore, natural restoration methods should be chosen to carry out the restoration of aquatic ecosystems. Submerged plants, as a traditional restoration method, have many successful cases in water ecological restoration at home and abroad. Sudong River belongs to the plain river network water system, is controlled by a dam, and has poor water flow. It has some similarities with shallow lakes and is suitable for the use of submerged plants to carry out water ecological restoration.

Submerged plants play an important role in water ecological restoration. There is a competitive relationship between submerged plants and algae. Submerged plants can suppress the growth of algae through competition for light, space, and nutrients, and can release allelochemicals to inhibit the growth of algae[22-23], such as allelochemicals secreted by Ceratophyllum demersum that can effectively inhibit the growth of Microcystis aeruginosa[24-25], thus improving transparency. The growth process of submerged plants has a better removal rate for nitrogen and phosphorus and other eutrophication factors in the water[26-27]. By regularly harvesting submerged plants, a certain amount of nutrients can be removed from the water to achieve true purification of the water and relieve the eutrophication status. Through primary productivity and respiration, the DO content in the water can be increased[28], effectively improving water quality. Submerged plants have an important impact on the water flow rate. Compared with the water without aquatic plants, aquatic plants can change the velocity field of water and create many completely different habitats. When the biomass of aquatic plants increases significantly, water flow resistance increases, water depth increases, and the average flow rate decreases, thereby reducing the intensity of water flow scouring the riverbed, preventing sediment suspension, and improving transparency[29-30]. Submerged plants can provide a habitat and shelter for fish, reduce the turbulence caused by the swimming of fish, and improve water transparency. They are also beneficial to building more complex and stable ecological systems.

4 Analysis of Configuration of Three Submerged Plants

4.1 Succession Regularity of Submerged Plants

In order to ensure the stability of the artificial reproduction ecosystem, ecological restoration of submerged plants should follow the natural succession regularity. As one end of Sudong River connects to Taihu Lake which belongs to the same water body, the succession regularity of submerged plants in Taihu Lake is taken as reference for ecological restoration. In the past 30 years, the succession of submerged plants in Taihu Lake has mainly experienced four stages [31]: the Myriophyllum spicatum-Ceratophyllum demersum stage, the Ceratophyllum demersum stage, the Vallisneria natans - Elodea nuttallii stage, and the Elodea nuttallii-Ceratophyllum demersum stage.

(1) Myriophyllum spicatum-Ceratophyllum demersum

stage: at the beginning of net cage aquaculture in Taihu Lake, the water body was low in eutrophication degree, and submerged vegetation was dominated by Myriophyllum spicatum, Ceratophyllum demersum, and other species of Ceratophyllum, while due to good water quality, the biomass and distribution area of Myriophyllum spicatum were also relatively large.

(2) Ceratophyllum demersum stage: under human intervention for net cage aquaculture in Dongting Lake, Ceratophyllum demersum, which is suitable for still water environment and pollution tolerant, grew in large quantities.

(3) Vallisneria natans - Elodea nuttallii stage: after the introduction of Elodea nuttallii to Taihu Lake, it gradually invaded the Myriophyllum spicatum - Vallisneria natans - Ceratophyllum demersum community, with its distribution area increasing year by year, becoming the main dominant species in Dongting Lake.

(4) Elodea nuttallii-Ceratophyllum demersum stage: in recent years, algal blooms have occurred frequently in Taihu Lake, and submerged vegetation in the western Taihu Lake has completely disappeared. The dominant species of submerged vegetation in Taihu Lake is mainly composed of pollution-tolerant species such as Ceratophyllum demersum.

4.2 Indigenous Submerged Plants in Suzhou

The selection of submerged plant species should be based on local indigenous species, limiting alien species, otherwise it may cause unpredictable ecological imbalances and cultivation difficulties. The selection of species should ensure diversity, and a single species submerged plant community is difficult to maintain normal growth. Through investigations of local submerged plants in Suzhou, the main submerged plants in Taihu Lake were found to include Myriophyllum spicatum, Ceratophyllum demersum, Vallisneria natans, Myriophyllum verticillatum, Potamogeton crispus, Vorticella sp., Anabaena spiroides, Zizania latifolia, Lemna minor, and Microcystis aeruginosa. The main submerged plants in Suzhou's rivers include Ottelia acuminata, Lemna minor, Vorticella sp., Zizania latifolia, Potamogeton crispus, and Ceratophyllum demersum. Due to the simple population structure and nutrient levels in river ecosystems, the minority species such as Ottelia acuminata, Lemna minor and Ceratophyllum demersum are the main dominant species, but they are still relatively scattered and with low coverage, and they are in a clear disadvantageous position in competition with algae.

Six submerged plants commonly used for river treatment were selected from the local submerged plants in Suzhou for comparison. The selection criteria include suitability for water depth, winter temperature, suitable temperature, seeding method, seeding season, total nitrogen removal rate, ammonia nitrogen removal rate, total phosphorus removal rate, lifespan, and planting cost. The survey results are shown in Table 7.

Table 7 Investigation Table of Local Submerged Plants in Suzhou

Name	Suitable Water Depth	Winter Temperature Tolerance	Optimal Temperature Range	Seeding Method	Season for Seeding	Total Nitrogen Removal Rate	Ammonia Nitrogen Removal Rate	Total Phosphorus Removal Rate	Perennial/Annual	Cost
Watermifoil	2-3m	>4℃	15-25℃	Cutting propagation	Spring	87.30%	72.80%	86.80%	Perennial	0.05
Ceratophyllum demersum	0.5-2.5	>4℃	15-20℃	Bud propagation	Autumn	86.90%	90.90%	89.80%	Perennial	0.05
Foxtail algae	0-2.5m	>4℃	16-28℃	Cutting propagation	Year-round	86.00%	89.90%	65.60%	Perennial	0.08
Azolla filiculoides	1-3m	>5℃	20-25℃	Sowing	Autumn	75.60%	86.50%	66.70%	Perennial	0.05
Azolla filiculoides	0-2.5m	>4℃	15-30℃	Cutting propagation	Spring, Summer	86.30%	87.10%	58.50%	Perennial	0.06
Myriophyllum verticillatum	2.5-4m	>0℃	18-22℃	Sowing	Spring	72.70%	76.50%	59.30%	Perennial	0.07

4.3 Configuration Results of Submerged Plants

Using the research methods described above, a comprehensive evaluation index system for submerged plants in Sudong River was constructed, and a scoring table for submerged plant configuration was obtained. The specific calculation results are shown in Table 8.

Table 8 Scoring Table for Submerged Plant Configuration

Name	Adaptability Indicators				Ecological Indicators						Economic Indicators		Total score
	Appropriate Water Depth		Cold Resistance		Ammonia Nitrogen Removal Capacity		Total Nitrogen Removal Capacity		Total Phosphorus Removal Capacity		Plant Purchase Cost		
	Grade	Score	Grade	Score	Grade	Score	Grade	Score	Grade	Score	Grade	Score	
Watermifoil	Excellent	5	Good	4	Good	4	Inferior	1	Excellent	5	Good	4	8.3
Ceratophyllum demersum	Good	4	Good	4	Good	4	Excellent	5	Excellent	5	Excellent	5	9.2

Foxtail algae	**Good**	**4**	**Good**	**4**	**Good**	**4**	**Good**	**4**	**Poor**	**2**	**Poor**	**2**	**7.4**
Azolla filiculoides	**Excellent**	**5**	**Average**	**3**	**Average**	**3**	**Good**	**4**	**Poor**	**2**	**Average**	**3**	**7.3**
Azolla filiculoides	**Good**	**4**	**Good**	**4**	**Good**	**4**	**Good**	**4**	**Inferior**	**1**	**Inferior**	**1**	**6.9**
Myriophyllum verticillatum	**Excellent**	**5**	**Excellent**	**5**	**Poor**	**2**	**Poor**	**2**	**Inferior**	**1**	**Good**	**4**	**7.3**

According to the comprehensive evaluation method for plant selection described above, the total scores of each plant were calculated, and the top three plants with the highest scores were selected: Ceratophyllum demersum, Watermifoil, and Foxtail algae. These three plants are native to Suzhou and meet the planting requirements. Moreover, Ceratophyllum demersum is a winter crop, while Watermifoil and Foxtail algae are summer crops, which can form a natural seasonal alternation and avoid the situation of no plants surviving, thus ensuring the stability and continuity of the aquatic ecosystem. All of the aforementioned submerged plants are perennial, which reduces the cost of annual maintenance and increases the sustainability of the system.

The main varieties of submerged plants in this project are Ceratophyllum demersum, Watermifoil, and Foxtail algae, which are planted at a proportional planting density of 49-128 buds/m² for Ceratophyllum demersum, 3-4 buds/clump for Watermifoil, and 20-30 clumps/m² for Foxtail algae. The project is located 1 km upstream of the Yuexi Bridge section, with a total river length of approximately 3,000 m and a width of approximately 40 m. The total planting area is about 12 ha.

5 Conclusion

Based on the historical data from 2016-2017 and field research data in 2021 along the national control section of Yuexi Bridge in the Sudong River, this study conducted a water environmental evaluation of the Sudong River and identified the main factors affecting its transparency. A plant selection evaluation system was constructed to screen suitable submerged plants for water ecological restoration in the Sudong River. The main conclusions are as follows:

(1) Analysis of historical and longitudinal data shows that the Sudong River is basically in a state of mild eutrophication. The main factors affecting the transparency of the Sudong River are water temperature, ammonia nitrogen, chlorophyll a, total phosphorus, and permanganate index.

(2) Based on the characteristics of local submerged plants in Suzhou and their succession laws, a plant selection evaluation method was established with 3 primary indicators and 7 secondary indicators. The indicator values are divided into 5 segments, and scores are assigned to each indicator based on plant performance. The scores of each plant were calculated through weighted expert scoring, and the targeted submerged plants were Ceratophyllum demersum, Watermifoil, and Foxtail algae.

(3) This paper aims to study the restoration plan of improving water transparency in the Sudong River mainly through submerged plants and provide references for restoring eutrophic urban rivers in similar plain river networks.

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