Correlation study of Submerged Macrophytes Growth and Environmental Factors in Lake Qionghai Wetland

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Abstract. The characteristics of submerged macrophytes communities, water environment factors and substrate environmental factors of Lake Qionghai wetland were investigated in April 2018 by laying out 21 sample points. A total of 8 submerged macrophytes species were recorded in the 21 sample points. Myriophyllum spicatum, Vallisneria natans, Ceratophyllum demersum, and Potamogeton malaianus were the main submerged macrophytes species in Lake Qionghai wetland. The depth of submerged macrophytes was less than 2m, and submerged plants were found in most areas of lakeside zone. Submerged macrophytes had a strong adaptability to substrate, it could grow in artificial stacked group rocks, natural lakeside stone sand, natural alluvial river sand, loess and silt, etc, but the substrate with high nutrition was more favorable to the growth of submerged macrophytes than the substrate with low nutrition. Water nutrients, bottom nutrients and water depth are the decisive factors affecting the growth of submerged macrophytes, while transparency, chemical oxygen demand, light, temperature, water flow and pH are the decisive factors affecting the survival of submerged macrophytes.

1. Introduction
Submerged macrophytes are large aquatic plants that live below the water layer. As a major primary producer of aquatic ecosystems, submerged plants can not only maintain the health of aquatic ecosystems, but also indicate the status of lake waters, which is of great significance for maintaining clear water lakes [1, 2]. Submerged macrophytes can absorb nitrogen and phosphorus and other nutrients in water bodies and sediments, and at the same time promote the deposition of water bodies nutrients salt in sediment, improve water transparency and dissolved oxygen, and provide food, places and other necessary conditions for the formation of complex food chains [3, 4]. At present, more than a third of the world's lakes eutrophication threats we face, and the degradation of lake ecosystems and cause submerged macrophytes species and distribution of reduced, such as East Lake, Taihu Lake, Dianchi Lake in China, Lake Aare in Denmark, Germany northeastern of lake, etc. There are different levels of submerged macrophytes recession and disappearing phenomenon [5-7]. In eutrophication lakes, restoration of submerged macrophytes is a key factor for the reconstruction of aquatic ecosystems [8, 9]. Domestic and foreign scholars have carried out a lot of research on the growth and restoration of submerged macrophytes. Light intensity, nutrient salt, substrate, temperature and water depth are all related to the growth of submerged macrophytes, which together affect the community
composition and distribution of submerged macrophytes [10-12]. Therefore, understanding environmental factors is of great significance to the distribution and growth of submerged macrophytes.

Qionghai is the second largest freshwater lake in Sichuan Province and one of the lakes in the Yunnan-Guizhou Plateau [13]. Since the 1960s, due to man-made damage caused by a large number of reclamation of ponds, reclamation of fields from the sea, disorderly development, etc., the wetland ecological function has been severely damaged, and the water quality was once eutrophic. From 2007 to 2014, the system implemented the ecological management and restoration project of the Qionghai River Basin, which restored the total area of wetlands to more than 20,000 mu. The Qionghai wetland is rich in habitat types, including reservoir pond wetland, River Wetland and lakeside wetland, etc. The environmental factors of the Qionghai wetland are complex and badly affected by external pollution. It is conducive to effective management of Qionghai wetland to understand the basic situation of hydrological and sediment in Qionghai lakeside belt and buffer zone as well as the distribution of submerged macrophytes in the wetland.

In this paper, the submerged macrophytes, water factor and sediment factor of Qionghai wetland were used as the survey object. The canonical correspondence analysis method was used to analyze the environmental factors affecting the distribution of submerged macrophytes, and the key factors affecting the distribution of submerged macrophytes in Qionghai Sea were identified. In order to put forward the wetland submerged plant restoration strategy provides a scientific basis for the restoration of wetland submerged macrophytes and water quality improvement.

2. Research methods

2.1. Sample selection and setting

According to the survey of aquatic vegetation in Qionghai wetland by Yang hong et al. [14], the submerged macrophytes of Qionghai wetland mainly include Myriophyllum spicatum, Vallisneria natans, Ceratophyllum demersum, Potamogeton ispus), and Potamogeton distinctus, Najas marina, etc. According to a comprehensive survey of the distribution of submerged macrophytes in Qionghai wetland in 2017, this paper used the sample points and sample methods to study the relationship between submerged plant growth and environmental factors in the Qionghai wetland in April 2018. A total of 21 samples were set up, as shown in Figure 1.

![Figure 1. Distribution of sampling points.](image_url)
2.2. Sample Collection
Considering that the lakeside zone of the Qionghai wetland is mostly sand and stone, in order to ensure accurate results, grass harrow and artificial launching were used to sample submerged macrophytes in this paper. In the selected sample area, three 1m*1m sample squares are randomly arranged to collect submerged macrophytes and water samples, and the latitude and longitude of each sample point is recorded by GARMIN handheld GPS. Before the collection, the composition of the community was observed by naked eyes, and the initial coverage was recorded. After the plants were collected, first identify the species, and then the plants were separated according to the species. Five plants with complete stems and leaves were selected to determine the plant height, and the coverage was corrected according to the amount of each plant. The underwater 0.5m water sample was collected by the water sampler, and each sample point was sampled for 3 times. After mixing all samples, they were put into sample bottles, concentrated sulfuric acid was added and adjusted to PH≤2.0, and then brought back to the indoor analysis. The matrix is sampled by the grab-type bottom sediment sampler, but because the matrix of some sample points in Qionghai lakeside zone is dominated by stone, the sediment sampler cannot collect samples, and the sediment is separated after collecting the water grass and the type and thickness of the matrix is recorded at the same time of sampling. According to the thickness of the Qionghai wetland matrix, it is divided into 6 grades, the division criteria are: grade 1 0-10cm; grade 2 10-20cm; grade 3 20-30cm; grade 4 30-40cm; grade 5 40-50cm; 50-60cm.

2.3. Sample determination
The water depth and transparency were measured by a water sampler and a black and white transparency disk. The total phosphorus content of the water quality is determined by ammonium molybdate spectrophotometry, the ammonia nitrogen is determined by Nessler's reagent spectrophotometry, and the COD is rapidly digested spectrophotometry. Total phosphorus of matrix nutrients was determined by forest soil phosphorus (LY/T 1232-2015), and the total nitrogen was determined by forest soil nitrogen (LY/T 1228/2015).

2.4. Data Analysis
The environmental factors (water depth, transparency, total phosphorus in water quality, ammonia nitrogen in water quality, matrix thickness, matrix total phosphorus, matrix total nitrogen) and species factors of the Qionghai wetland were collated, sorted by CANOCO for WINDOWS4.5 software, corresponding to analysis and mapping.

3. Results and analysis

3.1. Present distribution of submerged macrophytes
In this paper, 21 samples were laid in the Qionghai wetland, and 8 submerged macrophytes appeared (Table 1). The submerged macrophytes in the Qionghai Wetland are mainly composed of Myriophyllum spicatum, Vallisneria natans, Ceratophyllum demersum, and Potamogeton distinctus. Only a few parts of the sample area are found in Hydrilla verticillata, Potamogeton ispus, Najas marina, Potamogeton pectinatus, and so on. And Potamogeton ispus and Najas marina are often companion species of communities, and without any background distribution.

There are 20 sample points of submerged macrophytes distribution among the 21 sample points, and there were no submerged macrophytes distributed in the entrance of Zhujia River. At the time of investigation and sampling in April 2018, the Zhujia River treatment project has been implemented. It is forbidden to directly discharge domestic sewage into Qionghai without environmental protection control. Although the effect of the treatment project is remarkable, due to the short time, the submerged macrophytes in the lakeside zone at the entrance of Zhujia River have not been restored yet. Among them, the Myriophyllum spicatum was distributed in 18 samples, but there are 5 samples of abundance with less, only distributed sporadically, with the coverage of less than 5%. Except that there are more blank areas in the northern Dream Search Flower Sea, other areas are visible. In
addition, the bottom quality of the silt, sediment, and raw soil is larger than that of sandstone and river sand. For example, the coverage and plant height of the Myriophyllum spicatum in the artificial wetland of the bird-watching island are higher than that of the lakeside. The Vallisneria natans is distributed in 15 samples, and 13 samples have coverage of more than 5%. The west is distributed more and grows better, and the north is less distributed. The Ceratophyllum demersum are distributed in 7 samples, and the coverage of 3 samples is more than 5%. They were mostly distributed in artificial wetlands and less in lakeside zones, and only distributed in some lake estuaries or lake bays. The Potamogeton distinctus are distributed in 6 samples, and 4 samples have coverage of more than 5%. It is mainly distributed in Xincun to goose palm river estuary and small fishing village area. The Hydrilla verticillata are distributed in 4 samples, only the rivers in Baiyue Hotel, Qionghai Bay are background distributed, mainly distributed in artificial wetlands, into the lake estuary or lake bay. The Potamogeton ispus are distributed in 4 samples, and 2 samples have coverage of more than 5%, which are mainly distributed in the artificial wetland of Birding Island in the north of the Qionghai Lake. The Najas marina are distributed in 2 samples, but all of them were sporadic and the coverage was less than 5%. The Potamogeton pectinatus are distributed in 1 sample, which are mainly distributed in the small fishing village area.

| Species code | Species name (Latin name) | Appearance of sample points | occurrence-frequency |
|--------------|---------------------------|------------------------------|---------------------|
| sp1          | Myriophyllum spicatum      | P1, P2, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P21 | 85.7% |
| sp2          | Vallisneria natans         | P1, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P16, P17, P18, P21 | 71.4% |
| sp3          | Ceratophyllum demersum      | P2, P3, P4, P7, P14, P18, P19 | 33.3% |
| sp4          | Potamogeton malai anus      | P7, P8, P10, P11, P14, P18 | 28.6% |
| sp5          | Hydrilla verticillata      | P7, P8, P9, P18 | 19.0% |
| sp6          | Potamogeton crispus        | P4, P7, P11, P21 | 19.0% |
| sp7          | Najas marina               | P11, P14 | 9.5% |
| sp8          | Potamogeton pectinatus      | P18 | 4.8% |

3.2. Analysis of characteristics of submerged macrophytes communities

Community diversity studies are often applied to the survey of vegetation in terrestrial ecosystems. In terrestrial ecosystem surveys, herbaceous plants generally observe species composition, coverage, plant height, and abundance, and calculate community diversity index by important values and species numbers, to measure its diversity. In aquatic vegetation, plants are often distributed in clusters, mostly for seed and rhizome reproduction. Especially for submerged macrophytes, plant ramets and branches are very common, which is not conducive to density statistics. Therefore, this paper comprehensively estimates the niche status of submerged macrophytes in water by cover and plant height, and initially measures their community characteristics.

As can be seen from Figure 2, sample point 18 (small fishing village), sample point 8 (the rivers in Baiyue Hotel, Qionghai Bay) and other samples of submerged macrophytes with high coverage, total coverage greater than 100%; Sample point 5 (bird-watching island wetland lakeside zone), sample point 1 (dreamwater township wetland lakeside zone), sample point 17 (large fishing village) and other samples of submerged macrophytes have low coverage. Samples point 7 (New village), sample point 18 (small fishing village), sample point 14 (a lake bay in cucumber kiln), sample point 4
(dreamwater township wetland reservoir pond) and other samples of submerged macrophytes have higher plant heights. Sample point 12 (walnut village), sample point 11 (goose river into the lake mouth), sample point 1 (dreamwater township wetland wetland lakeside zone), sample point 16 (view sea stone), sample point 17 (large fishing village) and other samples of the plant height is low. Sample point 8 (the rivers in Baiyue Hotel, Qionghai Bay), sample point 4 (dreamwater township wetland reservoir pond), sample point 18 (small fishing village) and other samples of submerged macrophytes have high spatial niche, sample point 5 (bird-watching island wetland lakeside zone), sample point 17 (large fishing village), sample point 12 (walnut village), sample point 11 (goose river into the lake mouth), sample point 1 (dreamwater township wetland lakeside zone) and other sample s of submerged macrophytes have low spatial niche.

The coverage of submerged vegetation is positively correlated with the number of species, the distribution of species layers, and the degree of plant abundance. Sample point 18 has high transparency, deep water, and the upper layer of the matrix is silt, the lower layer is raw soil, there are 6 plant species distribution, each plant grows vigorously; Sample point 8 water is deep, the matrix silt is thick, the organic matter is high, and background distribution of black algae; Sample point 5 has a large number of Trapa bispinosa, and the sample point 1 has artificially planted (Nelumbo nucifera), the submerged macrophytes has less distribution and low coverage; the sample point 17 has deep water and sediment was hard soil, the transparency is 100%, and there are distribution of Myriophyllum spicatum and Vallisneria natans, but the distribution of Myriophyllum spicatum is very small. It is only distributed in the shallow water area of the lakeshore, and Vallisneria natans is short, about 10-15cm. Plant growth potential such as plant height is closely related to plant biological characteristics, matrix type, structure, nutrient content. Sample point 7, sample point 18, sample point 14, and sample point 4 have silt, deep water, the distribution of high submerged macrophytes including Myriophyllum spicatum, Potamogeton distinctus, Ceratophyllum demersum, Hydrilla verticillata; The sediment of sample point 12, sample point 1, and sample point 16 is stone sand, and the sand layer is shallow, the sediment of sample point 11 is river sand, the plant height is lower, but the root system is extremely developed.

Figure 2. Characteristics of submerged macrophytes communities at sampling points.
3.3. Environmental factor analysis

It can be seen from Table 2 that the sampling point has a water depth ranging from 0.4 to 1.7 m, and except for 5 sample points, namely sample point 3 (the river in the bird watching wetland), sample point 17 (big fishing village), sample point 19 (river in small fishing village), sample point 20 (Zhujia river into the lake mouth) and sample point 21 (Tucheng river into the lake mouth), the other sample points have high transparency and are all clear to the bottom. The characteristics of nitrogen and phosphorus in water are not consistent with those in sediment. Comparing the surface water environment quality standards (GB3838-2002), it can be seen that the total phosphorus, ammonia nitrogen and COD of the water samples in the Qionghai wetland are quite different. For the total phosphorus in water, Sample point 21 (Tucheng river into the lake mouth) is Class IV water; 10 sample points such as sample point 2, sample point 4, sample point 6, sample point 8, sample point 9, sample point 11, sample point 12, sample point 14, sample point 15, and sample point 17 are in surface water class I and Class II. For the water quality ammonia nitrogen, the sample point 19 (small fishing village river), sample point 20 (Zhujia river into the lake mouth), sample point 21 (Tucheng river into the lake mouth) and other misty rain egret continent wetland ammonia nitrogen is high, beyond the surface water environment quality standard (GB3838-2002) worse V limit; Sample point 1 (dreamwater township wetland lakeside zone), sample point 2 and sample point 4 (dreamwater township wetland reservoir pond), sample point 3 (the river in dreamwater township wetland), sample point 9 and sample point 10 (West wave crane shadow wetland lakeside zone) have low ammonia nitrogen, in the surface water class I and II. For chemical oxygen demand COD, sample point 2, sample point 3, sample point 7, sample point 19, and sample point 20 are in surface water type IV or above, 8 samples such as sample point 5, sample point 6, sample point 8, sample point 9, sample 10, sample 11, sample 15, and sample 17 are in surface water class I and class II.

The submerged macrophytes growth matrix resources of the Qionghai wetland are rich in species, which can be grown in artificially stacked group rocks, natural lakeside stone sand, natural alluvial river sand, raw soil and silt. There is a large difference between the total phosphorus and total nitrogen sample points in the Qionghai matrix. The total phosphorus in air-dried samples is 0.113~0.894 g/kg, and the total nitrogen is 0.496~5.59g/kg. In the same area, nutrient salts of the substrate are related to habitat, matrix type, and exogenous nutrient input. The total phosphorus and total nitrogen in different habitats are reservoir pond wetland/inner river> bay>lakeside zone, and the different matrixes are silt>stony sand>river sand, the ones with exogenous pollution are higher than those without exogenous pollution.
### Table 2. Environmental factor characteristics of sampling points.

| Sample point number | Water environment factor | Matrix environmental factor |
|---------------------|--------------------------|-----------------------------|
|                     | Total phosphorus (mg/L)  | Ammonia nitrogen (mg/L)     | COD (mg/L) | Water depth (cm) | Transparency (cm) | Type | Thickness level | Total phosphorus (g/kg) | Total nitrogen (g/kg) |
| 1                   | 0.170                    | 0.062                       | 20.111     | 50              | 50               | Stone soil | 1               | 0.467                  | 2.43                   |
| 2                   | 0.057                    | 0.06                        | 66.222     | 60              | 60               | silt       | 3               | 0.778                  | 3.88                   |
| 3                   | 0.241                    | 0.007                       | 42.333     | 160             | 110              | silt       | 3               | 0.631                  | 4.15                   |
| 4                   | 0.051                    | 0.064                       | 19.000     | 150             | 150              | silt       | 4               | 0.598                  | 3.07                   |
| 5                   | 0.226                    | 0.112                       | 8.444      | 50              | 50               | Stone sand | 1               | 0.567                  | 3.96                   |
| 6                   | 0.033                    | 1.415                       | 7.333      | 80              | 80               | soil       | 1               | 0.283                  | 2.94                   |
| 7                   | 0.265                    | 0.205                       | 40.111     | 125             | 125              | silt soil  | 3               | 0.656                  | 3.00                   |
| 8                   | 0.063                    | 0.792                       | 3.444      | 60              | 60               | silt       | 2               | 0.349                  | 2.34                   |
| 9                   | 0.017                    | 0.015                       | 6.778      | 170             | 170              | Stone sand | 1               | 0.202                  | 5.02                   |
| 10                  | 0.190                    | 0.063                       | 1.222      | 50              | 50               | Stone soil | 2               | 0.667                  | 1.36                   |
| 11                  | 0.015                    | 0.432                       | 10.667     | 50              | 50               | River sand | 4               | 0.432                  | 1.29                   |
| 12                  | 0.122                    | 0.409                       | 19.556     | 50              | 50               | Stone sand | 1               | 0.539                  | 3.73                   |
| 13                  | 0.020                    | 0.368                       | 16.222     | 105             | 105              | Stone sand | 1               | 0.501                  | 1.82                   |
| 14                  | 0.013                    | 0.376                       | 26.222     | 90              | 90               | Stone silt | 1               | 0.565                  | 4.20                   |
| 15                  | 0.099                    | 0.346                       | 6.778      | 110             | 110              | Stone silt | 2               | 0.686                  | 5.59                   |
| 16                  | 0.214                    | 0.366                       | 26.778     | 110             | 110              | Stone soil | 1               | 0.565                  | 3.17                   |
| 17                  | 0.009                    | 0.253                       | 14.556     | 137             | 115              | soil       | 1               | 0.185                  | 1.56                   |
| 18                  | 0.216                    | 0.236                       | 17.889     | 80              | 80               | silt soil  | 3               | 0.627                  | 5.04                   |
| 19                  | 0.263                    | 2.593                       | 34.556     | 70              | 55               | silt soil  | 2               | 0.590                  | 2.31                   |
| 20                  | 0.122                    | 2.034                       | 62.889     | 40              | 40               | silt       | 5               | 0.894                  | 3.80                   |
| 21                  | 0.317                    | 2.081                       | 20.667     | 50              | 40               | silt soil  | 3               | 0.113                  | 0.49                   |

### 3.4. CCA analysis of submerged macrophytes and environmental factors

In order to intuitively reflect the relationship between the growth of different submerged macrophytes and environmental factors, this paper selects the plant species characteristic values, and the environmental factors such as water quality total phosphorus, ammonia nitrogen, water depth, transparency, sediment thickness, total phosphorus, total nitrogen and other seven environmental factor indicators. The detrended-correspondence analysis (DCA) was performed using Canoco 4.5 software (species with elimination frequency of less than 15%). Due to the large difference between the environmental factors nutrient salt and the water depth and transparency data level, the water depth and transparency were treated logarithmically in advance. The DCA analysis results showed that the first axis was 4.152, which was more than 4, that is, the Canonical Correspondence Analysis (CCA) was performed. It can be seen from Table 3 that the correlation between submerged macrophytes and environmental factors in the first order axis reached 0.967, and the correlation between submerged macrophytes and environmental factors in the second order axis reached 0.930, and the correlation between submerged macrophytes and environmental factors in the third order axis reached 0.750, the correlation between submerged macrophytes and environmental factors in the fourth order axis reached 0.363, and the cumulative percentage of four order axis species and environmental variables reached 99.5%. 






Table 3. CCA analysis of statistical information of submerged macrophytes in Lake Qionghai

| Axis | Eigenvalues | Correlation between submerged macrophytes and environmental factors | Cumulative percentage of species variables | Cumulative percentage of species and environmental variables |
|------|-------------|---------------------------------------------------------------|------------------------------------------|----------------------------------------------------------|
| 1    | 0.873       | 0.967                                                         | 27.6                                     | 45.3                                                     |
| 2    | 0.707       | 0.930                                                         | 46.8                                     | 76.9                                                     |
| 3    | 0.395       | 0.750                                                         | 59.3                                     | 97.4                                                     |
| 4    | 0.041       | 0.363                                                         | 60.6                                     | 99.5                                                     |

It can be seen from Figure 3 that there is a significant positive correlation between the broad-spotted Myriophyllum spicatum and the matrix total phosphorus, matrix total nitrogen, water depth and transparency in the Qionghai wetland; Vallisneria natans is positive correlation with total nitrogen of the matrix and a negative correlation with total phosphorus of the matrix; Ceratophyllum demersum is positively correlated with total phosphorus of the matrix, transparency, water depth, water quality ammonia nitrogen, water quality total phosphorus, and negatively correlated with total nitrogen. The growth of Myriophyllum spicatum, Potamogeton distinctus, Hydrilla verticillata and Ceratophyllum demersum was mainly affected by water depth, and the growth of Vallisneria natans was mainly affected by the sediment. At present, the submerged macrophytes in the Qionghai wetland are mainly local species. Although there are differences in the adaptation intervals of the main submerged macrophytes, the water, sediment nutrients and depth are the decisive factors affecting their growth.

Figure 3. CCA ordination diagrams of species-environmental factors in Lake Qionghai.

Note: sTP (total phosphorus in water quality), sNH4 (ammonia nitrogen in water quality), sD (water depth), sT (transparency), Dh (matrix thickness), dTP (matrix total phosphorus), dTN (matrix total nitrogen).
4. Discussion

4.1. Distribution of submerged macrophytes

In this paper, a total of 21 sample points were collected in the study of the relationship between submerged macrophytes and environmental factors in the Qionghai wetland. 8 species of submerged macrophytes were found. It is mainly composed of Myriophyllum spicatum, Vallisneria natans, Ceratophyllum demersum, and Potamogeton distinctus, only a small number of samples appeared Hydrilla verticillata, Potamogeton ispus, Najas marina, Potamogeton pectinatus, and other species, and Potamogeton pectinatus and Najas marina for other community companion species, and no background distribution occurred. Submerged macrophytes are mainly distributed in the water area within 2m near the shore, and most of the points are distributed, indicating that the submerged macrophytes in the Qionghai Sea are widely distributed. However, the submerged macrophytes in the Qionghai Wetland are mainly pollut-resistant species. Compared with the Lugu Lake, the submerged macrophytes do not appear Ottelia acuminata var.crispa, pondweed, Potamogeton filiformis Pers. var. planatus (Y.D.Chen)Q.Y.Li, potamogton lucens, Utricularia aurea [15], but the number and distribution of its species are consistent with the results of the 2009 survey by Yang Hong et al [14]. The spatial distribution of different species in the Qionghai wetland is quite different. The Myriophyllum spicatum and Vallisneria natans are widely distributed in the Qionghai side zone and artificial wetlands; the Ceratophyllum demersum are mainly distributed in the relatively static areas such as in artificial reservoirs, artificial rivers, and estuaries; There is a narrow distribution range of Potamogeton distinctus in Qionghai wetland, but it is not found in the north, the rest are seen. Especially in the small fishing area, the distribution area of Potamogeton distinctus is increasing rapidly year by year. It is recommended to do systematic monitoring research.

The results of the survey indicate that the submerged macrophytes in the Qionghai have strong adaptability to the matrix, and are distributed in artificially stacked group rocks, natural lakeside stone sand, natural alluvial river sands, loess, silt, etc., but the growth characteristics such as their biomass, viability, root system, reproduction are closely related to the matrix, and the matrix with high substrate nutrient is more favorable to the growth of submerged macrophytes than the matrix with lower substrate nutrition. Yan Huimin and other studies have shown that the growth rate, maximum plant height and tiller of Myriophyllum spicatum and Hydrilla verticillata with large proportion of silt are better than the relatively poor sand-based matrix [16]. Li Pengshan and other studies have shown that high substrate nutrient treatment promotes the growth of three submerged macrophytes of Hydrilla verticillata, Vallisneria natans, and Najas marina [17]. Ma Mengjie et al [18] studied that the sediment quality of the silt can significantly increase the plant height and growth rate of Potamogeton distinctus and Hydrilla verticillata. There is a large difference in the total phosphorus and total nitrogen in the sediments of the Qionghai wetland. The total phosphorus in the air-dried samples is 0.113~0.894 g/kg, and the total nitrogen is 0.496~5.59g/kg. In the same area, nutrient salts of the substrate are related to habitat, matrix type, and exogenous nutrient input. The total phosphorus and total nitrogen in different habitats are reservoir wetland/inner river > bay > lakeside zone, and the different substrates are silt > stone sand > river sand, the ones with exogenous pollution are higher than those without exogenous pollution. Therefore, matrix selection and construction are one of the important factors in the restoration and reconstruction of submerged macrophytes.

4.2. Correlation analysis of submerged macrophytes distribution and environmental factors

The survival, growth and reproduction of submerged macrophytes are affected by multiple factors such as light intensity, nutrient salt, sediment, water flow, temperature and pH [10, 19]. Jian Minfei et al [20] studied the correlation between the distribution patterns of submerged macrophytes and water environment factors in typical wetlands of Poyang Lake, indicating that water depth, total phosphorus and dissolved oxygen are the main factors affecting the distribution of submerged macrophytes. Wang Qi et al [21] showed that the distribution pattern of submerged plants and water environment factors in Dianchi Lake showed that total nitrogen, total phosphorus, suspended solids, chemical oxygen demand...
and chlorophyll concentration were the main factors affecting submerged macrophytes species and biomass. Transparency is the main factor affecting the coverage of submerged macrophytes. Potamogeton distinctus and Potamogeton pectinatus are suitable for growth in high nutrient salt environments. Myriophyllum spicatum and Hydrilla verticillata are more tolerant to organic matter and algae. The results of this study indicate that the correlation between different submerged macrophytes and environmental factors is different. Nutrients, sediment nutrients and water depth of water are the decisive factors affecting the growth of submerged macrophytes. Different submerged macrophytes have different adaptability to the environment. The growth volume of Myriophyllum spicatum, Potamogeton distinctus, Hydrilla verticillata, and Ceratophyllum demersum is mainly affected by water depth and is suitable for growing in deep water. The growth of Vallisneria natans is mainly affected by the substrate. The Vallisneria natans can grow under different substrate types, but the growth of the substrate with higher nutrients such as sludge is as large as sample point 18. The Vallisneria natans and the Ceratophyllum demersum have strong adaptability to transparency, and some sample points with low transparency, such as sample point 3, 17 and 19, all have their growth. Song Yuzhi [22] and other studies have shown that submerged macrophytes can significantly improve the N and P cycles of sediments to achieve the purpose of degrading N and P in water. The results of this study indicate that there was no linear correlation between nitrogen and phosphorus nutrient salt and substrate nitrogen and phosphorus in different sample points of water, which may be related to the distribution characteristics of the sample points. The sample points of this survey are all located near the lakeshore and are highly susceptible to external pollution, and the nutrient salt is much higher than the lake area. In addition, the correlation between different species and environmental factors is different. The growth of Myriophyllum spicatum was positively correlated with matrix total phosphorus, matrix total nitrogen, water depth and transparency. Vallisneria natans was positively correlated with matrix total nitrogen and negatively correlated with matrix total phosphorus. Ceratophyllum demersum is positively correlated with matrix total phosphorus, transparency, water depth, water quality ammonia nitrogen, and total phosphorus in water, and negatively correlated with total nitrogen in sediment. It shows that the recovery and reconstruction of submerged macrophytes should be considered in two links. First, the primary condition for restoration and reconstruction is to meet the survival and reproduction of submerged macrophytes populations. Transparency, dissolved oxygen, light, temperature, water flow and pH are important factors to be considered in this process. Second, the environmental conditions to promote the growth of submerged macrophytes should also be considered. The Nutrient salts in sediment and water depth are important factors to be considered in this process, especially the limiting factors in nutrient salts.

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