Canonical correspondence analysis of relationship between characteristics of phytoplankton community and environmental factors in Wolong Lake

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Abstract. For the purpose of exploring the evolution process of aquatic ecosystem in Wolong Lake, the phytoplankton community structure and water quality were surveyed at 20 sampling sites around the lake in April, August and October, 2019. The results showed that Chlorophyta, Cyanophyta and Bacillariophyta accounted for 39.7%, 26.5%, 20.6% of all the species, respectively. The species biodiversity indices (included Shannon-Wiener index, Margalef species richness index and Pielou index) increased first and then decreased from April to October, while the phytoplankton density decreased simultaneously. CCA revealed that pH, Turb, TP, T, NH3-N, CODMn, TDS and TN were the main environmental factors affecting the community structure of phytoplankton in Wolong Lake, among which TP, T and pH had a greater impact on Chlorophyta, Cyanophyta and Bacillariophyta, respectively.

1. Introduction
Wolong Lake is located 1km to the west of Kang Ping County in the north of Liaoning Province, on the south edge of Horqin Sandy Land in Inner Mongolia. It is the largest inland wetland in Liaoning Province. Wolong Lake is a provincial nature reserve based on waterfowl habitat protection and aquatic resources, with a total drainage area of 1592 square kilometers, a water surface area of 60 square kilometers, a maximum storage capacity of nearly 100 million cubic meters, an average depth of 1.5-2 meters, and an average annual temperature of 6.9 degrees Celsius. The inland shallow lake natural wetland ecosystem, which is composed of water surface, swamp, pond, wet grassland and beach, is a typical plain fresh water lake wetland in the north of China, belonging to the first class ecological sensitive zone in China. The characteristics and changing process of Wolong Lake ecosystem have a great impact on aquatic organisms, which leads to the change of the whole food chain structure, thus forming the current ecosystem state of Wolong Lake. The lake has a very important ecological status. It is of great significance to study its ecological change process for the protection of the lake ecosystem [1,2].

Phytoplankton is the primary producer in lake’s ecosystem. The change of biomass and community composition has an impact on the function of water ecosystem. At the same time, the change of community structure and species composition of phytoplankton is also a direct reflection of environmental change. The community structure of phytoplankton in different trophic water bodies has different characteristics. Therefore, the study of phytoplankton is helpful to the evaluation of water
quality and nutritional status. Phytoplankton is also used to establish a biological monitoring system in water quality monitoring, so as to evaluate the water quality. By studying the community characteristics of phytoplankton and the seasonal characteristics of phytoplankton, the water quality of lakes and other water can be evaluated \[^{3,4}\]. This study takes phytoplankton as the research object, analyzes the relationship between the community characteristics of phytoplankton and water environment factors in Wolong Lake, in order to provide basis for monitoring and protection of water ecological environment in Wolong Lake.

2. Materials and methods

2.1. Sampling points and sampling frequency
According to the technical regulations for the design of water quality sampling scheme (HJ 495-2009), the grid method was used to evenly arrange points, and then fine-tuning was carried out according to the water inlet area, water outlet area, lake center area, shallow water area and shore area of Wolong Lake. Finally, 20 sampling points of phytoplankton and water quality are arranged (as shown in Figure 1). Sampling once in each water period (normal flow season, high flow season and low flow season), and sampling three times in April, August and October 2019 respectively, all of which were carried out at the beginning of the month\[^{5}\].

![Fig.1 Sampling sites in the Wolong Lake](image)

2.2. Sample collection and processing
The phytoplankton was sampled according to the observation and analysis of lake ecological investigation. 1000 ml of water sample was taken from 0.5m below the surface of the water surface, fixed with 15 ml of Lugol reagent, and concentrated to 30-50ml after 48 hours in the laboratory. The 0.1ml counting box was used for species identification and density counting. Species identification was referred to the atlas of freshwater microorganism and freshwater algae system, classification and ecology in China.

The water quality parameters such as water temperature (T), pH, conductivity (TDS), dissolved oxygen (DO) were measured on site. In addition, water samples were collected for laboratory analysis. The indicators include total nitrogen(TN), total phosphorus (TP), chemical oxygen demand (CODMn), chlorophyll a (Chla), cyanobacteria (PCY), NH\(_3\)-N, turbidity (Turb), suspended solids (SS), BOD\(_5\), etc. The methods were all in accordance with the water and wastewater monitoring and analysis method (Fourth Edition supplement) \[^{6-8}\].

2.3. Data processing and analysis
The Margalef species richness index (D), Shannon-Wiener index(H) and Pielou index (J) were used to describe the community characteristics of phytoplankton. The calculation formula was as follows:

\[
D = \frac{(S-1)}{\ln N} \\
H = \sum_{i=1}^{S} Pi \times \ln Pi \\
J = \frac{H}{\ln S}
\]

\(^{(1)}\)

\(^{(2)}\)

\(^{(3)}\)
Pi = Ni / N; Pi is the ratio of the density of the i th algae to the total density; Ni is the density of the i th algae; N is the total density; S is the number of phytoplankton.

Excel 2010 software was used for data analysis and SPSS17.0 software was used for variance analysis, and Canoco4.5 software was used for canonical correspondence analysis (CCA) of species and environment. The ranking results were represented by the double-sequence diagram of the relationship between species and environment factors.

3. Results

3.1. Composition of species

A total of 68 genera (species) of phytoplankton were identified in Wolong Lake, belonging to Chlorophyta, Cyanophyta, Bacillariophyta, Euglenophyta, Chrysophyta, Pyrrophyta, Cryptophyta and Xanthophyta. Among them, there are 27 species of Chlorophyta, accounting for 39.7% of the total species, followed by 18 species of Cyanophyta, accounting for 26.5%, 14 species of Bacillariophyta, accounting for 20.6%, 3 species of Euglenophyta, 2 species of Chrysophyta or Pyrrophyta, 1 species of Cryptophyta or Xanthophyta, accounting for 4.4%, 2.9%, 2.9%, 1.5% and 1.5% of the total species, respectively (Figure 2).

![Fig.2 Proportion of phytoplankton composition in the Wolong Lake](image)

The number of phytoplankton species was highest in August (68 species) and lowest in April (42 species). Chlorophyta, Cyanophyta and Bacillariophyta were the highest in August and the lowest in April. The number of Euglenophyta, Chrysophyta, Pyrrophyta, Cryptophyta and Xanthophyta species was small, so the variation between months was minor (Figure 3).

![Fig.3 The temporal variation of phytoplankton species in the Wolong Lake](image)

According to the research, August was more suitable for the survival and reproduction of phytoplankton, and the number of species was higher. The water temperature was relatively low in
April, and the number of phytoplankton species declined because temperature and light were essential for plant growth.

3.2. Spatiotemporal variation of phytoplankton abundance

The abundance of phytoplankton in Wolong lake in different sampling months was shown in Figure 4 and 5.

![Fig.4 Relative abundance of phytoplankton in different month of the Wolong Lake](image)

![Fig.5 Abundance of phytoplankton in different month of the Wolong Lake](image)

The results showed that the relative abundance of Chlorophyta, Cyanophyta and Bacillariophyta in Wolong lake varied greatly from month to month. In August, Cyanophyta was dominated. Combined with the abundance value, it could be seen that the order of the Cyanophyta abundance was August > April > October, the order of the Chlorophyta abundance was April > August > October, and the order of the Bacillariophyta abundance was August > October > April. The analysis suggested that as temperatures dropped, some species of Cyanophyta went into hibernation and sank to the bottom of the lake. The density of Chlorophyta and Bacillariophyta increased in April compared with August and October.

3.3. Variation of planktonic algal diversity

The variation of phytoplankton diversity in Wolong Lake was shown in Table 1.

| Biodiversity index | April    | August   | October  |
|--------------------|----------|----------|----------|
| H                  | 1.63±0.18a | 2.17±0.21b | 1.82±0.36ab |
| D                  | 0.72±0.19a | 1.16±0.15b | 0.92±0.17ab |
| J                  | 0.47±0.24a | 0.83±0.22a | 0.64±0.25a  |

Note: different superscript letters represent significant differences.

It can be seen from Table 1, the diversity index first increased and then decreased, and the variation trend of various indexes was relatively consistent. The results of one-way analysis of variance
(ANOVA) showed that the difference between $H$ value and $D$ value was significant in April or August ($P < 0.05$). The difference of $J$ value between months was not significant.

### 3.4. Relationship between phytoplankton abundance and environmental factors

In order to analyze the response of phytoplankton in Wolong Lake to environmental factors, a CCA analysis was conducted between phytoplankton abundance and water environment indicators (Figure 6). PCY, DO, pH, Chla, COD$_{ Mn }$, NH$_3$-N, TN, TP, Turb, TDS, T, SS, BOD$_5$, a total of 13 indicators.

![Fig.6 CCA biplot of phytoplankton abundance and environmental variables of the Wolong Lake](image)

Cyanophyta was significantly affected by $T$ and positively correlated. Bacillariophyta was positively correlated with pH and Turb. Chlorophyta was positively correlated with Turb and TP. Euglenophyta, Chrysophyta and Cryptophyta were positively correlated with COD, NH$_3$-N and BOD$_5$. Pyrrhophyta and Xanthophyta were significantly correlated with TDS and Chla.

### 4. Discussion and conclusion

Different species of phytoplankton had different responses to the environment and their community structure changes with the seasons. The Cyanophyta dominated the phytoplankton community in Wolong lake in August. In April, the number of phytoplankton species decreased, while the density increased. The species experienced the change of time from winter to spring, and the species that could adapt to the environment occupied the free resource space and multiplied massively. The phytoplankton species in the lake tended to be single. The phytoplankton abundance was related to nitrogen, phosphorus and other nutrients, but the influencing process and mechanism needed to be further studied. The diversity study results were consistent with the change of phytoplankton community characteristics. The species of phytoplankton decreased and the density increased, resulting in uneven population distribution and low diversity index. This study showed that pH, Turb, TP, T, NH$_3$-N, COD, TDS and TN were the main environmental factors affecting phytoplankton growth. Other studies had shown that pH and TP were important factors influencing the distribution pattern of phytoplankton in Bai Yang Dian lake, while transparency and temperature are the main environmental factors influencing the distribution pattern of phytoplankton in the Chang Jiang estuary in summer [9,10].

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