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Relationship between phytoplankton community structure and environmental factors in Yinchuan City water

Jixin Ma

Dalian Ocean University, Dalian, China

ABSTRACT

The freshwater ecosystem, formed through the interaction between biological communities and the environment, serves as a vital resource for sustainable human development. Phytoplankton plays a pivotal role in environmental monitoring and ecological assessment, serving as a biological indicator in water quality assessment. However, the rapid urban development poses a significant threat to aquatic ecosystems, leading to environmental changes that alter phytoplankton community structures and degrade ecosystem functions. The research on the phytoplankton community structure and its correlation with environmental factors in Yinchuan remains insufficient. Therefore, it is imperative for Yinchuan's water ecosystem to comprehensively understand the phytoplankton community structure and identify the driving factors influencing the water ecological environment.A survey of phytoplankton was conducted in 40 stations across the Diannong River Basin, Yuehai Wetland, Baohu Wetland, and Hequanhu Wetland in Yinchuan in April 2023. The results revealed the presence of seven phyla and 211 species of phytoplankton in Yinchuan. Bacillariophyta comprised the majority of observed species, followed by Chlorophyta and Cyanophyta, with a smaller proportion of other species distributed throughout. Key influencing factors included total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH3-N), dissolved oxygen (DO), and transparency (SDD). Significant disparities were noted in both the Simpson index and Pielou's evenness index of the phytoplankton community.

KEYWORDS

Phytoplankton; Community structure; Biodiversity; Environmental factor

1. INTRODUCTION

Water ecosystem refers to the ecosystem composed of aquatic community and environment, which plays a very important role in human living environment[1]. As important aquatic ecosystems, rivers and wetlands support various habitats of different biological communities and play an important role in the global food web, carbon cycle, oxygen release and biogeochemical cycle. Under some conditions, such as artificial nutrient enrichment, nutrient input into river and wetland ecosystems may lead to excessive growth of phytoplankton, which has a serious impact on river and wetland ecosystems, thus leading to changes in phytoplankton community structure and degradation of ecosystem functions. Further worsen water quality and threaten the supply of drinking water [2].

Phytoplankton is the main group of aquatic ecosystem and an important primary producer. It converts solar energy into organic matter through photosynthesis and provides energy for the ecosystem. They are also the main food webs, which play the role of energy flow, material circulation and information transmission to the whole water ecosystem, and have a chain reaction to the productivity and function of the water ecosystem [3]. Phytoplankton is an indicator of water quality. With the influence of climate change and human activities, the species and distribution of phytoplankton also change, which has an impact on the stability of the aquatic ecosystem[4, 5]. Understanding the composition of aquatic ecological phytoplankton community in Yinchuan is very important for the protection and restoration of ecosystem function in this basin.

Environmental factors are closely related to the temporal and spatial distribution of phytoplankton. Hydrological condition is the index of environmental change, and the change of water environment directly or indirectly affects the community structure of phytoplankton. Phytoplankton are particularly sensitive to changes in the biological, physical and chemical characteristics of the aquatic environment. It is found that water temperature, light and nutrients (such as total nitrogen) are important factors affecting the community structure of phytoplankton. For example, differences in light, inorganic carbon and other nutrients in lakes and ponds result in significant differences in species richness and biomass of phytoplankton [6]. Therefore, we can restore the community structure of phytoplankton by adjusting environmental factors, improve the functional structure of the ecosystem and maintain the balance of the ecosystem [7].

Located in Yinchuan City, the Diannong River Basin, Yuehai Wetland, Baohu Wetland and Hequhu Wetland are densely populated and urbanized seriously. Although Yinchuan has made great progress in environmental protection, its aquatic ecosystem is still facing a great threat due to a wide range of human activities and increasingly serious environmental pollution. However, the water ecological monitoring in Yinchuan is still in its infancy, and there are still some deficiencies in the study of the effects of environmental factors on the community structure of phytoplankton in this area. Through the field investigation in the study area, it is proved that the community structure and biodiversity of phytoplankton are closely related to environmental factors such as total nitrogen, ammonia nitrogen, dissolved oxygen and so on.

2. MATERIAL AND METHODS

2.1. Study area

The Diannong River is an artificial river at the summer autonomous district level, flowing through seven counties of Yinchuan City and Shizuishan City in turn, starting from the Xinqiao flood detention area in Yongning County in the south, and converging into Huangkou in the third and fifth drainage ditches in Huinong District, Shizuishan City in the north. The total length of Diannong River is 180.5km, and the watershed area is 4391km2. Along the way, Diannong River connects lake wetlands such as Qizilian Lake, Yuhai Lake and Shahu Lake, and is one of the water-saving social landmark projects in Ningxia, which integrates urban landscape, ecological construction, flood control and flood discharge. This area is located in the arid and semi-arid region of northwest China, with temperate continental climate, less precipitation, strong evaporation and large wind and sand[8]. Yuehai National Wetland Park is located in Jinfeng District, Yinchuan City, with a wetland area of 1934hm2, including water area 1466hm2 and swamp area 468hm2, which is connected with other lakes and marshes through returning farmland to wet and Diannong River. It is an important type of lake in the arid area of northwest China, and it is known as "the kidney of Yinchuan". Abundant water resources, complete aquatic vegetation and complete aquatic biodiversity, as urban wetlands, play an important role in urban biodiversity and ecological environment improvement [9]. Affected by resource exploitation, climate change, farmland drainage and other factors, water quality deteriorates and wetlands shrink frequently [10]. Baohu National Urban Wetland Park is located in Liangtian Town, Yinchuan City, with a total area of 82.6hm2 and a water surface area of 39.2hm2. The area has luxuriant reeds, bird habitat, beautiful natural landscape and good ecological environment. However, with human development and economic development, the wetland has been polluted and infringed, the degree of eutrophication is increasing, the water quality is seriously reduced, and aquatic organisms have also been seriously affected [11]. Hequahu National Wetland Park is located in Yongning County, Yinchuan City, with an area of 200hm2 in high water season and 30hm2 in low water season. Hequahu provides a good habitat for aquatic organisms, which is rich in aquatic plants, phytoplankton and benthos [12]. With the more and more intense human interference, the water resources pollution and habitat environment deterioration of urban river wetlands are becoming more and more serious, so targeted protection and construction is imminent.

2.2. Set the sampling point

A survey and assessment of plankton diversity in the aquatic ecosystem of Yinchuan City were conducted in April 2023, focusing on 40 sampling points along the Diannong River (Yinchuan section), Yuehai Wetland, Baohu Wetland, and Hequanhu Wetland. These sites comprised 21 sampling points along the main channel of the Diannong River (D1-D21), 6 sampling points in Yuehai Wetland (Y1-6), 7 sampling points in Baohu Wetland (B1-7), and 6 sampling points in Hequanhu Wetland (H1-6). The distribution of the survey sites is illustrated in Figure 1.

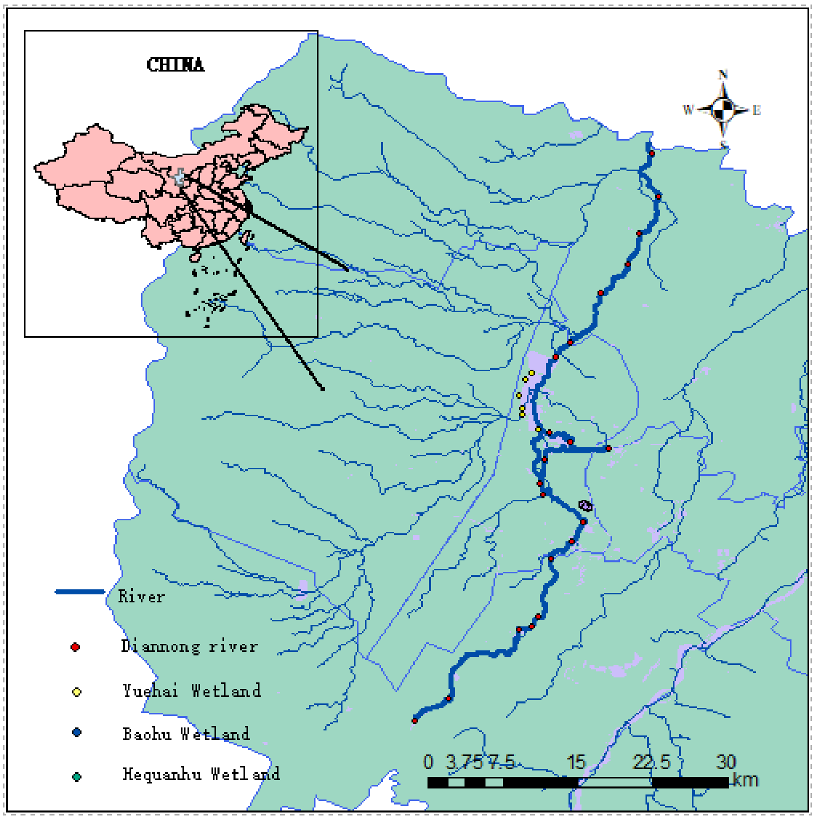

Figure 1. Location map of sample sites

2.3. Sample collection and processing

The determination of water environmental parameters at each sampling site was conducted using a combination of field and laboratory measurements. Initially, the latitude, longitude, and altitude of the sampling points were determined using a global positioning system (eXplorist-200). Subsequently, on-site measurements were performed for pH, water temperature (WT), electrical conductivity (EC), dissolved oxygen (DO), turbidity (NTU), water depth (Dept), and flow velocity (Velo). Simultaneously, water samples were collected and taken back to the laboratory for experimental measurements, including suspended solids (SS), total dissolved solids (TDS), silicate (SiO24-), total nitrogen (TN), total phosphorus (TP), and permanganate index (CODMn), following the relevant standards of China in 2002[13].

At each sampling point, water samples were taken at a depth of 0.5m below the water surface, with 1L of water collected and mixed in duplicates for qualitative and quantitative analysis. Subsequently, 10ml of Lugol's reagent was added for fixation. The water samples were then transported to the laboratory and left to settle for 48 hours. After settling, the samples were siphoned and concentrated to 100ml bottles for microscopic examination. Before microscopic examination, the concentrated precipitate was thoroughly mixed, and 0.1ml of plankton was drawn into a plankton counting chamber. Plankton identification and counting were conducted under a 400x microscope by examining 50 fields of view. Plankton identification was carried out based on relevant reference books and literature [14].

2.4. Data analysis

Statistical analysis of plankton community structure in the Diannong River (Yinchuan City section), Yuehai Wetland, Baohu Wetland, and Hequanhu Wetland. The density and dominant species were analyzed using Excel 2021 [15]. The formula for dominant species is as follows:

$$Y = \left(\frac{Ni}{N}\right) \times fi \tag{1}$$

Here:

Ni: represents the ith species

N: indicates the total number of individuals of all species

fi: signifies the frequency of occurrence

When Y≥0.02, the species is considered dominant.

The Vegan package in RStudio was utilized to calculate the species richness, Shannon-Wiener diversity index (H'), Pielou's evenness index (J), and Simpson diversity index (D) of plankton. The formulas for diversity indices are as follows:

Shannon-Wiener diversity index (H'):

$$H' = -\sum P_i(lnP_i) \tag{2}$$

Pielou's evenness index (J):

$$J = \frac{H'}{lnS} \tag{3}$$

Simpson diversity index (D):

$$D = 1 - \sum_{i=1}^{S} P_i^2 \tag{4}$$

Here:

Pi = Ni/N: represents the proportion of individuals of the ith species in the sample

S: denotes the number of taxa

N: indicates the total number of individuals of all species

Using SPSS, conduct one-way analysis of variance (ANOVA) or the independent samples t test for the diversity indices(Kruskal-Wallis), followed by the Turkey test or Bonferroni correction method to adjust significance values, to examine significant differences between the Diannong River basin (Yinchuan City section) and the three wetlands. Perform principal component analysis (PCA) on water environmental factors. In RStudio, utilize packages such as vegan and ggplot2, and conduct Mantel tests using the Pearson correlation coefficient for correlation analysis of environmental factors ($P<0.05$). The plotting processes can be carried out in OriginLab Origin 2019 and RStudio.

3. RESULTS

3.1. Environmental characteristics

Perform principal component analysis (PCA) on the water environmental factors of the Diannong River (Yinchuan City section), selecting ammonia nitrogen (NH3-N), total phosphorus (TP), and transparency (SDD) as the highly correlated driving factors. Conduct PCA analysis on the water environmental factors of Yuehai Wetland, identifying ammonia nitrogen (NH3-N), total nitrogen (TN), turbidity (NTU), and dissolved oxygen (DO) as the highly correlated driving factors. Similarly, conduct PCA analysis on the water environmental factors of Baohu Wetland, revealing ammonia nitrogen (NH3-N), total phosphorus (TP), turbidity (NTU, and dissolved oxygen (DO) as the highly correlated driving factors. Also, perform PCA analysis on the water environmental factors of Hequan Lake Wetland, identifying total nitrogen (TN), dissolved oxygen (DO), CODcr, and BOD5 as the highly correlated driving factors (Figure 2).

Measure hydrological indicators including relative depth and flow velocity, physical indicators such as water temperature, pH, conductivity, dissolved oxygen, transparency, turbidity, total dissolved solids, and suspended solids. Additionally, measure chemical indicators such as total nitrogen, total phosphorus, ammonia nitrogen, nitrate nitrogen, chlorophyll-a, permanganate index, chemical oxygen demand, and five-day biochemical oxygen demand. The numerical values for the above indicators are presented in Table 1.

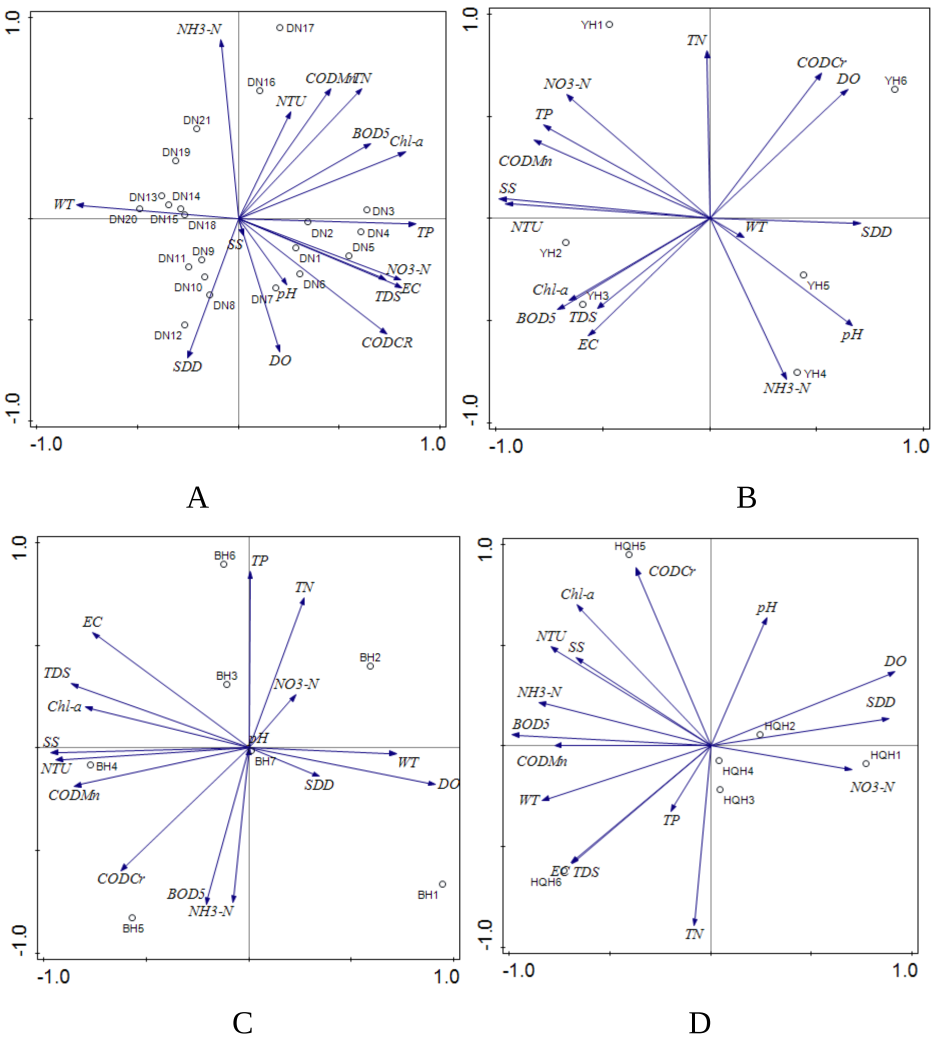

Figure 2. PCA analysis of physicochemical factors in Yinchuan City Waters

A: Diannong River (Yinchuan City section) B: Yuehai Wetland C: Baohu Wetland D: Hequan Lake

Table 1. Distribution features of environment indicators in Yinchuan City

Year	Environmental factors	Min	Max	Mean ±SD
2023	pH	7.9	8.9	8.33 ±0.03
	EC(μs/m)	0.84	4.76	2.03 ±0.19
	WT(℃)	11.6	16.5	14.57 ±0.17
	SDD(mg/L)	10	188	54.55 ±5.26
	DO(mg/L)	1.83	13.38	8.57 ±0.31
	NTU(mg/L)	0.4	14.7	5.60 ±0.44
	TDS(mg/L)	465.6	2723.2	1,120.64 ±115.00
	SS(mg/L)	2.14	16.98	6.37 ±0.46
	TN(mg/L)	0.24	1.86	0.80 ±0.07
	TP(mg/L)	0.01	0.09	0.03 ±0.00
	NH3-N(mg/L)	0	0.93	0.23 ±0.03
	NO3-N(mg/L)	0	1.1	0.20 ±0.05
	Chl-a(mg/L)	4.18	85.92	22.18 ±2.79
	CODMn(mg/L)	2.72	10.82	4.65 ±0.25
	CODcr(mg/L)	3.4	70	17.25 ±2.06
	BOD5(mg/L)	2.1	14	5.22 ±0.32
	Velo(cm/s)	0	3	0.60 ±0.18
	Depth(m)	0.76	2.21	1.52 ±0.06

3.2. Phytoplankton community characteristics

According to the pie charts depicting the characteristics of planktonic plant communities in the Diannong River (Yinchuan section) in April 2023 (Figure 3A), a total of 177 species of planktonic plants were collected. Among these, 94 species belong to the Bacillariophyta, accounting for 51%; 54 species belong to Chlorophyta, accounting for 30%; 12 species belong to Cyanophyta, accounting for 7%; 8 species belong to Euglenophyta, accounting for 4%; and 15 species belong to other phyla, accounting for 8%. Similarly, the pie chart representing the characteristics of planktonic plant communities in the Yuehai Wetland (Figure 3B) indicates the collection of 57 species of planktonic plants. Among these, 16 species belong to Bacillariophyta, accounting for 28%; 20 species belong to Chlorophyta, accounting for 35%; 6 species belong to Pyrrophyta, accounting for 11%; 7 species belong to Euglenophyta, accounting for 12%; and 8 species belong to other phyla, accounting for 14%.The planktonic plant community structure in the Baohu Lake Wetland (Figure 3C) reveals the collection of 96 species of planktonic plants, including 41 species of Bacillariophyta, accounting for 43%; 35 species of Chlorophyta, accounting for 37%; 6 species of Pyrrophyta, accounting for 6%; 6 species of Euglenophyta, accounting for 6%; and 8 species from other phyla, accounting for 8%.

Likewise, the planktonic plant community structure in the Hequanhu Wetland (Figure 3D) shows the collection of 66 species of planktonic plants, with 27 species belonging to Bacillariophyta, accounting for 41%; 20 species to Chlorophyta, accounting for 30%; 5 species to Cyanophyta, accounting for 8%; 5 species to Euglenophyta, accounting for 8%; and 9 species from other phyla, accounting for 13%.

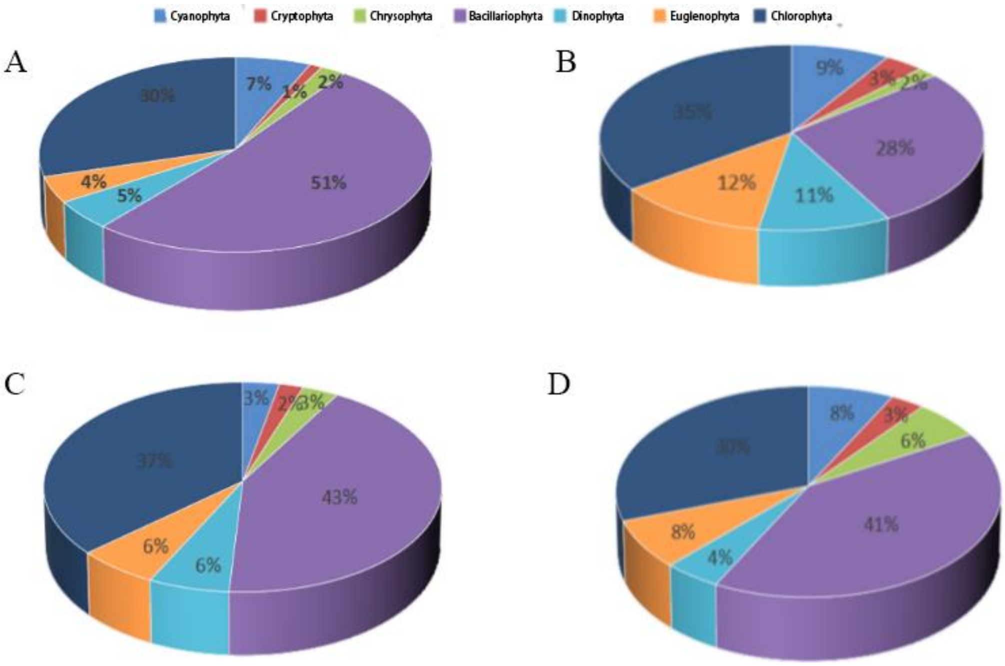

Figure 3. Pie charts depicting the planktonic plant community structure in water bodies of Yinchuan City.

A: Diannong River (Yinchuan City section) B: Yuehai Wetland C: Baohu Wetland D: Hequahu Wetland

According to the box plots of planktonic plant species richness in the Diannong River (Yinchuan section) and the Yuehai Wetland, Baohu Wetland, and Hequan Lake Wetland in April 2023 (Figure 4A), significant differences exist between the Diannonng River (Yinchuan section) and the Yuehai Wetland (One-way ANOVA, F=6.129, P=0.005), as well as between the Diannong River (Yinchuan section) and Hequan Lake Wetland (One-way ANOVA, F=6.129, P=0.014). However, according to the box plot of planktonic plant cell density (Figure 4B), there are no significant differences in planktonic plant cell density.

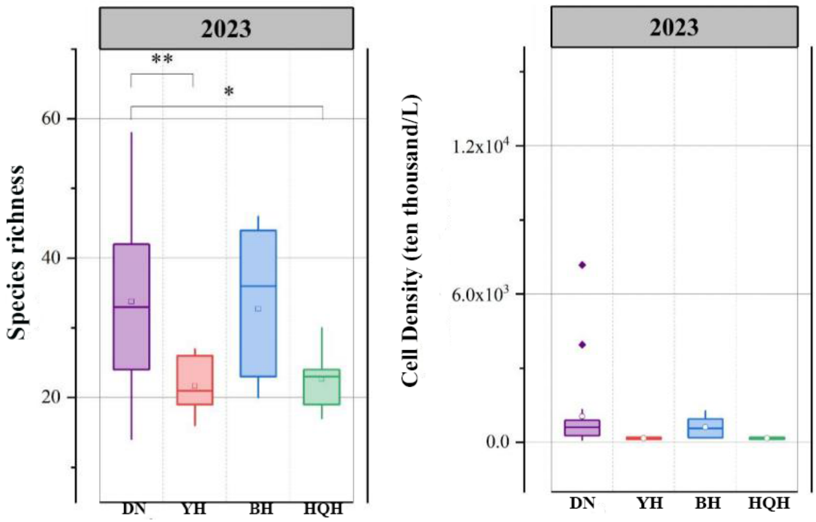

Figure 4. Phytoplankton species richness (A) and cell density of phytoplankton (B) in April 2023

(The line in the middle of the box represents the median of the data, and the bottom and bottom of the box are the upper and lower quartiles of the data, respectively. The upper and lower edges represent the maximum and minimum values of the set of data. Points above the maximum and below the minimum are outliers in the data. An asterisk indicates a significant difference between the two groups. * indicates $p \leq 0.05$, ** indicates $p < 0.01$, ***indicates $p < 0.001$)

According to the box plots of diversity indices of planktonic plants in the Diannong River (Yinchuan section), Yuehai Wetland, Baohu Wetland, and Hequanhu Wetland in April 2023 (Figure 5), significant differences are observed. The Simpson index of the Diannong River (Yinchuan section) differs significantly from that of Hequanhu Wetland (One-way ANOVA, P=0.014). The Pielou evenness index of Baohu Wetland and Hequan hu Wetland is significantly higher than that of the Diannong River (Yinchuan section) (One-way ANOVA, P<0.001; One-way ANOVA, P<0.001).

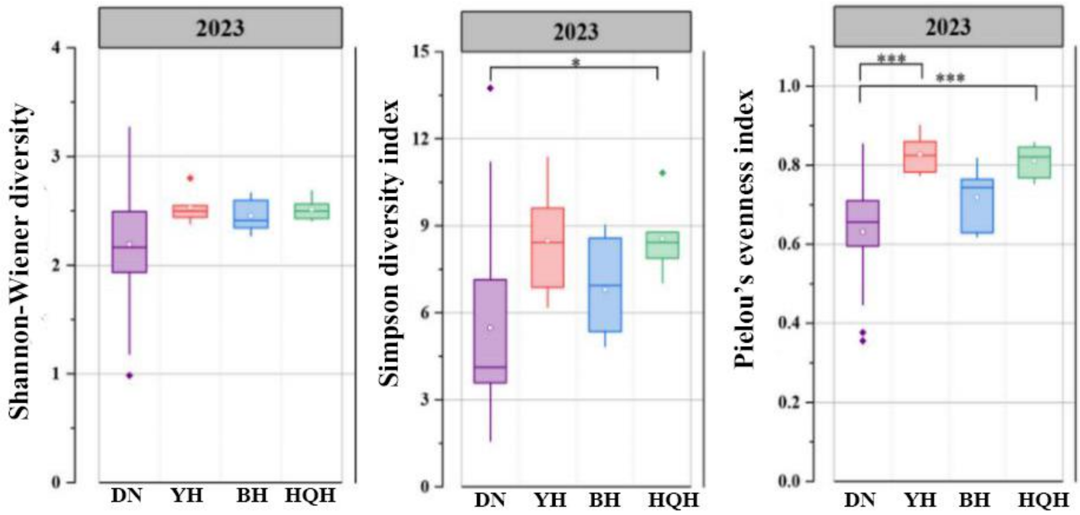

Figure 5. Diversity index of phytoplankton in Yinchuan

(The line in the middle of the box represents the median of the data, and the bottom and bottom of the box are the upper and lower quartiles of the data, respectively. The upper and lower edges represent the maximum and minimum values of the set of data. Points above the maximum and below the minimum are outliers in the data. An asterisk indicates a significant difference between the two groups. * indicates $p \leq 0.05$, ** indicates $p < 0.01$, ***indicates $p < 0.001$)

Based on the dominant species and dominance degree of planktonic plants in the Diannong River (Yinchuan section), Yuehai Wetland, Baohu Wetland, and Hequahu Wetland in April 2023 (Table 2), it is evident that the dominant species of planktonic plants mostly belong to the Cyanophyta and Chlorophyta phyla, including species such as Phormidium tenue, Microcystis aeruginosa, Merismopedia sp., and Ankistrodesmus sp.

In April, the main dominant species of planktonic plants in the Diannong River basin (Yinchuan section) are Phormidium tenue, Merismopedia sp., and Ankistrodesmus sp. In the Yuehai Wetland, the dominant species are Synedra sp., Gymnodinium sp., Scenedesmus sp., and Ankistrodesmus sp. In the Baohu Wetland, they are Phormidium tenue, Cyclotella sp., Scenedesmus quadricauda, and Chlorella vulgaris. In the Hequahu Wetland, they are Merismopedia tenuissima and Schroederia sp.

Table 2 Dominant species of phytoplankton in Yinchuan water

		Dominant species	Dominance
2023	Diannong River (Yinchuan section)	Phormidium tenue	0.06
		Merismopediapunciata	0.03
		Merismopediatenuissima	0.09
		Ankistrodesmusangustus	0.06
		Ankistrodesmusfalcatus	0.03
		Scenedesmus quadricauda	0.03
	Yuehai Wetland	Cyclotella sp.	0.03
		Synedra acus	0.02
		Synedra acusvar.angustissima	0.04
		Gymnodinium sp.	0.04
		Gymnodiniumeucyaneum	0.06
		Scenedesmus arcuatus	0.03
		Scenedesmus quadricauda	0.07
		Ankistrodesmusangustus	0.03
	Baohu Wetland	Ankistrodesmusangustus	0.04
		Phormidium tenue	0.21
		Dinobryaceae sp.	0.04
		Cyclotella sp.	0.07
		Chlorococcum sp.	0.05
		Scenedesmus quadricauda	0.06
		Ankistrodesmusacicularis	0.03
	Hequahu Wetland	Chlorella vulgaris	0.06
		Merismopediatenuissima	0.12
		Synura sp.	0.04
		Chlorella vulgaris	0.04
		Schroederia sp.	0.09
		Scenedesmus quadricauda	0.04
		Dinobryondivergens	0.04

3.3. Correlation between Planktonic Plant Community and Environmental Driving Factors

Using Mental test, an analysis was conducted on the relationship between 16 environmental factors including water temperature, dissolved oxygen, conductivity, pH, and the diversity of planktonic plants (Figure 6). In April 2023, species richness of planktonic plants showed positive correlations with CODMn index, TN, TP, Chl-a, and BOD5 ($P<0.01$, $0.01<P<0.05$, $0.01<P<0.05$, $0.01<P<0.05$, $0.01<P<0.05$). Shannon diversity index was positively correlated with DO, SDD, and NH3-N ($P<0.01$, $0.01<P<0.05$, $0.01<P<0.05$). Simpson index showed positive correlations with DO, SDDy, and NH3-N ($P<0.01$, $0.01<P<0.05$, $0.01<P<0.05$). Pielou's evenness index of planktonic plants was positively correlated with DO, SDD, pH, and NH3-N ($P<0.01$, $0.01<P<0.05$, $0.01<P<0.05$, $0.01<P<0.05$).

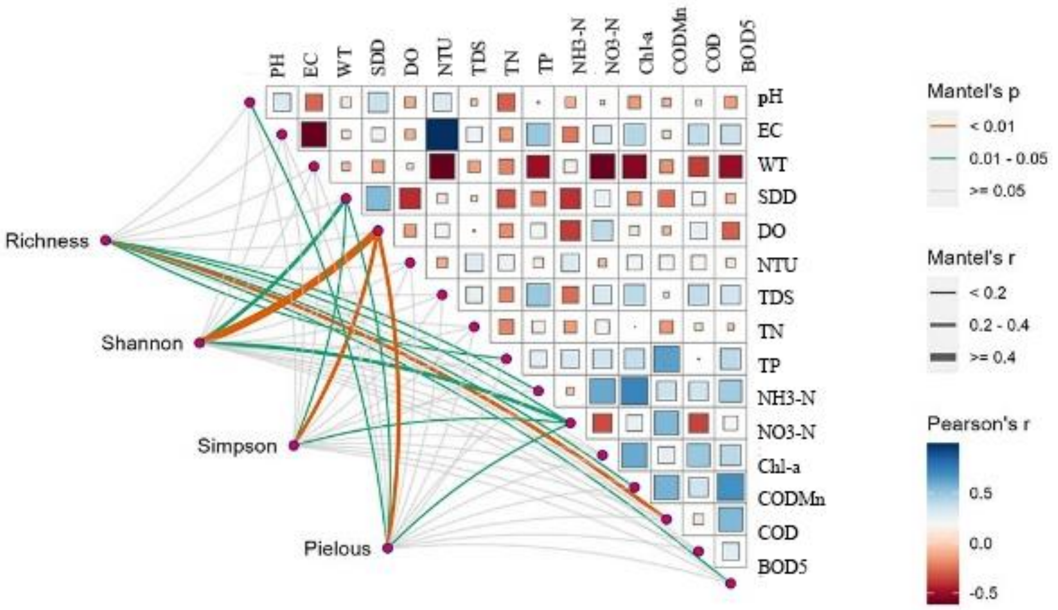

Figure 6. The correlation between planktonic plant community and environmental driving factors in the waters of Yinchuan City

4. DISCUSSION

The study area encompasses the river wetlands within Yinchuan City, characterized by high urbanization levels and intense human activity [16]. Planktonic plants in this area are primarily composed of Diatoms, Chlorophyta, and Cyanobacteria. Numerous studies have shown the widespread distribution of diatoms, which can tolerate various environmental conditions. When land use intensity and urbanization levels are high, and pollution levels are elevated, pollution-tolerant species of diatoms tend to dominate [17]. Chlorophyta, through photosynthesis, release oxygen. However, excessive proliferation can lead to nutrient competition, affecting the growth of other organisms and causing ecological imbalance in the water [18]. Cyanobacteria, capable of nitrogen fixation, including some species like Anabaena, convert nitrogen gas into biologically available forms, thereby serving as a potential nitrogen source for algal growth and contributing to eutrophication [19]. In April 2023, species richness increased significantly in the Diannong River Basin (Yinchuan section) and Baohu Wetland compared to Baohu and Hequahu wetlands. This difference may be attributed to variations in environmental factors such as water temperature and chemical constituents like total nitrogen and phosphorus content across different seasons. Several studies have demonstrated correlations between the total abundance of planktonic plants and factors such as water temperature, total nitrogen, total phosphorus, and nitrate content [20]. Planktonic plant densities showed no significant differences. The most dominant species in each group belonged to the phyla Cyanobacteria, Chlorophyta, and Bacillariophyta, with other phyla being less abundant. Samples from all four groups were mostly in stagnant water environments, characterized by slow or no water flow, facilitating the accumulation of nutrients conducive to the survival and reproduction of planktonic plants. Cyanobacteria and green algae, being species adapted to stagnant waters, proliferated widely in nutrient-rich environments, likely contributing to the dominance of these species in the planktonic plant community [21]. Diatoms, particularly species like Synedra and Cyclotella, dominated, consistent with research findings showing rapid diatom growth above 16 ℃, declining thereafter at 26 ℃ [22].

Planktonic plant diversity is a fundamental characteristic influencing the functionality of aquatic ecosystems, with diverse planktonic plant communities aiding in water stability maintenance [23]. Higher species diversity indices indicate stronger self-regulation capabilities of planktonic plants towards aquatic environmental conditions, thereby enhancing ecosystem stability [24]. The planktonic plant diversity indices in this study revealed increased Shannon diversity, Simpson, and Pielou indices for all three wetlands, surpassing those of the Diannong River Basin (Yinchuan section). This outcome may be attributed to the moderate sunlight conditions in April, facilitating photosynthesis and thereby enhancing growth rates. Additionally, the water temperature may have been more conducive for algal growth, as excessively high or low temperatures can limit planktonic plant growth [25]. Nutrient inputs in aquatic ecosystems, primarily nitrogen and phosphorus, are among the main factors contributing to eutrophication in urbanized water bodies globally. They lead to deteriorating water quality and increased proliferation of planktonic plants, favoring the abundant reproduction of pollution-tolerant diatoms, green algae, and cyanobacteria, thereby increasing species diversity [26]. Human disturbances and natural factors such as precipitation and temperature variations are also significant contributors to species diversity changes [27].

This study utilized the Mantel test to explore the relationship between planktonic plant community diversity and environmental factors in the aquatic ecosystems of Yinchuan City. The results indicated that planktonic plant diversity was largely positively correlated with dissolved oxygen, water temperature, and total nitrogen. Studies have shown that temperature is a primary ecological driver of planktonic plant diversity, with increasing temperatures affecting plant growth and reproduction, thereby promoting increased biological diversity by occupying different ecological niches [28]. The dissolved oxygen content in water affects the distribution and abundance of planktonic organisms, thereby influencing the overall community's taxonomic diversity. Excessive total nitrogen content can lead to a significant decrease in biological diversity indices, favoring the proliferation of pollution-tolerant species within diatoms and the excessive reproduction of green and blue-green algae. Elevated suspended solids in water reduce transparency, affecting the duration and intensity of light exposure for planktonic plants, thereby influencing their growth and reproduction [29]. Electrical conductivity and pH are also among the primary factors influencing the biological diversity of planktonic plant communities [30].

In summary, there exists a complex interaction between environmental factors and planktonic plant diversity. Through in-depth exploration of these relationships, a better understanding of the dynamic changes in aquatic ecosystems can be achieved, providing a scientific basis for water environment protection and management.

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