Structural Characteristics of Winter Phytoplankton Communities in the Middle and Lower Reaches of the Hanjiang River, China

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Abstract: The middle and lower reaches of the Hanjiang River of China occupy a very important position in the national water resources allocation. Since the first outbreak of diatom blooms in the spring of 1992, more than ten blooms have occurred so far, and the frequency of occurrence has gradually increased, and the outbreaks are mostly concentrated in the late winter and early spring (January-March). In this study, nine sampling sites were set up in the middle and lower reaches of the Hanjiang River in January 2020 (winter dry period) to investigate and analyze the phytoplankton community structure and water quality, and the results showed that 6 phyla and 28 genera of phytoplankton were identified in winter, among which Bacillariophyta accounted for the largest proportion. The abundance of phytoplankton at each point varied from 0.57×10^6 to 1.88×10^6 cells/L, and the biomass varied from 0.013 to 0.222 mg/L, which can be divided into 12 functional groups. The important functional groups are MP, P, D, E, and J, reflecting that the habitats of the middle and lower reaches of the Hanjiang River are characterized by frequent disturbance, high mixing, and turbid mesotrophic water bodies. The calculated values of phytoplankton diversity show that the individual distribution of phytoplankton genera is relatively uneven, and the eutrophication trend is gradually significant from the middle to the lower reaches, and the water body is generally moderately polluted.

1 INTRODUCTION

The Hanjiang River is the largest tributary in China's Yangtze River. The middle and lower reaches of the Hanjiang River usually refer to the section from Danjiangkou to Hankou, where the Danjiangkou Reservoir is the starting point of the South-to-North Water Diversion Project (He et al., 2007). Therefore, the middle and lower reaches of the Hanjiang River occupy a very important position in the national water resources allocation and the development of the Hanjiang River ecological and economic zone, and its water quality safety and water ecology are of great concern (Li et al., 2022).

Phytoplankton plays an important role in the material cycle and energy flow of the ecosystem, and is an important part of the surface water environment. Their diversity directly affects the functional structure of the ecosystem (Cardinale et al., 2002), which is of great importance in the study of rivers. Phytoplankton species, community structure, functional group composition, abundance distribution, diversity, and other characteristics are important criteria for evaluating the water quality of rivers and lakes, and can reflect the pollution of the water environment (Suikkanen et al., 2007), phytoplankton has become an important indicator for biological monitoring and evaluation of water quality, complementing the physicochemical monitoring of water quality, and is widely used in the investigation and analysis of surface water environment at home and abroad. Han et al. (2012) analyzed the phytoplankton community composition, abundance, and dominant species in Anxing Wetland, Heilongjiang Province in autumn, and inferred that the water quality of Anxing Wetland might be

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polluted to a certain extent. Zhang et al. (2022) analyzed the phytoplankton community structure and related hydrometeorological factors in the mainstream of Qiantang River in summer, and found that temperature and rainfall were the main drivers of water bloom outbreak.

In recent years, with the repair of water conservancy projects, the water ecological environment in the middle and lower reaches of the Hanjiang River has undergone major changes. Since the first diatom bloom in the middle and lower reaches of the Hanjiang River in the spring of 1992, more than ten blooms have occurred, and the frequency of the blooms has gradually increased, mostly in late winter and early spring (January to March), water blooms seriously affect the life and health of residents, and also have a negative impact on the ecological environment (Xin et al., 2020; Wu et al., 2019; Xin et al., 2019). Understanding the water quality in the middle and lower reaches of the Hanjiang River in winter and identifying the key drivers of phytoplankton growth is important for scientific prevention and control of water blooms and for ensuring water and ecological safety in the middle and lower reaches of the Hanjiang River.

In this study, we identified the structure and spatial distribution of phytoplankton communities, conducted statistics on their abundance and biomass, in the middle and lower reaches of the Hanjiang River, provided a scientific basis for scientific assessment of water quality conditions and prevention of water wars in the middle and lower reaches of the Hanjiang River, and provided theoretical support for water quality evaluation and ecosystem maintenance in the basin. Theoretical support for water quality assessment and ecosystem maintenance in the basin.

2 MATERIALS AND METHODS

2.1 Study Area and Sample Site Setup

The Hanjiang River is one of the major tributaries of the Yangtze River and ranks first in the Yangtze River system in terms of the watershed area. The mainstream of the Hanjiang River is divided by the Danjiangkou, with the upper reaches above the Danjiangkou; the middle reaches are from the Danjiangkou to Zhongxiang, with four tributaries (Beihe River, Nanhe River, Qinghe River, and Tangbaihe River) joining the middle reaches, passing through Shiyan, Xiangyang, and Jingmen, with a length of about 223 km; the lower reaches are from Zhongxiang to Hankou, passing through Tianmen, Qianjiang, Xiantao, Hanchuan and Wuhan in turn, with a length of about 382 km, finally joining the Longwangmiao in Wuhan. Yangtze River. The middle and lower reaches of the Hanjiang River (111 °~115°E, 30°~33°N) are located in Hubei Province, with the Danjiangkou, Wangfuzhou, Cuijiaying, Xinglongzha, and other water conservancy hubs, and the middle reaches are wider than the upper valleys, with less flooding capacity and a gradually narrowing river channel downstream. The average annual temperature of the basin is about 15~17°C, and the average annual precipitation is 800~900 mm.

According to the geographic location, hydrological characteristics, and location of water resources hubs in the middle and lower reaches of the Hanjiang River, nine sampling points (Figure 1), S1 at Yujiahu hydrological station in Xiangyang, S2 at the Hanjiang Bridge, downstream of Yicheng city, S3 at Linkuang county in Zhongxiang city, S4 at Shayang hydrological station in Jingmen city, S5 at Qianjiang hydrological station in Qianjiang city, S6 upstream of Xiantao city, S7 at Makou upstream of Hanchuan city, S8 upstream of Wuhan city, and S9 at Longwangmiao in Wuhan city. The survey of the above sampling sites was launched in January 2020 (winter dry period).

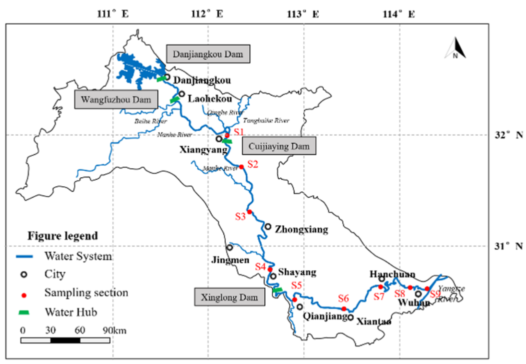

Figure 1: Distribution of phytoplankton sampling sites.

2.2 Sample Collection and Processing

Phytoplankton sampling was carried out according to Methods for *Freshwater Phytoplankton Research* (Zhang et al., 1991). Qualitative samples were taken using a No. 25 phytoplankton net and repeatedly dragged at a water depth of 0.5 m for 3~5 min with the figure "∞". Transfer the concentrated solution to a 50 mL plastic bottle, add Lugol's reagent for fixation, and bring it back to the laboratory to refer to *Freshwater Microbiological Atlas* (Zhou, 2005) and *Freshwater algae in China: System, ecology, and taxonomy* (Hu et al., 2006) for species classification identification, phytoplankton pollution indicator species analysis method reference *New technology of microbiological monitoring* (Shen et al., 1994) and *Environmental and Biological Indicator (water volumes)* (Ecological Society of Japan Panel on Environment, 1987).

Part of the conventional water quality physical and chemical indicators with multi-parameter water quality instrument (YSI EXO2, USA) for on-site determination, the measured water body physical and chemical indicators including water temperature (WT), dissolved oxygen (DO), pH, total dissolved solids (TDS), redox potential and conductivity, etc. The distribution of each sampling point and the basic conditions of the environment are shown in Table 1.

Table 1: Basic information on sampling sites in the middle and lower reaches of the Hanjiang River.

Sampling site	Geographical coordinates	Water temperature/℃	pH	Dissolved oxygen/(mg/L)	Total dissolved solids /(mg/L)
S1	112°8′54″E, 31°57′8″N	10.828	9.58	10.07	143
S2	112°17′36″E, 31°43′26″N	10.727	7.96	10.78	71
S3	112°26′19″E, 31°18′24″N	10.304	7.96	10.84	93
S4	112°36′15″E, 30°41′49″N	9.178	8.23	11.16	103
S5	112°52′16″E, 30°29′32″N	9.211	7.91	11.4	111
S6	113°27′58″E, 30°23′6″N	8.274	8.01	11.78	103
S7	113°56′27″E, 30°39′42″N	9.22	8.14	11.59	109
S8	114°2′9″E, 30°35′37″N	7.779	7.85	11.61	104
S9	114°17′8″E, 30°33′52″N	8.375	8.13	11.13	107

2.3 Phytoplankton Diversity Calculation

2.3.1 Margalef Diversity Index (*D*)

$$d = (S - 1)/ln\,N \quad (1)$$

Where: S is the number of species in the sample, and N denotes the total number of individuals of all species in the sample. d>3 is light or no contamination; 1<d⩽3 is medium contamination; 0< d⩽1 is heavy contamination (Hu et al., 2015).

2.3.2 Shannon-Wiener Index (H'_e)

$$P_i = n_i/N \quad (2)$$

$$H'_e = -\Sigma_{i=1}^{S} P_i \times ln\,P_i \quad (3)$$

Where: n_i is the number of individuals of the ith species, N denotes the total number of individuals of all species in the sample, and S is the number of species in the sample. The Shannon-Wiener index reflects the diversity of phytoplankton in the water column and the complexity of the community (Table 2).

Table 2: Shannon-Wiener index grading evaluation criteria (Tilman et al., 1976).

Index Range	Level	Status	Water pollution level
$H'_e > 3$	Enrichment	Species richness and even distribution of individuals	Cleaning
$2 < H'_e \leq 3$	Richer	High species richness and relatively even distribution of individuals	Light pollution
$1 < H'_e < 2$	General	Species richness is low, and individuals are relatively evenly distributed	Medium pollution
$0 < H'_e \leq 1$	Poor	Low species richness and uneven distribution of individuals	Heavy pollution
$H'_e = 0$	Extremely poor	Species homogeneity and basic loss of diversity	Severe pollution

2.3.3 Pielou's Evenness Uniformity Index (*J*)

$$J = H'_e / \ln S \quad (4)$$

Where: H'_e is the Shannon-Wiener index, S is the number of species in the sample. J value of 0.5 to 0.8 is light contamination; J value of 0.3 to 0.5 is moderate contamination; J value of 0 to 0.3 is heavy contamination (Shen et al., 1994).

2.4 Data Analysis

The species data and environmental data were compiled, statistically analyzed, and plotted using Microsoft Office 2020, SPSS, and Origin 2021 for Windows.

3 RESULTS

3.1 Phytoplankton Species Composition, Density, and Biomass Analysis

During the survey, microscopic examination identified 28 genera of phytoplankton in 6 phyla, of which Bacillariophyta was the most important group, with 13 genera, accounting for 46.4% of the total number of genera; Chlorophyta has 5 genera, accounting for 17.9% of the total number of genera; Cyanobacteria has 4 genera, accounting for 14.3% of the total number of genera; Dinoflagellates has 1 genus, accounting for 3.6% of the total number of classes; Cryptophyta has 2 genera, accounting for 7.1% of the total number of classes; Chrysophyta has 3 genera, accounting for 10.7% of the total number of classes.

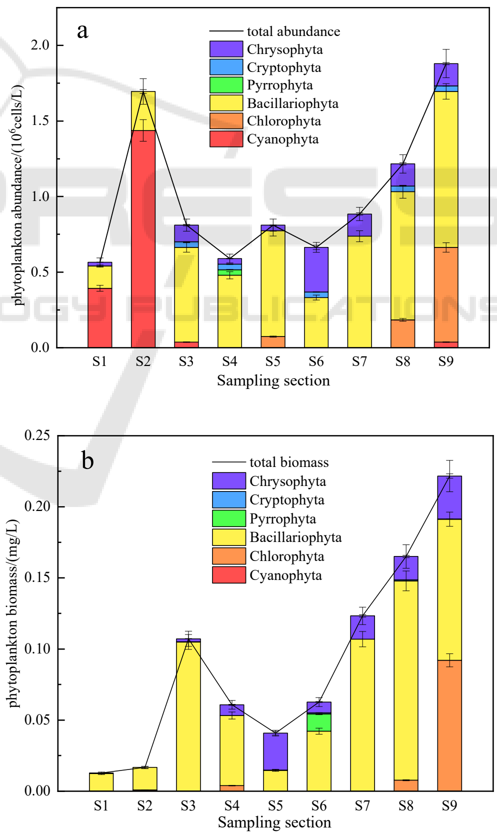

Figure 2: Spatial variation of phytoplankton abundance (a), biomass(b) in the middle and lower reaches of the Hanjiang River.

The total cumulative abundance of phytoplankton in the middle and lower reaches of the Hanjiang River was 9.12×10^6 cells/L, of which the diatom abundance was the largest at 5.16×10^6 cells/L, accounting for 56.60%, followed by Cyanobacteria at 1.90×10^6 cells/L, accounting for 20.89%. The total phytoplankton biomass was 0.811 mg/L, of which diatom biomass reached 0.585 mg/L, accounting for 72.16% (Figure 2 a).

The phytoplankton abundance and biomass have obvious spatial distribution differences, and the variation of abundance at each point ranges from 0.57×10^6 to 1.88×10^6 cells/L, with the mean value of 1.01×10^6 cells/L; the variation of biomass ranges from 0.13 to 2.22 mg/L, with a mean value of 0.90 mg/L. From Figure 2(b) it can be found that the phytoplankton abundance and biomass downstream increased gradually. Abrupt increase in cyanobacterial abundance and biomass in the lower reaches of Yicheng city(S2); the abundance and biomass of Chlorophyta increased significantly downstream of Wuhan City at Longwangmiao (S9); the abundance of diatoms showed a general increasing trend along the course, and the biomass reached a high level in the Linkuang town (S3) and the upstream of Wuhan (S8); the peak abundance and biomass of Chrysophyta appeared in the upstream of Xiantao (S6) and Longwangmiao (S9), respectively.

3.2 Classification of Phytoplankton Functional Groups

Ecologically, phytoplankton with similar habits and survival strategies are grouped into "functional groups", which reflect certain habitat characteristics. According to the classification of phytoplankton functional groups by Reynolds et al. (2002) and Hu Ren et al. (2015), the phytoplankton in the middle and lower reaches of the Hanjiang River can be divided into 12 functional groups (Table 3): B, C, D, E, J, Lo, MP, P, S1, X2, X3, Y; among them, there are five common functional groups with frequencies greater than 65%, namely B, D, E, MP, X2, where B and MP functional groups occur in each sampling site. The functional groups with relative biomass greater than 10% are defined as important functional groups, and there are five of them, namely MP, P, D, E, and J. The dominant functional groups are B, MP, D, S1, E, X2, and P. The functional groups reflect that the habitats in the middle and lower reaches of the Hanjiang River are characterized by frequent disturbance, high mixing, and turbid moderately eutrophic water bodies.

3.3 Species Diversity of Phytoplankton Communities and Biological Evaluation of Water Quality

The results of phytoplankton diversity index calculation are shown in Figure 3.

The Margalef diversity index (d) in the middle and lower reaches of the Hanjiang River ranges from 2.223 to 2.467, with a mean value of 2.364, $1< d \leqslant 3$, indicating that the overall pollution level in the middle and lower reaches of the Hanjiang River is medium; the Shannon-Wiener index (H'_e) ranges from 1.063 to 2.147, with a mean value of 1.571, indicating that the overall phytoplankton in the middle and lower reaches of the Hanjiang River is more evenly distributed but generally abundant, and the water quality is α-medium pollution level, only the Linkuang County and the upper reaches of Wuhan are more abundant, and the water quality is β-medium pollution; Pielou's evenness uniformity index (J) ranges from Pielou's evenness index (J) ranges from 0.319 to 0.644, with a mean value of 0.471, indicating that the distribution of individual genera in the middle and lower reaches of the Hanjiang River is uneven, and the water body is moderately polluted overall. The diversity index indicates that the eutrophication trend of the Hanjiang River from the middle to the lower reaches of the river is gradually significant, and the pollution level changes from mild to moderate.

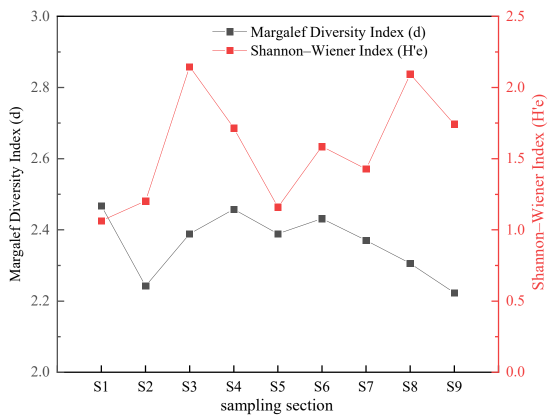

Figure 3: Phytoplankton diversity index in the middle and lower reaches of the Hanjiang River.

Table 3: Phytoplankton functional groups and representative species in the middle and lower reaches of the Hanjiang River.

Functional groups	Represent genus/species in the groups	Phylum	Functional Group Habitat Characteristics
B	*Cyclotella* sp.	Bacillariophyta	Mesotrophic small and medium-sized water bodies, sensitive to stratification, silica deficiency
C	*Asterionella formosa*	Bacillariophyta	Eutrophic small to medium-sized lakes, sensitive to stratification
D	*Synedra* sp.	Bacillariophyta	Nutrient-rich turbid shallow water bodies, sensitive to nutrient deficiencies
E	*Dinobryon* sp., *Mallomonas* sp.	Chrysophyta	Small shallow water bodies of poor or mesotrophic type
J	*Pediastrum simplex var. duodenarium*, *Crucigenia tetrapedia*	Chlorophyta	Mixed highly eutrophic shallow water bodies
Lo	*Merismopedia* sp., *Peridinium* sp.	Cyanophyta Dinoflagellates	Wide applicability, poor to eutrophic, deep or shallow, medium to large water bodies
MP	*Navicula* sp., *Cymbella* sp, *Cocconeis* sp, *Pinnularia* sp., *Stauroneis* sp.	Bacillariophyta	Frequent disturbance of turbid shallow water bodies
P	*Melosira* sp., *Melosira granulata var. angustissima*	Bacillariophyta	Highly mixed medium eutrophic shallow water bodies
S1	*Planktothrix* sp., *Dactylococcopsis* sp., *Planktolyngbya* sp.	Cyanophyta	Medium to eutrophic, mixed water bodies, low transparency
X2	*Chlamydomonas* sp., *Plagioselmis* sp.	Chlorophyta Cryptophyta	Highly mixed medium-eutrophic shallow water bodies
X3	*Cymatopleura* sp., *Schroederia* sp.	Bacillariophyta Chlorophyta	Shallow mixed water bodies, sensitive to grazing action
Y	*Cryptomonas* sp.	Cryptophyta	Medium to the eutrophic hydrostatic environment, sensitive to phagocytosis

4 DISCUSSION

The succession of phytoplankton communities is influenced by many factors, and the succession of functional groups corresponds to habitat changes, and changes in nutrient salinity and disturbance level of water bodies will cause corresponding changes (Tilman et al., 1976). In this study, Diatoms were found to be the dominant species in the middle and lower reaches of the Hanjiang River, and the frequency of population distribution showed that *Cyclotella* sp. of the Bacillariophyta was found in all sampling sites with the highest frequency of 100%, followed by *Synedra* sp. of the Bacillariophyta with a frequency of 78%, *Mallomonas* sp. of the Chrysophyta and *Navicula* sp. of the Bacillariophyta reached 67%. From Figure 2 the Cyanobacteria in downstream of Xiangyang and Yicheng in the midstream section were larger and more numerous, especially downstream of Yicheng, indicating the deepening of eutrophication in the water body; the percentage of Diatom increased significantly in the phosphate mining county of Zhongxiang, replacing Cyanobacteria the dominant species.

Figure 4 is the histogram of the abundance of functional groups stacked at each sampling site, from Figure 4 the abundance of functional group S1 increased dramatically in the downstream of Yicheng city increased dramatically, and the number and biomass of cyanobacteria increased, which indicates that the pollution is more serious, the water body is highly mixed, and the transparency is low; the abundance of functional group J in the upstream and downstream of Wuhan increased, and the pollution indicator level is β-medium pollution, which indicates that this section is a mixed highly eutrophic diving water body. Upstream of Xiantao (S6), the abundance of the E functional group is high, and the number of Chrysophyta has increased significantly, indicating that the water quality here is better. Sampling sites S2 (downstream of Yicheng) and S9 (downstream of Wuhan) are urban downstream, and S6, S7, and S8 are urban upstream. Comparing their phytoplankton species and functional groups, we can find that the populations of oligotrophic and α-medium fouling species are larger in the upstream, the frequency of β-medium fouling indicator species in the downstream has increased and the proportion is larger, the abundance of phytoplankton in the downstream is relatively high, and the changes of functional groups are consistent with the environmental conditions, so it is concluded that the water quality in the middle and lower reaches of the Hanjiang River is polluted to some extent. Comparing the upstream and downstream Margalef diversity indices (d), we can find that d_{S1} and d_{S3} are larger than d_{S2}, and the d value of the S6-S9 section continues to decrease; the above performance indicates that the water quality downstream of the city is inferior to that in the upstream, which is related to the discharge of sewage from urban towns and cities, and the discharge of urban sewage has a greater impact on water quality and phytoplankton community succession.

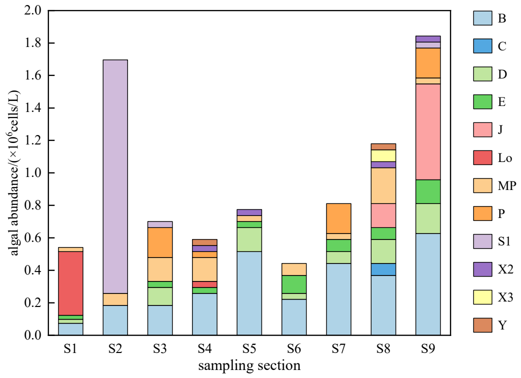

Figure 4: Composition of phytoplankton functional groups in the middle and lower reaches of the Hanjiang River.

The phytoplankton community composition in the middle and lower reaches of the Hanjiang River is not significantly different from that of other scholars, and the phytoplankton community is composed of Diatom, Chlorophyta, Cyanobacteria, and others (Dinoflagellates and Chrysophyta) in descending order, with *Cyclotella* sp. as the absolute dominant species, indicating that the water quality is still acceptable. However, the abundance of phytoplankton showed an upward trend along the river, which also reflected that the pollution gradually increased from the middle stream to the downstream.

5 CONCLUSION

A total of 28 genera of 6 phytoplankton were identified in the middle and lower reaches of the Hanjiang River, among which Bacillariophyta accounted for the largest proportion, followed by Chlorophyta and Cyanobacteria; *Cyclotella* sp. were the absolute dominant species. Phytoplankton could be divided into 12 functional groups, B, C, D, E, J, Lo, MP, P, S1, X2, X3, Y: the range of abundance variation at each site was 0.57×10^6 ~1.88×10^6 cells/L, and the biomass ranged from 0.013 to 0.222 mg/L. The important functional groups were MP, P, D, E, and J, reflecting that the habitat of the middle and lower reaches of the Hanjiang River is characterized by frequent disturbance, high mixing, and turbid Meso-eutrophic water bodies. The Margalef diversity index (d) ranged from 2.223 to 2.467, and the Shannon-Wiener index (H'_e) ranged from 1.063 to

2.147, and Pielou's evenness uniformity index (*J*) ranged from 0.319 to 0.644, indicating that the distribution of phytoplankton genera in the middle and lower reaches of the Hanjiang River was not uniform, and the eutrophication trend from the middle to the lower reaches was significant, and the water body was moderately polluted.

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