ANALYSIS OF PHYTOPLANKTON COMMUNITY STRUCTURE AND RESOURCE MANAGEMENT BASED ON FUNCTIONAL GROUPS IN THE ASHI RIVER, NORTHEAST CHINA

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Abstract. A three-quarterly survey and analysis of phytoplankton and environmental factors in the Ashi River basin was conducted from May 2022 to October 2022. It aims to explore the characteristic dynamics of phytoplankton functional groups in Ashi River basin and their relationship with environmental factors. We totally identified 54 species of phytoplankton in 7 phyla were identified and divided into 14 functional groups. There are six dominant function groups, namely C, D, J, MP, N and Y. Seasonal variation is manifested as spring (D)→summer (D/Y)→autumn (D). The results of redundancy analysis (RDA) showed that Chl-a and COD_{Mn} were positively correlated with functional group C, Cl^- and BOD_5 were positively correlated with functional group Y, DO and pH were positively correlated with functional group D. Conversely, NH_4^+-N, NTU and WT were negatively associated with the dominant phytoplankton functional groups. The main pollutants in the Ashi River basin are TP and TN. Aquatic biodiversity conservation strategies are recommended. According to the diversity needs of aquatic organisms in different regions, the necessary auxiliary measures are taken to maintain the aquatic biodiversity, integrity and specificity.
Keywords: *phytoplankton, functional groups, management decisions, Ashi River, environmental pollution*

Introduction

Phytoplankton are the main primary producers in aquatic ecosystems, which are sensitive and directly responsive to changes in the water environment. They are used as indicator species for assessing the status of the water environment (Loick-Wilde et al., 2016). Functional groups are proposed based on a comprehensive consideration of taxonomy, ecology, physiology, and other characteristics, and their species traits are more closely related to environmental conditions (Kruk et al., 2020). In 2002, the method of classifying freshwater phytoplankton into functional groups based on their habitat was first proposed, initially dividing them into 31 groups, which were later expanded to 39 in subsequent applications (Padisák et al., 2003； Pham Quang et al., 2019). Xu et al. (2019) applied the functional group classification to the Muling River basin and found that the dominant functional groups exhibited different succession trends across the four seasons. Chengxue et al. (2019) also applied the functional group classification to Dali Nur Lake and found that the phytoplankton functional groups exhibited varying trends during different hydrological periods. The functional group structure of phytoplankton is influenced by various abiotic and biological factors. Studying these influencing factors helps to accurately assess changes in water environmental quality, which is of great significance for subsequent environmental management and monitoring (Zhao et al., 2020).

The Ashi River, located in southern Heilongjiang Province, China, is the largest tributary of the Songhua River. The Songhua River is the primary source of drinking water, as well as industrial and agricultural water, in Heilongjiang Province, and is of great significance to the region’s development. If the aquatic ecological environment of the Ashi River is degraded, it could pose a significant threat to the water quality of the Songhua River. In this study, phytoplankton and water environmental factors in the Ashi River basin were monitored in 2022 using functional group classification. This study aims to explore the characteristic dynamics of phytoplankton functional groups in the Ashi River Basin and their relationship with environmental factors, comprehensively evaluate the water quality status of the water source, and provide a theoretical basis for urban water quality improvement and protection management.

Materials and methods

Overview of the research area

The Ashi River originates from Ma’er Mountain in Shangzhi City. It flows from east to west through Acheng District, Wuchang City, and Harbin City, and finally empties into the Songhua River in Daowai District of Harbin City, becoming a south-bank tributary of the Songhua River. Based on the local climate and geographical characteristics, we investigated the phytoplankton in the Ashi River in Northeast China. Samples were collected seasonally (spring: May 8, 2022; summer: July 20, 2022; autumn: October 9, 2022) at 27 sampling stations (*Fig. 1; Table 1*). Among these sampling stations, S01 to S13 are located in the upper reaches of the Ashi River, where the substrate types are diverse, including sandy, gravel, sandy-gravel, and muddy bottoms, among others. S14 to S27 are located in the lower reaches of the Ashi River, where the substrate types are relatively simple, predominantly muddy bottoms.

Monitoring methods and contents

Qualitative phytoplankton samples were collected using a 25-μm plankton net by towing it vertically from the surface to a depth of 0.5 m at a slow speed for approximately 5 min. The collected samples were transferred into a 100 mL sample bottle, with a volume of 30-50 mL retained, and fixed with formaldehyde solution. Phytoplankton quantification samples were collected using a 5 L water sampler at a

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depth of 0.5 m. The samples were transferred to a sampling bottle, fixed with 10 mL of Lugol’s solution (1.0%-1.5% of the water sample volume), stored at room temperature for 48 h, and then concentrated to 30-50 mL.

Table 1. *Names and locations of sampling sites in the Ashi River Basin, Northeast China*

Number	Station	GPS	Riverbed sediment
S01	No.3 bridge	N:45°23′54″ E:127°37′34″	Sandy bottom
S02	No.2 source	N:45°22′45″ E:127°36′10″	Gravel bottom
S03	No.3 source	N:45°21′2″ E:127°34′12″	Gravel bottom
S04	Fu Ming ditch	N:45°18′15″ E:127°35′15″	Gravel bottom
S05	The lower Fu Ming ditch	N:45°17′58″ E:127°31′31″	Sandy bottom
S06	Huangni River	N:45°16′25″ E:127°30′26″	Muddy bottom
S07	Downstream of Huangni River	N:45°16′41″ E:127°29′44″	Muddy bottom
S08	Upstream of Big Rock River	N:45°15′29″ E:127°11′50″	Muddy bottom
S09	Big stone River	N:45°19′40″ E:127°19′20″	Gravel bottom
S10	The upper reaches of shahe ditch	N:45°17′50″ E:127°24′12″	Gravel bottom
S11	Shahe ditch	N:45°16′46″ E:127°8′8″	Sandy bottom
S12	The lower reaches of Shahe ditch	N:45°16′44″ E:127°7′9″	Mud rock bottom
S13	The upper reaches of the Haigou River	N:45°37′25″ E:126°58′15″	Muddy bottom
S14	The sea ditch river	N:45°38′13″ E:126°57′48″	Muddy bottom
S15	Downstream of Haigou River	N:45°38′26″ E:126°56′27″	Muddy bottom
S16	No. 1 offtake	N:45°39′40″ E:126°56′20″	Muddy bottom
S17	No. 2 offtake	N:45°39′41″ E:126°55′51″	Muddy bottom
S18	No. 3 offtake	N:45°40′9″ E:126°55′59″	Muddy bottom
S19	Upstream of the Little Yellow River	N:45°40′4″ E:126°54′41″	Muddy bottom
S20	Fan Jiagou	N:45°40′30″ E:126°53′54″	Muddy bottom
S21	Little Yellow River	N: 45°41′44″ E: 126°53′49″	Muddy bottom
S22	Upstream of Miaotai Ditch	N:45°41′22″ E:126°51′44″	Muddy bottom
S23	Temple ditch	N:45°41′47″ E:126°51′3″	Mud rock bottom
S24	Miaotai ditch downstream	N:45°42′15″ E:126°52′11″	Mud rock bottom
S25	Upstream Dongfeng ditch	N:45°46′10″ E:126°47′22″	Muddy bottom
S25’	Downstream Dongfeng ditch	N:45°46′3″ E:126°47′9″	Muddy bottom
S26	Xinyi ditch	N:45°45′53″ E:126°46′6″	Sandy bottom
S27	Xinyi ditch downstream	N:45°48′59″ E:126°43′26″	Mud rock bottom

Species identification was performed based on the morphological classification method using the quantitative and qualitative samples collected. A 0.1 mL sample was placed in a 10×10 lattice plankton counting plate for species identification and counting under an Olympus BX51 light microscope. In this study, the phytoplankton functional groups were classified into 39 functional groups based on seasonal variations, and the functional habitat of each group was described.

A multiparameter water quality analyzer (YSI Pro Plus) was used to measure water temperature (WT), pH, dissolved oxygen (DO), and electrical conductivity (Cond). Transparency (SD) was measured using a Secchi disk, and water depth (WD) was measured using a portable depth meter (SM-5). At the same time, water samples were collected using a water sampler, stored in 1 L plastic bottles, and immediately transported to the laboratory. Total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_4^+-

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N), permanganate index (COD_{Mn}), and chlorophyll a (Chl-a) were analyzed according to the Water and Wastewater Monitoring and Analysis Methods (Fourth Edition).

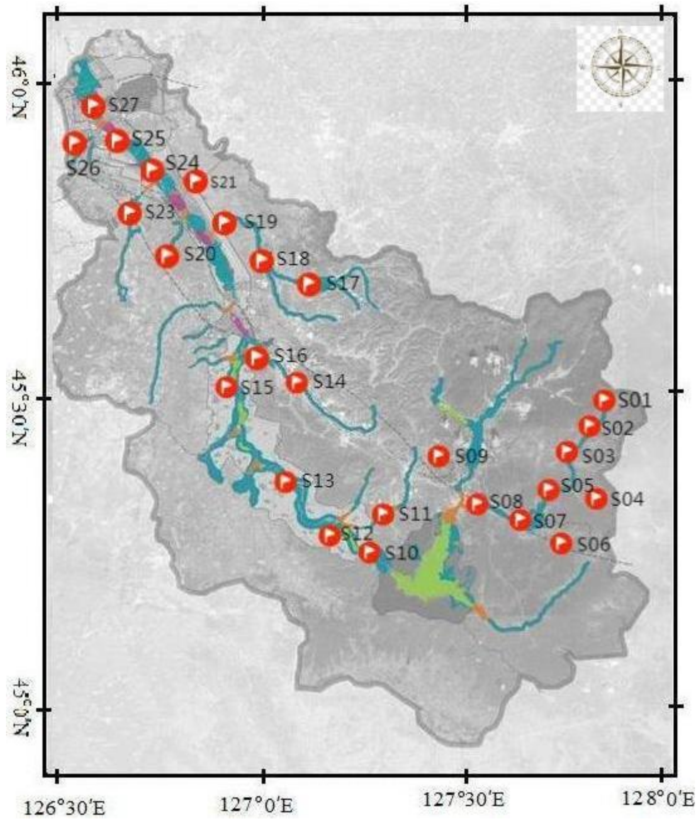

Figure 1. *Distribution of the main stream and sampling points in the Ashi River basin, Northeast China*

Statistical analyses

We selected one-way analysis of covariance (ANCOVA) to determine the significant differences in physico-chemical characteristics during the study period, and the ordinations were performed using the computer program SPSS 20.0. We considered a significant difference at $p < 0.05$ and a highly significant difference at $p < 0.01$. The relationships between functional groups and physicochemical parameters were analyzed using detrended correspondence analysis (DCA) and redundancy analysis (RDA) in CANOCO 4.5 software (Microcomputer Power).

Results

Physical and chemical characteristics of water environment

The physical and chemical characteristics of the Ashi River basin across different seasons are presented in *Table 2*. Water temperature (WT) and turbidity (NTU) were highest in summer and lowest in autumn. The highest values of chlorophyll (Chl-a) and total nitrogen (TN) were observed in autumn, while the lowest values were recorded in spring. Water depth (D), ammonia nitrogen (NH_4^+-N), and the nitrogen to phosphorus ratio (N:P) were highest in spring and lowest in autumn. The environmental factors that

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showed significant correlations were WT, NTU, SD, pH, DO, Cl^-, NH_4^+-N, TP, and BOD_5 ($P < 0.01$). The correlation analysis indicated that TN and COD_{Mn} were significant environmental factors ($P < 0.05$).

Table 2. *The environmental variable factors in different seasons in Ashi River basin*

Environmental factor	Spring season	Summer season	Autumn season	Conspicuousness (P)
WT (℃)	15.94 ± 4.18	18.16 ± 3.08	9.83 ± 2.24	0.000**
D (m)	0.37 ± 0.22	0.31 ± 0.30	0.24 ± 0.19	0.148
NTU	32.89 ± 34.80	105.66 ± 97.09	16.57 ± 16.21	0.000**
v (m/s)	0.76 ± 0.78	0.37 ± 0.40	0.44 ± 0.57	0.061
SD (m)	0.25 ± 0.16	0.14 ± 0.13	0.18 ± 0.10	0.003**
Cond (ms/m)	0.18 ± 0.15	0.14 ± 0.10	0.20 ± 0.16	0.365
pH	9.03 ± 0.21	8.76 ± 0.33	8.95 ± 0.23	0.003**
DO (mg/L)	8.57 ± 1.44	7.26 ± 0.83	8.19 ± 1.58	0.003**
Chl-a (mg/L)	10.42 ± 8.61	14.43 ± 6.99	17.72 ± 14.86	0.060
Cl^-(mg/L)	35.47 ± 32.12	14.89 ± 10.53	43.02 ± 35.92	0.003**
NH_4^+-N (mg/L)	31.98 ± 14.27	25.36 ± 14.79	11.72 ± 3.83	0.000**
NO_3^- (mg/L)	11.34 ± 13.47	68.48 ± 88.76	49.85 ± 113.56	0.050
TN (mg/L)	0.86 ± 1.13	2.63 ± 1.34	3.55 ± 5.99	0.032*
TP (mg/L)	0.12 ± 0.11	1.11 ± 1.03	0.97 ± 0.86	0.000**
N:P	12.69 ± 26.12	6.24 ± 8.76	5.42 ± 9.99	0.270
COD_{Mn} (mg/L)	20.45 ± 14.21	11.76 ± 5.40	17.04 ± 11.84	0.038*
BOD_5 (mg/L)	3.59 ± 2.92	1.62 ± 1.35	1.63 ± 1.33	0.001**

*p < 0.05.
**p < 0.01

Functional group characteristics of the phytoplankton

During the monitoring of phytoplankton in the Ashi River, 54 species and varieties belonging to 38 genera were identified using microscopy. Among them, the largest number of species belonged to Bacillariophyta and chlorophyta, with 21 species each. The remaining phytoplankton groups had relatively few species, with 5, 3, 2, and 1 species each. Phytoplankton were divided into 14 functional groups (*Fig. 2*): C, D, F, H1, J, L0, MP, N, P, T, W1, X1, X2, and Y. The main species, habitat characteristics, and functional group assignments are shown in *Table 3*.

Spatiotemporal differences in biomass of phytoplankton functional groups

When the biomass ratio at a sampling site exceeded 40% of the total biomass, we defined it as the dominant functional group of phytoplankton in the Ashi River Basin. The results identified six dominant functional groups: C, D, J, MP, N, and Y. The distribution of phytoplankton functional groups across sampling points is shown in *Figures 3–5*. The predominant group in spring was the phytoplankton functional group D. At sampling point S05, the biomass ratio of the dominant functional group D exceeded 90%. The predominant groups in summer were the phytoplankton functional groups D and Y. S04, S09, S13, S18, and S22 were all dominated by functional group D. S01, S02, and S27 were dominated by functional group Y. In autumn, phytoplankton biomass was mainly dominated by functional group D.

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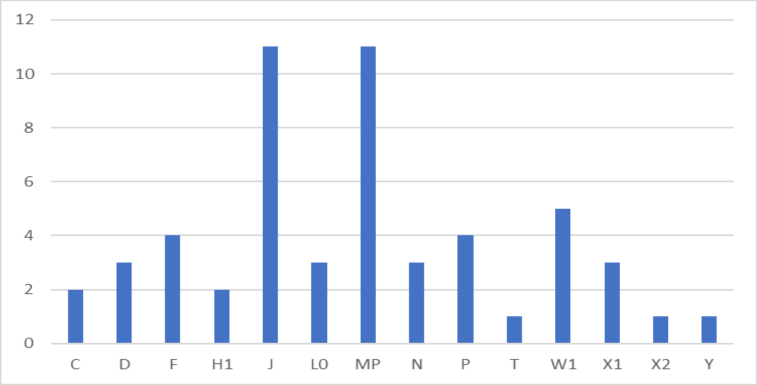

Figure 2. *The composition species composition of the functional phytoplankton group in the Ashi River basin*

Table 3. *Appendix list of phytoplankton functional groups in the Ashi River basin*

FGs	Genera	Habitat characteristics
C	*Cyclotella meneghiniana; Asterionella formosa*	Mixed/medium-small lakes
D	*Synedra acus; Synedra a f finis Kutz; Synedra ulna*	Shallow, turbid water bodies (including rivers)
F	*Dictyosphaerium pulchellum Nag; Dictyosphaerium pulchellum; Westella botryoides; Selenastrum gracile*	Mesotrophic or eutrophic, homogeneous, clear deep-water lakes
H1	*Aphanizomenon flosaquae; Anabaena variabilis*	Shallow, mixed eutrophic water bodies
J	*Dinobryon divergens; Chodatella quadriseta; Coelastrum sphaericum Nag; Coelastrum microporum; Crucigeniella rectangularis; Crucigenia quadrata; S. armatus var. boglariensis f. bicaudatus; Scenedesmus bijuga; Scenedesmus dimorphus; Scenedesmus quadricauda; Scenedesmus arcuatus*	Mesotrophic water bodies
L0	*Gyrosigma acuminatum; Amphora ovalis; Merismopedia minima*	Shallow mesotrophic lakes, frequently disturbed
MP	*Diatoma vulgare; Surirella ovata; Surirella elegans; S. linearis; Surirella linearis; Gomphonema acuminatun var. coronata; Gomphonema constrictum; Gomphonema constrictum var. capitata; (Nitzch.) Ehr.; Navicula exigua; Cymbella ventricosa*	Thermocline of eutrophic water bodies
N	*Tabellaria sp.; Cosmarium obtusatum; Staurastrum gracile*	Water bodies receiving organic matter from agricultural or domestic sewage
P	*Fragilaria brevistriata; Fragilaria ca pucina; Melosira granulata; Closterium kützingii*	Mixed layer of eutrophic water bodies
T	*Tribonema* sp.	Shallow water bodies ranging from mesotrophic to highly eutrophic
W1	*Phacus acuminatus Stok; Euglena viridis; Euglena pisciformis; Strombomonas schauinslandii; Euglena gasterosteus*	All water bodies with low grazing intensity
X1	*Ankistrodesmus falcatus; Ankistrodesmus angustus; Ankistrodesmus acicularis*	All water bodies with low grazing intensity
X2	*Chroomonas acuta*	Continuous or semi-continuous mesotrophic mixed water bodies
Y	*Cryptomonas ovata*	Continuous mixed layer, epilimnion of deep-water lakes that are clear in summer

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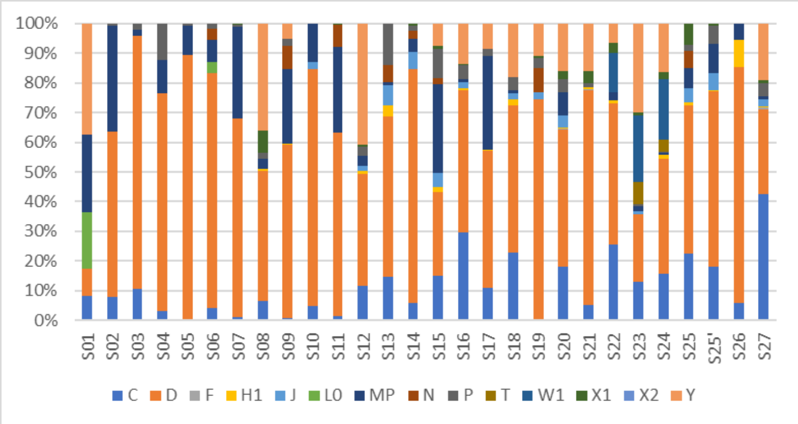

Figure 3. *The relative biomass distribution of phytoplankton functional groups in the Ashi River in spring*

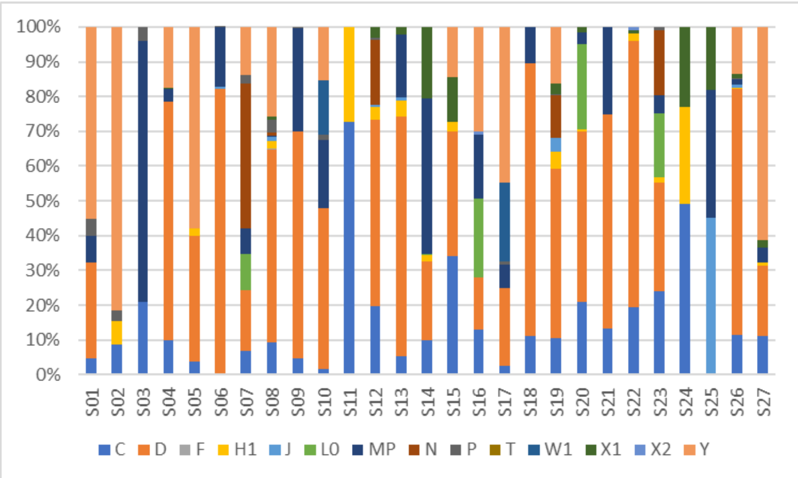

Figure 4. *The relative biomass distribution of phytoplankton functional groups in the Ashi River in summer*

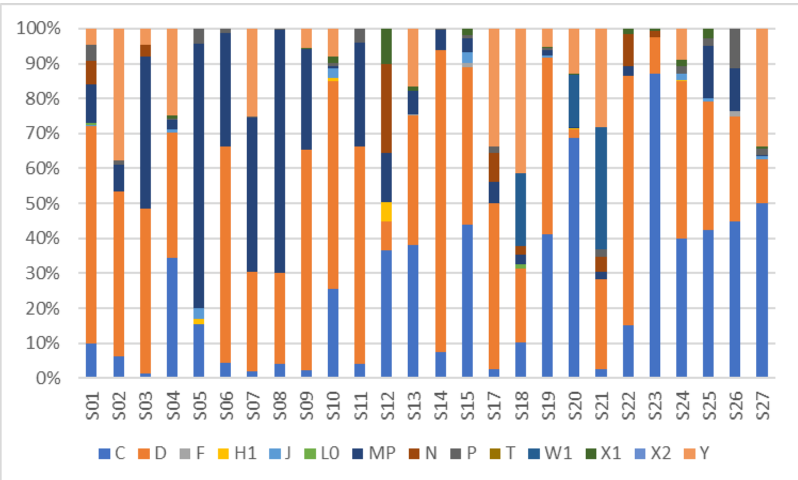

Figure 5. *The relative biomass distribution of phytoplankton functional groups in the Ashi River in autumn*

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Relationship between the dominant functional groups of phytoplankton and environmental factors

Since the standard deviation (SD) was 0.408, the redundancy analysis (RDA) method was selected. The first two axes in the RDA results collectively explained 37.6% of the cumulative variance in phytoplankton functional groups and 92.2% of the cumulative variance in environmental factors related to the ecological processes of the water environment. As shown in *Figure 6*, Chl-a and COD_{Mn} were the main factors promoting the growth of phytoplankton functional group C. Cl^- and BOD_5 were the main environmental factors promoting the growth of phytoplankton functional group Y. DO and pH were the factors promoting the growth and development of phytoplankton functional group D. Conversely, NH_4^+-N, NTU, and WT were the main environmental factors inhibiting the functional groups of dominant phytoplankton.

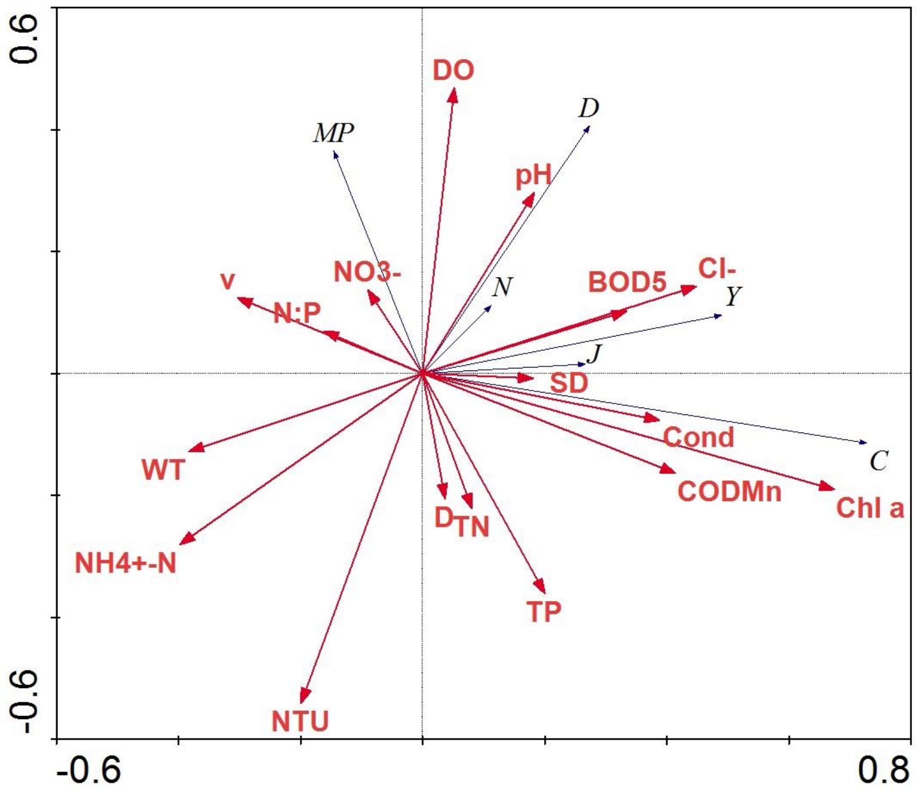

Figure 6. *Redundancy analysis (RDA) biplot ordination diagram showing phytoplankton functional groups (represented by blue lines with black labels) and environmental factor variables (represented by red lines with red labels) in the Ashi River basin*

Discussion

Characteristics of phytoplankton functional groups

Phytoplankton functional groups are classifications of phytoplankton that can adapt to specific habitat characteristics and share similar sensitivities, grouped together to better reflect the relationship between phytoplankton and habitat characteristics. Therefore, phytoplankton functional groups are more applicable and representative than individual species or populations in reflecting the characteristics of water sources (Zanon et al., 2021). During the survey period, 14 phytoplankton functional groups

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were identified in the Ashi River basin, among which 6 were dominant: C, D, J, MP, N, and Y. Most functional groups in the Ashi River basin are adapted to shallow, cloudy, or mixed small lakes, consistent with the actual water depth of approximately 1 meter. Functional groups C, D, J, MP, and Y are adapted to mixed water environments with high fluidity and turbidity. In 2019, the rising water level of the Songhua River extended into the Ashi River basin, resulting in high water mobility and turbidity, which may explain why these functional groups became dominant. In addition, the J, MP, and N functional groups commonly prefer water bodies with moderate to eutrophic conditions, consistent with the nutrient status of the Ashi River basin.

Over the three seasons, the dominant functional groups exhibited a seasonal succession pattern: D in spring, D and Y in summer, and D in autumn. Among them, the dominant functional group D primarily occurs in shallow and turbid water bodies (including rivers), making it more likely to dominate in environments with sediment bottoms and high turbidity. Functional group D is composed of *Synedra acus* and Kütz *Synedraaffinis Kutz* from the Bacillariophyta. In 2019, a 50-year major flood occurred in the Ashi River basin, characterized by heavy rainfall and high water levels. Some studies have shown that functional group D thrives in turbid water environments that are significantly affected and frequently disturbed by rainwater erosion (Devercelli and O'Farrell, 2012). Only in summer did functional group Y become dominant, primarily occurring in water bodies with low light and low grazing intensity, with *Cryptomonas ovata* as the main species. Studies indicate that the optimal growth temperature for *Cryptomonas ovata* ranges from 20℃ to 25℃, and it thrives in water environments with low flow velocity, low light intensity, and low grazing pressure (Melles et al., 2023).

Relationship between phytoplankton environmental groups and environmental factors

Phytoplankton functional groups are influenced by water temperature, light, and nutrient concentration, and their abundance varies with environmental changes (Xianjing et al., 2023). In this study, WT, NTU, SD, pH, DO, Cl^-, NH_4^+-N, TP, and BOD_5 were the main environmental factors affecting the biomass of dominant phytoplankton functional groups in the water source, and this conclusion is consistent with findings from related studies (Bone et al., 2022). Cl^-, COD_{Mn}, and BOD_5 are essential for maintaining water quality and phytoplankton reproduction, and they are also important factors influencing the composition and distribution of functional groups (Huijuan, 2023). In this study, Chl-a showed the strongest positive correlation, while NH_4^+-N showed the strongest negative correlation. Chlorophyll and chemO are water environmental factors significantly positively correlated with phytoplankton functional group C. Functional group C is primarily composed of diatoms, which can tolerate low light conditions for extended periods. Cl^- and BOD_5 are water environmental factors significantly positively correlated with phytoplankton functional group Y. Functional group Y primarily consists of cryptophytes, which can tolerate low light conditions for extended periods. This result is consistent with findings on phytoplankton functional groups in cold regions of China (Anquan et al., 2015). DO and pH are factors promoting the growth and development of phytoplankton functional group D. Phytoplankton functional group D, primarily composed of Bacillariophyta, is commonly found in shallow water bodies with low nutrient levels and poor visibility, suggesting that the river can be classified into temperate regions based on the characteristics of this functional group.

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In addition, SD, NTU, and other factors also differentially affect the distribution of functional groups (Jiachen, 2020). The SD in the Ashi River basin is relatively low, with high amounts of suspended matter and sediment. This situation is primarily caused by the combined effects of phytoplankton and organic suspended debris. Based on the analysis of functional group distribution, phytoplankton functional groups were positively correlated with SD and negatively correlated with NTU. This indicates that SD promotes phytoplankton growth, while NTU suppresses their reproduction and spatial distribution. WT regulates the enzyme activity involved in phytoplankton photosynthesis and respiration, directly influencing their growth and reproduction rates (Liu, 2024). The Ashi River basin is located in a temperate region. Under global warming, the accumulated temperature of rivers is expected to increase slightly, potentially leading to algal blooms in temperate regions and adversely affecting water environment health.

Water resource management strategy

According to literature reports, agricultural non-point source pollution in the Ashi River basin accounts for 60% to 80% of the total pollutant load, with TP and TN being the main pollutants. The planting structure near the Ashi River basin is suboptimal, with a generally low level of agricultural productivity. The production methods remain relatively extensive, and the development of green ecological industries is still in its early stages. Additionally, the prevention and control of non-point source pollution, including pesticide and fertilizer runoff, livestock pollution, and rural domestic pollution, are ineffective.

Aquatic biodiversity conservation strategies should be implemented. Based on the conservation needs of aquatic biodiversity in different regions, necessary auxiliary measures should be implemented for rare, endangered, and endemic species to ensure the size of supplementary populations, promote population recovery, and maintain genetic diversity (Xie, 2021). For river sections without specific protection requirements, human disturbance should be minimized, and the natural form of the river and its banks should be preserved. By leveraging existing conditions, channelized rivers should be transformed, healthy and natural meandering river courses should be restored, natural deep pools, shoals, and floodplains should be created, and the natural habitats of tributaries should be rehabilitated. The protection of important aquatic habitats should be strengthened, and the structure and function of tributary ecosystems should be further enhanced. Aquatic biodiversity, ecosystem integrity, and endemism should be maintained, while promoting the recovery of rare and endemic species populations and the preservation of genetic diversity. For key tributary habitats characterized by high flow rates, diverse habitat types, and the presence of various rare and endemic fish species, priority should be given to the protection and restoration of fish habitats. Efforts should be made to improve the biological community structure and habitat conditions to sustain natural populations.

Conclusions

In this current study, a total of 54 species of phytoplankton species belonging to 14 functional groups (C, D, F, H1, J, L0, MP, N, P, T, W1, X1, X2 and Y) were identified in the Ashi River basin, northeast China. There were 6 dominant functional groups: C, D, J, MP, N and Y. The seasonal dominant functional group succession: D

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(spring)→D/Y (summer)→D (autumn). The result of one-way ANOVA test and RDA showed that WT, NTU, SD, pH, DO, Cl^-, NH_4^+-N, TP, BOD_5, TN and COD_{Mn} were the major factors that influencing phytoplankton functional groups in the Ashi River basin, northeast China. RDA result revealed that Chl-a and COD_{Mn} were positive correlated with the functional group C; Cl^- and BOD_5 were positive correlated with the functional group Y; DO and pH were positive correlated with the functional group D; NH_4^+-N, NTU and WT were negatively correlated with the dominant functional groups. This study revealed that the phytoplankton functional groups followed certain predictable pattern in the seasonal and spatial gradient. Therefore, it is recommended to implement an aquatic biodiversity conservation strategy. To improve the biological community structure and habitat structure to maintain the natural population.

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