SURVEY AND ANALYSIS OF PHYTOPLANKTON COMMUNITY STRUCTURE IN THE NORTH YELLOW SEA IN 2023

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Abstract. This article uses the Utermöhl method to identify and analyze 300 samples of phytoplankton from the North Yellow Sea obtained in the summer of 2023. A total of 105 species (excluding unidentified species) belonging to 57 genera and 3 phyla of phytoplankton were identified, including 73 species in 38 genera of diatoms, 30 species in 17 genera of dinoflagellas, and 2 species in 2 genera of cyanobacteria. The community composition is mainly composed of diatoms, followed by dinoflagellates and then golden algae. The ecological types of phytoplankton in the surveyed sea area are mainly temperate nearshore, with dominant species including *Dictyocha fibula, Gymnodinium simplex, Gyrodinium spirale, Diploneis bombus, Paralia sulcata,* and *Thalassionema nitzschioides*. In this survey, *Dictyocha fibula* appears as an absolute dominant species. The abundance of phytoplankton cells ranges from 0.0381×10^3~33.3×10^3 cells · L^{-1}, with an average value of 2.34×10^3 cells · L^{-1}; The abundance of surface phytoplankton cells gradually decreases from nearshore to offshore, with the highest value reaching 33.3×10^3 cells · L^{-1} in the surface water near the western coast of the South Yellow Sea. High abundance areas also appeared in the southeastern part of the survey area near the open sea. The Shannon Wiener diversity index is high in the northern and southern parts of the survey area, while the Pielou evenness index shows a high value area in the eastern part.
Keywords: *phytoplankton, community structure, North Yellow Sea, CCA analysis, historical comparison, Utermöhl method, ecological characteristics, diversity index distribution*

Introduction

As primary producers of marine ecosystems, phytoplankton play a crucial role in material circulation and energy flow. At the same time, certain species can also serve as indicator species for ocean currents, water masses, or cause red tides. Changes in phytoplankton community structure have also become important indicators of marine environmental change. The study of phytoplankton is of great significance for understanding and mastering the status, variation patterns, and replenishment mechanisms of marine biological resources (Li, 2004). In addition, phytoplankton communities can have an impact on the marine ecological environment, and they play a crucial role in changing carbon flux, cloud albedo, seawater luminous flux, and heat flux (Sun et al., 2002). Previously, research on phytoplankton in the Yellow Sea area of China mostly used trawl sampling analysis (Lin and Lin, 2007; Wang, 2001, 2003), which easily overlooked small particle size phytoplankton and could not obtain information on their vertical distribution in the water body. This article uses the Utermöhl (Sun, 2002) analysis method to analyze the distribution characteristics of phytoplankton communities in the North Yellow Sea area in August 2023. At the same time, the statistical method Canonical correspondence analysis (CCA) is used to analyze the correlation between phytoplankton data and environmental factors in the survey area, in order to provide basic information for the study of ecosystem structure and function in the Yellow Sea.

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Materials and Methods

Station setting and sampling method

From July 29, 2023 to August 7, 2023, we conducted a marine survey in the central part of the North Yellow Sea (34.0º N to 36.5º N, 120.0º E to 124.5º E). In this survey, we set up a total of 45 stations, as shown in *Figure 1*. The survey dates for each station are shown in *Table 1*. The sampling level of each station follows the sampling principle of the standard layer in the "Ocean Survey Specification" (National Marine Standards and Metrology Center, 2007), that is, for stations with a water depth of less than 60 meters, three layers were taken: surface, middle, and bottom layers; For stations with a water depth greater than 60 meters, four layers were taken: surface, subsurface, middle, and bottom. We collected 250 mL of phytoplankton water samples from each level and added them to bottles made of polyethylene, then immediately fixed them with neutral formalin (final volume fraction is 1% to 2%). We obtained a total of 211 samples throughout the entire investigation process.

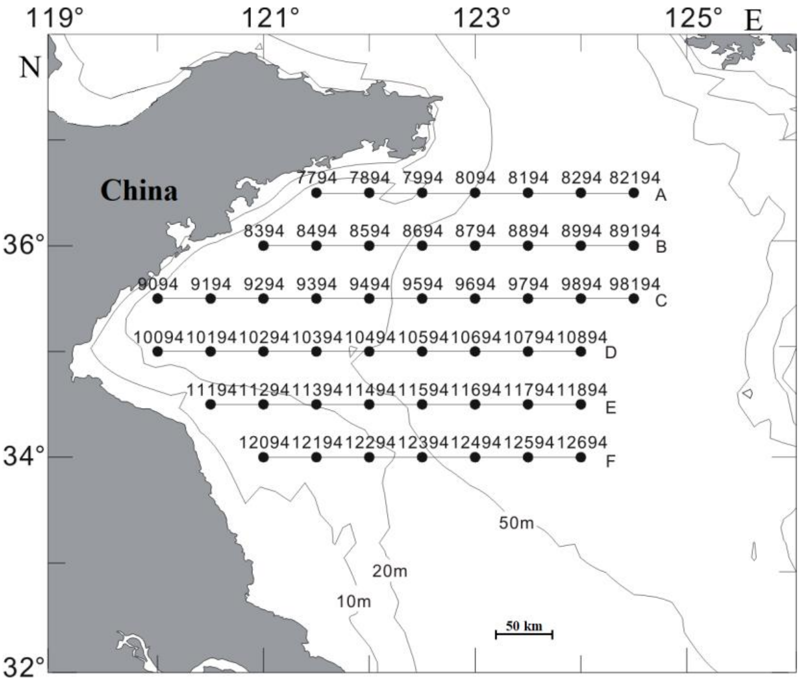

Figure 1. *Study area and sampling stations*

Table 1. *Survey dates of sampling stations*

Date	Station
7.29	7794,7894,7994,8094,8194
7.30	8294,82194,8394
7.31	8494,8594,8694,8794,8894
8.1	8994,89194,9094,9194
8.2	9294,9394,9494,9594,9694,9794
8.3	9894,98194,10094,10194
8.4	10294,10394,10494,10594,10694,10794
8.5	10894,11194,11294,11394
8.6	11494,11594,11694,11794,11894
8.7	12094,12194,12294,12394,12494,12594,12694

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Sample analysis method

Samples were subjected to phytoplankton species identification and cell abundance analysis in the laboratory. We analyzed the samples using the internationally recognized Utermöhl method. 27 mL of phytoplankton samples were taken and placed in the Ultramöhl counting box of Hydrobios, settled for 24 hours, and using an AO inverted microscope to identify and count phytoplankton species at 200 or 400 times. Sun (2002) for cell abundance statistics and error handling.

Nutrient samples (nitrate NO_3-N, nitrite NO_2-N, ammonia nitrogen NH_4-N, phosphate SRP, and silicate DSi) are immediately filtered after collection, using a pre HCL treated acetate fiber filter membrane. The determination of NH4-N was carried out using a 722 spectrophotometer; The determination of NO_3-N, NO_2-N, and SRP was carried out using the AA3 nutrient automatic analyzer produced by the German company "Bran+Luebbe"; The determination of DSi was carried out using Tri-223 three synchronous nutrient automatic analyzer that manufactured by HACH in the United States.

Analysis of phytoplankton community structure

The analysis of phytoplankton communities adopts the Shannon Wiener species diversity index (Shannon, 1951), Pielou evenness index (Pielou, 1984), and dominance index (Simpson, 1949), as follows:

The formula for calculating the Shannon Wiener index (*H'*) is:

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \qquad \text{(Eq.1)}$$

The formula for calculating the Pielou's index (*J*) is:

$$J = \frac{H'}{\log_2 S} \qquad \text{(Eq.2)}$$

The calculation formula for dominance (*Y*) is as follows:

$$Y = \frac{n_i}{N} f_i \qquad \text{(Eq.3)}$$

In the above equation, N represents the total number of individuals of all species in the collected sample; S is the total number of species in the sample; n_i is the total number of individuals in the *i*th species; $p_i=n_i/N$, which is the probability of cell abundance of the *i*th species in the sample; f_i is the frequency at which the species appears in each sample.

Surfer 24 was applied for plotting the abundance and diversity distribution data.

Canonical correspondence analysis (CCA) of phytoplankton and environmental factors was conducted using MVSP3.1 to obtain a biplot of the abundance of major dominant species and environmental factors.

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Results and Discussion

Phytoplankton species composition

In this survey, a total of 105 species (excluding unidentified species) belonging to 57 genera and 3 phyla of phytoplankton were identified, including 73 species in 38 genera of diatoms, 30 species in 17 genera of dinoflagellas, and 2 species in 2 genera of cyanobacteria.

The main species of phytoplankton are temperate nearshore species, with a larger proportion being *Dictyocha fibula*, *Gymnodinium sp.*, *Gyrodinium spirale*, *Diploneis bombus*, *Paralia sulcata*, and others.

The frequency and dominance of each dominant species are shown in *Table 2*. In addition, *Skeletonema* spp. is also a common species found in the southern and nearshore waters of the Shandong Peninsula, while *Cossinodis* spp. and *Thalassiosira* spp. are almost all distributed in most of the surveyed waters.

Table 2. *Phytoplankton dominant species in the survey area in summer of 2023*

Latin name	Frequency of occurrence (f_i)	Dominance (Y)
Dictyocha fibula	0.663	0.103
Gymnodinium sp.	0.611	0.047
Gyrodinium spirale	0.497	0.026
Diopploneis bombus	0.294	0.010
Paralia sulcata	0.246	0.019

Cell abundance of phytoplankton

Surface distribution of cell abundance

The overall distribution of surface phytoplankton cell abundance is shown in *Figure 2*, with cell abundance ranging from 0.0381 to 33.3 × 10^3 cells · L^{-1}, with an average value of 2.34 × 10^3 cells · L^{-1}. Among them, diatoms account for the largest proportion of phytoplankton cell abundance, at 0.0160 × 10^3-31.0 × 10^3 cells · L^{-1}, with an average value of 1.67 × 10^3 cells · L^{-1}, similar to the overall distribution of phytoplankton cell abundance; Next is dinoflagellate, with an abundance of 0.0120 × 10^3-13.3 × 10^3 cells · L^{-1}, with an average value of 1.18 × 10^3 cells · L^{-1}; The frequency of golden algae occurrence has increased significantly compared to previous years, with an abundance of 0.0100 × 10^3-11.9 × 10^3 cells · L^{-1}, with an average value of 0.420 × 10^3 cells · L^{-1}.

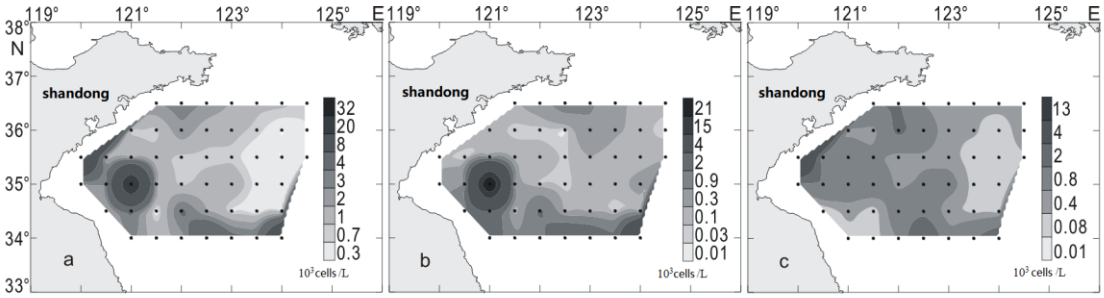

Figure 2. *The distribution of surface phytoplankton cell abundance (Unit: 10^3 cells/L), a. phytoplankton; b. diatom; c. dinoflagellates*

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The overall trend of cell abundance distribution is gradually decreasing from nearshore to offshore, with high value areas appearing along the coast of northern Jiangsu. Among them, the surface phytoplankton cell abundance at station 10294 reached the highest value of 32.3×10^3 cells · L^{-1} in the survey area, also reaching 25.4×10^3 cells · L^{-1} at station 9094, the relatively high abundance is mainly due to the abundant nutrients and light in the nearshore areas, such as the *Dictyocha fibula*, *Gymnodinium* sp., *Chaetoceros* spp., and *Pseudo-nitzschia pungens*.
In addition, there are also high cell abundance areas at station 12694 in the open sea, with a surface cell abundance of 19.1×10^3 cells · L^{-1}, with higher relative abundance being *Chaetoceros* spp. and *Leptocylindrus danicus*, which are largely influenced by upwelling and the Yangtze River's freshwater, transport nutrients to the sea area and promote the growth of phytoplankton (Zou, 2001).

The low abundance of phytoplankton in the central eastern and northern parts of the survey area is largely due to an important marine phenomenon in the North Yellow Sea shelf area - the Yellow Sea Cold Water Mass. July was the peak of its intensity. Previous studies have shown that the Yellow Sea cold water mass has a significant impact on the vertical distribution of seawater chemical elements and planktonic ecosystems. Due to the presence of cold-water masses, summer has become the strongest period in the thermocline, thereby blocking the upward transport of nutrients. At the same time, the nutrients in the upper water body are almost depleted due to the uptake of phytoplankton, thereby limiting the reproduction and growth of phytoplankton (Yu et al., 2006).

Overall, diatoms account for the largest proportion of phytoplankton cell abundance in the survey area, and their abundance distribution determines the overall distribution of phytoplankton cell abundance; But dinoflagellates also account for a certain proportion, and even have higher abundance at certain stations, such as at station 9094, where the abundance of dinoflagellate cells on the surface reaches 13.3×10^3 cells · L^{-1}. The *Dictyocha fibula* found in the phylum Chrysophyta in this survey has become a species with higher abundance at many sites.

Vertical distribution of phytoplankton cell abundance

Plot the cell abundance of six parallel sections A, B, C, D, E, and F in the survey area (*Figure 3*) to characterize the vertical distribution characteristics of phytoplankton in the survey area. Overall, the distribution characteristics of phytoplankton in these six sections decrease with increasing water depth, gradually decreasing from nearshore to offshore. However, in sections B, C, and E, the abundance of phytoplankton cells in the nearshore area increases with the increase of water depth. This is because throughout the summer after the spring bloom in the North Yellow Sea, the surface nutrients in the central sea area of the North Yellow Sea are depleted, and the presence of the thermocline hinders the upward transfer of nutrients in the lower layers. In the horizontal direction, the flow field has a circulation structure, with less exchange between the central and boundary waters. At this time, nutrients are the main limiting factor for the growth of upper layer phytoplankton. Due to the lack of nutrients, the cell abundance is low. However, in the lower part of the thermocline, there is abundant nutrients and appropriate lighting, and the water body is stable, which is more conducive to the growth of phytoplankton (Wei et al., 2002).

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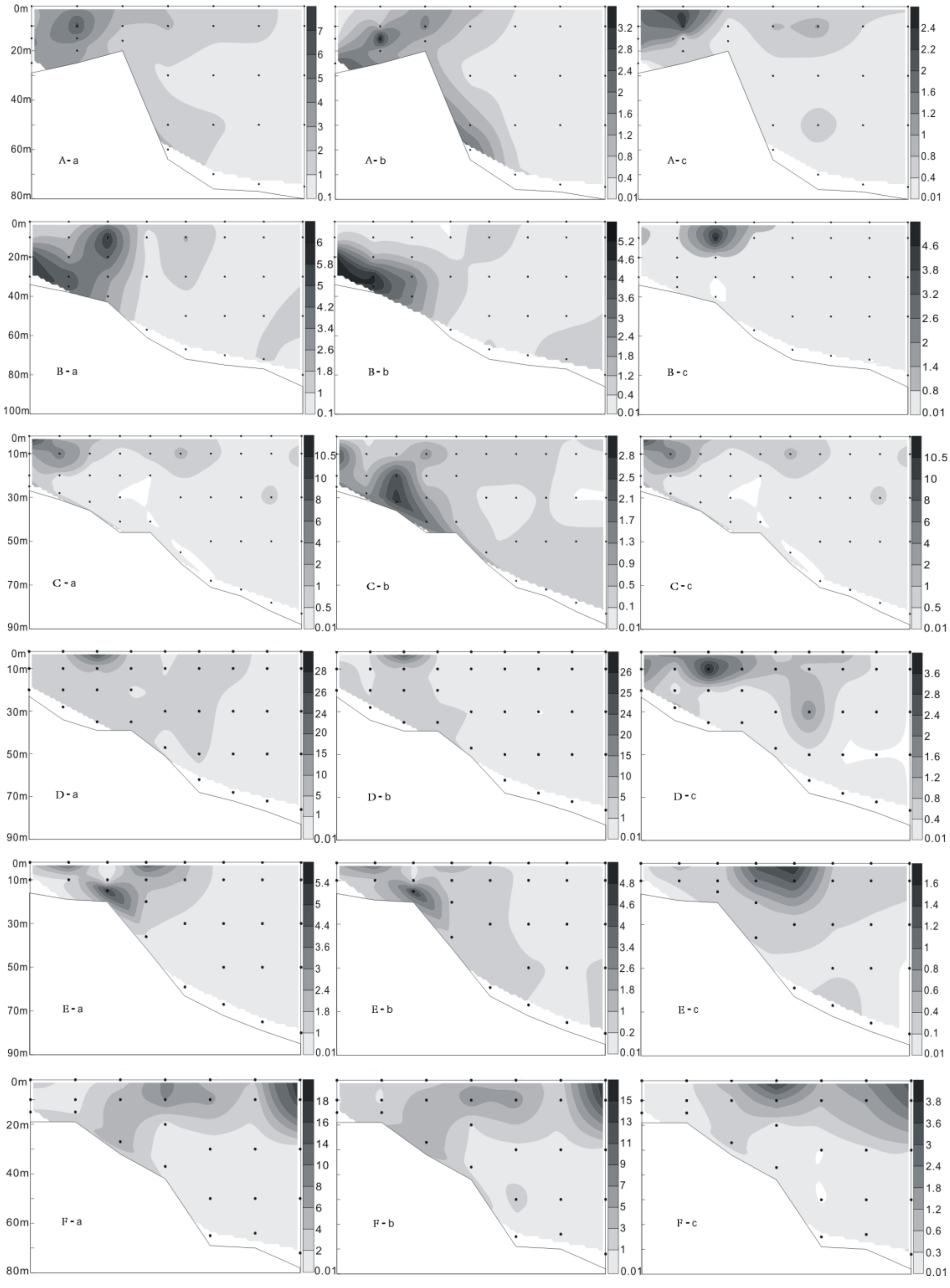

Figure 3. *The vertical distribution of phytoplankton cell abundance along sections in survey area (Unit: 10^3cells/L), a: phytoplankton; b: diatom; c: dinoflagellates*

Ecological characteristics of phytoplankton in the sea area

The investigation of phytoplankton in the sea area mainly includes coastal wide temperature and wide salinity species, as well as a certain number of exocean and benthic or attached species (Jin, 1965). *Chaetoceros affinis*, *Chaetoceros debilis*, and other species in the genus Chaetoceros, as well as *Chlamydomonas aeruginosa* and *Dictylum brighwellii*, belong to coastal broad-temperature species. Both *Pleurosigma pelagicum* and *Cylindrotheca closterium* belong to benthic species.

As a dominant species, there are many species of the genus Trichophyta, mainly nearshore temperate and tropical species. There are also found that the diamond shaped seaweed is a widely distributed global species, while other species are widely distributed and coastal species with a wide range of temperature and salt tolerance. There are also a few species that belong to the exotic species, such as *Chaetoceros convolutus*, *Cossinodis astrophorus*, and *Rhizosolenia styliformis*, which are tropical and subtropical species. The discovered weak *Guinardia delicatula* is a nearshore species in the southern temperate zone, often found in warm seas.

Diversity index distribution of phytoplankton communities

The Shannon Wiener index of phytoplankton diversity in the surveyed sea area ranges from 0.863 to 3.56, with an average value of 2.49. The overall distribution is relatively uniform and there are no particularly high or low value areas. However, there are two relatively high value areas on the southern coast of the Shandong Peninsula and the southern part of the North Yellow Sea, reaching 3.45 and 3.56, respectively. In the northeast of the survey area, a low value area appeared, with a value of 0.863. The Pielou evenness index of phytoplankton ranges from 0.460 to 0.967, with an average value of 0.581. The evenness index gradually increases from nearshore to ocean, with high value areas located in the eastern part of the survey area, while low value areas appear in the nearshore position in the northern part of the survey area (*Figure 4*).

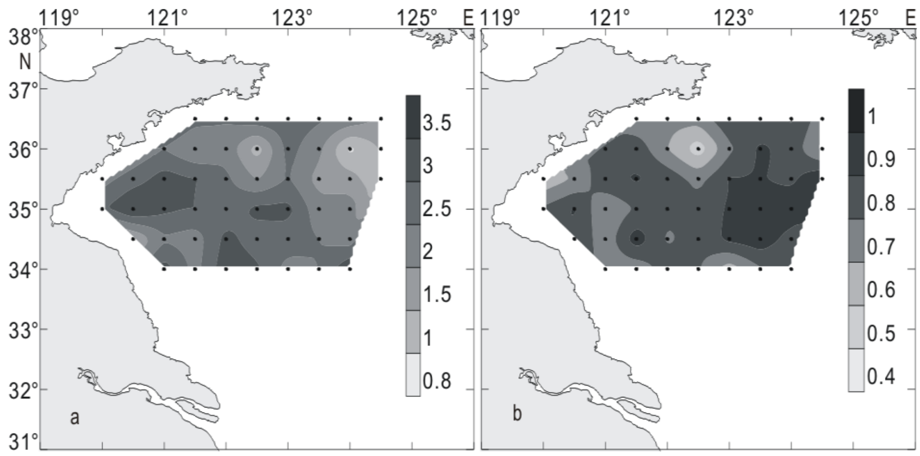

Figure 4. *Distribution of diversity indices of surface water in survey area (a. Shannon-Wiener index; b. Pielou's evenness index)*

Correlation analysis between dominant species of phytoplankton and environmental factors

The CCA analysis method (Jongman et al., 1995) was used to analyze the correspondence between functional groups and environmental variables (*Figure 5*), and a correlation analysis was conducted on the top ten species in terms of relative abundance in this survey.

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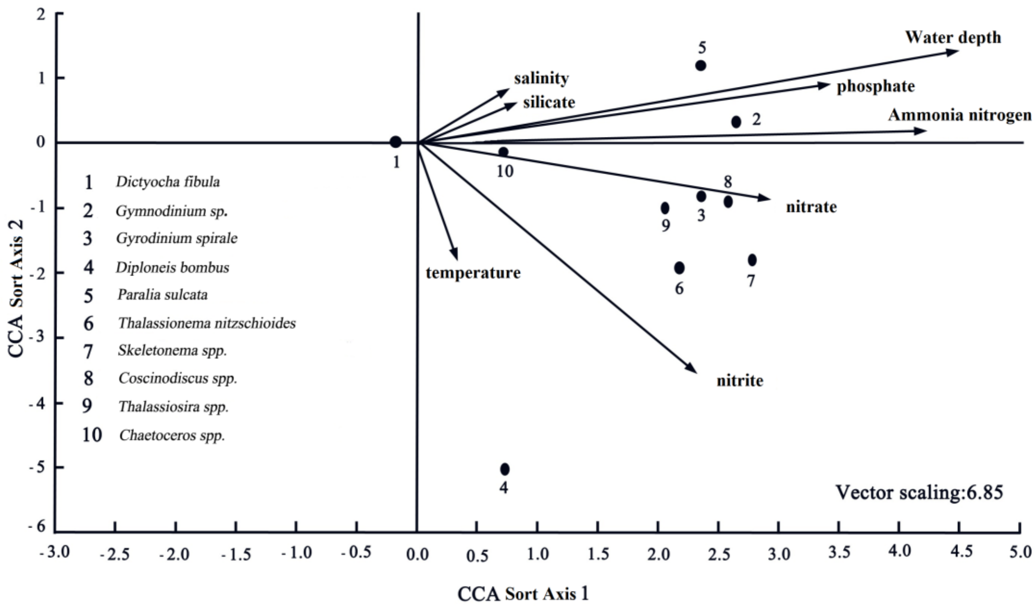

Figure 5. *Biplots of dominant species abundances and environmental variables in the survey area*

As shown in *Figure 5*, ammonia nitrogen, nitrate, phosphate, etc. are close to sorting axis 1, so nutrient conditions are important factors affecting the environmental conditions of the sea area. On the sorting axis, the abundance of *Dictyocha fibula* is close to the center of the sorting chart, but the correlation between its abundance and environmental factors is not significant; However, there is a certain positive correlation between the depth of water and the abundance of *Paralia sulcata*, confirming that its high values are mainly distributed in the bottom layer. There is a significant positive correlation between *Gymnodinium* sp. and ammonia nitrogen, phosphate, and water depth, and the concentrations of ammonia nitrogen and phosphate are relatively high here; Meanwhile, the correlation between *Gymnodinium* sp. and temperature is not significant, and the optimal temperature value may be low. *Gyrodinium spirale*, *Thalassionema nitzschioides*, *Skeletonema* spp., *Coscinodiscus* spp., and *Chaetoceros* spp. are all positively correlated with nitrate and nitrite, with *Gyrodinium spirale*, *Coscinodiscus* spp., and *Chaetoceros* spp. showing a highly significant positive correlation with nitrate. The optimal nitrate concentration for the three is highest for *Coscinodiscus* spp. and lowest for *Chaetoceros* spp.. The relationship between *Diploneis bombus* and nutrients is not close, and it is positively correlated with temperature. Temperature may be an important factor affecting its abundance.

Comparative analysis of this study and historical data

The comparison between this survey and existing historical data is shown in *Table 3*. Historical data shows that the species composition of phytoplankton communities in the Yellow Sea is mainly composed of diatoms and dinoflagellas, with diatoms being the predominant species. However, there are significant changes in the dominant species of phytoplankton communities in different sampling seasons and regions. One of the dominant species discovered in this survey is the *Dictyocha fibula* in the phylum Chrysophyta, which has not been recorded in the past. In this survey, *Gymnodinium* sp.

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and *Gyrodinium spirale* also appeared as dominant species, both belonging to the phylum Dinoflagellates. In all previous investigations, the dominant species of *Paralia sulcata* has emerged, and its distribution in the sea area is relatively stable. However, based on comprehensive historical and current survey data, it is currently insufficient to have a comprehensive understanding of the phytoplankton communities in the North Yellow Sea and even the entire Yellow Sea.

Table 3. *Comparisons of historical data with this study*

Survey area	Investigation time	method	community composition	Advantages (ranked in the top three)	References cited
33°00′~36°30′N 121°00′~124°30′E	2009-06	Water sample collection	51 genera and 73 species	Prorocentrum dentatum Pseudo-nitzschia delicatissima Paralia sulcata	Tian (2011)
36°00′~40°00′N 121°00′~125°00′E	2011-11	Water sample collection	31 genera and 64 species	Paralia sulcata coscinodiscus oculus-iridis Ceratium tripos	Guo et al. (2013)
36°00′~40°00′N 121°00′~125°00′E	2011-06	Water sample collection	23 genera and 36 species	Prorocentrum minimum Paralia sulcata Coscinodiscus spp.	Zhang (2014)
34°00′~36°30′N 120°00′~124°30′E	2023-07—08	Water sample collection	60 genera and 114 species	Dictyocha fibula Gymnodinium sp. Gyrodinium spirale	this paper

Discussion

The North Yellow Sea is an important shallow sea on China's continental shelf, characterized by a hydrological phenomenon of the Yellow Sea cold water mass, and has received widespread international attention. The Yellow Sea cold water mass forms in spring and matures in summer. In this study, the bottom water temperature in the investigated area in summer was lower than 7℃, forming a stable cold-water zone below the thermocline. Due to the presence of cold-water masses, summer is the strongest period for the thermocline, thereby blocking the upward transport of nutrients and maintaining a high concentration of nutrients inside. However, the strong temperature and density of the thermocline in summer hinder the transport of nutrients from the lower layer to the true light layer. The nutrients in the upper layer of water are almost depleted due to the uptake of phytoplankton, thereby limiting their reproduction and growth.

The Yellow Sea cold water mass leads to changes in nutrient structure, resulting in the distribution characteristics of phytoplankton in this study: in vertical distribution, the abundance is higher in the middle layer, and lower in the upper and lower layers; In terms of cross-sectional distribution, the higher abundance values mainly occur in the nearshore and middle layers.

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Conclusion

A survey conducted in the central part of the North Yellow Sea in the summer of 2023 showed that diatoms dominate the phytoplankton community, followed by dinoflagellates. The cell abundance of phytoplankton is between 0.0381×10^3~33.3×10^3 cells · L^{-1}. The dominant species in the phylum Chrysophyta is the *Dictyocha fibula*, which has not been recorded in previous investigations. The distribution of phytoplankton cell abundance in the survey area shows a clear regional pattern. The phytoplankton cell abundance in the nearshore stations of the North Yellow Sea is significantly higher than that in the offshore stations. The high value areas are along the coast of northern Jiangsu and in the southeast of the North Yellow Sea. The abundance of cells generally decreases vertically from the surface to the deeper layers.

The diversity index of phytoplankton ranges from 0.863 to 3.56, and the Pielou evenness index ranges from 0.460 to 0.967. The CCA analysis results show that the main factor affecting the abundance distribution of dominant species of phytoplankton is nutrient, and the correlation with salinity and temperature is not significant. The levels of nutrients such as phosphorus, nitrogen, and silicon are important factors affecting the structure of phytoplankton communities.

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