

Size Structure of Autumn Phytoplankton and Its Influencing Factors in Zhangzi Island and Adjacent Waters: Postprint

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Abstract

A cruise survey was conducted in the Zhangzi Island and adjacent waters in October 2015 to investigate the spatial distribution characteristics of phytoplankton size structure and its environmental driving factors. The results showed that in autumn, the ranges of total chlorophyll-a (Chl-a) concentration in the surface layer and Chl-a concentrations of micro- (>20 μm), nano- (2-20 μm), and pico- (0.45-2 μm) phytoplankton were 0.52-1.25, 0.03-0.81, 0.33-0.91, and 0-0.09 g/L, respectively, with average concentrations of 0.76, 0.19, 0.53, and 0.03 g/L, respectively. The contributions to total Chl-a were 23.77%, 72.26%, and 3.98% for micro-, nano-, and pico-phytoplankton, respectively. In the bottom layer, the ranges of total Chl-a and Chl-a concentrations of micro- (>20 μm) and nano- (2-20 μm) phytoplankton were 0.14-1.5, 0.04-1.04, and 0.08-0.47 g/L, respectively, with average concentrations of 0.46, 0.22, and 0.24 g/L, respectively, contributing 41.46% and 58.50% to the total Chl-a. Regarding vertical distribution, total Chl-a concentration showed a pattern of surface layer > bottom layer; micro-phytoplankton exhibited relatively uniform vertical distribution; nano-phytoplankton showed a pattern of surface layer > bottom layer; pico-phytoplankton showed a pattern of surface layer > bottom layer and remained at low levels in both surface and bottom layers. In autumn, nano-phytoplankton (2-20 μm) concentration in the surface layer was positively correlated with salinity. In the bottom layer, total Chl-a concentration was positively correlated with phosphate concentration; micro-phytoplankton (>20 μm) concentration showed positive correlations with both phosphate and silicate concentrations; nano-phytoplankton (2-20 μm) concentration was positively correlated with temperature. Statistical analysis indicated that temperature, salinity, phosphate, and silicate concentrations are important factors influencing the variation of phytoplankton size structure in the Zhangzi Island and adjacent waters during autumn.

Full Text

Size-Fractionated Phytoplankton and Its Influencing Factors in Autumn Near Zhangzi Island and Its Adjacent Waters

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Abstract

A cruise was conducted in October 2015 to investigate the size-fractionated phytoplankton near Zhangzi Island and its adjacent waters. The spatial distribution characteristics of phytoplankton size structure and their correlation with environmental factors were examined in both surface and bottom layers. The concentrations of total chlorophyll a, microplankton (>20 μm), nanoplankton (2–20 μm), and picoplankton (0.45–2 μm) were measured. In the surface layer, total chlorophyll a concentration ranged from 0.52 to 1.25 g/L with an average of 0.76 g/L. The corresponding concentrations for microplankton, nanoplankton, and picoplankton were 0.03–0.81, 0.33–0.91, and 0–0.09 g/L, with averages of 0.19, 0.53, and 0.03 g/L, respectively, contributing 23.77%, 72.26%, and 3.98% of the total chlorophyll a. In the bottom layer, total chlorophyll a ranged from 0.14 to 1.5 g/L with an average of 0.46 g/L, primarily composed of microplankton and nanoplankton ranging from 0.04–1.04 and 0.08–0.47 g/L with averages of 0.22 and 0.24 g/L, contributing 41.46% and 58.50% to the total, respectively. Surface chlorophyll a concentration was significantly higher than that in the bottom layer. Nanoplankton showed homogeneous vertical distribution, whereas microplankton and picoplankton tended to be more abundant in the surface layer. Picoplankton concentration was lower than the other two size classes throughout the entire water column in autumn. Pearson correlation analysis revealed significantly positive correlations between nanoplankton concentration and salinity in the surface layer. In the bottom layer, significantly positive correlations were found for several parameter pairs, including total chlorophyll a and phosphate concentration, microplankton and phosphate and silicate concentrations, and nanoplankton and temperature. Temperature, salinity, and phosphate and silicate concentrations were important factors affecting the size structure of phytoplankton near Zhangzi Island and its adjacent waters.

Keywords: phytoplankton; chlorophyll-a; size structure; environmental fac-

tors; Zhangzi Island

Introduction

Phytoplankton form the foundation of marine ecosystems, and their community structure reflects marine environmental conditions to a certain extent. The abundance, structure, and other characteristics of phytoplankton are inextricably linked to environmental factors, while phytoplankton themselves play crucial roles in material cycling and energy flow within ecosystems. Understanding the dynamic changes in phytoplankton size structure and their environmental mechanisms helps elucidate variations in marine planktonic food web structure and the efficiency of the biological pump [1]. In recent years, research on phytoplankton size structure has increased, with numerous scholars conducting in-depth studies on the spatiotemporal distribution characteristics and environmental influencing factors of phytoplankton size structure in the Bohai Sea [6], Yellow Sea [1,7], East China Sea [7-8], and other regions, providing scientific foundations for analyzing the role of various size-fractionated phytoplankton in marine ecosystems.

As the primary contributor to marine primary productivity, phytoplankton represent a key link in energy flow and material cycling in marine ecosystems and serve as important support for mariculture activities. They are one of the main food sources for filter-feeding shellfish [9-10]. Zhangzi Island, located at the southernmost tip of the outer Changshan Islands in the northern Yellow Sea, hosts the largest *Patinopecten yessoensis* (Yesso scallop) farming base in China and is the country's only national-level original and improved scallop seed farm [9]. However, research reports on the waters of Zhangzi Island, China's largest Yesso scallop farming base, are relatively limited. Investigating the size structure and spatial distribution of phytoplankton biomass in the Zhangzi Island sea area helps understand the ecosystem dynamics and microbial food loop functions in this region and can guide the development and utilization of biological resources.

Materials and Methods

Survey Stations The survey was conducted in October 2015 in the waters near Zhangzi Island and adjacent areas. A total of 49 stations were surveyed, including stations in the Zhangzi Island area (6#-34#) and stations in the Wumang Island area (41#-49#) [Figure 1: see original paper].

Sample Collection and Analysis Surface and bottom water samples were collected at each station with a volume of 500 mL. All sample collection followed the national standard "Marine Monitoring Specifications" [10]. Samples were sequentially filtered through custom-made American standard sieves and

Shanghai Xingya cellulose acetate micropore membranes with pore sizes of 20 μm , 2 μm , and 0.45 μm to collect phytoplankton of different size fractions. After filtration, saturated magnesium carbonate solution was added dropwise to the filters. The filtered membranes were frozen at -20°C and transported back to the laboratory for analysis.

Size fractions were defined as: microplankton ($>20 \mu\text{m}$), nanoplankton (2–20 μm), and picoplankton (0.45–2 μm). Chlorophyll a concentration was measured using the acetone extraction fluorometric method with a Turner-Designs Trilogy fluorometer.

Environmental parameters including temperature (T), salinity (S), pH, total nitrogen (TN), total phosphorus (TP), nitrate ($\text{NO}_3\text{-N}$), nitrite ($\text{NO}_2\text{-N}$), ammonium ($\text{NH}_4\text{-N}$), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and silicate ($\text{SiO}_3\text{-Si}$) were measured using a YSI 6600 multi-parameter water quality meter according to GB 17378.4-2007 “Marine Monitoring Specifications.”

Statistical analysis was performed using Microsoft Excel 2010 and SPSS 17.0 software. Pearson correlation analysis was used to examine relationships between size-fractionated chlorophyll a and environmental factors, with ANOVA single-factor analysis used to test for significant differences between groups.

Results

Environmental Parameters In autumn, the surface water temperature in the Zhangzi Island area ranged from 15.67 to 18.64 $^{\circ}\text{C}$ with an average of 17.49 $^{\circ}\text{C}$, while bottom temperature showed uniform vertical distribution. Other physico-chemical factors showed no significant differences between layers .

Nutrient concentrations in surface and bottom waters are presented in . The mean DIN concentration was $1.78 \pm 0.99 \text{ mol/L}$ in surface waters and $2.05 \pm 1.42 \text{ mol/L}$ in bottom waters. DIP concentrations were $0.03 \pm 0.002 \text{ mol/L}$ and $0.03 \pm 0.002 \text{ mol/L}$ in surface and bottom waters, respectively. Silicate concentrations averaged $11.91 \pm 4.78 \text{ mol/L}$ in surface waters and $10.73 \pm 17.38 \text{ mol/L}$ in bottom waters.

Total Chlorophyll a Surface total chlorophyll a concentration ranged from 0.52 to 1.25 g/L with a mean of $0.76 \pm 0.18 \text{ g/L}$, while bottom concentrations ranged from 0.14 to 1.5 g/L with a mean of $0.46 \pm 0.30 \text{ g/L}$. Surface chlorophyll a was significantly higher than bottom concentrations ($P < 0.05$). Horizontally, surface high-value areas appeared in the northwest of Zhangzi Island and southeast of Wumang Island, while low-value areas occurred in the northeast of Zhangzi Island. Bottom high-value areas were found in the north of Wumang Island, with low-value areas in the northeast of Zhangzi Island and south of Wumang Island [Figure 2: see original paper].

Size-Fractionated Chlorophyll a Microplankton (>20 m)

Surface microplankton chlorophyll a concentration ranged from 0.03 to 0.81 g/L with a mean of 0.19 ± 0.15 g/L, while bottom concentrations ranged from 0.04 to 1.04 g/L with a mean of 0.22 ± 0.24 g/L. No significant difference was observed between surface and bottom layers ($P > 0.05$). Horizontally, surface high-value areas occurred in the northwest of Zhangzi Island and north of Wumang Island, with low-value areas in the northeast of Zhangzi Island and Wumang Island. Bottom high-value areas appeared in the north of Wumang Island, with low-value areas in the northeast of Zhangzi Island [Figure 3: see original paper].

Nanoplankton (2-20 m)

Surface nanoplankton chlorophyll a concentration ranged from 0.33 to 0.91 g/L with a mean of 0.53 ± 0.11 g/L, while bottom concentrations ranged from 0.08 to 0.47 g/L with a mean of 0.24 ± 0.09 g/L. Surface concentrations were significantly higher than bottom concentrations ($P < 0.05$). Horizontally, surface high-value areas appeared in the southwest of Zhangzi Island and southeast of Wumang Island, with low-value areas in Wumang Island waters. Bottom high-value areas occurred in the central part of Zhangzi Island and northwest of Wumang Island, with low-value areas in the southwest of Zhangzi Island [Figure 4: see original paper].

Picoplankton (0.45-2 m)

Surface picoplankton chlorophyll a concentration ranged from 0 to 0.09 g/L with a mean of 0.03 ± 0.03 g/L. In autumn, picoplankton was only detected in the bottom layer at one station (0.02 g/L); no picoplankton chlorophyll was detected in bottom water samples at other stations. Vertically, surface picoplankton concentration was significantly higher than bottom concentration ($P < 0.05$). Horizontally, surface high-value areas appeared in the northwest of Wumang Island [Figure 5: see original paper].

Contribution of Different Size Fractions In autumn, the contribution of microplankton, nanoplankton, and picoplankton to total chlorophyll a in surface waters ranged from 5.36–64.80%, 34.40–94.55%, and 0–15.38%, respectively, with average contributions of 23.77%, 72.26%, and 3.98%. The contribution order was nanoplankton > microplankton > picoplankton. In bottom waters, the contributions ranged from 16.67–74.24%, 25.76–83.33%, and 0–4.76%, respectively, with average contributions of 41.46%, 58.50%, and 0.05%. The contribution order was nanoplankton > microplankton > picoplankton. Nanoplankton and microplankton dominated the phytoplankton community in the Zhangzi Island area during autumn [Figure 6: see original paper].

Correlation Analysis Pearson correlation analysis showed that in the surface layer, nanoplankton (2-20 m) concentration was positively correlated with salinity. In the bottom layer, total chlorophyll a concentration was positively

correlated with phosphate concentration; microplankton ($>20\ \mu\text{m}$) concentration was positively correlated with phosphate and silicate concentrations; and nanoplankton ($2\text{-}20\ \mu\text{m}$) concentration was positively correlated with temperature .

Discussion

Distribution Characteristics of Phytoplankton Size Structure

Zhangzi Island sea area is located at the southernmost tip of the outer Changshan Islands in the northern Yellow Sea and belongs to temperate waters. Previous studies have shown that in phytoplankton size structure, larger-sized microplankton ($>20\ \mu\text{m}$) concentrations increase with latitude, while smaller-sized picoplankton ($<2\ \mu\text{m}$) concentrations decrease with latitude [7-8, 11-12]. This study demonstrates that microplankton and nanoplankton dominated the size composition in the Zhangzi Island area during autumn, with picoplankton contributing less than 5.45% to the total, basically conforming to this pattern .

Song et al.' s study on net-collected phytoplankton size structure in Liaodong Bay showed that autumn phytoplankton size was mainly concentrated in the medium size range [16]. Zhang' s research on phytoplankton community structure in the Zhangzi Island area indicated that dominant autumn species were larger-sized algae such as *Paralia sulcata* and *Karenia mikimotoi* [17]. This cruise identified diatoms, *Karenia mikimotoi*, and silicoflagellates as the dominant phytoplankton in the Zhangzi Island area, with total phytoplankton abundance of [MATH_0] cells/mL, diatom abundance of [MATH_1] cells/mL, and dinoflagellate abundance of [MATH_2] cells/mL. Diatoms dominated the community (unpublished data). The average contributions of microplankton ($>20\ \mu\text{m}$) and nanoplankton ($2\text{-}20\ \mu\text{m}$) were 32.62% and 65.38%, respectively, with larger-sized diatoms dominating, consistent with results from higher latitude cold-water regions [15].

The ecological environment of the northern Yellow Sea is influenced by continental climate, terrestrial diluted water, and seasonal cold water masses, resulting in different regional distribution characteristics of phytoplankton communities [16-18]. Wang' s research shows that the Liaonan coastal current, including the Yalu River and Bilu River, adds nutrients to the Changshan Islands sea area, creating a decreasing trend from north to south [21]. This study found similar spatial distribution patterns for all three size fractions, with high-value areas appearing in Wumang Island waters and low-value areas in the south of Zhangzi Island. Surface concentrations were higher than bottom concentrations. Wumang Island' s geographic location to the north results in overall higher temperature and nutrient levels than Zhangzi Island waters, indicating that temperature and nutrients are important factors influencing the spatial distribution of phytoplankton size structure in the Zhangzi Island area.

Influencing Factors of Phytoplankton Size Structure Nutrient concentration in seawater is typically an important limiting factor for phytoplankton growth, largely regulating the size structure and distribution of phytoplankton biomass. Previous studies have shown that nutrient concentration and zooplankton grazing are key environmental factors determining phytoplankton size structure composition, with nutrients having rapid and sensitive effects on phytoplankton community structure [24]. N, P, and Si are essential nutrients for marine phytoplankton growth, and any of these may become limiting factors depending on regional conditions [23].

This study combined two methods proposed by Fisher and Justic to determine whether phytoplankton in the Zhangzi Island area were nutrient-limited [22, 25-26]. Results showed that bottom $\text{DIN} < 2 \text{ mol/L}$, $\text{DIN/P} < 10$, and $\text{Si/N} > 1$ in autumn, indicating nitrogen limitation in bottom waters of the Zhangzi Island area during autumn. This is consistent with findings by Wang and Jiao [27] and Zhang et al. [9], showing that inorganic nitrogen is an important factor affecting phytoplankton growth and community structure in autumn in this area.

The distribution of phytoplankton size structure is closely related to the distribution and variation of directly utilizable nutrients. The Zhangzi Island waters perennially meet national Class I seawater quality standards and are mostly oligotrophic [9]. Phosphate concentrations are below national Class I standards with $\text{Si/P} = 43 > 22$, indicating potential phosphorus limitation. This study found positive correlations between bottom total chlorophyll a and phosphate concentration, and between microplankton ($>20 \text{ m}$) and phosphate concentration, suggesting phosphate may become a limiting factor for microplankton growth in autumn.

Zhang et al. [17] found that bottom phytoplankton in the Zhangzi Island area during autumn were dominated by diatoms, dinoflagellates, and chrysophytes, with diatoms being dominant. Silicate is an essential nutrient element for diatoms [28], and diatoms prefer low temperatures, with optimal temperatures typically below 3°C . This study found a positive correlation between bottom microplankton ($>20 \text{ m}$) concentration and silicate concentration, indicating silicate may be an important factor affecting microplankton growth in the Zhangzi Island area during autumn.

In addition to bottom-up effects from nutrients, top-down effects from grazing can also significantly pressure phytoplankton size structure [9, 30-31]. Large-scale filter-feeding shellfish farming and heavy zooplankton grazing can influence community composition. Zhang [17] found that the dominant species in autumn bottom-cultured Yesso scallop stomach contents were *Paralia sulcata*, *Coscinodiscus radiatus*, and *Dictyocha fibula*, with *P. sulcata* having significantly higher dominance than other species. McQuoid et al. [32] reported that *P. sulcata* has a cell size range of 10-18 μm . Li's morphological comparison of *Thalassiosira* and *Coscinodiscus* showed that most *Thalassiosira* species have cell diameters between 3-20 μm , while *Coscinodiscus* cell diameters vary widely, mostly concentrated in the 40-100 μm range [33]. This study found that bottom total chloro-

phyll a concentration was lower than surface concentration, while microplankton (>20 m) concentration was significantly lower than nanoplankton (2-20 m) concentration. The contribution rate of nanoplankton (72.66%) was significantly higher in surface than in bottom waters (58.50%). Autumn water temperatures are within the optimal range for Yesso scallop growth, and scallops have strong grazing capacity [9]. The top-down grazing effect from scallops in the Zhangzi Island farming waters may be an important factor affecting seasonal changes in bottom phytoplankton size structure.

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