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Feature of phytoplankton community and canonical correlation analysis with environmental factors in Xiaoqing River estuary in autumn

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Abstract

A multidisciplinary study was carried out in Xiaoqing River estuary in November 2008. Community feature of phytoplankton and water quality were assessed. Furthermore, the relationship was discussed between phytoplankton and environmental factors. In total, 52 species of phytoplankton were identified (including uncertain species), of which 36 diatom species dominated in composition. The abundance of phytoplankton ranged from $0.6 \times 10^4$ to $213.30 \times 10^4$ cells m\textsuperscript{-3}. Seven species were dominant, among which \textit{Skeletonema costatum}, \textit{Tribonema affine}, and \textit{Chlorella sp.} were mainly dominated. Canonical correspondence analysis (CCA) showed that salinity (S), pH, chemical oxygen demand (COD), and nitrite (NO\textsubscript{2}\textsuperscript{-}-N) were importantly environmental factors influencing the distribution of phytoplankton community. Since different species demanded different environment, CCA biplot revealed the ecological suitability of plankton.

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Key Words: Xiaoqing River estuary; phytoplankton; canonical correspondence analysis

1. Introduction

Estuary is the habitat ecotone between freshwater and marine organism and is subject to both marine and river influence. The high levels of nutrients from freshwater and seawater make estuaries among the...
most productive natural habitats in the world. However, estuaries suffer degradation due to dense population and developed economic along estuary area [1]. As the primary producer, phytoplankton has great impact on structure, function, resources, and environment of estuary ecosystem. Species composition and distribution of phytoplankton are closely related with environment, thus the research on community structure and the impacted environmental factors is of great importance to assessment of productivity as well as development and sustainable utilization of resources in estuaries [2]. Xiaoqing River, the typical river in Shandong province, originates in Jinan and flows into Laizhou Bay in Shouguang. Wastewater is poured into Xiaoqing River by citizens and industrial units, which caused heavy pollution to the river. Furthermore, the pollution has adversely affected resource and environment in Laizhou Bay [3]. However, a few researches on the plankton have been carried out in Xiaoqing River. In order to make clear the relationship between phytoplankton community structure and environmental factors and to provide scientific basis for the sustainable development of environment and resources in Xiaoqing River, community structure of phytoplankton and impacted environmental factors in autumn were analyzed by ecological methods of classification and ordination.

2. Materials and methods

2.1. Investigation areas and samples collection.

The investigation was conducted among eleven stations in Xiaoqing River estuary (37°16′09″N~37°21′02″N, 118°52′27″E~119°07′29″E) in November 2008 (Fig. 1a.). Sample collection, processing, and determination of surface and bottom water as well as plankton were in accordance with standard methods of “The specification for oceanographic survey” (GB12763-2007)[4] and “The specification for marine monitoring” (GB17378-2007)[5]. Phytoplankton was sampled using WWC-3 net (mouth size, 0.1 m², mesh size, 0.077 μm) by towing vertically from the bottom to the surface. The collected samples were preserved immediately in 5% formaldehyde. Organisms were identified to species level when possible and counted under an inverted microscope (Nikon TS100). Water quality factors including salinity (S), dissolved oxygen (DO), pH, chemical oxygen demand (COD), nitrite (NO₂⁻-N), nitrate (NO₃⁻-N), ammonia (NH₄⁺-N), phosphates (PO₄³⁻-P), silicate (SiO₃²⁻-Si), and oil were analyzed.

![Fig. 1. (a) Target stations; (b) Phytoplankton abundance in Xiaoqing River estuary in autumn 2008](image)

2.2. Data analysis

The dominance (Y) of phytoplankton was calculated according to Sun et al [6]. The relationship between the phytoplankton community and environmental factors was analyzed by canonical correlation
analysis (CCA) using Canoco for Windows 4.0 soft. Emergent frequency of the species for CCA was bigger than 30% and relative density was greater than 1% at least one station.

3. Results

3.1. Phytoplankton composition

A total of 52 phytoplankton species, which belonged to 4 phylum and 34 genera, were identified during the autumn survey in the Xiaoqing River estuary, including 22 genera and 36 species of diatom, 6 genera and 7 species of cyanobacteria, 4 genera and 7 species of chlorella, and 2 genera and 2 species of zooxanthellae. The species proportion of diatom ranged from 50% to 100% among the 11 investigated stations with the average of 79.9%. Thus, diatom was dominant in number of species. Species number inside of the estuary was higher than outside.

3.2. Phytoplankton abundance

Phytoplankton abundance varied between $0.6 \times 10^4$ and $213.30 \times 10^4$ cells m$^{-3}$ with the average of $42.68 \times 10^4$ cells m$^{-3}$ (Fig. 1b.). It is generally higher inside than outside. Inside of the estuary, diatom dominated phytoplankton community averaging 88.2% of the total abundance (range: 51.2~100%). However, diatom was no longer dominant outside with the quit abundance proportion of diatom, chlorella, and zooxanthellae.

3.3. Dominant species

According to the dominance, seven species were dominant phytoplankton species (Table 1.). *Skeletonema costatum*, the representative species of extensive temperature and salt, was the main dominant species with the frequency of 0.73 and average abundance of $6.7 \times 10^4$ cells m$^{-3}$ in Xiaoqing River estuary. It peaked to $20.8 \times 10^4$ cells m$^{-3}$ at station 10. *Tribonema affine*, a typical xanthophyceae suitable for living in fresh water and brackish water, and *Chlorella sp.*, a typical fresh water chlorella, were also the dominant species in Xiaoqing estuary in autumn 2008. A large number of these species were found inside of estuary. Moreover, other species of fresh water chlorella such as Scenedesmus were also recorded with large amount inside of estuary.

Table 1. Phytoplankton dominant species in Xiaoqing River estuary in autumn 2008

| Dominant species     | Cell abundance proportion(%) | Frequency | Dominance |
|----------------------|------------------------------|-----------|-----------|
| *Skeletonema costatum* | 11.3                         | 0.73      | 0.0756    |
| *Oscillatoria sp.*   | 9.9                          | 0.82      | 0.0743    |
| *Tribonema affine*   | 26.1                         | 0.18      | 0.0436    |
| *Navicula sp.*       | 4.1                          | 0.73      | 0.0274    |
| *Chlorella sp.*      | 7.7                          | 0.27      | 0.0255    |
| *Melosira sulcata*   | 6.5                          | 0.36      | 0.0216    |
| *Coscinodiscus centralis* | 2.8                  | 0.73      | 0.0211    |

3.4. CCA analysis between phytoplankton distribution and environmental factors

There were 32 species of phytoplankton and 8 environmental factors screened for CCA analysis based on abundance and frequency of phytoplankton (Table 2.). CCA biplot showed the eigenvalues of the first two axes were 0.554 and 0.314, respectively (Fig. 3.). The correlation coefficient between the first environmental factors axis and species axis was 0.999, while that for the second axes was 0.973, indicating a close relationship between phytoplankton and environmental variables analyzed. Two canonical roots were extracted explaining 54.8% of the variance observed. The first two environmental factors axes were mutually vertical with the correlation coefficient of 0. The first two species axes were
nearly perpendicular with the correlation coefficient of 0.0103. This indicated the credibility of sequencing results [7].

| Code | Latin name                  | Code | Latin name                  | Code | Latin name                  |
|------|-----------------------------|------|-----------------------------|------|-----------------------------|
| 1    | Scenedesmus armatus         | 12   | Coscinodiscus granii        | 23   | Ditylum brightwellii        |
| 2    | Scenedesmus cavinatus       | 13   | Coscinodiscus Sp.           | 24   | Licmophora Sp.              |
| 3    | Scenedesmus quadricauda     | 14   | Coscinodiscus centralis     | 25   | Nitzschia longissima        |
| 4    | Crucigenia quadrata         | 15   | Cyclotella Sp.              | 26   | Nitzschia Sp.               |
| 5    | Chlorella Sp.               | 16   | Leptocylindrus danicus      | 27   | Nitzschia delicatissima     |
| 6    | Oscillatoria Sp.            | 17   | Skeletonema costatum        | 28   | Navicula Sp.                |
| 7    | Spirulina                   | 18   | Melosira sulcata            | 29   | Gyrosigma balticum var. balticum |
| 8    | Chroococcus Sp.             | 19   | Rhizosolenia setigera       | 30   | Mastogloia Sp.              |
| 9    | Dactylococcopsis Sp.        | 20   | Chaetoceros lorenzianus     | 31   | Pleurosigma fals            |
| 10   | Synechococcus Sp.           | 21   | Chaetoceros densus          | 32   | Synedra affinis             |
| 11   | Tribonema affine            | 22   | Bidduphia sinensis         |

Eight environmental factors affected phytoplankton distribution with different degrees. S, pH, COD, and NO₂⁻-N had great influence on phytoplankton as indicated by their high correlation with the two significant canonical roots. The first canonical root was strongly related to pH, S, and DO, with correlation coefficient of -0.9524, -0.8955, and -0.8196, separately. The second canonical root had positive correlation with NH₄⁺-N (0.7819), and negative correlation with NO₃⁻-N (-0.2436).

Chlorella, cyanobacteria, and zooxanthellae in Xiaoqing River were mainly located in the third quadrant of biplot (Fig. 2.) related to COD, NO₂⁻-N, and PO₄³⁻-P, while 21 species of diatom were scattered in four quadrants. There was a change in appropriate environment for phytoplankton along two canonical roots. A decreasing demand of COD, NO₂⁻-N, and PO₄³⁻-P and an increasing demand of pH, S, and DO were observed towards the right along the first canonical root. Furthermore, a decreasing demand of NO₃⁻-N and an increasing demand of NH₄⁺-N were found upwards the second canonical root.

![Fig. 2. CCA biplot of phytoplankton and environmental factors in Xiaoqing River estuary](image-url)
4. Discussion

Due to its complex in estuarine ecosystem, environmental factors were crucial to the distribution of phytoplankton [8]. Phytoplankton community in Xiaoqing River estuary in autumn 2008 was composed of diatom, chlorella, cyanobacteria, and zooxanthellae. Moreover, the eight dominant species were belonged to the four phyla. Locations of phytoplanktonic species in CCA biplot indicated its dependence on environmental factors [9]. The ecological adaptation of species with close position was similar. Chlorella, cyanobacteria, and zooxanthellae were mainly concentrated in the third quadrant corresponding to the environment of high concentrations of COD, NO$_2$-N, and NO$_3$-N and low S. The demand for PO$_4^{3-}$-P of chlorella and cyanobacteria was higher than diatom. Chlorella, cyanobacteria, and zooxanthellae identified in this investigation were common freshwater species with tolerance of pollution. For example, Scenedesmus armatus and Scenedesmus quadricauda were the indicators of moderate pollution and Oscillatoria Sp. was the indicator of organic pollution. That was in agreement with CCA biplot.

In CCA biplot, Skeletonema costatum, the first dominant species, was distributed in the area with moderate S and pH as well as high concentration of NO$_3$-N, which was consistent with results of laboratory and field experiments [10,11]. It was noticed that most of the dominant species were distributed in the third quadrant, which might be related to the heavy pollution of Xiaoqing River. The annual discharge amount of contamination was 17017 t in the years of 1998-2002, among which COD and NH$_4^+$-N accounted for 98.8% [12]. Under such environmental pressure, it was the ecological suitability of phytoplankton to environment that the dominant species adapted to high concentrations of COD and NO$_2$-N.

There were many environmental factors affecting the growth and distribution of phytoplankton. However, the main impacted factors varied among water areas. Transparency was the primary factor effecting phytoplankton distribution in Changjiang River estuary in summer, followed by NO$_3$-N and silicate with CCA analysis [11]. In Loch Lomond, environmental factors affected phytoplankton community with the order of temperature, DO, transparency, and COD [13]. The main factors impacting phytoplankton community in Xiaoqing River estuary were S, pH, COD, and NO$_2$-N in this study. It was reported that water quality in Xiaoqing River estuary was characterized by obvious gradient of S and ph, as well as high concentrations of COD and NO$_2$-N [14-16]. That was also detected in this investigation. Thus, it was inferred that the condition of water quality in Xiaoqing River made great impact on phytoplankton community.

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