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Bioassessment of water quality status using a potential bioindicator based on functional groups of planktonic ciliates in marine ecosystems

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ABSTRACT

The feasibility of a potential ecological indicator based on functional groups of planktonic ciliates for bioassessment of water quality status were studied in a bay, northern Yellow Sea. Samples were biweekly collected at five stations with different water quality status during a 1-year period. The multivariate approach based on "bootstrap-average" analysis was used to summarize the spatial variation in functional structure of the samples. The functional patterns represented a significant spatial variability, and were significantly correlated with the changes of nutrients (mainly nitrate nitrogen, NO_3-N), alone or in combination with dissolve oxygen and salinity among five stations. The functional diversity represented a clear spatial variation among five stations, and was found to be significantly related to the nutrient NO_3-N. According to the results, we suggest that the ecological parameter based on functional groups of planktonic ciliates may be used as a potential bioindicator of water quality status in marine ecosystems.

1. Introduction

As an important component of zooplankton fauna, planktonic ciliates play an indispensable role in the functioning of microbial food webs by transferring the flux of carbon and energy from low trophic levels (e.g., bacteria, pico- and nano-algae) to the high in aquatic ecosystems (Sime-Ngando et al., 1995; Crawford et al., 1997; Finlay and Esteban, 1998; Kchaou et al., 2009). The changes of environmental conditions may result in significant variations in functional structures of the ciliate communities (Montagnes and Lynn, 1989; Dolan and Coats, 1990; Crawford et al., 1997; Kchaou et al., 2009; Jiang et al., 2011, 2013a, 2013b).

With short life cycle, rapid response to environmental changes and the easy comparison on temporal and spatial scales, planktonic ciliates have been successfully used to indicate water quality status in marine ecosystems (Jiang et al., 2011, 2014, 2016; Feng et al., 2015; Xu et al., 2015, 2016). So far, a number of investigations on planktonic ciliates have been carried out on monitoring programs (Jiang et al., 2011, 2013a, 2013b; Feng et al., 2015; Xu et al., 2015, 2016). Recently, several functional groups were identified in the planktonic ciliate communities, which occur in a variety of biotopes with different water conditions at specific time period in a 1-year cycle (Jiang et al., 2013a). So far, however, as regards the feasibility of ecological parameters based on functional groups of the ciliates for bioassessment to, little information have been known.

In this study, the spatial changes in functional structure of planktonic ciliate communities were studied based on an annual dataset from Jiaozhou Bay, near Qingdao, northern China. The aim of this study was to evaluate the feasibility of ecological parameters based on the functional groups of the ciliate assemblages for bioassessment of water quality status in marine ecosystems.

2. Materials and methods

2.1. Study areas and data collection

Jiaozhou Bay is a semi-enclosed basin surrounded by Qingdao, northern China (Fig. 1). It is a part of the Yellow Sea, with an area of about 390 km^2 and an average depth of 7 m. In recent decades, since several sources of pollutants (mainly industrial effluents and urban wastewaters) enter the bay from Qingdao city, the water column in the bay is heavily impacted (Shen, 2001; Liu et al., 2004, 2005).

The dataset was collected from five sampling stations in the bay during a 1-year cycle (June 2007–May 2008). Station A was located in area far from the sources of pollutants; station B was an area near two rivers with organic pollutants, nutrients and heavy metals (e.g., Pb, Zn) entering the bay; station C was located in a mariculture area; station D was near a small river with both organic and heavy-metal pollutants (e.g., Cr, Cu); and station E was located in the mouth of the bay and subjected strong water exchanges (Fig. 1) (Liu et al., 2005).

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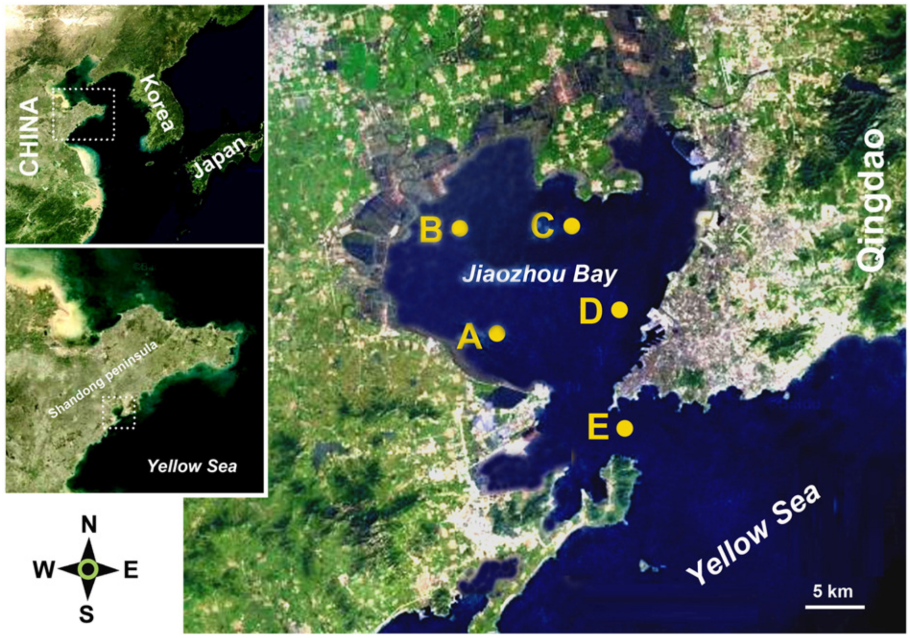

Fig. 1. Sampling stations in Jiaozhou Bay, near Qingdao, northern China. A–E = stations A–E.

A total of 120 samples were collected biweekly at a depth of 1 m from five sampling stations. Sample processes, species identification, individual enumeration, and measurement of environmental variables were followed as that described by Jiang et al. (2011). The functional groups of the ciliates were determined according to Jiang et al. (2013a) (Table S1).

Salinity (Sal), pH, and the concentrations of dissolved oxygen (DO) were detected in situ, using a multi-parameter sensor (MS5, HACH). Soluble reactive phosphate (SRP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and nitrite nitrogen (NO_2-N) were measured according to the 'Standard Methods for the Examination of Water and Wastewater' (APHA, 1992).

2.2. Data analyses

Shannon-Wiener index (H') is used to summarize the functional diversity of the ciliate communities, and is computed following the equation:

$$H? = -\sum_{i=1}^{s} Pi(\ln Pi)$$

where H' = observed diversity index; P_i = proportion of the total count arising from the ith functional group; and S = total number of functional group.

Boxplots were plotted to summarize the variations in species diversity by whiskers (minimum and maximum), boxes (±25%) and lines (medians).

Multivariate analyses were carried out with the software package PRIMER v7.0.10 (Clarke and Gorley, 2015). The Bray-Curtis similarity matrices among communities were computed on fourth root transformed functional-group occurrence/abundance data, while the Euclidean distance matrices for environmental variables were obtained from log-transformed and normalized abiotic data (Clarke and Gorley, 2015). The spatial variations in functional structure of the ciliate communities among five stations were ordinated using non-metric multidimensional scaling (nMDS) based on the analysis "bootstrap averages" for Bray-Curtis similarity matrices (Clarke and Gorley, 2015). For showing the spatial species distributions of the ciliates in each functional groups among five stations, the 'index of association' among species was used to construct the similarity matrices on variable-standardized species-abundance data (Clarke and Gorley, 2015). Mental analyses were done by running the routine RELATE to signify the relationships between similarity matrices, and the routine BIOENV was used to identify the environmental drivers to the spatial variations in annual distribution of the protozoa with the significance at the P value < 0.05 level (Clarke and Gorley, 2015).

Univariate correlation analyses were carried out using the statistical program SPSS v22 to explore the relationships between functional diversity and environmental variables. Data were log-transformed before analyses (Xu et al., 2011).

3. Results

3.1. Environmental conditions

The average values of environmental conditions at five sampling stations are shown in Table S2. The values of pH showed minor differences at five sampling sites. Salinity ranged from 29.5 psu to 31.3 psu with minimum value at station B and maximum at station A. DO were generally higher than 8 mg l^{-1} at five stations, with the minimum value at site D and the maximum at site B. Concentrations of NO_3-N were high at sites B and C and low at the other three stations, although NH_4-N reached maximum values at site D, mainly (Table S2).

3.2. Spatial variation species distributions

Based on the functional grouping system by Jiang et al. (2013a), a total of 64 species of the dataset belonged to 13 functional groups (A, B, C, D, E, F, G, H, I, J, K, L and M) (Table S1, Fig. 2a). Their spatial distributions were summarized in Fig. 2.

3.3. Spatial pattern of functional structures

In terms of average relative occurrence and average relative abundance, the spatial variations in functional structures of the ciliate communities were shown in Fig. 3. Two structural types could be recognized: (1) those dominated by groups indicating "clean" (e.g., A and B) and "moderate" stress (e.g., I) (stations A and E); (2) those