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Trophic-functional patterns of biofilm-dwelling ciliates at different water depths in coastal waters of the Yellow Sea, northern China

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Abstract

Vertical variations in trophic-functional patterns of biofilm-dwelling ciliates were studied in coastal waters of the Yellow Sea, northern China. A total of 50 species were identified and assigned to four trophic-functional groups (TFgrs): algivores (A), bacterivorous (B), non-selective (N) and raptors (R). The trophic-functional structures of the ciliate communities showed significant variability among different water depths: (1) with increasing water depth, relative species numbers and relative abundances of groups A and R decreased sharply whereas those of groups B and N increased gradually; (2) in terms of the frequency of occurrences, group A dominated at depths of 1–3.5 m whereas group B dominated at 5 m, while in terms of the probability density function of the trophic-functional spectrum, group A was the highest contributor at 1 m and group B was highest at the other three depths; (3) distance-based redundancy analyses revealed significant differences in trophic-functional patterns among the four depths, except between 2 and 3.5 m ($P > 0.05$); and (4) the trophic-functional trait diversity increased from 1 to 3.5 m and decreased sharply at 5 m. Our results suggest that the biofilm-dwelling ciliates maintain a stable trophic-functional pattern and high biodiversity at depths of 1–3.5 m.

Keywords: Biofilm-dwelling ciliates; Coastal waters; Trophic-functional groups; Vertical variation; Yellow Sea

Introduction

Protozoa, particularly ciliates, have been widely used as bioindicators in ecological research and monitoring programs (Jiang et al. 2013a; Kathol et al. 2009; Kchaou et al. 2009; Morin et al. 2008; Patterson et al. 1989). In recent years, a number of investigations have demonstrated that community-based parameters (e.g., colonization dynamics, species richness, taxonomic/body-size distinctness and functional diversity) of biofilm-dwelling protozoa can be utilized for discriminating water quality status in marine/coastal ecosystems (Ismael and Dorgham 2003; Jiang et al. 2013b; Xu et al. 2014; Xu and Xu 2016; Xu et al. 2016; Zhang et al. 2014; Zhao et al. 2016; Zhong et al. 2017).

Most biofilm-dwelling protozoa are primary consumers and play an important role in controlling the transfer of energy to higher trophic levels in aquatic microbial food webs (Gong et al. 2005; Kathol et al. 2009; Parry 2004; Xu et al. 2011). The availability of different types of food (e.g., bacteria, algae, flagellates and detritus) down the water column may, however, significantly influence trophic-functional patterns of the protozoan communities (Kathol et al. 2011; Norf et al. 2009b; Zhang et al. 2012). Pratt and Cairns (1985) classified the feeding types of protozoa into six trophic-functional groups (TFgrs): photoautotrophs (P), bacterivores (B), algivores (A),

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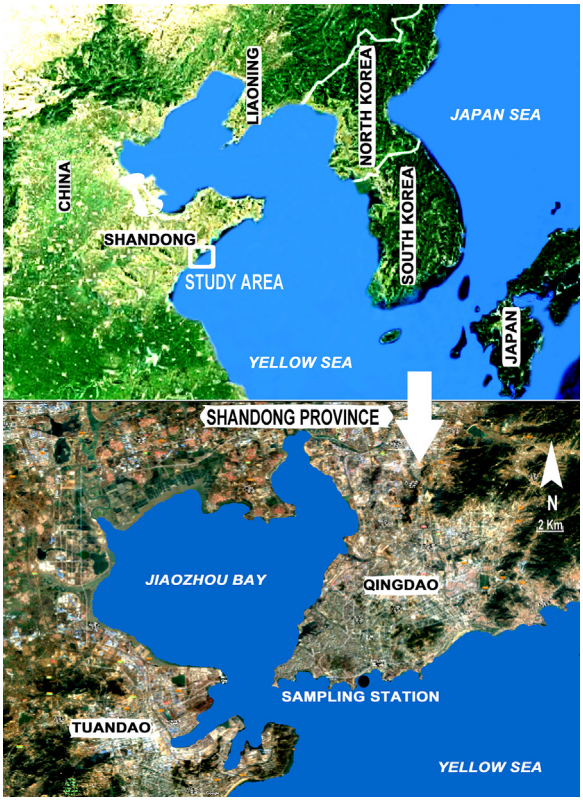

Fig. 1. Sampling station in coastal waters of the Yellow Sea, near Qingdao, northern China.

saprotrophs (S), raptors (R) and non-selectives (N) with each group performing an individual function in trophic food webs (e.g., photoautotrophic protozoa are responsible for primary production). Thus, the variations in the functional structure may indirectly reflect water quality status (Zhang et al. 2012; Zhang et al. 2012, 2013). It is noteworthy that mixotrophs, which can perform more than one function, were not included in this system. Furthermore, little is known about vertical variation in trophic-functional community structure of protozoa in coastal waters (Li and Xu 2012; Wang and Xu 2015; Xu et al. 2010).

In the present study, the vertical patterns of trophic-functional structure of ciliate communities were studied at four water depths in coastal waters of the Yellow Sea northern China. The aims of this study were: (1) to document the trophic-functional groupings of biofilm-dwelling ciliates at different water depths, and (2) to reveal the vertical variations in trophic-functional patterns of ciliate communities.

Material and Methods

Study area and dataset selection

The sampling site was located in coastal waters of the Yellow Sea at Zhongyun dock near Qingdao (Garmin GPS 60: 36°3′2.2″ N–120°17′57.4″ E), northern China (Fig. 1), which has an average depth of ~9 m with a tidal variation of ~3 m. Due to continuous inputs of domestic sewage and industrial organic contamination from several rivers and other discharges into the nearby Jiaozhou Bay and the mixing of bay- and sea waters, the average transparency was about 2.5–3 m (Zhang et al. 2014).

Samples of biofilm-dwelling ciliates were collected using glass microscope slides as artificial substrates as described by Xu et al. (2011). A total of 80 glass slides were immersed at four depths, i.e., 1, 2, 3.5 and 5 m below the water surface. At each depth, two PVC frames holding a total of 20 glass slides were collected after an exposure time of 14 days. The slides were transferred into Petri dishes containing in situ water and stored in a cool box for transporting to the laboratory.

Observation and enumeration of ciliates were carried out following the methods outlined by Xu et al. (2011). Ciliates were examined in vivo at 10–400× magnification under an inverted microscope as soon as possible, i.e., 2–4 h after collection. Identifications were carried out using published references (e.g., Song et al. 2009).

Each ciliate species was assigned to one of four TFgrs, i.e., bacterivores (B), algivores (A), raptors (R) and non-selectives (N), according to the published literature and direct observations (Fernandez-Leborans and Fernandez-Fernandez 2002; Pratt and Cairns 1985; Xu et al. 2010).

Data analysis

The diversity (Shannon–Winner, H'), evenness (Pielou's, J') and richness (Margalef, D) indices both of trophic-functional traits and of species were used to summarize the biodiversity of trophic-functional groupings of the ciliates. These measures were computed using PRIMER package (v7.0.13) following the equations:

$$H' = -\sum_{i=1}^{s} P_i(\ln P_i)$$

$$J' = \frac{H'}{\ln S}$$

$$D = \frac{(S-1)}{\ln N}$$

where P_i = proportion of the total counted arising from the ith trait/species; S = total number of species, and; N = total number of species/trophic-functional groups.

A shade-plotting analysis was used to show the species contribution in terms of relative abundance of each trophic-functional group at the four water depths in Fig. 2. The frequency of occurrences and probability density (i.e., the relative abundance/100) of the four trophic-functional groups were used to summarize the trophic-functional spectrum or structure of the ciliate communities. For multivariate analyses, the distance-based redundancy analysis (dbRDA), a routine of PRIMER v7.0.13 with PERMANOVA, was used to explore vertical variations in the trophic-functional structure