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Benthic ciliate and meiofaunal communities in two contrasting habitats of an intertidal estuarine wetland

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ABSTRACT

Annual variations in benthic meiofaunal and ciliated protozoan communities were investigated using monthly samplings from June 2006 to May 2007 in two habitats characterized by different vegetal coverage in an estuarine intertidal wetland of Qingdao Jiaozhou Bay, China. The sediment composition was stable at each site: sediments densely covered with seagrass (*Suaeda glauca*) in the lower estuarine site (Station S) were finer, with higher content of organic matter, phaeopigments and water than sediments at the upper estuarine site (Station S-P) which was unvegetated other than for patches of *S. glauca* and common reed (*Phragmites australis*). Chlorophyll a exhibited a similar distribution in the two habitats. A total of 14 meiofaunal groups, and 249 species of ciliates belonging to 37 genera, 28 families and 16 orders, were isolated from the two sites. Univariate and multivariate measures of the communities were significantly different between the two habitats. There were higher abundances of ciliates and meiofauna, and a greater diversity of ciliates, at Station S than Station S-P (223 *vs.* 61 species). Herbivorous ciliates were numerically predominant in ciliate communities at both sites. The representative ciliates at Station S-P belonged to the Cyrtophorida and appeared to be a reduced subset of the assemblage at Station S, which was characterized by members of the Prostomatida, Cyrtophorida, Hypotrichida and Scuticociliatida. More than 96% of the total meiofauna were nematodes, accounting for 93% of the differences in the abundance compositions of the meiofaunal communities between habitats. The average individual weights of nematodes were nearly 3 times greater at Station S than Station S-P, indicating a distinctive species composition at each site. Temperature, salinity and food availability were key factors that regulated the ciliate and meiofaunal community structure. Nematodes were the dominant group in terms of the combined abundance, biomass and benthic metabolism of ciliates and meiofauna. With respect to the dominance of herbivorous ciliates and epistrate-feeder nematodes in seagrass sediment, predator–prey relationships and competition for food resources between nematodes and ciliates are likely to be important factors in controlling the abundances of these groups.

1. Introduction

Estuaries are widely recognized as highly specialized types of ecosystem with unique marine and brackish water communities of organisms (Levin et al., 2001; McLusky and Elliott, 2004). The benthic realm forms an integral and important component of estuarine ecosystems, with the benthos encompassing a large variety of fauna whose body sizes span more than nine orders of magnitude (Schmid et al., 2000). The ciliated protozoa (ciliates), which are members of the microfauna, and the microscopic metazoans, which constitute the meiofauna, are considered to be important elements in the benthic microbial food web. They are characterized by their small size, short life span, high turnover rate and complicated trophic structure (Coull, 1999; Epstein, 1997a,b; Kuipers et al., 1981). Additionally, their high sensitivity to anthropogenic inputs makes them excellent sentinels of estuarine pollution (Grego et al., 2009; Irizuki et al., 2011; Moreno et al., 2011; Sutherland et al., 2007). In comparison to the intensively studied meiofauna, the distribution and ecological importance of ciliates in marine sediments have received little attention. This is largely due to the methodological difficulties involved in extracting these fragile microorganisms from sediments for the purpose of qualitative and quantitative analyses. In recent years, however, the application of silica sol density gradient centrifugation in combination with the quantitative protargol stain (QPS) has enabled quantitative investigations of the benthic ciliate assemblages to be carried out with high taxonomic resolution (Hamels et al., 2004, 2005; Wickham et al., 2000; Xu et al., 2010).

Jiaozhou Bay is located on the southern coast of the Shandong Peninsula in eastern China (Fig. 1). It is a semi-enclosed bay of the Yellow Sea that has undergone extensive environmental changes in

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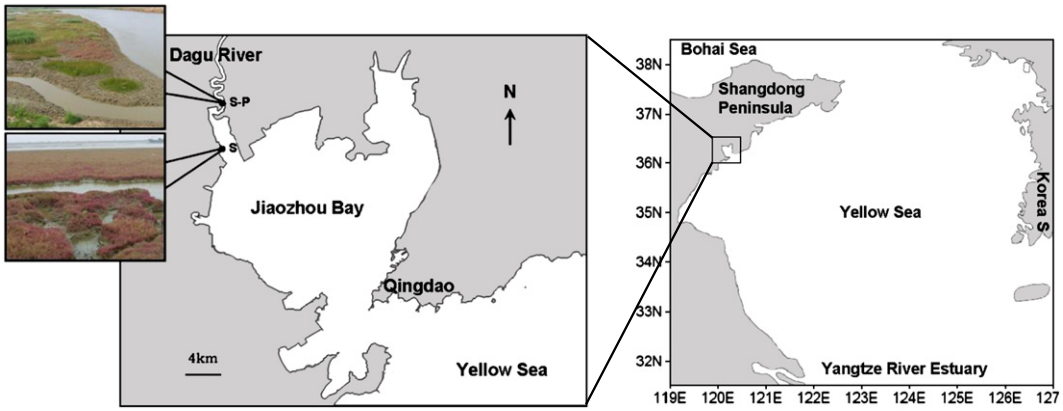

Fig. 1. Map showing the intertidal sampling sites (●) at the Dagu River estuary discharging into Jiaozhou Bay (36°14′N, 120°06′E). Station S was covered by *Suaeda glauca* and station S-P was covered by *S. glauca* and *Phragmites australis* during monthly samplings.

recent years, due both to natural factors (including sediment supplies) and human activities such as farming and construction. For example, the world's longest bridge over water crosses Jiaozhou Bay. Nevertheless, the perimeter region of Jiaozhou Bay is one of only seven estuarine wetland ecosystems listed in China Biodiversity Conservation Strategy and Action Plan as requiring priority conservation attention. The estuarine wetland of the River Dagu, the largest river discharging into Jiaozhou Bay, supports about 75% of the total vegetation in the region. Thus it is one of its most important ecosystems and has led to its establishment of a nature reserve (Ministry of Environmental Protection of the People's Republic of China, 2010). However, for a number of historical and methodological reasons, the micro- and meiofauna of the River Dagu estuary has received far less attention than other biotopes in Jiaozhou Bay such as the pelagium and macrofauna (Yuan et al., 2007; Zhang et al., 2001). Furthermore, there is a paucity of knowledge of the fauna in unvegetated patches within seagrass-dominated estuaries worldwide despite the ecological importance of seagrass biotopes (Boström et al., 2006).

We investigated the benthic ciliate and meiofauna communities in the River Dagu estuary using the recently developed Ludox-QPS method (Du et al., 2009; Xu et al., 2010). We compared the environmental characteristics, and the communities of ciliates and meiofauna (*i.e.* species composition, diversity, abundance, biomass, spatial and seasonal distributions) in seagrass sediments in the lower part of the estuary with those in sediments with a patchy distribution of halophytes, or which are otherwise unvegetated, in the upper part of the estuary. The main aims are to determine: (1) whether the seagrass habitat supports ciliate and meiofaunal communities that are as distinctive as that of the macrofauna; (2) the most important factors regulating the ciliate/meiofaunal variation spatially and seasonally, and; (3) the relative importance of ciliates and nematodes in terms of their abundance, biomass and metabolism in the benthic ecosystem. Potential trophic interactions between ciliates and nematodes are also discussed.

2. Materials and methods

2.1. Study sites

This investigation was undertaken in the tidal estuary of the River Dagu which is located in the northwestern part of Jiaozhou Bay (Fig. 1). The shoreline of the estuary consists mainly of muddy sediments and is extensively covered with halophytes (Ma et al., 2006). Much of the area of sediment deposition has been reclaimed for shrimp farming or salt production (Song et al., 2008). A number of jetties for fishing boats have also been constructed along the estuary.

Two sites representing two distinct habitats were selected for the investigation. One was located in the lower section of the estuary and was exposed to a strong tidal flow of marine waters. This area of the estuary is covered by a dense canopy of the seagrass (also known as or seepweed) *Suaeda glauca* (Bunge). The other site was located in the upper section of the estuary and was more protected from strong tidal flows of marine waters. In this area of the estuary most of the sediment was unvegetated and subaerially exposed over much of the ebb tidal phase, although *S. glauca* and the common reed, *Phragmites australis*, occurred in patches. The two habitats are designated Stations S and Station S-P respectively, based on the type and extent of plant cover.

2.2. Sample collection and measurement of environmental factors

Monthly sampling was carried out during ebb tide from June 2006 to May 2007. Eight randomly selected replicate samples were collected at each site by coring sediments to a depth of 8 cm using a modified syringe with an inner diameter of 23 mm. The sediment was extruded carefully through the bottom of the cores and sectioned immediately into 0–0.5 cm, 0.5–2 cm, 2–4 cm and 4–8 cm depth layers. For the analysis of benthic organisms, each of the four samples was initially diluted *in-situ* with filtered water, fixed with an equal volume of ice-cold glutaraldehyde (2% final concentration) and stored at 4 °C in the dark until being processed. The corresponding layers of the other four replicate cores were pooled and stored in a frozen state for later environmental analyses.

On each sampling occasion, the *in situ* temperature was measured using a thermometer with the bulb immersed in the sediment to a depth of 5 cm. Seepage water from the uppermost 10 cm layer of the sediment was collected for salinity measurement using a refractometer. The water content of the sediment was determined as the percentage of weight loss after drying the sediment at 60 °C for 72 h. The organic matter (OM) content of the sediment was measured using the $K_2Cr_2O_7$–H_2SO_4 oxidization method (Gaudette et al., 1974; Nelson and Sommers, 1982) The concentrations of sediment chlorophyll a (chl-*a*) and total phaeopigments (pheo) were determined *via* spectrophotofluorimetry (Lorenzen and Jeffrey, 1980; MacIntyre and Cullen, 1995) using the corrected formula of Wang (1986) for the calculation of pheo. Surface sediment samples were used for determination of grain size distribution using a Laser Diffraction Particle Size Analyzer (Cilas 940L).

2.3. Extraction, enumeration and identification of organisms

The Ludox-QPS method, which combines Ludox density gradient centrifugation (Xu et al., 2010) and quantitative protargol staining