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Application of macrobenthos functional groups to estimate the ecosystem health in a semi-enclosed bay

Shitao Peng [a,b], Ran Zhou [a], Xuebo Qin [a,c,*], Honghua Shi [b], Dewen Ding [b]

[a] Laboratory of Environmental Protection in Water Transport Engineering, Tianjin Research Institute for Water Transport Engineering, Tianjin 300456, China
[b] First Institute of Oceanography, SOA, Qingdao 266061, China
[c] MOE Key Laboratory of Pollution Processes and Environmental Criteria, College of Environmental Science and Engineering, Nankai University, Tianjin 300071, China

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ABSTRACT

In this study, the functional group concept was first applied to evaluate the ecosystem health of Bohai Bay. Macrobenthos functional groups were defined according to feeding types and divided into five groups: a carnivorous group (CA), omnivorous group (OM), planktivorous group (PL), herbivorous group (HE), and detritivorous group (DE). Groups CA, DE, OM, and PL were identified, but the HE group was absent from Bohai Bay. Group DE was dominant during the study periods. The ecosystem health was assessed using a functional group evenness index. The functional group evenness values of most sampling stations were less than 0.40, indicating that the ecosystem health was deteriorated in Bohai Bay. Such deterioration could be attributed to land reclamation, industrial and sewage effluents, oil pollution, and hypersaline water discharge. This study demonstrates that the functional group concept can be applied to ecosystem health assessment in a semi-enclosed bay.

1. Introduction

With population growth, the expansion of industrial and agricultural activity, and global climate change (Lotze et al., 2006; Airoldi and Beck, 2007; Waycott et al., 2009), the degradation of ocean ecosystems has become a global issue (Lotze et al., 2011). Semi-enclosed bays are among the most important marine ecosystems in the world. Over the past several decades, semi-enclosed bays have been significantly affected by anthropogenic actions, such as reclamation for agriculture and aquiculture, occupation of areas for urban industrial and port development, wastewater discharge, and emerging oil spills (Caddy, 2000; Shi et al., 2011; Peng et al., 2012). One of the most important problems is that seawater quality has deteriorated gradually due to high concentrations of nutrients (Peng et al., 2009). Because of poor water exchange with the ocean in semi-enclosed bays (Lim et al., 2012), a decline in ecosystem health was to be expected as a consequence of the increased pollutant concentrations.

Semi-enclosed bays are among the most important areas for economic development and aquaculture (Chen and Yu, 2011; Gu et al., 2012). The ecosystem health of semi-enclosed bays is particularly relevant to economic growth and social progress at both regional and larger scales. The decline in ecosystem health in a semi-enclosed bay deserves urgent attention and action. Hence, the classification of the health state of semi-enclosed bays is very important. After the classification, the critical factors of ecosystem health may be defined, and then, suitable ecological restoration, management and regulation practices may be established to reduce the effects of degradation.

Ecological indicators are an effective way to characterize marine ecosystem health (Shin et al., 2010). A number of indicators, such as biomass, productivity, and structural indicators, have been widely applied to describe marine ecosystem health (Vethaak et al., 2009; Mallory et al., 2010; Rombouts et al., 2013). Due to their position at the sediment–water interface and their relatively long and sedentary life, macrobenthos have been considered to be potentially powerful indicators in the assessment of marine ecosystem health (Dauer et al., 2000; Lavesque et al., 2009). Traditionally, the assessment of marine ecosystem health using macrobenthos was performed using a taxonomic approach (Bonsdorff and Pearson, 1999; Muniz et al., 2011). Such a taxonomic approach is more appropriate in the evaluation of biodiversity or sensitivity to a given chemical contaminant rather than ecosystem conditions (Cummins et al., 2005). This finding indicates that the taxonomic approach may not be appropriate in the assessment of ecosystem health; thus, other methods are necessary. Recently, a new approach using macrobenthos functional groups in ecosystem health assessment was proposed (Bremner et al., 2006; Gamito and Furtado, 2009). These groups of species have more or less precisely defined demands through several different combinations of morphological and behavioral properties. In contrast with the

* Corresponding author at: Laboratory of Environmental Protection in Water Transport Engineering, Tianjin Research Institute for Water Transport Engineering, Tianjin 300456, China. Tel.: +86 022 59812345x536; fax: +86 022 59812113.
E-mail address: qinxuebo@126.com (X. Qin).

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taxonomic approach, functional groups have been more precise in evaluating responses to changes in environmental conditions. For example, changes have been observed in the macrobenthos feeding groups (e.g., changes in the dominance of the feeding groups, in the presence of all types or in the absence of some types) in a stressed environment subjected either to anthropogenic action or to natural physical stress (Gamito and Furtado, 2009). Therefore, functional feeding groups are a useful tool in ecosystem health assessment. This approach has been successfully applied in estuaries (Gamito and Furtado, 2009; Gamito et al., 2012) and marine ecosystems (Bremner et al., 2006). However, few studies have been performed in semi-enclosed bays.

Bohai Bay is a semi-enclosed bay, located in the western region of the Bohai Sea in northern China. During the recent three decades, Bohai Bay suffered a reduction in size due to rapid industrialization and urbanization (Peng et al., 2012). Moreover, Bohai Bay is the only recipient of the wastewater from Beijing, Tianjin, and Hebei province. It is expected that the ecosystem health of Bohai Bay has gradually deteriorated. However, little information is available on the ecosystem health of Bohai Bay. Assessment of marine ecosystem health using macrobenthos functional groups in China is lacking.

In this study, we engage in the first attempt to apply the concept of functional groups to identify macrobenthos and to evaluate the ecosystem health of Bohai Bay. The primary objectives of this study were (1) to investigate the composition and abundance of macrobenthos functional feeding groups, (2) to assess ecosystem health using macrobenthos functional feeding groups, and (3) to establish the relationships between the environmental variables and the macrobenthos functional feeding groups.

2. Materials and method

2.1. Field sampling and measurements

Thirty sampling stations were sampled for macrobenthos in the spring (May) and summer (August) of 2007 in Bohai Bay (Fig. 1). At each station, three to five sediment replicates were randomly taken using a Van Veen benthic grab (0.025 m^2). The sediment samples were washed through a 0.5 mm sieve to separate the macrobenthos. The macrobenthos were preserved in 5% buffered formalin and were returned to the laboratory for further analysis.

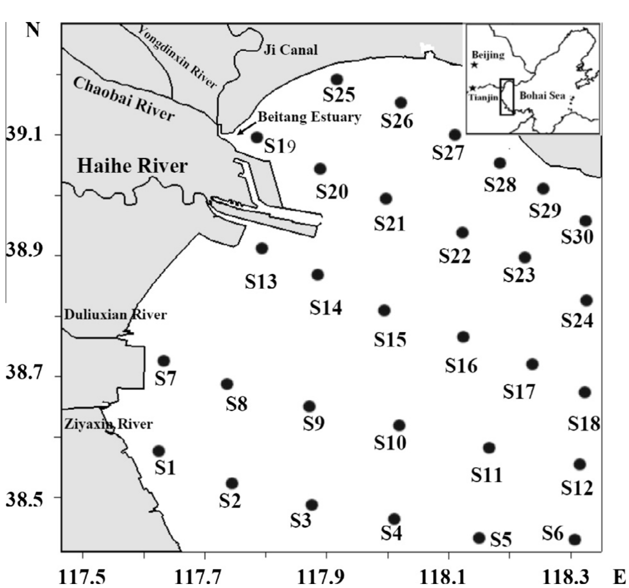

Fig. 1. The sampling stations in Bohai Bay.

Water temperature (WT), pH, salinity (SAL) and dissolved oxygen (DO) at the basin bottom were measured in the field using a multi-parameter kit (MS5, HACH). Depth (DEP) was measured at each station using a GARMIN FishFinder 240. Water samples from the basin bottom were collected to determine the concentrations of nutrients and total petroleum hydrocarbons (TPH).

2.2. Nutrient and total petroleum hydrocarbons measurements

Concentrations of ammonium (NH_4-N), nitrate nitrogen (NO_3-N), nitrite (NO_2-N), soluble reactive phosphorus (SRP), and silicate (SiO_4) were determined following the standard methods of the APHA (APHA, 1998). All measurements were completed within 24 h of sampling. Because the nitrite and ammonium concentrations were negligible compared with nitrate in this study, these three nitrogen sources were integrated into a single value of dissolved inorganic nitrogen (DIN).

Total petroleum hydrocarbons (TPH) were measured following the US-EPA Method-1664 (US-EPA, 1999).

2.3. Definition of macrobenthos functional groups and assessment of ecosystem health

Macrobenthic taxa were classified as main species whenever they occurred at densities greater than 5% of the total abundance at one site during at least one sampling period. Only the main species were grouped into functional groups in this study. The macrobenthos functional groups were defined according to feeding types. In this study, five functional feeding groups were defined according to feeding types, including a carnivorous group (CA), omnivorous group (OM), planktivorous group (PL, feeding on plankton), herbivorous group (HE, feeding on macroalgae and macrophytes), and detritivorous group (DE).

Ecosystem health was estimated from the macrobenthos functional feeding groups based on the feeding evenness index (j_{FD}) following the methodology of Gamito and Furtado (2009):

$$j_{FD} = \frac{H'_{FD}}{\mathrm{Log}_2\, n}$$

where H' is the Shannon–Wiener index (Shannon and Weaver, 1963) and n is the number of feeding groups, in this case, five groups. In a healthy environment, almost all feeding groups will be present, whereas a degraded environment will be dominated by a few groups (Gamito and Furtado, 2009). The ecosystem health state (EHS) was determined from the identical ratio intervals following the method of Gamito et al. (2012): evenness values greater than 0.80 correspond to a high EHS; values between 0.80 and 0.60 indicate a good EHS; values 0.40–0.60 indicate a moderate EHS; values 0.20–0.40 indicate a poor EHS; and evenness values less than or equal to 0.20 signal a bad EHS.

2.4. Statistical analyses

The differences among environmental variables in different seasons were tested by a one-way ANOVA using SPSS 15.0. Multivariate ordination techniques were used to analyze the effects of environmental variables on the macrobenthos functional groups using CANOCO version 4.5. The measured environmental factors, including WT, DEP, pH, SAL, DO, DIN, SRP, SiO_4, and TPH, were used as the explanatory variables. All of these environmental variables were log10 transformed before analysis except pH. The macrobenthos functional group data were log10 $(x + 1)$ transformed before analysis to reduce the effect of highly variable densities on the ordination scores. Detrended correspondence analysis (DCA) of the macrobenthos functional group data was employed to