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Heavy metal spatial variation, bioaccumulation, and risk assessment of *Zostera japonica* habitat in the Yellow River Estuary, China

Haiying Lin, Tao Sun *, Sufeng Xue, Xiangli Jiang

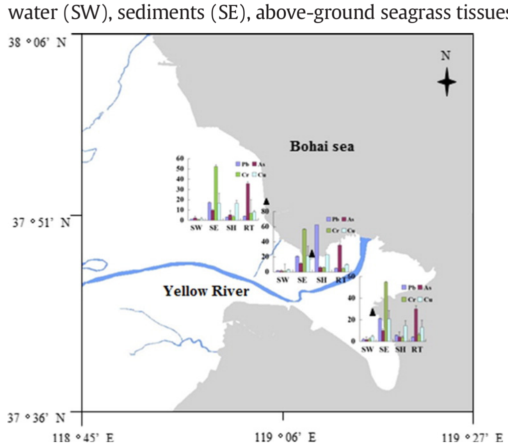
State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, PR China

HIGHLIGHTS

- *Zostera japonica* are reported in the Yellow River Estuary in China.
- Higher heavy metal accumulation found at seagrass sites than at non-seagrass sites.
- As, Cr, Cu and Pb may be associated with adverse ecological effects in this study area occasionally.

GRAPHICAL ABSTRACT

High risk heavy metal contamination and its contents in the seagrass sites along the Yellow River Estuary (in seawater (SW), sediments (SE), above-ground seagrass tissues (SH) and below-ground tissue (RT) respectively).



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ABSTRACT

Globally, seagrass habitats are decreasing due to both natural and environmental contaminations by human activities, including heavy metal pollution. To expand the global seagrass detection network, this study reports the spatial distributions of *Zostera japonica* seagrass habitats in the Yellow River Estuary, China. In addition, heavy metal concentrations of *Z. japonica* tissue, sediment, and surface seawater were analyzed to determine the bioaccumulation and consequent ecological risk to *Z. japonica* habitats due to the effects of heavy metals. It was found that concentrations of heavy metals were 1.00–2.03 times higher in seagrass-rooted sediment than in adjacent non-seagrass sediment, except for Mn (with a factor of 0.99). Pb and Hg concentrations in sediments exceeded background values more than the other heavy metals, by factors of 1.74 and 1.24, respectively. Metal concentrations in the surrounding seawater were 2.60–4.63 times higher at seagrass sites than at non-seagrass sites, except for Hg (factor of 0.97). Metal concentrations were much higher in seagrass tissues than in the sediment (e.g., bioconcentration factor of Cd is 30.95). Pb concentrations in water may cause the greatest adverse reactions among aquatic organisms, while As, Cr, Hg, Mn and Cu in sediments may occasionally cause negative ecological effects. *Z. japonica* showed higher bioaccumulation of Cd and Pb in the above-ground tissues. Among other recent studies of seagrasses from other parts of the world, Cd concentrations are similar to the results of the present

* Corresponding author.
E-mail address: suntao@bnu.edu.cn (T. Sun).

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study, but Pb concentration in present study is higher than in other studies. In conclusion, Pb and As in the surrounding environment present potential risks to the seagrass habitats of the Yellow River Estuary, China.

1. Introduction

Seagrass is globally abundant and has important ecological functions. Specifically, seagrass has a high rate of productivity, drives coastal nutrient cycling, and provides food sources and feeding grounds for several species (Orth et al., 2006). Seagrass ecosystems are directly exposed to human impacts from sea traffic, industrial, dredging, and reclamation activities (Luy et al., 2012; Roca et al., 2014). Consequently, seagrass die-offs have been documented worldwide, leading to concern about the health of these systems (Short et al., 2014; Holon et al., 2015). *Zostera japonica*, also known as dwarf eelgrass, belongs to the family Zosteraceae, which is native to the seacoast of eastern Asia. *Z. japonica* mainly occurs in intertidal and shallow subtidal areas, from temperate to subtropical regions, along the Pacific coasts of East Asia, along the North Pacific coast, and especially in East Asia (China, Korea, and Japan) and North America (den Hartog, 1970; Short et al., 2001; Short et al., 2007; Mach et al., 2014). *Z. japonica* has the widest distribution of the seagrass species, and occurs in temperate and subtropical coastal regions. In subtropical regions, it usually occurs near mangrove swamps or in co-occurrence with *Halophila* spp. (Fan et al., 2011), while in temperate zones it often occurs near eelgrass in intertidal regions (Lee et al., 2001; Zhang et al., 2015). In China, it has been found in areas including Pearl Harbor, Qinzhou Bay, Beihai Sea (Guangxi Province), Leizhou Island (Guangdong Province), Lantau Island (Hong Kong), Swan Lake in Weihai City, and Huiquan Bay in Qingdao City (Shandong Province), and Taiwan province etc., from the nationwide investigation research in recent years (Fan et al., 2011; Zheng et al., 2013; Zhang et al., 2015). The most recent studies are focused on seasonal variation of nutrients like C, N, and P in the different tissues of *Z. japonica*, and some works looked into restoring *Z. japonica* habitats using transplanting techniques, etc. (Zhang et al., 2015). To date, there have been few ecological studies on *Z. japonica* (Lee, 1997; Lee et al., 2005, 2001; Abe et al., 2003, 2009; Fan et al., 2011; Mach et al., 2014; Zhang et al., 2015). Additionally, there are no reports on the spatial distribution of *Z. japonica* in the Yellow River Estuary of China and effects on *Z. japonica* of heavy metals.

The Yellow River, located in northern China, is regarded as the second-largest river in the world in terms of sediment discharge. Large volumes of suspended sediment comprising particulate heavy metals, organic matter, nutrients, and minerals are transported to the ocean by rivers every year (Milliman and Meade, 1983). However, heavy metals from both natural and human activities have been shown to impact seagrass habitats through atmospheric and terrestrial contributions (Halpern et al., 2008). Heavy metals may be incorporated into seagrass tissues from the water or sediments (Lyngby et al., 1982; Ward, 1987). The potential of heavy metal accumulation in seagrass has been investigated for bioremediation purposes (e.g., Bunluesin et al., 2007; Govers et al., 2014). Although some of elements are essential to plant growth (e.g., Cu, Fe, Mn, Ni, and Zn), several studies have shown that heavy metals negatively impact seagrass photosynthetic physiology (Prange and Dennison, 2000; Macinnis-Ng and Ralph, 2002; Papathanasiou et al., 2015). For instance, Prange and Dennison (2000) found that two *Halophila* species were affected by exposure to Fe and Cu, whereas *Zostera capricorni* was only impacted by Cu.

Few studies have investigated the sensitivity of seagrass species to heavy metals. Consequently, there is limited data for determining the actual risks of toxic metals for seagrass ecosystems (Richir and Gobert, 2014). To date, the specific ecological risks to *Z. japonica*, of frequent exposure to water containing high concentrations of suspended metals, remain unclear, and little is known about the bioaccumulation of heavy metals by *Z. japonica* in these coastal ecosystems. Therefore, it is necessary to identify the responses of *Z. japonica* to heavy metal contamination, and to understand the ecological risks of toxic metals to different taxa.

This study reports the distribution and heavy metal contamination risks for *Z. japonica* in the Yellow River Estuary. This study aimed to: (i) investigate the heavy metal concentrations in *Z. japonica* tissue, sediment, and surface seawater around seagrass habitats in the Yellow River Estuary temperate zone, which forms part of the global seagrass monitoring network; (ii) understand the bioaccumulation of heavy metals in *Z. japonica* by investigating heavy metal contents in sediments and seawater at the seagrass sites; (iii) identify the ecological stress of heavy metals on this seagrass biotope. The results are intended to demonstrate the potentially high ecological risk of heavy metals for the seagrass *Z. japonica*, and will provide reference data necessary for managing and protecting *Z. japonica* ecosystems in the Yellow River Estuary.

2. Methods

2.1. Sampling locations

The Yellow River is the second-largest river in China. The Yellow River Estuary enters the northeastern Gulf of China (Fig. 1). It is the main channel to the sea for terrigenous sediment, and is a major area of terrigenous pollution. Based on data from the China Ocean Environment Gazette, the total heavy metal pollutant load in the Yellow River was 687 t in 2011. However, only two years later, approximately 4.40×10^5 t of pollutants (including 1110 t of heavy metals) were carried from the Yellow River to the estuary (State Oceanic Administration of China, 2013).

Both non-seagrass (NSt.) and seagrass sites (SSt.) were chosen in a single linear transect running from west to east along the coastal area, to detect possible contamination gradients from August to September 2014 (from N 38°00′28″, E 118°5′45″ to N 37°43′45″, E 119°14′02″). Sites 1–3 (St. 1–St. 3) were non-seagrass sampling sites and Sites 4–6 (St. 4–St. 6) were seagrass sampling sites. For the seagrass sites, Site 4 was located the farthest from the mouth of the Yellow River Estuary; Site 5 was located mid-way along the transect; and Site 6 was located closest to the Yellow River, to the south of the mouth of the Yellow River Estuary. *Z. japonica* is reported to inhabit intertidal sandy or muddy bottoms at depths approximately 1–2 m. The water depth at all sampling sites was approximately 1 m.

2.2. Sample collection

Z. japonica samples were collected from the three seagrass sites (4 replicates per site with a distance of 50 m). The samples were then washed, cleaned of sediments and epiphytes, manually ground to a coarse powder, and freeze-stored before being transferred to the laboratory for heavy metal analysis. In addition, surficial sediment samples were collected from the top 5 cm of the *Z. japonica* stands ($n = 4$ per site, mixed together to represent one sample; 4 replicates), using an acrylic plastic corer to avoid contamination. The samples were freeze-stored until heavy metal and grain-size analyses were conducted. Seawater samples were also collected from the same *Z. japonica* stands, using a plastic bottle to avoid contamination. The bottles were new and had been washed with acid. From the non-seagrass sites, randomized sediments and seawater mixed samples were taken back to the lab. The same storage methods were used.

The seagrass was separated into above-ground and below-ground plant parts for *Z. japonica*. Epiphytes, where present, were removed