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Unusual pattern in characteristics of the eelgrass *Zostera marina* L. in a shallow lagoon (Swan Lake), north China: Implications on the importance of seagrass conservation

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ABSTRACT

Since the 1980s, seagrass populations have declined greatly in most coastal waters of China. Nevertheless, we documented, in this study, an unusual occurrence of the eelgrass *Zostera marina* L. in north China, with biomass markedly higher than other temperate areas in the world. Seasonal changes in biometric variables and the biomass of *Z. marina* were examined in a shallow marine lagoon of Swan Lake, an important nature reserve for swans (*Cygnus cygnus*). Results showed that shoot height of eelgrass varied seasonally, with maximum values (>170 cm) being recorded in June 2009 and minimum values (<25 cm) in January–March 2010. The highest shoot density was recorded in August 2009 (645 shoots m^{-2}) and the lowest in March 2010 (334 shoots m^{-2}). Eelgrass biomass also varied seasonally, from >1000 g DW m^{-2} in August 2009 to <100 g DW m^{-2} in March 2010. Carbon, nitrogen and phosphorus content in different parts of eelgrass also varied seasonally. The N and P contents in rhizomes were significantly lower than that in leaves and leaf sheaths. Annual average C/N ratios in leaves, leaf sheaths, and rhizomes were 14.99 ± 2.97, 13.31 ± 4.59, and 18.50 ± 4.99, respectively; and annual average C/P ratios were 248.82 ± 81.7, 199.8 ± 87.5, and 289.2 ± 95.1, respectively; the abovementioned deviations suggest P enrichment of eelgrass in the lagoon, compared with the global range for the species. Water temperature is the most important environmental factor that impacts the seasonal variation in this species. The increased distribution area and high productivity of *Z. marina* were mostly attributed to local conservation efforts.

1. Introduction

Seagrasses, a group of marine underwater angiosperms, are widely distributed along tropical and temperate coastlines of the world. Seagrasses play a key ecological role in coastal ecosystems. They are clonal plants that can form extensive meadows supporting high biodiversity, and they have a direct value to humankind (Short et al., 2007; Duarte et al., 2008). Seagrasses are important habitat-formers and ecosystem engineers; seagrass ecosystems have a complex physical structure, and have great ecological value since they provide a habitat for commercial and recreational fish, shellfish, and Holothurians, as well as being an important source of food for a variety of marine herbivores, including waterfowl, dugongs, manatees, turtles, and sea-urchins (Beck et al., 2001; Jackson et al., 2001; Duffy, 2006; Heck and Valentine, 2006; Dissanayake and Stefansson, 2010; Barbier et al., 2011; Liu et al., 2013). By enhancing sedimentation, seagrass ecosystems remove nutrients from the water column, thereby regulating nutrient cycles and increasing sea water clarity. In the long-term, a fraction of eelgrass biomass buried in the bottom of the sea will transform into a carbon sink (Duarte, 1999). Seagrass is an important absorber of carbon dioxide, which is of major significance to global warming; Seagrass beds are key sites for global carbon storage in the biosphere (Duarte et al., 2005; Fourqurean et al., 2012; Lavery et al., 2013). These ecosystem services are, however, currently diminishing as seagrass beds disappear at an alarming rate around the world, due to anthropogenic influences (Orth et al., 2006; Waycott et al., 2009; Short et al., 2011). A global conservation effort and active management

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of seagrass beds is therefore becoming increasingly important (Orth et al., 2006; Unsworth and Cullen, 2010; Cunha et al., 2013).

Zostera marina is the most common and widespread seagrass species in shallow marine environments in the northern hemisphere, and has been undergoing declines and local extinctions in many coastal waters around the world (Short et al., 2011; Fertig et al., 2013; Dooley et al., 2013). *Z. marina* is also an important representative seagrass in north China, and it is distributed in Liaoning, Hebei and Shandong provinces (Yang and Wu, 1981; Zhou et al., 2014). In the coastal waters of Shandong province, especially in Weihai, dry leaves of eelgrass were traditionally-available raw material used for thatching houses. Currently, there are many seagrass-roofed dwelling house reserves in the coastal areas of Weihai. However, seagrasses have received little attention in China. Due to the low economic value of eelgrass itself, eelgrass meadows have not been treated in a reasonable way, and have even been removed completely, as a fouling organism. There has been a dramatic reduction (>80%) in the distribution of eelgrass meadows inhabiting waters between 2 and 6 m deep in Shandong inshore areas, and some eelgrass meadows have disappeared since the 1980s (Ye and Zhao, 2002). According to existing reports, changes in natural conditions and human activities are the major causes underlying the degradation of eelgrass meadows. In this context, the effect of human activities (habitat destruction and pollution) is predominant. So far, there are few reports on the seasonal variations in biometric and biomass features of the eelgrass *Z. marina* in coastal waters of China.

Swan Lake, where the present study was conducted, is a shallow marine lagoon that functions as a national natural swan reserve. Our previous work showed that the lagoon also inhabits considerable sea cucumbers (*Apostichopus japonicus*), and eelgrass detritus acts as a food source for the deposit feeder (Liu et al., 2013). In the present study, we conducted a field survey of biometric and biomass features of *Z. marina* in Swan Lake. Also, nutrient elements C, N, and P in the rhizome, leaf sheath, and leaf was investigated; to our knowledge, few data on nutrient contents in all the three parts mentioned above have been reported. We also investigated the relationship between the annual changes in eelgrass and a number of major environmental factors. The aim of this study was to understand the unique annual dynamics of eelgrass in a shallow lagoon in northern China and the importance of conservation efforts. Our work will provide necessary data for the conservation, management, and restoration of *Z. marina* in temperate zones of China.

2. Materials and method

2.1. Study area

The survey was conducted in Swan Lake, a small cove of a marine lagoon, in the southeast of Chengshan Town, in Rongcheng City of Weihai, north China. It is the biggest swan lake in northern China, with an area of about 4.8 km^2. The cove is connected to the Yellow Sea by a quite narrow inlet of 86 m in width. There are a number of coves in this area, including Swan Lake, that retard winds and waves, creating a quiet low-wind environment, an ideal overwintering habitat for wetland birds, such as the whooper swan *C. cygnus*. Our recent work shows that eelgrass in the cove is an important food source for swans (Wang and Zhou, unpublished data). The cove is part of a national natural swan reserve in China, and is the largest wintering habitat for *C. cygnus* in Asia. Every year approximately ten thousand swans overwinter in the cove and in the nearby area. The cove is rich in bioresources, such as sea cucumbers (Liu et al., 2013), shellfish, and fish. The annual average water temperature of the area is about 11.4 °C, which is equivalent to a warm temperate continental monsoon climate. The substrate of Swan Lake is mainly sandy. The cove is much shallow, with an average water depth <1.5 m. The cove has an average tide range ca. 0.9 m with a maximum tide range 1.65 m. Swan Lake is part of an irregular semi-diurnal mixed tidal area. We surveyed three geographical seagrass sites in the lagoon (Fig. 1).

2.2. Sampling methods and data analysis

Based on the eelgrass distribution area, depth, and distance from the shore, we selected three sites in Swan Lake, i.e. SL-1 (E122.579°, N37.350°), SL-2 (E122.574°, N37.351°), and SL-3 (E122.576°, N37.349°), with average depth of water in spring low tide being 0.3 m, 1.0 m, and 1.2 m, respectively. The seagrass survey was carried out on a monthly basis from May (SL-1), June (SL-3), or August (SL-2) 2009 to June 2010; and the sampling at the different sites were in similar periods of time.

The shoot density of *Z. marina* (shoots m^{-2}) was estimated by counting shoots within a quadrat of 30 × 30 cm in situ. Density was estimated 4–6 times per season at low tide in the intertidal site SL-1. The shoot density at site SL-2 was also determined in August, 2009, and there was no statistical difference between site SL-2 and site SL-1 (1-way ANOVA, $F = 0.173$, $p = 0.685$). Therefore a survey on seasonal variation in shoot density was only conducted at site SL-1. In the same area, eelgrass shoots, together with rhizomes and roots, were collected to determine shoot-height and total biomass (sum of above- and below-ground biomass) from a randomly-located quadrat of 20 × 20 cm (down to a depth of 15 cm in sediment). The shoot height was measured with a meter ruler from the bottom of the sheath to the top of the longest leaf. During this survey, measurements were taken at 1–2 month intervals. A total of four to five replicates were randomly collected at each site on each sampling occasion. All samples were placed in plastic bags and transported to the laboratory in darkness while being kept at a low temperature. Samples of eelgrass shoots with rhizomes were separated and rinsed with fresh water, to remove salt and sediment. During this process all attachments (epibiota and other material) on the shoots were cleaned of. All shoots collected in each replicate were counted and measured for shoot height, after which the weight of the wet eelgrass was determined. We also recorded the constant weight after drying at 60 °C. The fresh eelgrass was dissected into leaves, leaf sheathes, and root-rhizomes and dried at 60 °C for C, N, and P determinations. The carbon and nitrogen content of different parts of eelgrass was determined using a VarioEL III CHONS analyzer, and the phosphorus content by means of a modified method after Solórzano and Sharp (1980) for particulate total P determination (Zhou et al., 2003).

At each of the three survey sites, 50 mL of surface sea water (two replicates) was collected and cryopreserved as soon as possible. An automatic nutrient analyzer was used to determine the nutrient concentrations (of NH_4—N, NO_3—N, NO_2—N, and PO_4—P) of sea water. Surface sediment (5 cm) was sampled seasonally for the determination of organic carbon, organic nitrogen, and organic phosphorus. During one survey period (January 2010), three replicate sediment samples (collected to a depth of 15 cm by means of a shovel) were also collected at each site and the grain size distribution of the sediments were analyzed using a particle sizer. To determine organic carbon and nitrogen in sediments, the samples were treated with 0.2 mol L^{-1} HCl, to remove carbonates, and organic carbon and nitrogen were determined using a VarioEL III CHONS analyzer. Total phosphorus (TP), inorganic phosphorus (IP), and organic phosphorus (OP) in sediments were determined in duplicate by means of a modified method after Solórzano and Sharp (1980) for particulate P determination (Zhou et al., 2003).

Results are presented as mean ± SD. Elemental content of C, N, and P in sediments and eelgrass was calculated on a dry weight basis; elemental ratios were calculated on a mole: mole basis.