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Effect of silt and clay percentage in sediment on the survival and growth of eelgrass *Zostera marina*: Transplantation experiment in Swan Lake on the eastern coast of Shandong Peninsula, China

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ABSTRACT

This study tested the responses of eelgrass *Zostera marina* transplants to changes in the silt and clay content of sediments. A transplantation experiment using the staple method was conducted in Swan Lake on the eastern coast of Shandong Peninsula, China. We subjected *Z. marina* to different weight percentages of silt and clay in sediments (0%, 25%, 38%, 50%, 75%, and 100%) for 120 days and then measured plant response in terms of survivorship, growth rate, individual shoot weight and productivity. Natural sediments (38% silt and clay content) from the experimental site were used as reference sediment. The survival rate of *Z. marina* transplants was 100%. Aboveground absolute growth rate, shoot weight, and productivity of *Z. marina* transplants grown on different sediment types varied significantly with maximum values recorded at 75% silt and clay content and the minimum value in reference sediment. However, the rhizome elongation rate was not significantly affected by the silt and clay content of the sediment. The results indicated that sediments with high silt and clay content could promote successful eelgrass transplantation. However, no negative responses were found on sediments with low silt and clay content. The sediment with 75% silt and clay content may be the most suitable for the growth and establishment of *Z. marina* transplants.

1. Introduction

Seagrass meadows were decreased worldwide because of natural and anthropogenic causes (Short and Wyllie-Echeverria, 1996; Tomasko et al., 2005; Burkholder et al., 2007; Montefalcone et al., 2010). Seagrasses are generally unavailable as commercial nursery stock, unlike emergent wetland plants and other freshwater plant species, which are commercially propagated and available in sufficient quantities for restoration. This scarcity limits restoration projects, and forces these projects to rely on wild plants collected from donor sites (Shafer and Bergstrom, 2010). Numerous restoration projects using mature transplants or adult seagrasses have been attempted worldwide (Davis and Short, 1997; Orth et al., 1999; Meehan and West, 2002; Fishman et al., 2004; Park and Lee, 2007; Bastyan and Cambridge, 2008; Li et al., 2010).

Sediment type is a critical and important factor affecting the success of seagrass transplantation (Lanuru, 2011). The silt and clay content of the sediment affects nearly all biological and chemical properties and functions of the sediment. Thus, silt and clay content might jointly serve as a major function in determining seagrass distribution, growth, and abundance (Terrados et al., 1998; Halun et al., 2002; Thangaradjou and Kannan, 2007). Some studies revealed that seagrasses can grow in various sediment compositions, but the species composition and biomass of seagrasses will definitely vary (Rajeswari and Kamala, 1987; Koch, 2001; Green and Short, 2003; Charpentier et al., 2005).

Eelgrass *Zostera marina* has been the focus of most of seagrass restoration activities along temperate coasts of Europe, North America, and the northwest Pacific (Fonseca et al., 1998; Hizon-Fradejas et al., 2009; van Katwijk et al., 2009; Tanner and Parham, 2010). Although *Z. marina* can grow in different types of substratum, from muddy sand to fine sand, the species is also generally abundant on sediments with high silt and clay content according the reports by Koch (2001), Bos et al. (2007), and Jiang et al. (2012). However, studies focusing on the most suitable silt and clay content of the sediment for the transplantation remain lacking.

This study aims to test experimentally the responses of *Z. marina* transplants to variations in the silt and clay content of sediments

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and to obtain the most suitable sediment texture for establishment of *Z. marina* transplants. The responses of *Z. marina* transplants to different levels of silt and clay contents were studied through a transplantation experiment focusing on shoot survival and growth in Swan Lake on the eastern coast of Shandong Peninsula, China.

2. Materials and methods

2.1. Experimental site

The study was conducted in Swan Lake on the eastern coast of Shandong Peninsula, China (37.3382°–37.3588°N, 122.5551°–122.5793°E). The lake is a tidal lagoon with an area of 4.94 km^2. It is separated from the open sea (i.e., Rongcheng Bay and the Yellow Sea) by a 2.5 km-long sand spit, which lies to the east of the lagoon (Wei and Zhuang, 1997). The entrance channel connecting the lagoon with the open sea is 132 m wide at its narrowest part (Jia et al., 2003). The mean water depth was about 1.0 m relative to the mean sea level. The tidal range is 1.15 m on springs and 0.64 m on neaps when measured at the entrance to the lagoon. The floor of the lagoon is generally dominated by fine-grained material, with mud and sandy mud covering approximately 40% of the lagoon area (Jia et al., 2003).

Anecdotal reports, fishery practices, and local historical knowledge indicate that *Z. marina* was very abundant in Swan Lake in the early 1970s. However, the eelgrass beds were almost completely eliminated by the end of 1982 because of the poor water exchange induced by the artificial closure of the entrance to the lagoon for aquaculture purposes in 1979 (Gao et al., 1998). The upper part of the artificial dam was removed in 1986. The ecosystem of the lagoon gradually recovered, and the seagrass beds became reestablished. *Z. marina* is currently the dominant seagrass species and is estimated to occupy approximately 2.0 km^2, with most plants being distributed in the middle of the lagoon.

Four 10 cm sediment cores with a diameter of 4.8 cm were randomly collected in the sampling station and were frozen at −18 °C until processed to determine the sediment characteristics. The samples were freeze-dried. Small pieces of plant material and shells were removed from the sample, which was then analyzed with a CILAS 940 L Laser Particle Sizer.

Sediment size analyses revealed that the sediment at the experimental site contained 8.0% coarse sand (particle size between 0.5 mm and 2 mm), 17% medium sand (particle size between 250 μm and 500 μm), 37% fine sand (particle size between 63 μm and 250 μm), 29% silt (particle size between 4 μm and 63 μm), and 9% clay (particle size <4 μm). The weight percent of the silt and clay sediments (particle size <63 μm) ranged from 29% to 46% with an average of 38%.

2.2. Experimental design and procedure

Six different levels of weight percentages of silt and clay in sediments (0%, 25%, 38% [reference sediment], 50%, 75%, and 100%) were set in this experiment. Sediments were collected at the beach just outside the experimental site. Fine sand (sediment particle size between 63 μm and 250 μm) and silt and clay (sediment particle size <63 μm) were obtained using a standard series of sieves. Natural sediments from the experimental site were used as reference sediment.

The experiment was conducted from May to September 2010 and lasted for 120 days. Vegetative shoots with attached roots and rhizomes were gently collected individually by hand from bottom sediments of a 10 m × 10 m donor bed located at the east of *Z. marina* bed in the Swan Lake. Intact shoots were selected and then rinsed thoroughly in seawater to remove sediments, shells, and other debris. To standardize the experiment, all plant fragments, including the apical meristem, were carefully selected to obtain comparable basal rhizomes (approximately 10 cm) with similar lengths (12–14 cm) and numbers of leaves (four–six). All rhizomes of the shoots were marked by wrapping a piece of wire around the rhizome as closely behind the rhizome meristem as possible to determine the plastochrone interval (PI). The rhizomes were then immersed in seawater to avoid desiccation and transplanted within 2 h.

Eelgrass plants were planted manually using the staple method, in which three eelgrass shoots (one planting unit) were attached to one robust, U-shaped staple made of 3 mm plastic-coated steel wire, 25 cm in length with 5 cm bent back and anchored to the sediment (Li et al., 2010). Seven plastic boxes (replicates) of 50 cm × 40 cm × 30 cm (length × width × height) were filled with each of the six sediments, and nine planting units (i.e., 27 shoots) were evenly planted in plastic boxes each filled with a 20 cm thick layer of sediment. All plastic boxes (a total of 42) were numbered with red paint and arranged 1 m apart from one another following a complete randomized design within a 9 m × 5 m (length × width) unvegetated sediment transect. The transect was oriented parallel to the shoreline to provide similar water column conditions for all treatments, which maintained a water depth of 0.5 m on neaps.

2.3. Sample collection and calculations

The experiment was terminated after 120 days. The total number of shoots in each box was counted, and the percentage of plants that survived on each sediment type at the end of the experiment was calculated.

2.3.1. Biological measurements of shoots

Four–five intact shoots were haphazardly collected from each box to test the effect of sediment texture. Shoots were carefully collected by hand to avoid damage to belowground structures, and samples were rinsed thoroughly in seawater to remove sediments and other debris. Samples were placed in sealed polythene bags, stored on ice, transported to the laboratory, and kept at 4 °C before sorting for analysis.

Samples were sorted, gently cleaned with gauze to remove epiphytes, and washed with tap water in the laboratory. The number of new rhizome segments was counted and the rhizome plastochrone interval (P_R, in days), the time between the production of new rhizome segments, were calculated by dividing the number of days since marking by the number of new rhizomes produced. The P_R is equal to the leaf plastochrone interval (P_L) for *Z. marina* (Short and Duarte, 2001; Gaeckle and Short, 2002; Li et al., 2010). Then the shoot height and the lengths of all new internodes were measured to calculate the aboveground absolute growth rate (aGR, in cm day^{-1}) and rhizome elongation rate (RER, in mm day^{-1}, Marbà and Duarte, 1998) divided by the PI, respectively. After morphological measurements, sections of leaf, root, and rhizome material were cut with a razor blade and rinsed in deionized water. Subsamples were dried at 60 °C for 48 h to obtain above- and below-ground tissue weight.

2.3.2. Above- and below-ground productivities

Above- and below-ground productivities were estimated using the plastochrone method from rhizome marking as above. The dry weights (DWs) of the youngest fullgrown leaf (usually the third leaf) and of the mature (fully expanded) rhizome/root segments were measured at the end of experiment. Aboveground productivity (mg DW $shoot^{-1}$ day^{-1}) was calculated as leaf weight divided by P_L, and belowground productivity (mg DW $shoot^{-1}$ day^{-1}) was determined as rhizome/root weight divided by P_R.