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# An effective seed protection method for planting *Zostera marina* (eelgrass) seeds: Implications for their large-scale restoration

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ABSTRACT

We describe an innovative method of planting *Zostera marina* (eelgrass) seeds in which hessian bags filled with high-silted sediments are used as a seed protecting device. Here, we evaluated the effectiveness of the method through a field seed-sowing experiment over a three year period. The suitable seed planting density required by the seeds of *Z. marina* in this method was also investigated. In the spring following seed distribution, seedling establishment rate of *Z. marina* subjected to different seed densities of 200–500 seeds bag$^{-1}$ ranged from 16% to 26%. New eelgrass patches from seed were fully developed and well maintained after 2–3 years following distribution. The seed planting density of 400 seeds bag$^{-1}$ may be the most suitable for the establishment of new eelgrass patches. Our results demonstrate that seed-based restoration can be an effective restoration tool and the technique presented should be considered for future large-scale *Z. marina* restoration projects.



## 1. Introduction

Seagrass meadows are considered to be one of the most important shallow marine ecosystems for humans, because they play a major role worldwide in the marine ecology of coastal and estuarine areas (Lemmens et al., 1996; Costanza et al., 1997; Green and Short, 2003; Heck et al., 2003). However, they were decreased worldwide because of natural and anthropogenic causes (Short and Wyllie-Echeverria, 1996; Ruiz and Romero, 2003; Tomasko et al., 2005; Burkholder et al., 2007; Montefalcone et al., 2010). Accordingly, protection and restoration of these habitats has become a major management priority (Shafer and Bergstrom, 2010).

Many studies have demonstrated that seagrass seeds could play an important role in potential contribution to population structure and genetics, plant demographics, bed maintenance, development of new beds, and more rapid recovery of disturbed stands than expected from vegetative propagation alone (Orth et al., 2000, 2006; Whitfield et al., 2004; Greve et al., 2005). Thus the recent efforts in seagrass habitat restoration have been attempted on the use of seeds rather than plants or sods as planting stock. Some field seed-planting experiments have been developed and focused on *Zostera marina* (eelgrass) using seed broadcast method (Orth et al., 2008, 2009; Busch and Golden, 2009; Busch et al., 2010; Golden et al., 2010), buoy-deployed seeding method (Pickerell et al., 2005; Boyer et al., 2008; Busch and Golden, 2009; Busch et al., 2010; Golden et al., 2010; Marion and Orth, 2010a), seed protection method with burlap bag (Harwell and Orth, 1999), and mechanical seed planter (Orth et al., 2008, 2009; Marion and Orth, 2010a).

Restoration efforts varied with seedling establishment generally less than 15% of seeds used in most studies. Of those that did report "success" (i.e., at least some planting units survived), many were based on <1 year of monitoring, therefore longer term success is likely to be even lower (Tanner, 2014). Low seedling establishment rates remain a bottleneck for seed-based eelgrass restoration (Orth et al., 2009). Previous studies showed that dispersal of seagrass seeds and seedlings can be controlled by both abiotic and biotic elements (e.g. currents, waves, wind, sediment grain size, habitat type, physical barrier, predation and human activities) (Orth et al., 2006; Koch et al., 2010; Marion and Orth, 2010b). Once the seeds and seedlings settled within an unsuitable habitat, seed germination and seedling growth are likely to be limited, and may contribute to the lack of plant establishment. Therefore, an efficient and effective planting method capable of holding seeds in the suitable site is important for the success of large-scale

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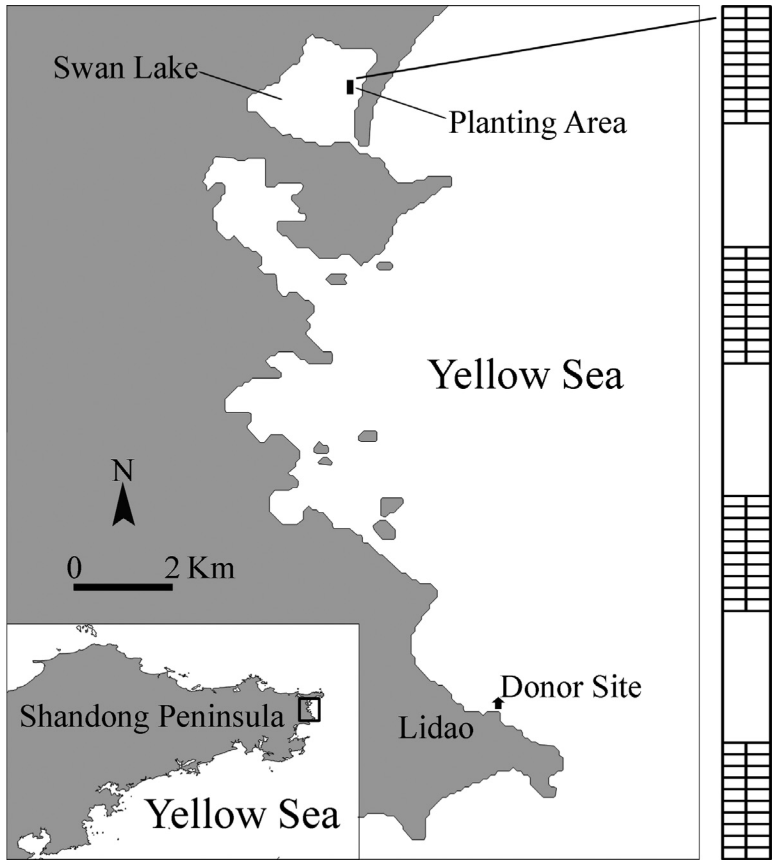


**Fig. 1.** Map of Shandong Peninsula showing donor and planting sites and arrangement of four experimental plots within a unvegetated sediment transect. □ means the protective bag.

seagrass restoration. Also, long-term monitoring in growth and expansion of restored plants is necessary.

Harwell and Orth (1999) conducted a field protection experiment using seeds in burlap bags in the lower York and Piankatank Rivers. Protective bags (5 cm × 5 cm) made by sewing burlap with a mesh size of approximately 1 mm were filled with 10 viable seeds, stapled shut, and then buried the bags 2–3 cm deep. One of the two most scarcities of the method is that no sediments were filled in the bags, disadvantageous for sediment stabilization and plant growth according to several previous studies (Ailstock et al., 2010; Tanner, 2014; Zhang et al., 2015). The other is that the bags are buried in the sediment, easy to be covered by sand thereby not only resulting in deep burial of seeds but also preventing the development of seedlings. In fact, successful seedling growth noted in the protected treatment after 6 months was lost by 8 months because of significant sand accumulation over anchored seed bags.

In this study, we improve the method presented by Harwell and Orth (1999). On the one hand, protective bags (120 cm × 90 cm) made by sewing burlap are filled with high-silted sediments and *Z. marina* seeds; on the other hand, bags are placed on the surface of sediment, levelled as a 2–3 cm thick layer and anchored with a u-shaped. The objective of this study was to assess the effectiveness of this method improved for increasing the development of new patches from seeds, through a field seed-sowing experiment over a three year period. In the meantime, seed germination, seedling establishment, and clonal growth of plants exposed to different seed densities were monitored to find the suitable seed planting density required by the seeds of *Z. marina* in this method.

## 2. Materials and methods

### 2.1. Experimental site

The study was conducted in Swan Lake (Yuehu) on the eastern coast of Shandong Peninsula, China (Fig. 1). The lake is a tidal lagoon with an area of 4.94 $km^2$ and 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 and the ecosystem of the lagoon gradually recovered.

### 2.2. Seed collection and storage

Reproductive shoots of eelgrass with inflorescences containing developed or developing seeds were collected by hand on 6–7 July 2010 at Gaojia Inlet, in the Rongcheng, Shandong Peninsula