Ecological Engineering 120 (2018) 266–273

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

# Designing microtopographic structures to facilitate seedling recruitment in degraded salt marshes

Qing Wang, Baoshan Cui*, Meng Luo, Wei Shi

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

ARTICLE INFO

*Keywords:*
Seedling recruitment
Seed retention
Bare area
Trap agent
Microtopography
Facilitation

ABSTRACT

Seedling recruitment in many ecosystems depends upon seed dispersal to, and retention at, sites that are suitable for seed germination and seedling establishment. Seed retention has been well known to be facilitated by vegetation structures in ecosystems. In many degraded ecosystems (e.g., bare salt marsh areas), this facilitative effect of vegetation structures on seed retention is often restricted, limiting vegetation recovery. The role of vegetation structures as seed traps may be replaced by microtopographic structures, but the effectiveness of microtopographic structures in seed retention across temporal and spatial scales has been seldom tested, leaving its application value in restoration of degraded ecosystems unclear. We tested the facilitative effect of microtopographic structures on seedling recruitment in degraded, bare areas in a salt marsh ecosystem. Field experiments revealed that most (≥94.4%) microtopographic structures facilitated seedling recruitment via seed trapping and the number of recruited seedlings increased with the increasing size and depth treatment of microtopographic structure. However, when excluded the effect of size, recruited seedling density decreased with size. Moreover, this trend will be modified by variation rate in depth at smaller-sized structures, when the variation in depth was significant. The stability of those induced microtopographic structures would be influenced by tidal events, thus tidal frequency can modify the effect of structural characteristics on seed retention and seedling recruitment. Our results indicate that, the most efficient microtopographic structures in seedling recruitment will be different at different locations. These findings are valuable in designing suitable microtopographic structures to facilitate seedling recruitment in microtopography-lacking degraded or restored wetlands.

## 1. Introduction

Salt marshes provide humans many vital ecosystem services, such as enhancing biodiversity (Gedan et al., 2009), high primary productivity (Mitsch and Gosselink, 2000), the storage of sediments, pollutants, nutrients, carbon (Mudd et al., 2009; Kirwan and Mudd, 2012; Pendleton et al., 2012), and one of the most important may be their role as buffers in protecting coastlines (Leonardi et al., 2018; Shepard et al., 2011; Temmerman et al., 2012). However, under the influence of climate change (e.g., extreme events) and human activities (e.g., land reclamation), salt marshes have been found to be extremely vulnerable (Kirwan and Megonigal, 2013; Leonardi et al., 2018), and have declined globally, and over 50% of salt marshes in the world have been lost in the last century (Moreno-Mateos et al., 2012; Silliman et al., 2009). In face of climate change, the continued delivery of salt marsh ecosystem services, such as mitigation of flood risks, erosion risks, and carbon sequestration, is increasingly important (Leonardi et al., 2018; Temmerman et al., 2012). Hence, extensive marsh conservation and restoration programs were proposed recently (Leonardi et al., 2018; Temmerman et al., 2012).

Seedling establishment may be particularly important for the colonization of large bare areas disconnected from existing vegetation (Cao et al., 2018). A variety of biotic and abiotic factors may affect target species development and therefore delay or accelerate the covering of bare areas (Connell and Slatyer, 1977; Farrell, 1991). The establishment of a target plant community at a restoration site depends on the presence of seeds—or on a seed bank at the site or on seed dispersal to the site (Dausse et al., 2008; Wolters and Bakker, 2002). If seeds disperse to the target sites, germination, recruitment, establishment and survival of the species develop through environmental filters, here mostly identified as waterlogging and salinity (Ivajnsic and Kaligaric, 2014).

During seed dispersal stage, tidal waters are important factors affecting seed dispersal in salt marshes (Chang et al., 2007; Peterson and Bell, 2012). Different factors can influence the probability of seed movement or retention in tidal systems during primary and secondary

* Corresponding author.
*E-mail address:* cuibs@bnu.edu.cn (B. Cui).

https://doi.org/10.1016/j.ecoleng.2018.06.012
Received 16 January 2018; Received in revised form 6 June 2018; Accepted 13 June 2018
0925-8574/ 

dispersal (Chang et al., 2007, 2008; Griffith and Forseth, 2002; Huiskes et all., 1995). The final seed distribution is highly influenced by interactions between waves, tidal flows, and trapping agents (i.e., vegetation or microtopography) (Chang et al., 2007, 2008; Griffith and Forseth, 2002). After seed dispersal, where seeds stop determines whether a plant can establish (Chang et al., 2008; Clark et al., 2007; Erfanzadeh et al., 2010a,b). Spatial variation in seed deposition in most empirical studies has often been related to landscape elements that trap seeds more than to the theoretical probability of dispersal distance travelled from the seed source (Levine and Murrell, 2003). In this way, seeds may more likely to stop and strand when met vegetative or microtopographic structures (e.g., pit). Therefore, facilitation can occur via trapping seeds during intertidal plant recruitment processes, as shown for various ecosystems, including recruitment in mangroves. Observations on plant succession after mangrove clear-cutting provided evidence for the role of emergent vegetation in directing mangrove recruitment. For example, Huxham et al. (2010) reported that natural recruitment of mangroves was greater within assemblages of planted mangrove seedlings than in adjacent bare areas. For bare areas of salt marshes, it is more difficult for seeds to become established (Clark et al., 2007) because of the lack of trapping agents (Nilsson et al., 2010). In addition, seeds are not easily retained on smooth surfaces (Johnson and Fryer, 1992). These factors could explain the slow or stagnant natural recovery on bare patches in salt marsh or mangrove ecosystems.

If there is no vegetative structure for trapping seeds to facilitate recruitment in bare areas, microtopographic structures might be used to facilitate seedling recruitment. Reproducing a diverse short-range microtopography is important for recreation of wetland forests (Barry et al., 1996) and effects of this practice have been studied on a range of restored sites (Barry et al., 1996; Deitz et al., 1996; Mccuskey et al., 1994). Usually, microtopography is defined as topographic variability on the scale of individual plants (Bledsoe and Shear, 2000; Huenneke and Sharitz, 1986; Titus, 1990), and describes soil surface variation within an elevation range from approximately 1 cm to 1 m, encompassing both vertical relief and surface roughness (Moser et al., 2007). It can be caused by sedimentation, erosion, root growth, litter accumulation, animal activities, peat compaction or shrink-swell processes (Cahoon et al., 2011; Moser et al., 2007; Rogers et al., 2006; Vivian-Smith, 1997). These small-scale variations in surface elevation are of importance for the temporal and spatial variability of flooding, water retention, and seed retention (Moser et al., 2007). It is suggested that re-creation of microtopography may improve restoration success (Barry et al., 1996; Cantelmo and Ehrenfeld, 1999), especially in restored wetland where microtopography has been reported to be missing (Barry et al., 1996; Stolt et al., 2000; Whittecar and Daniels, 1999). Many studies have demonstrated microtopography's effects on wetland hydrology, physicochemistry, and habitat variability (e.g., soil physicochemical properties, temperature, light penetration), and it is thus important in determining vegetation patterns and, ultimately, ecosystem function (Moser et al., 2007). Although seed retention is also an important effect of microtopography (Moser et al., 2007), it has not been documented adequately, especially in coastal wetlands. As microtopography is difficult to measure and quantify (most ecological studies have categorized microtopography qualitatively with descriptors such as mound/pit or hummock/hollow/flat; Bruland and Richardson, 2005; Huenneke and Sharitz, 1986; Paratley and Fahey, 1986; Titus, 1990), the quantitative assessment of microtopography and its effectiveness, such as seed retention and seedling recruitment, is poorly understood. Moreover, with the influence of erosion and deposition resulting from tidal flows, the structures might be variated during seed dispersal stage, which might in turn affect seed retention and seedling recruitment. Thus, these structural variations might be regulated by tidal frequency, result in different structural characters in seed retention and seedling recruitment at different locations.

This study focuses on the recruitment seedlings, especially the dominant species, *Suaeda salsa*, in degraded salt marshes of the Yellow River Delta (YRD), via the facilitation of quantified hollowed microtopographic structures to trap seeds. The structures are fixed with specific sizes and depths to quantify the microtopography. Specifically, we examined the relationship between the structural characters (size and depth) and the recruited seedlings at first, to figure out the appropriate structural characters in facilitating seedling recruitment. Second, since tidal disturbance (i.e., erosion and deposition) will affect microtopographic structure and the effect will vary with locations, we examined whether this influence will regulate the effect (in seedling recruitment) of the microtopographic structures. This further understanding will benefit the application of microtopographic structures in plant restoration in some degraded salt marshes and other similar microtopography-lacking ecosystems.

## 2. Materials and methods

### 2.1. Site description

This study was conducted in the YRD Nature Reserve (37.64°–38.15°N, 118.62°–119.37°E) in Shandong Province, Eastern China. The study area experiences an irregular semidiurnal tide, with an average spring tidal range of 1.06–1.78 m and an average neap tidal range of 0.46–0.78 m, (Zhao and Song, 1995). The salt marshes have relatively simple plant communities, with the zonal distribution of *Spartina alterniflora*, *Suaeda salsa*, *Tamarix chinensis* and *Phragmites australis* on the elevation gradient, respectively (He, 2012). Among them, *S. salsa* community occupies the most extent range from the low marsh to high marsh, even the supratidal zones (He, 2012; Xie et al., 2017). It is a succulent euhalophytic herb that is highly saline tolerant, with an optimum ecological salinity threshold of 12.71 ppt (Cui et al., 2008). Its seeds are characterized by a low mass and a waxy seed coat (Li et al., 2005), enabling them to be easily dispersed by the tide throughout salt marshes. Following seed maturation during October–December, they fall to the ground, whereupon they are picked up by the tide to then be dispersed across both mudflats and salt marshes.

Those disturbance-generated bare patches are widespread in middle to high marshes (Fig. 1a and b), with a distance from the shoreline of 2–4 km and a tidal frequency of less than 30% (based on tide-arrived days per annum). Different from natural salt marsh surface, these bare patches are lacking microtopographic heterogeneity, revealing bare, hard, flat and lacking sufficient amounts of liter and/or coarse surface sediment, making it difficult for seeds to be retained (Aguiar and Sala, 1997; DeFalco et al., 2009; Kinyua et al., 2010). We conducted microtopography restoration experiments across an elevation gradient in these bare areas, located in middle (A, with an elevation of 0.95 m), middle-high transition (B, with an elevation of 1.26 m) and high (C, with an elevation of 1.35 m) marsh (Fig. 1). During dispersal stage in this study (October to April), sites A, B and C had experienced 19, 10 and 6 times tidal events, respectively. Only very high tidal waters can inundate these areas. The soil salinity of the three sites are 8.44 ± 1.22 (mean ± se), 9.74 ± 1.77, and 12.16 ± 1.87 ppt, respectively, which are all within the tolerance of *S. salsa* seedlings and adult plants. Besides, there are no crab holes or crabs observed in these patches, which is in according with the investigation of He (2012). In this way, herbivory by crabs were not take into account in this experiment.

### 2.2. Field experimental design

The experimental microtopographic structures were established in October 2014. To test the ability of microtopographic structures to trap seeds and recruit seedlings, we established 18 microtopographic structures of six sizes (squares with side lengths of 20, 40, 60, 80, 100, and 150 cm) and at three depths (5, 10, and 15 cm) in each site. The sizes and depths of microtopographic structure were chosen based on the scales of natural microtopographic structures (e.g., Fig. 1c)