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Rethinking the role of edaphic condition in halophyte vegetation degradation on salt marshes due to coastal defense structure

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ABSTRACT

Determining how human disturbance affects plant community persistence and species conservation is one of the most pressing ecological challenges. The large-scale disturbance form defense structures usually have a long-term and potential effect on phytocommunity in coastal saltmarshes. Coastal defense structures usually remove the effect of tidal wave on tidal salt marshes. As a consequence, edaphic factors such as the salinity and moisture contents are disturbed by tidal action blocking. However, few previous studies have explicitly addressed the response of halophyte species persistence and dynamics to the changing edaphic conditions. The understanding of the response of species composition in seed banks and aboveground vegetation to the stress is important to identify ecological effect of coastal defense structures and provide usefully insight into restoration. Here, we conducted a field study to distinguish the density, species composition and relationships of seed bank with aboveground vegetation between tidal flat wetlands with and without coastal defense structures. We also addressed the role of edaphic condition in vegetation degradation caused by coastal defense structures in combination with field monitor and greenhouse experiments. Our results showed the density of the seed bank and aboveground vegetation in the tidal flat without coastal defense structures was significantly lower than the surrounded flat with coastal defense structures. A total of 14 species were founded in the surrounded flat seed bank and 11 species in the tidal flat, but three species were only recorded in aboveground vegetation of the tidal flat which was much lower than 24 aboveground species in the surrounded flat. The absent of species in aboveground vegetation contributed to low germination rate which depend on the edaphic condition. The germination of seeds in the seed bank were inhabited by high soil salinity in the tidal flat and low soil moisture in the surrounded flat. Our study supported the hypothesis that the change of edaphic condition caused by coastal defense structures was the main reason for the difference of the species composition similarity between aboveground vegetation and the soil seed bank between the tidal and surrounded flats. Therefore, mitigating the hydrological disturbance and maintaining the original state of edaphic factors would be useful implications for reducing the ecological effect of defense structure to vegetation communities in coastal salt marshes.

1. Introduction

Soil seed banks provide the last natural regeneration source of vegetation communities in isolated and highly fragmented areas (Adams et al., 2005). Coastal wetland is one of the most fragile ecosystems facing the severe threat of fragmentation (Barbier et al., 2008). Coastal wetlands have been developed to meet the growing demand of land resources. With the dramatic growth of population in coastal cities, more and more coastal wetlands are exploiting to provide development spaces and resources for increased urbanization (Firth et al., 2014). To protect settlements and artificial facilities against erosion, storm surges, and sea level rises, artificial coastal defense structures, such as seawalls, dykes, breakwaters, groynes, and jetties have proliferated around the world (Firth et al., 2013). Over 50% of the coastline is turning into hard coastal defense structures in Europe, the USA, and Australia (Airoldi and Bulleri, 2011; Dafforn et al., 2015; Fauvelot et al., 2009). In China, seawalls have increased 8000 km during the last ~20 years, and over 60% China's coastline has covered by coastal defense structures (Ma

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et al., 2014; Wang et al., 2014). The coastal defense structure expansion has caused fragmentation and isolation of coastal wetlands at large scales, and the defense structures keep growing in response to increased global climate change (Bulleri and Chapman, 2010).

Model simulations and empirical studies have successfully shown that coastal defense structures disturb natural coastlines (Chapman and Blockley, 2009). The majority of studies have compared artificial substrata with natural habitats to confirm the effects of re-shaped assemblages (Coombee et al., 2015). With the proliferation of coastal defense structures and their expanding ecological impacts, ecologists have turned their attention to adjacent tidal marsh ecosystems, which had been largely ignored previously (Martins et al., 2009). Determining ecological effects of human disturbance on plant population persistence and conservation is an urgent ecological challenge (Freville et al., 2013; Talluto and Benkman, 2014), especially for annual halophyte populations.

Halophyte species dominate the harsh intertidal saltmarsh systems, and all of their life stages, including seed production, seed dispersal and reservation, seedling emergence, seedling survival, and adulthood, are exposed to disturbance from the coastal defense structures (Balke et al., 2011; Silinski et al., 2015). Disturbances are primarily associated with blocking of tidal creeks and subsequent changes to edaphic factors, as a consequence of alteration of tidal action (Bouma et al., 2009). There has been increasing evidence that seed banks, seedlings emergence and survival are substantially disrupted by the ecological effects of coastal defense structures (Friess et al., 2012). Soil seed banks provide an important natural potential in regeneration of plants in coastal ecosystems. Identifying effects of coastal defense structures on soil seed banks and evaluating viability of seed banks are essential in coastal conservation strategies, and this can also provide scientific supports for restoring integrity of isolated and fragmented coastal wetland ecosystems.

Seed banks are more tolerant to disturbances than standing plants and play important roles in maintaining plant biodiversity and persistence in plant communities (Bossuyt and Honnay, 2008). The potential of soil seed banks in plant community persistence relies on the density of viable seeds in the soil, species composition and the relationships between soil seed banks and standing plants (Adams et al., 2005). Tidal salt marshes are among the most sensitive and disturbed ecosystems, which experience natural disturbances such as saline intrusion and wave erosion and anthropogenic disturbances including fragmentation by hard coastal defense structures (Scarton et al., 2000). Seed banks cannot be overlooked in maintaining plant community and conserving tidal salt marshes, because they are efficient ways for plant regeneration, even in harsh conditions (Bossuyt et al., 2006). However, little is known about effects of coastal defense structures on seed banks potential values in species density, composition, and regeneration of plants in tidal salt marshes (Shang et al., 2013).

The dynamic between inputs and outs of seeds is one of critical determinants of the stability and viable of seed banks (Badger and Ungar, 1994; Maranon, 1998). The main processes of inputs and output of seed banks are seeds production, seeds dispersal (Yang et al., 2012), herbivore forage, dormancy, seeds death and seeds germination (Baskin et al., 2000). Many previous studies have considered the dynamics of inputs and outputs of seeds as a significant examination to the persistence of vegetation communities and effect of disturbances form nature or human activities (Baskin et al., 2000; Holzel and Otte, 2004). As a crucial process of seed banks dynamics and vegetation regeneration, the seeds germination depends on the environmental conditions and was most sensitive to external disturbances (dos Santos et al., 2013). Disturbances of coastal defense structures are associated with blocking of tidal creeks and cutting off the tidal wave which result in subsequent changes to edaphic factors such as soil salinity, soil moisture content (Valko et al., 2014). The effect of disturbances from coastal defense structures on edaphic factors on seed density and species richness of the soil seed banks may be the critical knowledge to understand the impact of coastal defense structure on tidal marshes seed banks.

In order to investigate the disturbance effect of coastal defense structure on edaphic factors and seed banks, we conducted field research in an unaltered tidal flat and a surrounded flat within coastal defense structures in Yellow River delta, China. In the Yellow River delta, more than 50 km seawalls were built from 1960 to 2010 to protect oilfields and aquaculture ponds, and a port was built against erosion and storm surges, which surround about two thirds of the Yellow River delta coastline (Murray et al., 2014; Wang et al., 2014). We monitored the density and species composition of seed banks and aboveground vegetation in the tidal flat and the isolated flat which was surrounded by defense structure. We examined the similarity of species composition between aboveground vegetation and soil seed banks and distinguished the relationship of the similarity with edaphic factors. Meanwhile, mechanisms underlying the response of seed banks to edaphic factors changes caused by coastal defense structure stress were examined through controlled greenhouse experiments to find out the favorable conditions for germination of main species. More specifically, we addressed the three questions:

- How does the seed density and species composition in seed banks change under disturbance of coastal defense structure?
- Are there differences of relationship between seed banks and aboveground vegetation in the tidal flat and the surrounded flat?
- What is the role of edaphic factors in soil seed banks dynamics?

2. Materials and methods

2.1. Study site

The research was conducted at Bohai bay, the Yellow River delta, located in Shandong province, China (118°68′E–119°34′E; 37°77′N–38°12′N) (Fig. 1). The region has a semi-humid continental monsoon climate with irregularly and semi-diurnal tides. The average annual temperature is 12.1 °C and average annual precipitation and evaporation are 551.6 mm and 1962 mm, respectively (Li et al., 2016).

The tidal marshes are dominated by an annual halophytic herb, *Suaeda salsa* L. (Chenopodiaceae), which has a high salt tolerance (He et al., 2012). In Yellow River delta, more species, including *P. australis*, *L. sinense*, *S. glauca*, *G. soja*, *A. scoparia*, *M. officinalis*, *P. major*, *B. japonicas*, *S. validus*, *A. lavandulaefolia*, *D. chrysoblephara*, *K. scoparia*, *R. cordifolia*, *S. europaea*, *S. alterniflora*, *I. cylindrica*, *S. arvensis*, *C. chinense*, *S. viridis*, *T. laxmannii*, *A. venetum*, *T. sacchariflora*, *S. glauca*, *T. vulgare*, *T. mongolicum*, *S. oleraceus* can be founded.

2.2. Vegetation sampling and seeds collection

The vegetation was sampled in October 2012. Sampled plots were established across the surrounded and tidal flat and were 10 × 10 m. Eighteen plots in the tidal flat and twelve plots in the surrounded flat were set. We recorded the coordinates of the central point of every plot using a GPS instrument (4600LS, Trimble GPS, Sunnyvale, California, USA). Before sampling work, all plant species in each plot were identified and recorded. Three 1 × 1 m