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Analysing how plants in coastal wetlands respond to varying tidal regimes throughout their life cycles

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ABSTRACT

Important to conserve plant species in coastal wetlands throughout their life cycle. All life stages in these habitats are exposed to varying tidal cycles. It is necessary to investigate all life stages as to how they respond to varying tidal regimes. We examine three wetlands containing populations of an endangered halophyte species, each subjected to different tidal regimes: (1). wetlands completely closed to tidal cycles; (2). wetlands directly exposed to tidal cycles (3). wetlands exposed to a partially closed tidal regime. Our results showed that the most threatened stage varied between wetlands subjected to these varying tidal regimes. We hypothesis that populations of this species have adapted to these different tidal regimes. Such information is useful in developing management options for coastal wetlands and modifying future barriers restricting tidal flushing.

1. Introduction

Artificial coastal defense structures have proliferated around the world to protect coastal wetlands against erosion, storm surge, and sea level rise (Airoldi and Bulleri, 2011; Bulleri and Chapman, 2010; Fauvelot et al., 2009; Firth et al., 2014; Ma et al., 2014; Wang et al., 2012). Recently, researchers have suggested that instead of completely restricting tidal flow by coastal defense that some tidal flow should be allowed to ensure the long term viability of such wetlands (Temmerman et al., 2013). However, there is limited understanding of the ecological impacts of different tidal regimes on coastal ecosystems, especially in coastal wetlands (Roman et al., 1984; Sun et al., 2003; Temmerman et al., 2013).

Model simulations and empirical studies have shown that modifying tidal regimes disturb natural coastlines (Chapman and Blockley, 2009; Coombee et al., 2015). With the proliferation of coastal defense structures such as seawalls and associated ecological impacts, ecologists have turned their attention to adjacent tidal marsh ecosystems, which had been previously largely ignored (Martins et al., 2009). Determining the ecological effect of changed tidal cycles on species persistence is an ecological challenge for coastal wetlands (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 susceptible to changes in tidal regimes (Balke et al., 2011; Silinski et al., 2015). Disturbances are primarily associated with blocking of tidal creeks and subsequent changes to edaphic factors, leading to modification of inundation cycles (Bouma et al., 2009). Seed dispersal, seedlings emergence and survival are substantially disrupted by these changes (Friess et al., 2012).

Almost every single life stage of halophyte populations has been investigated (Albers and Schmitt, 2015; Hu et al., 2015; Maun, 1998; Qi et al., 2016; Sun et al., 2003), however, few studies have identified the effects of changing tidal cycles on the life cycle of these species. A comprehensive life stages analysis provides a useful perspective for exploring the effectiveness of vegetation conservation in contrast to those based on a single life stage (Meyer-Grunefeldt et al., 2015). There is little information that explicitly addresses plant population persistence and dynamics across life stages under stress from disturbances related to such changes in tidal inundation. This lack of information makes it difficult to evaluate the effect of varying levels of tidal barriers on wetland conservation.

Here, we provide the hypothesis that life cycle of the halophyte population shifted among the three wetlands with varying tidal cycles. We monitored the density and spatial distribution of the seed bank, seed production, seedlings, and adult numbers throughout the life cycle. We determined the most threatening stages in the three study areas through controlled greenhouse experiments and a spatial analysis of seed bank distribution.

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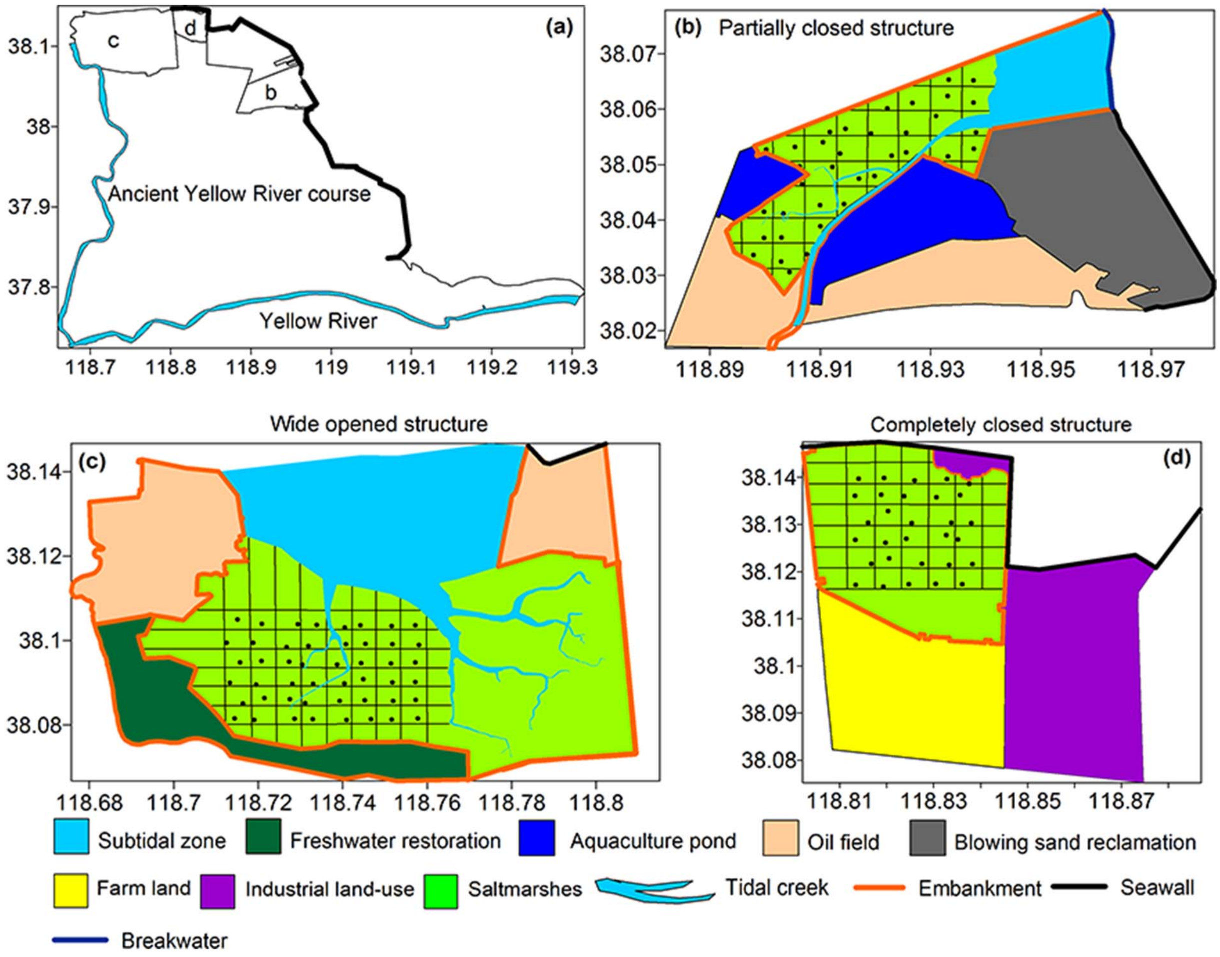

Fig. 1. Maps of the study sites and sampling plots. (a) location of three study regions: PCS, WOS, and CCS in the Yellow River delta; and (b), (c) and (d) the arrangement of sampling plots and the 500 × 500 m grids in the three defense structures. There were 30 in the CCS, 48 plots in the WOS, and 36 in the PCS. The study area and the coastal defense structures were mapped using ArcGIS 10.3 software (Esri China Information Technology Co. Ltd., Hong Kong, China, http://www.esri.com/) based on the remote sensing image data was purchased from SPOT 2 and 3. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Material and methods

2.1. Study area

We conducted field research to investigate the life stages of the annual halophytic herb, *Suaeda salsa* Linnaeus (Chenopodiaceae) (Li et al., 2011; Song and Wang, 2015) which dominated tidal marshes in the Yellow River delta (He et al., 2012) (118°68′E–119°34′E; 37°77′N–38°12′N) at three sites. The sampled tidal marshes were close to the old course of the Yellow River and subjected to significant erosion since the Yellow River changed its course in 1976. Since the 1960s, oilfields, aquaculture ponds, and a port have been built on reclaimed tidal marsh in the delta. > 50 km of seawalls have been built over the past 40 years, surrounding about two thirds of the Yellow River delta coastline (Murray et al., 2014). We conducted field experiments at three coastal wetlands characterized by the presence of different types of tidal inundation (Fig. 1):

1) Wetlands completely closed (CCS), and by a seawall which severely restricts tidal flow.
2) Wetlands with wide opened structure (WOS), in which the incoming wave transmit without attenuation and tidal wetlands are directly exposed to tide. The wetlands provide a buffer to wave action.
3) Wetlands with partially closed structure (PCS), which was surrounded by breakwaters. The breakwaters built with large blocks of quarried rock and was below the mean high water level (MHWL, which was about 0.3 m, unpublished data), so only the high water spring tide can enter the region.

The spatial information of study area got from remote sensing data interpretation. The remote sensing image data was purchased from SPOT 2 and 3. The spatial information interpretation and sampling grid drawings were conducted using ArcGIS 10.3 software (Esri China Information Technology Co. Ltd., Hong Kong, China, http://www.esri.com/) (Fig. 1).

2.2. Field sampling based on life cycle

A grid sampling method was used to select sites within each wetland and georeferenced observation in our field studies at large regional scale. A 500 × 500 m grid was established at each site, and within each of the grid quadrats a 50 × 50 m plot quadrat was randomly chosen for the sampling. We investigated the life cycle of *S. salsa* populations focusing mainly on seed production, seed banks, seedlings and adult vegetation.

2.2.1. Stage 1: vegetation sampling and seed collection

Three 1 × 1 m quadrats were randomly placed in each 50 × 50 m plot quadrats for vegetation sampling. We counted the number of *S. salsa* adults and harvested all the *S. salsa* in each quadrat. The weight of the *S. salsa* seeds was measured and they were about 3.48 ± 0.08 g/1000 seeds. Seed production in every quadrat was estimated by the