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Sand dune stabilization changes the vegetation characteristics and soil seed bank and their correlations with environmental factors

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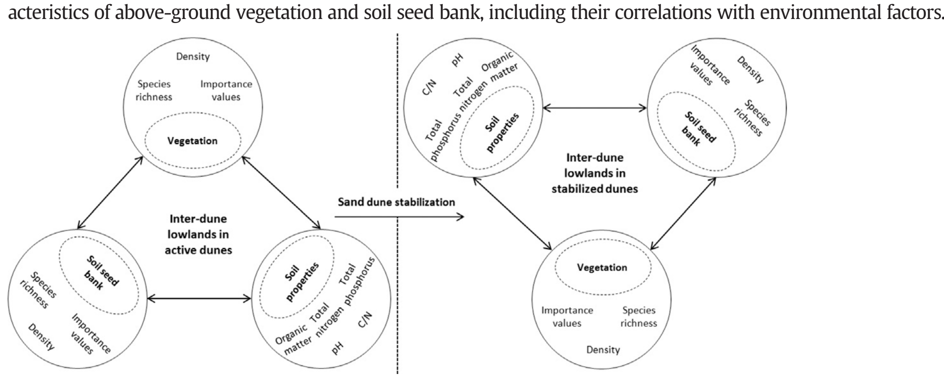
HIGHLIGHTS

- Aboveground vegetation species richness increased with sand dune stabilization.
- Soil seed bank species richness declined with sand dune stabilization.
- Inter-dune lowland of active sand dunes is suitable for some endemic species.
- Conservation areas should be set up in active sand dunes to protect biodiversity.

GRAPHICAL ABSTRACT

This study contributes towards a better understanding of sand dune stabilization by showing the changes in the characteristics of above-ground vegetation and soil seed bank, including their correlations with environmental factors.



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ABSTRACT

Currently the amount of data available on the effect of sand dune stabilization on species conservation in inter-dune lowland is very limited, especially for the sand dune systems in semi-arid regions. In this study, we determined whether the characteristics of above-ground vegetation, soil seed bank and their relationships with environmental factors changed with sand dune stabilization in the inter-dune lowlands in Horqin Sandy Land, China. Species composition, abundance and coverage of aboveground vegetation as well as soil seed bank composition and density were surveyed and their correlations with environmental factors (pH, organic matter content, total nitrogen and total phosphorus) were determined. The results showed that changes in the relationship between aboveground vegetation, soil seed bank and soil quality followed the changes in aboveground vegetation and soil seed banks. Aboveground vegetation species richness increased with sand dune stabilization, but soil seed bank species richness declined. The inter-dune lowland of active sand dunes could provide specific habitats for some endemic species and pioneer psammophyte species as indicated by data on aboveground vegetation and soil seed bank. Our results suggested that both active and stabilized sand dunes should be maintained since active sand dunes are essential for the survival of endemic or pioneer species and stabilized sand dunes are important for sustaining species richness.

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1. Introduction

Sand dune mobility in desert ecosystems reflects the underlying ecological processes, including biotic interactions, seed dispersal, vegetation succession, and environmental change (Fan et al. 2017; Hao et al. 2017; Liu et al. 2014a). Population pattern in sand dunes is a result of long term interactions between living vegetation and seed bank as well as their relationships with the environment (Zhang et al. 2015). Previous studies have shown that dune stabilization in semi-arid areas has led to distinct dune habitat types. For example, sand pioneer plants are the dominant species in barren soils of active dunes, and herbaceous plants are the dominant species in the stabilized dunes (Zuo et al., 2008; Yan and Liu 2010). Over time, stabilization and the accumulation of organic material increase available nutrients and stimulate the growth of strong competitors, as well as shrubs and tree species (Gunster 1994). In many dune habitats, shrub species occupy older surfaces due to greater substrate stability and decreased sand movement (Pake and Venable 1996).

Horqin Sandy Land located in the semi-arid of southeast Inner Mongolia, China, is one of the most severely desertified regions in China (Liu et al. 1996; Wang et al. 2016). Therefore, different artificial acceleration regeneration methods have been adopted to promote sand dune stabilization in the last 40 years, such as building physical sand barriers and excluding livestock grazing. By conducting these methods, some mobile dunes can also be gradually restored to semi-stabilized or stabilized dunes (Zuo et al. 2014), including the interdune lowlands which provide refuge for a relatively large number of rare and endangered species (Gunster 1994) such as invertebrates, amphibians, and other wildlife (McLachlan et al. 1996; Everard et al. 2010). Surrounded by crescent dunes, they provide relatively sufficient levels of moisture and generally have better soil condition than the surrounding sand dunes.

Vegetation and seed bank are the most important biotic components in sand dune habitat as they have direct and indirect impacts on the stability and resilience of dune structure (Wang et al. 2015; Liu et al. 2014b). Vegetation is integral to dune structure as it facilitates accretion and stabilization (Yan et al. 2009; Liu et al. 2012). Currently there are two contrasting ecological perspectives on sand dune stabilization. One favors dune stabilization due to its positive influence of plant diversity (Zuo et al. 2014), while the other considers dune stabilization to have adverse impacts on endemic and pioneer species due to pioneer species adapting to unstable substrate (Yan and Liu 2010). However, our knowledge on how the characteristics of above-ground vegetation and soil seed bank and their correlations with environmental factors change in the inter-dune lowlands in Inner Mongolia, China is still lacking, including the effects of sand dune mobility that have been known to influence vegetation and soil seed bank patterns in inter-dune lowland (Liu et al., 2007). The influence of environmental factors on the variations in plant diversity and community composition is also unknown, despite their importance for understanding ecological patterns and processes (Zuo et al. 2014), as well as for providing management decisions for conservation or restoration measures (McLachlan et al. 1996). We therefore conducted a series of field surveys and specifically asked the following questions: (1) Do the characteristics of above-ground vegetation and soil seed bank change with sand dune stabilization? (2) How do the environmental characteristics change with sand dune stabilization? (3) How do the relationships between vegetation, soil seed bank and environmental factors change with sand dune stabilization? We hypothesized that the characteristics of above-ground vegetation and soil seed bank and their correlations with environmental factors would change with sand dune stabilization.

2. Materials and methods

2.1. Study area

The study was conducted at the Wulanaodu region (42°29′-43°06′N, 119°39′-120°02′E, altitude approx. 480 m) in south-western Horqin Sandy Land, Inner Mongolia, China. The study area is located in a semi-arid climate with an average annual temperature of 6.3 °C. The coldest and hottest months are January and July, respectively. The annual average precipitation is 340.5 mm, 70% of which falls between June and September and the frost-free period extends over 130 days. The average annual wind velocity varies between 3.2 and 4.5 m s^{-1}, and is dominantly from the north-west in March–May and the south-west in June–September. The area has been intensively grazed since 1950, thus, overgrazing is the major force leading to its desertification. Active dunes (AD), stabilized dunes (SD) and the inter-dune lowland are distributed in mosaics. Similarly, the pattern of natural vegetation is characterized by a mosaic of grasslands and sand dunes, including the flood plain grasslands, lowland grasslands, meadows, stabilized dunes, semi-stabilized and active dunes (Zuo et al. 2012).

2.2. Experimental design and data collection

In early April 2011 we randomly selected several inter-dune lowlands and set up 6 sticks in each inter-dune lowland to monitor sand dune movement. After one year monitoring, in early April 2012, four inter-dune lowlands were randomly selected, two in AD and the other two in SD. The height of the sand dunes around the inter-dune lowlands were all approximately equal. At each lowland site we set up two parallel transects, each running along the direction of dune movement from the leeward slope to the windward slope. Then we set up 2 m × 2 m quadrats along each transect; distance between quadrats was 5 m apart. A total of 94 quadrats were set up across all sites. There were more quadrats in AD (58) compared to SD (36) because the length of the transects along the direction of dune movement from the leeward slope to the windward slope were different between AD and SD.

2.3. Above-ground vegetation investigation

Species composition and abundance were recorded in each quadrat at the end of July and August 2012, during the peak of the growing season. Percentage cover of all species within each quadrat was recorded using visual assessment. Additionally, we estimated the abundance of each species according to their growth form to subsequently determine an index of importance. For bunchgrasses, we counted the number of clusters, whereas for clonal species we counted the number of ramets. For species with discrete individuals, we counted the number of individuals. Frequency of each species was determined using data from all transects within each inter-dune lowland (Liu et al., 2007).

2.4. Seed bank sampling

Soil cores were collected in early April 2012, after winter stratification but before the emergence of early spring annuals. Using a 7 cm diameter soil corer, soil samples were collected close to every quadrat (subplots) to a depth of 10 cm; each was divided into upper layer (0–5 cm) and deep layer (5–10 cm) section to estimate soil seed bank composition. A total of 188 soil cores were sampled for seed bank analysis, covering a total area of 0.72 m^2. The seed bank was first assessed by monitoring seedling emergence (Thompson and Band 1997). Each soil sample was air dried and then sieved to remove stones, roots and rhizomes, before being spread out in a 16 cm diameter plastic tray in an unheated greenhouse. The trays were then watered over a period of 90 days (June 2012 to September 2012) and regularly inspected for emerging seedlings. These seedlings were identified, counted and removed as soon after emergence as possible. Any seedlings that could not be identified at the seedling stage were removed and grown on until identification was possible. At the end of 90-days period, soil samples were air-dried and sieved through a 0.5 mm mesh to extract the remaining seeds. Their viability was then tested using tetrazolium chloride. Only viable seeds were used to assess the composition and density of soil seed banks.