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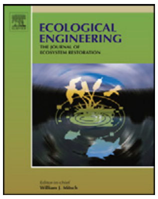

The role of local species pool, soil seed bank and seedling pool in natural vegetation restoration on abandoned slope land

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ABSTRACT

Theory and empirical evidence suggest that natural vegetation restoration depends on both the availability of seed resources and on successful seedling establishment. In the hill-gully Loess Plateau region, it remains unclear whether a rich diversity of species persists in the fragmented landscape in spite of intensive human activities and whether the distribution of the soil seed bank and the establishment of seedlings are threatened by serious soil erosion. We investigated vegetation composition in a series of plots with different slope aspects and degrees in a watershed of 8.26 km^2 in Shaanxi Provence, China to determine the local species pool. The soil seed bank and seedling recruitment on typical eroded slopes over varied erosion zones were simultaneously studied to characterize soil seed bank resources and seedling establishment. In this study, 133 species were identified in the local species pool. The species' frequency within the soil seed bank, seedling and standing vegetation was positively correlated with the frequency of matched species in the local species pool. The soil seed bank density and species richness had no significantly decreasing with the soil erosion intensity increasing on the hill slope. However, the seedling density and species composition showed significant difference among the investigative times and different erosion zones. Furthermore, the species frequency declined with increasing seed mass. Results of this study indicate that the seeds of widely distributed species always have small size, persist in soil under eroded conditions and have stable seedling density over the growing season. Therefore, these species can successfully recolonize in abandoned slope land. However, late-successional species with large seeds that lack dispersal vectors are less able to disperse and recolonize in areas that need to be restored.

1. Introduction

Restoration of fragmented habitats and degraded ecosystems is an increasingly relevant focus of current ecological research (Eriksson, 1996; Krauss et al., 2010). The successful restoration of plant communities often depends on the richness of a local species pool, the availability of seeds (Duncan et al., 2009; Eriksson and Ehrlén, 1992; Zobel et al., 1998), and the spatial interconnection of species-rich (source) and species-deficient (sink) habitats (Bruun and Ejrnaes, 2006; Zobel and Kalamees, 2005). However, habitat fragmentation can lead to shortages of seed sources (Russell and Roy, 2008) and long distances to remnant patches, influencing the rate and trajectory of succession (Poulsen et al., 2007). While, the persistent soil seed banks play an important role in the species reappearance after disturbance (Bakker et al., 1996; Stöcklin and Fischer, 1999). But, missing species must be actively seeded during restoration (Török et al., 2012).

The available species pool and soil seed bank are not always sufficient, however, to ensure the recovery of degraded vegetation, and seedling recruitment is often a central limitation to plant community restoration (Bakker et al., 1996; Seabloom et al., 2003). The period between seed germination and seedling establishment is considered to be one of the most vulnerable transitions in life cycle of plants (Garrido et al., 2005; Harper, 1977). In arid and semiarid climates, drought is one of the major causes of mortality in natural seedling populations (Bochet and García-Fayos, 2004; García-Fayos et al., 1995; Lauenroth et al., 1994). The precipitation regime, micro-topographical characteristics of ground surface, soil crust, litter and vegetation canopy are main factors influencing seed germination, seedling emergence and seedling colonization

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patterns (García-Fayos et al., 2000; Lauenroth et al., 1994; Tsuyuzaki and Haruki, 2008).

Geographical, topographical, historical and environmental circumstances influence local species richness (Maestre, 2004). In the study region, land surfaces in hill-gully region are fragmented by deeply incised and densely distributed gullies, creating many small areas of slopes with different gradients and aspects (Zhang and Liu, 2009). Uniform agricultural activity thus cannot be applied in this type of region, and many sloped lands are quickly abandoned due to nutrient loss resulting from soil erosion. Additionally, steep slopes or small patches that are not used as farmland can conserve many native species and serve as diaspore sources (LeCoeur et al., 2002; Moore and Swihart, 2007). There are abandoned slope farmlands, grasslands, scrublands and artificial woodland areas in a mosaic landscape pattern within the Loess Plateau (Fu et al., 2004). The unique landscape and agricultural history may be favorable to conserve a large species pool and to connect diaspore sources and sink habitats. On the other hand, slope gradients and aspects influence the distribution of solar radiation and soil water availability as well as the soil erosion intensities, and then influence the plant colonization and distribution (Bochet et al., 2009).

Due to the special geographic landscape, soil and climatic conditions, and long history of human activity, the Loess Plateau region is well known for its serious soil erosion (Shi and Shao, 2000). Erosion as an ecological driver influences vegetation composition, structure and spatial pattern (Bochet et al., 2009; García-Fayos et al., 2010). On the slope land with serious soil erosion, overland flow and sediment transport can carry away both the seeds that arrive at the soil surface and those that were previously deeper in the soil (García-Fayos et al., 1995, 2000). And seed size and shape also influence the seed remove during erosion process (Cerdà and García-Fayos, 2002; García-Fayos and Cerdà, 1997; García-Fayos et al., 2010). Additionally, the high erosion rates lead to soil impoverishment and a very short duration of available water, limiting plant colonization in eroded slope lands (Bochet et al., 2009; Cipriotti et al., 2008; García-Fayos et al., 2000). However, the species from the local species pool with high colonizing capacity and resistance to seed removal are able to colonize the slope lands with serious erosion and water stress (Bochet et al., 2009).

Thus, knowledge of local species pool, characteristics and distribution of soil seed bank on eroded slopes, and patterns of seedling emergence and establishment will increase our understanding of the factors limiting establishment from the soil seed bank in this eroded habitat. We investigated the following three questions: how many species persist in the local species pool in this special landscape; whether an available soil seed bank persists in the soil on the eroded slope; and whether the establishment, survival and growth of the seedlings are limited by the harsh habitat on eroded slopes.

2. Materials and methods

2.1. Study site

The Zhifanggou watershed, with an area of 8.26 km^2, is located in the north of Shaanxi province in the Loess Plateau region, China (109°19′30″E, 36°51′30″N) at 1010–1431 m above sea level. The watershed has a semiarid climate with an average annual precipitation of 504 mm based on data from 1970 to 2006. Over 60% of the precipitation falls during the rainy season in July–September, usually during storms. The annual evaporation is over 1460 mm, and the mean temperature is approximately 8.8 °C (−11 °C to 30 °C), and the annual average of frost-free days is 159 days. The landscape within the study region includes hill and gully slopes and the soil erosion on slopes shows clear vertical zonation (Zheng et al., 2005). The soil erosion patterns change from sheet and rill erosion to shallow gully (like ephemeral gully) erosion from top to bottom along the hill slopes, and the dominant gully erosion zone includes water and gravity erosion on the gully slope. Additionally, abandoned lands always distribute on the hill slope and remnant vegetation always distribute on the gully slope.

Although this area is located in the forest-steppe region, natural forest is almost absent and has been replaced by typical steppe as a result of long-term human activities which destroy the natural vegetation and farm on slope land. But in the past decades many slopeland were abandoned in order to restore the vegetation and control soil erosion. The main species in different successional stages and landscapes include annual herbs *Artemisia scoparia*, perennial herbs *Artemisia giraldii*, grasses *Stipa bungeana* and *Bothriochloa ischaemun*, sub-shrubs *Artemisia gmelinii*, *Lespedeza davurica*, and shrubs such as *Sophora davidii*, *Rosa xanthina*, *Syringa oblata* and *Ostryopsis davidiana* (Jiao et al., 2007).

2.2. Vegetation survey

To determine the richness of local species pool, sample plots were located in a series of slopes. Several aspect and slope angle classes were defined in order to evenly sample them. The slope angle classes were classified as follows: 1, <15°; 2, 15–25°; 3, 25–35°; 4, 35–45°; 5, >45°. The slope aspect was classified as follows: 1, north (315–45°); 2, east (45–135°); 3, west (225–315°); 4, south (135–225°). In every of each aspect and slope classes we searched for at least three different slopes and installed one sampling plot per slope. The sample plots were laid where there was a homogeneous natural population or community. In each plot, six quadrats (2 m × 2 m) were randomly chosen and all of the vascular species were investigated in each quadrat. The density and coverage of each species was recorded. In total, 69 plots were investigated during August and September in 2010.

2.3. Soil seed bank

To determine the soil seed bank distribution patterns of the eroded slopes, soil samples were collected from different erosion zones. There were four erosion zones on a typical slope with a gradient of increasing erosion intensity (Zheng et al., 2005): a zone dominated by sheet erosion (Zone 1), a zone dominated by rill erosion (Zone 2), a zone dominated by ephemeral gully erosion (Zone 3) located from top to bottom along loessial hill slopes, and a zone on gully slopes dominated by water and gravity erosion (Zone 4). Two typical slopes were selected for soil sample collection. Three sampling plots of 5 m × 5 m each were located in each erosion zone. In each plot, 20 soil cores with a diameter of 4.8 cm were collected from the 0 to 2 cm, 2 to 5 cm and 5 to 10 cm soil layers. The soil samples were collected in April, July and October in 2008 and in 2009.

The soil seed bank was identified using the seedling emergence method. It has been reported that concentrating the soil samples by washing and sieving will improve the germination of most species and reduce emergence time and space requirements (TerHeerdt et al., 1996). Accordingly, air-dried soil samples were sieved using a pore size of 0.15 mm (Wang et al., 2011a) the unsieved/larger fragment soil fraction tested for germination. The concentrated soil samples were distributed in a depth of 0.5 cm over a 2-cm-deep perlite layer in 24 cm × 15 cm × 5 cm plastic trays. Six trays containing only the perlite layer were placed among the sample trays as a control to check for windborne seed. The trays were watered during the trial as necessary. The temperature in the greenhouse varied from 11 to 35 °C, with a mean value of 25 °C. The seedlings were identified and removed or replanted for later identification.