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Original Research Article

Patches structure succession based on spatial point pattern features in semi-arid ecosystems of the water-wind erosion crisscross region

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ABSTRACT

Spatial point-pattern analysis can give insights to the underlying processes of patch succession and restoration. It is unclear whether inter-shrub competition determines patch succession. In this paper, we assessed the spatial patterns along patch succession using spatial statistics such as univariate and bivariate *O*-ring statistics, in the water-wind erosion crisscross region in semi-arid ecosystems of the Loess Plateau. Point pattern analysis results showed that there were no significant difference in three positions of the slope. The small and middle shrub patches were aggregatedly distributed in small spatial scale, meanwhile the large shrub patches were regularly distributed and dead shrub patches were randomly distributed. The small shrub patches were respectively aggregated to the middle and large patches at fine scales. Competition-induced regular distribution or negative relationship becomes obvious when analyzing the shift towards less aggregated perceptible effect of competition, a time component should always be included in spatial pattern-based inference of competition. Our results revealed that regular, clumped and random shrub patch patterns could occur, pending on size of shrub patches, and the shrub patches are distributed in different ways and they can present variant spatial point pattern features along patch size succession.

1. Introduction

The spatial structure of a plant community observed at any point in time is related to many processes, including biotic processes, such as plant dispersal, growth, mortality and herbivory, as well as other factors and processes, such as substrate, topography, climate, fire, disturbance, or land-use history (Schenk et al., 2003). The spatial distribution and size of plants mediates ecosystem function in water-limited ecosystems by influencing soil erosion and deposition, decomposition, spread

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of disturbance, and land use (Ludwing et al., 2005; De Knegt et al., 2008; Neff et al., 2008). As the spatial areas in which species interactions and processes occur have come to be seen as an important determinant factor of ecological dynamics, there has been growing interest in using spatial data to test ecological theory (Wiegand and Moloney, 2004; Perry et al., 2006; Law et al., 2009).

Some forces contributed to the patchy distribution of the vegetation, such as wind, water, seeds redistribution. Patchy distribution allows a system for water redistribution (Cerdà, 1997). Slope angle has a clear influence on runoff initiation, with cracks and crusts as the main factors controlling the time to ponding and time to runoff (Cerdà and García-Fayos, 1997). Size in the main factor explaining seed removal, whereas the shape becomes important only when the seeds are larger than 50 mg (Cerdà and García-Fayos, 2002). Vegetation succession in response to land abandonment positively influenced soil quality since SOC andSOC stock (van Hall et al., 2016). The plants are a key component on the fate of the ecosystems. Onthe one hand, they change the soil water repellency (Keesstra et al., 2016), runoff discharge (Keesstra et al., 2012), and the connectivity of the flows in the slopes (Cerdà et al., 2017).

Spatial point-pattern statistics can be used to infer the presence of competition and facilitation by assessing the spatial distribution of plants and determining the scales at which a spatial pattern is significantly aggregated or regular (Wiegand and Moloney, 2004). First-order statistics describe large-scale variation in the intensity of points in a study region, and second-order analysis based on Ripley's K-function is increasingly used in ecology to characterize spatial patterns and to develop hypotheses on underlying process (Meyer et al., 2008; Schleicher et al., 2011a). When using point pattern spatial statistics, the plant in a plot is represented as a point, and the analysis of the spatial pattern indicates whether the distribution of the points is random, aggregated, or regular by comparing the distribution pattern of plants under a null model (Schleicher et al., 2011b).

The spatial point pattern analysis was widely applied to trees (Meyer et al., 2008; Perry et al., 2008; Pillay and Ward, 2012), shrubs (Schenk et al., 2003; Schleicher et al., 2011a,b; Perry et al., 2013; Browning et al., 2014) and grasses (Browning et al., 2014). Perry et al. (2013) found that most species plants were aggregatedly distributed, site was consistently important in predicting a species' spatial pattern and site effects were as important as functional traits in explaining spatial pattern.

In semiarid areas, shrub patch pattern is a common vegetation pattern. There are many researches on the shrub patch pattern, such as litter decomposition rate and soil organic matter quality, the effects on runoff and erosion, plant diversity and soil water content (Hao et al., 2016), plant community (Koyama et al., 2014), soil property (Zhao et al., 2010), and the fate of seeds in patchy ecosystems. However, studies of spatial point pattern features of shrub patch have been comparatively scare, especially the shrub patch in the water-wind erosion crisscross regions.

In this paper, the aim was to analyze the shrub patch number structure and assess the spatial pattern of shrub patches in the southern part of the Mu Us desert. According to previous studies we specifically hypothesize that: (i) cluster processes predominate in the small and middle size shrub patches, and mutual exclusion processes predominate in the large size shrub patches; (ii) positive spatial association between small size shrub patches to middle, large and dead shrub patches. Moreover, negative spatial association between middle and large size shrub patches. We used second-order spatial statistics to determine the overall pattern of population shrub patches and the difference in spatial structure of four size classes of shrub patches. In addition, we examined the spatial distribution relationships of four size classes of shrub patches. We can explore processes determining the spatial distribution of shrub patches applying spatial point pattern analysis. The approach is also applicable to other systems where the population distribution of is controlled by the individuals and the environment element.

2. Materials and methods

2.1. Study site

The study was conducted in the Liudaogou catchment (latitude 38°46′-38°51′N and longitude 110°21′-110°23′E), 14 km west of Shenmu County and situated on the northern Loess Plateau of China bordering the Maowusu desert. The site is approximately 1081–1274 m above sea level and 7.0 km^2 in the area. It was characterized as continental monsoon climate, with an average annual precipitation of 437 mm. In general, most of the precipitation falls from June to September during intense rainstorms. Mean annual potential evapotranspiration was 785 mm. The mean aridity index is 1.8, and an annual average of 135 days are frost-free (Zheng et al., 2006). The study area is situated in the centre of the water-wind erosion crisscross region, which sustains serious soil erosion. The Liudaogou catchment is mainly characterized by sloping lands, which account for 76.5% of the total area. The soil of the study region is classified as Aeolian soil, which belongs to the order Arenosol according to FAO/ISRIC/ISSS Soil Taxonomy. The landscape is typically transitional and subject to severe erosion from both wind and water. At the study site, the dominant species is *Artemisia ordosica* (*A. ordosica*, with some commom species, such as *Artemisia sphaerocephala*, *Salix cheilophila*, *Lespedeza davurica*, and *Astragalus adsurgens*).

2.2. Experimental design and sampling

To explore the spatial pattern of shrub patches in the study area, we set up three 11 m × 11 m plots in each position (top, middle and base) of three slopes from June to October in 2015. The height from the ground surface (H) and the average diameter (D) of the shrub canopy, based on two perpendicular measurements for each shrub patch of *A. ordosica* population