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Spatial characteristics of two dominant shrub populations in the transition zone between oasis and desert in the Heihe River Basin, China

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ABSTRACT

Changes in spatial patterns of vegetation and their underlying hydrological mechanisms has significant implications for landscape ecological researches. However, empirical studies which test the relationships between vegetation spatial pattern and hydrology are scarce. Based on an in situ investigation and on geostatistical analysis, we described spatio-temporal changes in population characteristics in two shrub populations in the transition zone between oasis and desert in the Heihe River Basin, northwestern China. Our results showed that the density and cover of two dominant species were significantly greater in 2016 than in 2002. Total species richness also increased with time. *N. sphaerocarpa* population was distributed in small strips in 2002 and in big strips in 2016. *R. soongorica* population exhibited uniform distribution in 2002, and big-strip distribution pattern in 2016. The results of a semi-variogram analysis showed that the nugget/sill ratio of the two populations was 0.077 to 0.116 in 2002, and 0.066 to 0.144 in 2016. This indicated that the random variance of spatial heterogeneity occupied 7.7–11.6% of total spatial heterogeneity in 2002, and 6.6–14.4% in 2016. In 2002, the range values (A_0), respectively for density and cover, were 33.09 and 14.7 m for *N. sphaerocarpa*, and 24.9 and 25.2 m for *R. sphaerocarpa*. In 2016, these values increased to 37.2 and 30.3 m for *N. sphaerocarpa*, and 57.3 and 75 m *R. sphaerocarpa*. This indicated that the scale of spatial heterogeneity for density and cover of the two dominant species increased from 2002 to 2016. Correlation analysis showed that summer precipitation and soil water content significantly related to total species richness. We concluded that summer precipitation was a key factor which affected population characteristics and spatial patterns. The mechanism driving this was a rise in summer precipitation leading to an increase in soil water content and, eventually, to a change in the spatial patterns of plants.

1. Introduction

Spatial patterns of plant communities have been an important topic in ecology because they are critical to the understanding of the functions and processes of ecosystems across variable scales (Condit et al., 2000; Rietkerk et al., 2004; Perry et al., 2012). Vegetation in arid and semiarid landscapes is commonly distributed in patches within a matrix of bare ground and low vegetation cover (Bautista et al., 2007). Vegetation patterns include banded vegetation in the Chihuahuan desert (Aguiar and Sala, 1999), stripes and labyrinths of bushy vegetation in the Niger (Rietkerk et al., 2002; Barbier et al., 2006), and spots and gap vegetation in the Niger (Rietkerk et al., 2002, 2004). The spatial structure of vegetation is typically described in terms of source-sink systems, with bare soil and vegetation patches acting, respectively, as sources and sinks of vital resources (Mayor et al., 2008). Plant spatial patterns have been shown to be related to key variables such as biodiversity, thought to affect many ecosystem processes and services (Maestre, 2004). Soil properties such as soil water condition and soil biota also affect ecosystem processes (Belnap et al., 2005). Therefore, evaluation of the spatial patterns of vegetation is critical to the understanding of the functions and processes of ecosystems across variable scales (Rietkerk et al., 2004; Perry et al., 2012).

Disturbances, such as grazing, significantly affected spatial patterns of some plants (Deangelis, 2012; Komac et al., 2011), but a response of spatial patterns to grazing exclusion was detected only at patch size (Deangelis, 2012). Slope gradient and rainfall also controlled spatial patterns of vegetation in some systems (Bautista et al., 2007; Perry et al., 2012). For example, in semi-arid regions, when slope gradient is < 0.2% and mean annual rainfall ranges from 200 to 550 mm per year, vegetation patterns include spots, labyrinths, and gaps,

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respectively with diameters from 5 to 20 m, from 10 to 50 m, and from 5 to 20 m, were observed (Couteron and Lejeune, 2001). However, when slope > 0.2% in arid regions, the main vegetation pattern was regular-banded with band width in the range of a few tens of meters (d'Herbes et al., 2001). Further, species functional traits related to their spatial distribution at the landscape level, but site effects were as important as functional traits in determining the spatial pattern at fine scales (Perry et al., 2012). Irrespective of the origin, site-to-site variation in environmental conditions influenced spatial patterning through habitat selection (Getzin et al., 2008; Burton et al., 2011). Under some conditions, spatial patchiness of vegetation may be sufficient to precipitate sudden changes in ecosystems (Pascual and Guichard, 2005). Given the complexity of these interactions, a better understanding of the factors which determine the formation of vegetation spatial patterns is still greatly needed.

In water limited systems, landscapes can generally be described as mosaics of vegetation and bare-soil patches of various forms (Zelnik et al., 2013). A substantial body of empirical evidence indicated that this type of vegetation patchiness is a self-organization phenomenon which can occur in different physical environments (Rietkerk et al., 2002; Deblauwe et al., 2008; Zelnik et al., 2013). These self-organized vegetation patterns are very important for maintaining productivity in arid ecosystems (Noy-Meir, 1973; Rietkerk et al., 2002). The main mechanism of spatial self-organization is a positive feedback between plant growth and availability of water, because water infiltrates faster into vegetated ground (due to root penetration) than into bare soil (due to shading), leading to a net displacement of surface water to vegetated patches (Rietkerk et al., 2004; Deangelis, 2012). The formation of self-organized patchiness in arid brush-lands was related to the redistribution of surface runoff, driven by differences in water infiltration at a scale of 10 m (Rietkerk et al., 2002).

Geostatistical techniques are useful tools for quantify the spatial characteristics of arid landscapes. They assist in sampling design, and in defining the spatial resolution for remote sensing, thereby enabling the monitoring of desert vegetation (He and Zhao, 2006). Geostatistics comprise a group of spatial statistical techniques which evaluate autocorrelation commonly observed in spatial data; in autocorrelation, data values associated with proximal locations are more similar to each other than data values associated with locations that are further apart (i.e., statistical variation in the data is a function of distance) (Isaaks and Srivastava, 1989). The spatial structures of different plant communities could characterized by nugget, range and sill parameters of geostatistical models such as spherical or exponential model variograms (He and Zhao, 2006). Therefore, geostatistical models were often used in quantify the spatial characteristics and explore the succession process of different plant communities (He and Zhao, 2006; He et al., 2007).

The main vegetation type in the transition zone between oasis and desert in northwestern China is desert vegetation dominated by several super-xerophytic shrubs such as *Reaumuria soongorica* and *Salsola passerina*. These shrubs exhibit strong adaptability to drought and sand habitats, and have important roles in soil water conservation and wind prevention. Although the vegetative structures are relativity simple and species composition is very poor, vegetation in the transition zone between oasis and desert plays a very important conservation role for the oases in northwestern China (He and Zhao, 2004). Rainfall is almost the only source of soil water in this extremely arid environment, and the importance of hydrological behavior for the spatial pattern of vegetation is widely acknowledged (Li et al., 2013). However, there is little empirical work addressing the relationships between vegetation spatial pattern and hydrology. We address this research gap by focusing here on answering the following questions. 1) What are the changes of density and cover of dominant populations in the transition zone between oasis and desert over time? 2) What are the drivers of change in spatial patterns and heterogeneity of the dominant populations?

Table 1
Nutrient concentrations and texture of soil in the study site (sampling depth of soil layer was 0–50 cm, the number of samples was 35; He et al., 2007).

Soil properties	Average	Minimum	Maximum	Standard deviation
Soil organic matter content (%)	0.23	0.17	0.34	0.07
Total				
N (%)	0.041	0.021	0.087	0.05
P (%)	0.092	0.045	0.112	0.07
K (%)	2.17	1.97	2.56	0.24
Readily available				
N (%)	0.003	< 0.001	0.007	0.001
P (%)	0.001	< 0.001	0.003	0.001
K (%)	0.015	0.008	0.023	0.002
PH	8.31	8.10	8.63	0.21
Quadrat content of 0.25–0.05 mm (%)	86.2	74.5	90.7	4.5
Average depth of groundwater (m)	12.6	11.2	13.8	1.5

2. Methods

2.1. Study site

The study was conducted in the transition zone (39°20′N, 100°08′E) between desert and oasis near the Linze Inland River Basin Research Station of the Chinese Academy of Sciences, located in central Gansu province in northwestern China. Average annual rainfall is 117 mm, of which 65% is distributed mainly in summers as short-duration showers. Precipitation events can be characterized as rainfall pulses with discontinuous, highly variable, and largely unpredictable frequency and intensity (Zhao and Liu, 2010). Mean annual temperature is 7.6 °C. There is a mean number of 165 days with freezing temperatures which occur mainly in December and January.

The selected sites are located within an alluvial plain with relatively flat topography; elevation is about 1250 m. Vegetation is a xerophytic scrub. Vegetation patterns can be described as patches of dense scrub (for example, an association of *Nitraria sphaerocarpa* Maxim. and *Reaumuria soongorica* (Pall.) Maxim.) surrounded by bare areas with vegetation cover of < 10%. Soils exhibit sandy and sandy loam texture with low nutrient levels (Table 1). Groundwater depth is between 11 m and 13 m, and soil moisture content is very low, about 3% (He et al., 2007).

2.2. Sampling design and data collection

One plot of 500 m × 500 m was selected subjectively in the transition zone between oasis and desert. A hill is located 2 km west of the plot, and desert is north of the plot. East and south edges are bordered by the oasis at a distance from plot edge of 1.5 and 0.5 km, respectively. The plot was divided into 2500 quadrats of 10 m × 10 m. In each quadrat, the number, percent cover, and spatial position (the position of each plant in each quadrat) of two dominant species (*Nitraria sphaerocarpa* and *Reaumuria soongorica*) were assessed visually, and with a ruler. Then, twenty 10 m × 10 m quadrats were selected for examination of species composition and abundance in the plot. Species composition and number were recorded in each quadrat in June of every year during 2012 to 2016.

The density of each population was defined as the total number of each species in the area of $10 \times 10\,m^2$. The cover was obtained by measuring the scrub-projection area, and then calculating the percent of scrub projection area within each quadrat area. The spatial position of each species distribution was determined by recording the x and y coordinates of each quadrat (He et al., 2007).

Depth of groundwater table was automatically measured using a water sensor (HOBO water level logger, Onset Computer Corporation,