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Changes in species diversity, aboveground biomass, and vegetation cover along an afforestation successional gradient in a semiarid desert steppe of China

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ABSTRACT

Afforestation is a key technique for the control of desertification and environmental deterioration in arid and semiarid regions. Therefore, it is important to quantify the influence of the succession that results from afforestation on biodiversity conservation and ecological environment. Here, we describe a case study in the sand-binding vegetation communities in China's semiarid desert steppe in which we evaluated the effects of afforestation and key ecological processes on the community characteristics, and explored the ecological mechanism of the succession paradigm of afforestation in arid and semiarid regions. 42 species from 20 families and 40 genera along the afforestation successional gradient were collected during a comprehensive vegetation survey in 2013. The community was dominated by species in the Leguminosae, followed by the Poaceae, Compositae, and Zygophyllaceae. Our results show that the succession significantly affected community and habitat characteristics. The numbers of families, genera, and species decreased primarily during succession and then increased sharply to a maximum. Species diversity appeared to reach its maximum towards the middle of the succession, and shrubs had a greater contribution and accounted for 80.6% of the community biomass, whereas herbaceous plants contributed 64.8% of the total vegetation cover. Soil crusts significantly altered the rainfall infiltration and redistributed soil water balance, and water in the 40- to 100-cm soil layer played a decisive role in vegetation productivity and cover. Therefore, the interactional feedback between vegetation development, soil crusts and soil water was the main driver responsible for the feedback mechanism of the succession paradigm for the sand-binding vegetation communities in the semiarid desert steppe of China.

1. Introduction

The desert steppe is a critical component of China's grassland ecosystem (Kang et al., 2007), and covers 34.7% of China's northern grasslands (Zhang et al., 2014). It thus plays important roles in China's ecological environment, biodiversity conservation, and socioeconomic characteristics at a regional scale (Kang et al., 2007; Wang and Ba, 2008). However, human activities have led to declining biodiversity and vegetation cover, along with accelerated soil erosion (Zhou et al., 2002; Alrababah et al., 2007). Consequentially, desertification has become one of the most serious environmental problems in China during the last half century, and threatens the survival and sustainable development of human at both local and regional scales (Jiang et al., 2006). Therefore, afforestation has been used as the major ecological project to control desertification and environmental deterioration with the sand-binding vegetation by restoring the vegetation cover in China, and provides a paradigm of successful desertification mitigation in the world's desert regions (Houerou, 2000; Chen and Duan, 2009; Li et al., 2009).

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Afforestation affects natural resources and biodiversity conservation during the restoration of forested landscapes because it is expected to promote secondary succession in desert steppe ecosystems (Huebner and Vankat, 2003; Baessler and Klotz, 2006; Amici et al., 2012; Souza et al., 2013). In addition, vegetation restoration can be viewed as a continuous process from establishment of the new vegetation to successful development of attributes that seem likely to improve ecosystem resilience and stability in both the short term and the long term (Alrababah et al., 2007; Zhu et al., 2009; Yang et al., 2012). Therefore, afforestation has gained increasing attention in desert steppe ecosystems (Alhamad, 2006; Alrababah and Alhamad, 2006). However, biodiversity changes during the different stages of the succession that follows afforestation (Jing et al., 2014), which has recently generated great debate over several conflicting hypotheses about this change (Howard and Lee, 2003). One hypothesis is that biodiversity should increase continuously as succession continues, since the ecosystem complexity increases (Vallauri et al., 2002; Ruiz-Jaén and Aide, 2005; Rayfield et al., 2005; Letcher and Chazdon, 2009; McClain et al., 2011; Sansevero et al., 2011). A second hypothesis suggests that biodiversity is greatest at the beginning of succession and gradually decreases as a result of processes that affect succession (Chapin et al., 2002; Gárdenfors, 2001; Souza et al., 2013). A third hypothesis predicts that biodiversity will increase from early succession to reach a maximum at mid-succession, followed by a decrease during late succession (Aubert et al., 2003; Malacska et al., 2004; El-Sheikh, 2005; Zhu et al., 2009; Suganuma et al., 2014). A fourth hypothesis predicts that there will be no general pattern for changes in biodiversity during forest succession (Zhu et al., 2009; Bu et al., 2014). Therefore, effective conservation of biodiversity in the face of increasing human impacts and ongoing environmental change will require a better understanding of the influence of afforestation on the species composition, community structure, and biodiversity of ecosystems at both regional and global scales.

Desert steppes are among the ecosystems that are most vulnerable to environmental changes associated with human disturbance in China (Jing et al., 2014). The species richness is lower than that in humid regions (Coppedge et al., 2008), so that the fragile ecological environment makes biodiversity conservation even more important (McNeely, 2003; Liu et al., 2009) because species loss is more significant in desert steppes than the equivalent loss in a species-rich ecosystem (Al-Eisawi, 2003; McNeely, 2003; Liu et al., 2009). Biodiversity conservation can help to improve the sustainability of a desert steppe's natural resources with the sand-binding vegetation by controlling desertification. However, afforestation can also decrease biodiversity (Brockerhoff et al., 2008; Bremer and Farley, 2010), with widespread species loss and the replacement of endemic and specialist species by ruderal and exotic species (Bremer and Farley, 2010; Souza et al., 2013). More importantly, afforestation can increase desiccation of soils and have negative effects on the long-term sustainability of forest ecosystems in regions such as the Loess Plateau of China (van Dijk and Keenan, 2007; Jiao et al., 2012). Therefore, the effects of afforestation on the species composition and biodiversity of ecosystems has been debated around the world.

In China, little work has been done to determine the effects of afforestation processes on biodiversity conservation in semiarid desert steppes. In this paper, we presented a study on the influence of afforestation on the species composition, aboveground biomass, and vegetation cover of the sand-binding vegetation communities in semiarid desert steppes of China to determine whether key ecosystem processes have been restored and whether the restored system will be ecologically sustainable, with a high potential for biodiversity conservation. Our specific objectives were (1) to describe the species composition, aboveground biomass, and vegetation cover along a chronosequence of post-afforestation succession; (2) to examine the influence of the interaction between afforestation and environmental variables on the characteristics of community succession; (3) to determine the ecological mechanism of the succession paradigm for the artificial sand-fixation plant community; and (4) to evaluate whether the restoration accomplished by afforestation has been ecologically successful. The results will improve our understanding of the mechanisms that underlie ecosystem stability during the succession caused by afforestation in the semiarid desert steppes of China.

2. Materials and methods

2.1. Study area

The study area is located in an ecotone between prairie and desert steppe, in Yanchi County of the Ningxia Hui Autonomous Region in China, between 37°40′N and 38°10′N and between 106°30′E and 107°41′E (Fig. 1). The region has a semiarid continental monsoonal climate characteristic of the mid-temperate zone. Annual temperature averages 8.1 °C, and ranges from a minimum monthly mean of −24.2 °C in January to a maximum of 34.9 °C in July. Annual precipitation ranges from 250 to 350 mm, with a mean of 289.4 mm, and about 62% of the total rainfall falls

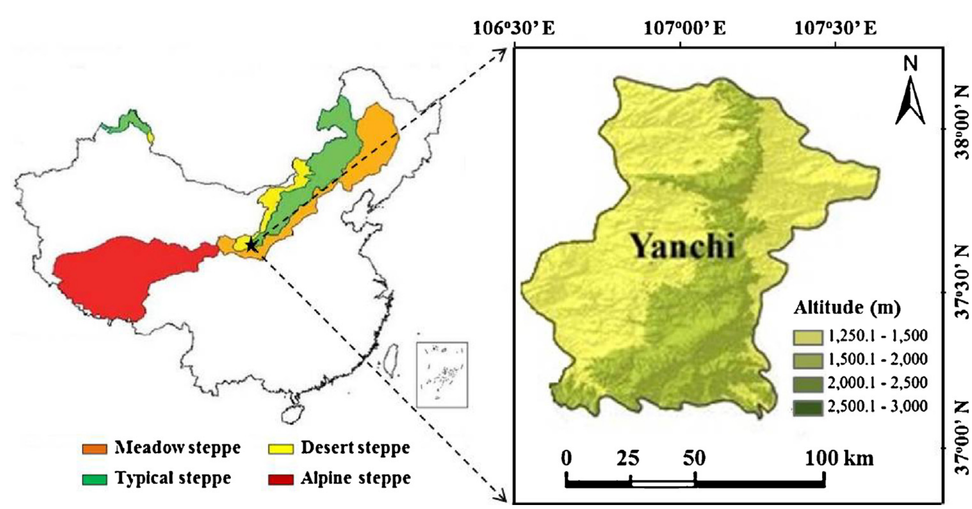

Fig. 1. (Left) Distribution of the four main steppe types in China. Source: Kang et al. (2007). (Right) Map of the study area.