Science of the Total Environment 651 (2019) 979–989

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effects of reforestation on plant species diversity on the Loess Plateau of China: A case study in Danangou catchment

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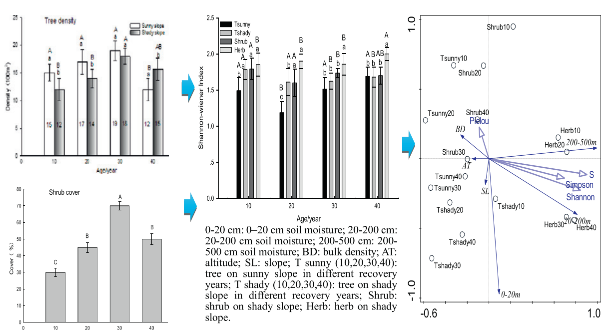
HIGHLIGHTS

- Diversity of woody plants were changing with its coverage.
- Soil moisture was significant correlated with species diversity.
- Herb diversity was increasing with years of recovery.
- If mankind's demand for wood is not considered, natural recovery was recommended.
- If human demand for materials is considered, thinning of woody plants was suggested.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 May 2018
Received in revised form 16 September 2018
Accepted 20 September 2018
Available online 21 September 2018

Editor: Elena Paoletti

Keywords:
Vegetation restoration
Recovery period
Vegetation types
Community stability
Recovery strategy

ABSTRACT

Large-scale vegetation restoration has important impacts on plant species diversity, which then influences plant community stability and resilience. The purpose of this paper is to compare the diversity of plantations as well as the diversity of artificially restored and naturally restored grasslands under different years of recovery and to identify the plots with the highest species diversity by vegetation type and restoration duration to determine strategies for vegetation restoration in hilly and gully regions of the Loess Plateau. Stands of *Robinia pseudoacacia* and *Caragana korshinskii* of different ages (10, 20, 30 and 40 years old) in the Danangou catchment on the Loess Plateau of China were selected as a case study to analysis effects of afforestation on the structure and function of ecosystems. The results showed that (1) under different numbers of years of recovery, the species diversity of woodland changes with changes in the coverage of woody plants, and the species diversity of *R. pseudoacacia* plantations planted on sunny slopes and *R. pseudoacacia* and *C. korshinskii* plantations planted on shady slopes reaches its maximum when coverage reaches a minimum value after 20 and 30 years of recovery, respectively; (2) soil moisture (in both shallow and deep layers) is the key factor controlling species diversity in woodlands, as the soil moisture changes with the coverage of woody plants following different numbers of years of recovery, which then influences the species diversity; (3) compared to the woodlands, the natural grassland exhibited higher species diversity under all recovery duration. Therefore, natural recovery is recommended if only species diversity is considered rather than human demand for wood, but if demand for materials is considered, we recommend thinning *R. pseudoacacia* on sunny and shady slopes at the ages of 10–20 and 10–30 years, respectively.

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https://doi.org/10.1016/j.scitotenv.2018.09.266
0048-9697/

1. Introduction

Species diversity plays important roles in ecosystem stability, particularly in arid and semi-arid areas under the background of climate change. The management and protection of understory vegetation has gradually become the focus of ecological studies on the stability of forest communities because understory vegetation is an indispensable part of the forest community and has high heterogeneity and a complex layered structure (Vanderschaaf, 2008). Canopy renewal can be affected by the seed propagation dynamics of the upper trees. Although the upper layer of the tree canopy is dominant in forest vegetation communities, the diversity of forest vegetation communities mainly occurs in the understory vegetation layers (Carr and Krueger, 2011; Rivaie, 2014). Understory vegetation also plays an important role in the study of energy flow in forest ecosystems, the dynamics of forest carbon stocks, and nutrient cycling, as it is a producer of organic matter in forest ecosystems (Sullivan et al., 2007; Mcglone et al., 2012; Saleem and Kumar, 2014). As a result of the irrational use of natural resources, the understory vegetation could be influenced by artificial or natural effects. Under such conditions, ecological problems can occur, such as the simplification of the understory plant structure, soil erosion, or a decline in species diversity. The characteristics of the understory vegetation (e.g., its biomass, quantity, and height) are closely related to the type and intensity of disturbance (Wang et al., 2008; Sikorski et al., 2011). However, in existing ecological studies, the understory vegetation is often neglected because the biomass of the understory vegetation only accounts for a very small part of the total forest biomass (Mulugeta and Alemayehu, 2014).

Vegetation restoration is one of the main approaches used to address global soil erosion problems and has a great influence on plant diversity dynamics (Peng et al., 2015; Cerda et al., 2017; Zhan et al., 2017). The loess hilly and gully region of the Loess Plateau in China has experienced the most severe soil erosion and anthropogenic disturbance around the world in history. During the long history of soil and water conservation in this area, vegetation restoration has been the main method used to solve such problems (Fu et al., 2011). Large-scale comprehensive surveys were conducted in the 1950s and 1980s, field monitoring was established in the 1970s, and small watersheds were remediated in the 1980s. In 1999, the Chinese government implemented the Grain to Green project, which brought greater changes to the vegetation structure and plant diversity than ever before. According to the recommendations of this project, *Robinia pseudoacacia* and *Caragana korshinskii* are considered to be promising tree species for afforestation because of their high growth rate and nitrogen fixation capacity. This project has greatly contributed to soil and water conservation on the Loess Plateau through vegetation restoration. Tens of years have passed since the implementation of this project, and some unsuitable vegetation restoration efforts have caused unexpected negative effects, such as dry soil layers, plant invasion, reduced biodiversity, and frequent fires (Guo et al., 2005; Jiao et al., 2012; Jiang et al., 2013). Therefore, there have been disagreements among scholars on the positive and negative effects of vegetation restoration (Wang et al., 2014; Woziwoda and Kopec, 2014; Oelofse et al., 2016; Viedma et al., 2017;)

Many studies have focused on the impacts of restoration on plant species diversity to understand the different changes in species diversity in the artificial forest and the natural restoration plots since the Grain to Green project began (Deng et al., 2016; Hao et al., 2016; Kou et al., 2016). In the loess hilly and gully region, some studies have regarded species distributions and species diversity as functions of altitudinal gradients (Vetaas and Grytnes, 2002). Wang et al. (2017) assessed the influence of afforestation on the soil seed bank and understory vegetation after 30 years of natural recovery, and Zhao et al. (2011) suggested that long-term grazing exclusion can significantly improve both aboveground and belowground species diversity and density. In addition, Chen and Cao (2014) investigated the effects of three different stand densities on species diversity and the natural regeneration of mature *Pinus tabulaeformis* in the hilly and gully region of the Loess Plateau. However, most of these studies have only concentrated on the interactions among plants in the upper tree or shrub layers in artificial forests, and little research has been conducted on understory vegetation. The focus on forest understory vegetation. There has been insufficient focus on forest understory vegetation (shrubs and herbs).

In this study, 36 plots containing *R. pseudoacacia* and *C. korshinskii* as the dominant species and 12 plots containing natural grassland were chosen as the sampling sites, and the coverage, abundance, and soil moisture content were measured to analyze the effects of afforestation on the structure and species diversity of ecosystems of different ages (10, 20, 30 and 40 years old). Natural grassland after the same number of years of recovery was used as a control. The aims of this study were to (1) identify changes in species diversity in plantations that have been restored for different periods of time since the Gain for Green project was implemented on the Loess Plateau, (2) analyze the relationships between species diversity and environmental factors and identify the environmental factors that have the greatest impact on species diversity, and (3) identify the plots with the highest species diversity in different vegetation types and numbers of years of restoration and provide strategies for vegetation restoration in hilly and gully regions of the Loess Plateau. We hypothesize that the species diversity of different vegetation restoration types will exhibit distinct regularity over the years after farmland is returned to forest. We also hypothesize that soil moisture is an important factor that affects species diversity, and the impact of soil moisture is proportional to the species diversity.

2. Materials and methods

2.1. Study area

The Yan River Basin is located in the central part of the Loess Plateau in northern Shaanxi. This study was conducted in the Danangou watershed (109°16′~109°18′E, 36°54′~36°56′N), which is located in the Yan River Basin. It covers an area of approximately 3.5 km^2. The terrain is high in the northwest and low in the southeast, with an elevation of 1075–1370 m. The average annual temperature and precipitation in this typical semi-arid loess hilly region are 9 °C and 549 mm, respectively. During the summer months, from July to September, most of the rains occur in the form of thunderstorms. The soil types in the study area have low fertility, and the loess is susceptible to soil erosion (Wang et al., 2003; Qiu et al., 2014). The soil texture varies throughout the entire basin; the silt content varies from 64% to 73%, while the clay content varies from 17% to 20%.

The area is a zone of interlaced forest and grasslands. Current land-use types include forest, grassland, shrub land, residential areas, farmland and orchards. The forest is made up of *R. pseudoacacia* plantations. Shrub lands include introduced species, such as *C. korshinskii* and *R. pseudoacacia*, as well as some native shrub species, such as *Sophora viciifolia*. *Periploca sepium* occurs as a liana. The grassland consists of *Artemisia sacrorum*, *Artemisia scoparia*, *Thymus mongolicus*, *Leymus secalinus*, *Bothriochloa ischaemum* and *Stipa bungeana*.

2.2. Sampling locations and description

Our study sites included stands *R. pseudoacacia* and *C. korshinskii* of 10–40 years of age, with each decade representing an age class; natural grasslands restored for the same amount of time were also identified.

The dates of planting following farmland abandonment were obtained from interviews with local farmers. All the *R. pseudoacacia* and *C. korshinskii* plantations were planted in a 2 m × 2 m layout, and the initial tree densities of all forest stands were similar. Twelve plots of *R. pseudoacacia* on a sunny slope, 12 plots of *R. pseudoacacia* on a shady slope, 12 plots of *C. korshinskii* on a shady slope and 12 plots of natural grassland were selected. We selected a total of 48 plot. We selected 36 plots representative of shady slopes with the same site conditions (altitude, slope, aspect, and topography) but different vegetation