Ecological Engineering 73 (2014) 676–683

Contents lists available at ScienceDirect

Ecological Engineering

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

Dynamic changes in soil and vegetation during varying ecological-recovery conditions of abandoned mines in Beijing

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ARTICLE INFO

Article history:
Received 11 February 2014
Received in revised form 13 September 2014
Accepted 29 September 2014
Available online 14 October 2014

Keywords:
Vegetation restoration
Engineering measures
Canonical correlations
Abandoned mines
Soil fertility
Site conditions

ABSTRACT

Vegetation restoration in abandoned mines is very difficult and time consuming because of the harshness of the ecosystem, i.e., the extremely high and steep slopes. To accelerate the process of vegetation recovery in abandoned mines, understanding the rules of vegetation succession and the variation in soil characteristics during this process is very important. In the Zhoukoudian vegetation restoration experiment demonstration area (a 12 ha area located in Fangshan District, Beijing, China), engineering measures, such as biological greening bags, eco-stick slope protection, container seedling planting and vegetative-carpet greening technologies, were applied to accelerate the process of vegetation recovery. In this study, 149 human-restored and spontaneously recovering slopes under three substrates were sampled to investigate the dynamic changes in soil and vegetation in different stages of succession by means of space-for-time substitution. WinTWINS was used to classify the samples, which experienced different recovery periods, into 6 plant community types. According to the results, the species richness index, Simpson's predominance index, the Shannon–Wiener index and the soil fertility of the communities dominated by young trees (V, VI) were higher than those of the communities dominated by grasses (I, II) or shrubs (III, IV); thus, plant communities V and VI are considered optimal representations of severely damaged surface-mine ecosystems. Our results suggest that native species should be planted to accelerate the succession process by implementing the best engineering measures for different substrate types during the initial restoration.

1. Introduction

Beijing contains large areas of forests with high species richness. However, since the 1980s, as the mineral demand and industrial development have rapidly increased, the ecological destruction caused by mining has become increasingly serious (Zhang et al., 2013a; Babu et al., 2014). The irrational exploitation of mineral resources without planning or management has led to a huge waste of resources and has seriously damaged the ecosystem, which used to be stable and healthy (Stefanescu et al., 2013). The bare slopes and damaged soil structure cause soil and water loss, as well as other geological disasters, such as landslides and collapses, that threaten human survival and urbanization (Andrews-Speed et al., 2003; Silva et al., 2013a; Bhebhe et al., 2013; Dai et al., 2013).

Based on the theory of ecosystem succession, the reconstruction of the vegetation ecosystem is an important method for the ecological recovery of degraded surface mines (Parraga-Aguado et al., 2013). Large-scale mining activities decelerate the process of secondary succession. Furthermore, the infertility and plant degradation in abandoned mines impede ecological recovery. As a result, vegetation recovery and species reinvasion span several decades (Bradshaw, 1997; Silva et al., 2013b).

According to the studies by Prach et al. (2013) and Anawar et al. (2013), spontaneous revegetation in abandoned mines follows the general rules of secondary succession, i.e., the species composition is strongly influenced by the native species (Woch et al., 2013; Hendrychová, 2008; Alday et al., 2011; Evans et al., 2013) and the recovery is affected by the initial site conditions (Martinez-Ruiz and Marrs, 2007; Wiegleb and Felinks, 2001). Tremendous efforts have been made to study the impacts of different types of human disturbances on species composition, community structure, biomass and other aspects of vegetation diversity under various

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http://dx.doi.org/10.1016/j.ecoleng.2014.09.113
0925-8574/

environmental conditions (Yin et al., 2012; Cohen-Fernandez and Naeth, 2013). However, few studies focus on the effects of slope engineering measures applied to vegetation restoration under different human disturbances. The primary purpose of ecological restoration in abandoned mines is to identify a proper vegetation restoration method for mineral waste accumulations and steep rock slopes.

On the regional and global scale, factors such as climate, soil parent material, vegetation and fauna determine the existing vegetation types (Burke, 2001), but on the smaller scale of a microsite, non-zonal environmental factors play a significant role in the community structure and species composition (Burga et al., 2010). Natural revegetation in abandoned mines is impeded during the early stages of vegetation succession, resulting in poor soil conditions, severe soil erosion and soil water pollution (Lin et al., 2005; Liu et al., 2010). Following this research on the correlations among soil, topography, vegetation and their effects on vegetation succession, an engineering-based application of the results will lead to improved ecological restoration.

The primary purpose of this paper is to analyze the canonical correlations between environmental factors and vegetation distributions. The secondary goals are to investigate the dynamic changes in vegetation composition and soil properties during different successional stages and to discuss the effectiveness of human-based restoration methods compared with natural recovery. It is hypothesized that, our study would benefit the ecological reconstruction of abandoned mines.

2. Method and materials

2.1. Study area

The study area is located in the town of Zhoukoudian, Fangshan District, Beijing, China (115°25′ –116°15′E, 39°30′–39°55′N; 70–250 masl) (Fig. 1). The area is a limestone landform at the intersection of the North China Plain and the Taihang Mountains. Beijing has a semi-humid monsoonal climate and distinct seasons. The average temperature is −4 °C in January and 26 °C in July and August. The annual surface evaporation is 1800 mm, and the annual rainfall is 655 mm, on average. The precipitation is unevenly distributed, with more than 80% concentrated in June, July and August. The common vegetation types are *Asteraceae*, *Chenopodiaceae*, *Crassulaceae*, *Asclepiadaceae*, *Rosaceae* and *Poaceae* (Zhang et al., 2013b).

The soil reaction is alkaline. The average amount of organic matter (OM) is 40.87 g/kg. The available potassium (AK) is 189.00 mg/kg, the available phosphorus (AP) is 2.89 mg/kg, and the total nitrogen (TN) is 1.42 mg/kg in the non-mining area. In the new mining area, the average values are lower: OM is 4.50 g/kg, AK is 25.96 mg/kg, AP is 3.16 mg/kg and TN is 0.17 mg/kg.

The substrate types of the study areas are composed of soil, soil–rock and rock. The details of the soil physical properties are shown in Table 1. The soil thickness is between 20 cm and 30 cm. The soil–rock mixture is the accumulation of mineral residue, which is constituted by 11.37% soil (<2 mm) and 88.63% gravel (>2 mm). Limestone, which is the main mineral resource in the study area, is a type of carbonate rock that is mainly composed of calcite.

2.2. Restoration

Many types of demonstration projects have been implemented to standardize the technologies of vegetation restoration and to rebuild the natural landscape in abandoned surface mines. Over the past ten years, many types of engineering measures were practiced in three restoration demonstration areas. The fish-scale hole-planting method during 2000–2004 was successful (Fig. 2a), but this method is not suitable for steep rock slopes and mineral waste accumulations. The Beijing government funded a vegetation recovery project during 2006–2008 in Zhoukoudian (Fig. 2b) by primarily using a vegetation-carpet-growth method. Biological greening bag, eco-stick slope protection, container seedling planting and vegetative-carpet greening technologies were also used for vegetation restoration during 2009–2011 with supported from the R&D Special Fund for Forestry Public Welfare Industry-“Key re-vegetation technology research on woodland damaged by construction” (Fig. 2c). The recovery area is presently 12 ha.

2.3. Assessment

In Zhoukoudian, 149 samples were obtained from human-restored (Fig. 2) or naturally recovering post-mining slopes and non-destroyed slopes of three substrate types. The vegetation was investigated using the space-for-time method from July to August 2011. The slopes were divided into 3 sections for the investigation (top, middle and bottom). In total, 447 plots were investigated.

The species, number of individuals, diameter at breast height (DBH), ground diameter, height, canopy and coverage were measured in young tree plots. The species, number of individuals, mean height and coverage were recorded in shrub and grass plots. The coverage, slope aspect, slope length, soil features, substrate type (soil, soil–rock, or rock), degree of disturbance (null, light, moderate, or serious), restoration type (restored or natural) and

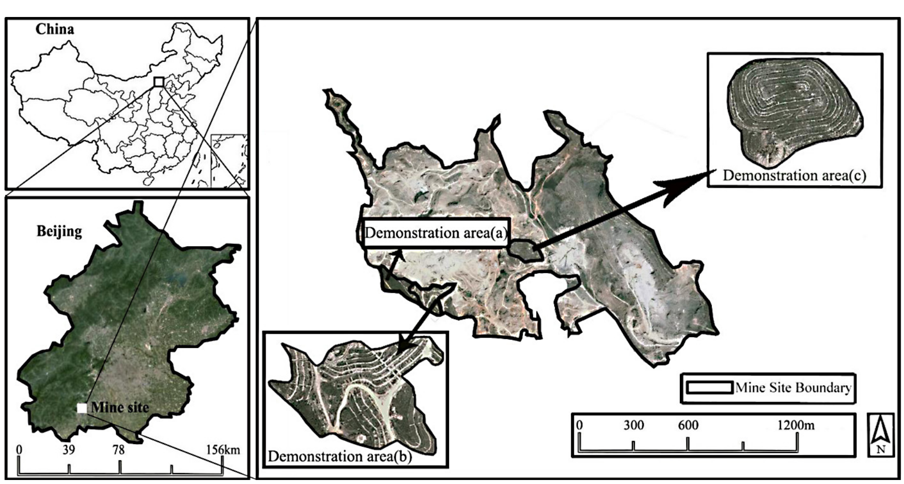

Fig. 1. Aerial view of the Zhoukoudian surface mine showing that the demonstration area experienced human-induced restoration.