Ecological Engineering 124 (2018) 23–30

Contents lists available at ScienceDirect

Ecological Engineering

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

Interaction mechanism between floristic quality and environmental factors during ecological restoration in a mine area based on structural equation modeling

Xiaoyun Hou, Shiliang Liu*, Shuang Zhao, Yueqiu Zhang, Xue Wu, Fangyan Cheng, Shikui Dong

State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

ARTICLE INFO

Keywords:
Floristic Quality Index
Environmental factors
Structural equation modeling
Toxicity
Mining restoration

ABSTRACT

Open-pit mining activities cause great damage to the local ecosystems. It is therefore necessary to assess and recover the vegetation status to maintain ecological stability. In this study, the Floristic Quality Index (FQI) was used to assess the vegetation habitat and the structural equation model (SEM) was applied to quantify the influences of different environmental factors on FQI in the Kunyang open-pit phosphate rock mine in Yunnan Province, China. Non-metric multidimensional scaling analyses revealed that great differences of vegetation community composition existed in the sampled plots, even those at similar distances to mining areas, which indicates that disturbing distance was not the only factor to determine the vegetation community. SEM results showed that Cu promoted the FQI most obviously (0.84), followed by Co (0.75), while the inhibition of Cd content in soil to the FQI was the most significant (−0.88), followed by TK (−0.82), and C (−0.79). Soil fertility quality and soil pollution indexes were also established to analyze the effects of comprehensive soil parameters on FQI. The results showed that the soil fertility quality index had a strong negative effect on FQI, which revealed that higher levels of TP, TN, TK, and other nutrients in the soil would produce 'toxicity' to the growth of vegetation. Findings from our study could provide a scientific method for assessing the ecological restoration results in the mining area.

1. Introduction

Open-pit mining makes an important contribution to the local economic development, but it also generates environmental pollution, vegetation destruction, and ecological degradation (Wick et al., 2014; Hu et al., 2015). These issues have gained more and more attention, especially in China's move towards ecological civilization (Harantová et al., 2017; Lee et al., 2017). In order to restore the local ecosystem function, vegetation in open-pit mining areas should be restored to accelerate the processes of soil natural restoration and to enhance biodiversity (Hu et al., 2015; Hendrychová and Kabrna, 2016).

Monitoring and assessing the status during vegetation restoration is essential when evaluating the restoration success (Hobbs and Harris, 2001), and it needs meaningful and interpretable metrics. There are many metrics to describe the plant community, such as species abundance, species richness, or evenness (Bauman et al., 2015; Li et al., 2017; Shackelford et al., 2017). Each metric provides certain information and has application limitations (Taft et al., 2006). Alatalo (1981) considered that evenness measures of calculations which include richness were limited by sampling biases. Abundance and diversity as the commonly used metrics were used to describe the essential characteristics of vegetation communities, but they were not weighted by vegetation composition (Taft et al., 1997).

Ecosystems consist of a complex set of temporally and spatially variable components; thus, it is difficult to characterize their integrity. Vegetation community composition could be a diversity indicator of ecosystem function and reflect site conditions (Cadotte et al., 2011). Government agencies and land managers require reproducible and quantifiable metrics to monitor a natural region's vegetation community. Therefore, a scientific and comparable approach for assessing the vegetation conditions during the restoration process is urgently needed. Wilhelm (1977) proposed the Coefficient of Conservatism (CC) to quantify the tolerance of each individual native species to human disturbance. Swink and Wilhelm (1994) combined the richness of the native species with the vulnerability measure CC value to create the Floristic Quality Index (FQI). The CC value is a number from 0 to 10 which is assigned to each taxa within a region. Species with high CC values have high allegiance to a specific habitat where disturbance is

* Corresponding author.
E-mail address: shiliangliu@bnu.edu.cn (S. Liu).

https://doi.org/10.1016/j.ecoleng.2018.09.021
Received 7 April 2018; Received in revised form 10 September 2018; Accepted 19 September 2018
0925-8574/

minimal. Species with low CC values are somewhat tolerant of human disturbance and can be found in common plant communities (Taft et al., 1997). The FQI value is calculated by multiplying the square root of native species richness for a site by the mean CC value for the same sampling unit, thus combining the plant diversity with weighted value of vegetation composition (Taft et al., 1997).

At present, some scholars have studied the application of Floristic Quality Index to assess vegetation condition. It has been a proven indicator of human disturbance when evaluating various habitat conditions (Chamberlain and Brooks, 2016; Bell et al., 2017). A study by Maginel et al. (2016) suggested that FQI could be a good indicator for monitoring the restoration of vegetation communities in forest ecosystems after fire. FQI has been used by conservation organizations and government agencies to monitor and assess a variety of areas (Freyman et al., 2016). However, studies on FQI change associated with multiple and comprehensive environmental factors are still lacking. Struckhoff et al. (2013) found that Zn and Pb concentrations in the soil had negative relationships to FQI in southeast Missouri, USA while their relative contributions of these factors is not well understood. Soil, as a major environmental factor affecting vegetation reconstruction, is often accompanied by a shortage or excess of nutrient or pollutant contents in mining areas, and it would accelerate or inhibit the growth of vegetation (Lei et al., 2016; Ahirwal et al., 2017). Therefore, it is necessary to measure the effects of soil and other environmental factors on vegetation restoration (van Swaay et al., 2011).

However, understanding the mechanisms by which environmental factors influence FQI is important when implementing ecological restoration in the mining areas. To reveal the mechanism between environmental factors and FQI for the ecological restoration, many quantifiable methods have been used. Among them, the structural equation modeling (SEM) is an effective approach to explore the mechanisms between selected multi-factors. In the past decade, SEM has been used in some scientific disciplines (Sarstedt et al., 2014; Mammides et al., 2015a; Zhang et al., 2017).

In this study, we used the SEM approach to study the mechanisms of the interaction between FQI and environmental factors in restoration areas of the Kunyang phosphate mine. The objectives were to: 1) determine vegetation community change during restoration and apply FQI index to reflect the habitat quality in restoration areas; and 2) reveal the influential mechanism of environmental factors on FQI using the structural equation model.

2. Methods

2.1. Study area

This study was conducted in the Kunyang phosphate rock mine (24°43′ N, 102°34′ E) located in Jinning county of Yunnan Province (Fig. 1). The mine is the largest open-pit phosphate rock mine in China and has been exploited for 52 years. It is the first phosphate recovery area for vegetation restoration and the first batch of national green mine pilot units in China. The annual average temperature is 14.7 °C, the altitude of the landscape is between 2118 m and 2828 m, the mean annual rainfall is 918 mm, and the rainfall events are mainly concentrated from May to August. The mining area is located in the subtropical evergreen broadleaf forest zone. The soil type is mainly red soil and the soil texture is mainly loam. The local natural forest has experienced destruction due to long-term human activities in the mining area, and the existing vegetation types are mainly secondary vegetation formed under the vegetation restoration process. The area of vegetation restoration has exceeded 1000 acres. For the vegetation restoration of this mining area, the surface soils that have been stripped prior to mining activities were stored separately for later vegetation restoration. The reclamation area is mostly covered by forests, as well as some shrubs and herbs.

2.2. Experimental design and field sampling

A typical sample method was used to conduct a vegetation survey in phosphate rock mine areas (Fang et al., 2009). In September 2016, we investigated 18 plots of restoration area along different distances from the mining area. Three quadrats were randomly selected in each plot (Fig. 2). Typical sample method was adopted for the arbor, shrub, and herb layers. The arbor layer was investigated in a 10 × 10 m-quadrat, the internal shrub layer was chosen in a 5 × 5 m-quadrat, and the herb layer was surveyed in a 1 × 1 m-quadrat. In the quadrats, each tree was identified and measured for total height and layer coverage. Each shrub species was identified and measured for total height and layer coverage, whereas each herb was identified for layer coverage and height. In each quadrat, we also investigated habitat characteristics, including altitude, slope, slope position, aspect, and the distance to nearest road (Dr) and the mining area (Dm).

For soil sampling, we collected the 0–10 cm topsoil and took a quarter of the total after mixing four random soil samples from each quadrat. Soil samples were ground and sieved after removing the large roots and stones, and the soil properties were determined in our laboratory. We used a Euro EA3000 elemental analyzer to analyze total carbon (TC) and total nitrogen (TN), and used ICP-AES to define total phosphorus (TP), total potassium (TK), Zn, Pb, As, Mn, Co, Ni, Cd, Cu, Cr, and Ca (Bai et al., 2011).

2.3. Data analysis

Based on the obtained vegetation and environmental data, we first analyzed the influence of Dm on the composition of the vegetation community using non-metric multidimensional scaling (NMDS) analyses to determine that Dm was not the only determinant. Then we calculated the FQI, soil pollution index, and soil fertility quality index, respectively. Finally, SEM was used to analyze the effects of environmental factors on FQI. The schematic diagram of the study framework was shown in Fig. 3.

2.3.1. Floristic Quality Assessment

FQI and mean CC value were calculated as the primary dependent variables. Based on each native species' affinity for natural vegetation communities and its tolerance of human interference, each native species in the geographic area was assigned a CC value from 1 to 10. The least conservative species could adapt to extremely naturally- or artificially-degraded habitats (CC values < 3). Matric species could tolerate human disturbance and occur in common vegetation communities (CC values from 4 to 6), while the most conservative species depend mainly on undisturbed sites (CC values > 7).

For each vegetation sampling quadrat (n = 54), we calculated total species richness, mean CC value, and the FQI as follows:

$$S = \text{number of species (native + exotic)} \tag{1}$$

$$\text{Mean CC} = \sum \text{CC/S} \tag{2}$$

$$FQI = Mean\ CC \times \sqrt{N} \tag{3}$$

where *CC* is the Coefficient of Conservatism for each species occurring in a quadrat, mean *CC* is the average Coefficient of Conservatism for the quadrat, *S* is number of all species, *N* is native species richness, and *FQI* is the Floristic Quality Index. Additionally, we assigned all exotic species a *CC* value of 0 in *mean CC* calculations (Francis et al., 2000).

2.3.2. Analysis of vegetation community composition and distribution

Non-metric multidimensional scaling analyses (NMDS) based on the lower-triangular dissimilarity matrix was used to display the differences between vegetation community compositions in the Vegan package in R 3.4.2 (R Development Core and Team, 2017). The result of the NMDS analysis was measured by stress. The two-dimensional point map of