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LIGHT FACTOR DYNAMICS RESPOND TO PLANT ECOLOGICAL RE-VEGETATION PROCESS IN LARGE-SCALE MINING AREAS

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Abstract

This study deals with 2 planting large open-air coal mine recovery mode by taking the fixed monitoring sample areas as the investigation platform, having studied the monitoring number of all the natural regeneration seedlings and young trees and spatial distribution of the dynamic characteristics and the related correlation. On the basis of this, research focuses on exploring the different modes of sapling seedlings survival and the correlation between light factors. The results showed that the height and biological factors of seedling trees are more important to the survival of seedling trees than light factors, and there are obvious density restriction effects, but there is no obvious niche differentiation, that is, seedlings height and density restriction jointly affect the survival of seedling trees.

Key words: Large-scale mining areas; Plant re-vegetation; Renewal mode; Light factor.

Introduction

Large-scale mining in Antaibao open-pit coal mine has resulted in the significant destruction of land resources and potential safety hazards of ecological environment in mining areas, Shanxi, China. Previous study of the ecological restoration in mining area generally believed that vegetation restoration is the premise and basis for the ecological restoration of the damaged land in mining areas (Shao, 2014). Whether the artificial plant community constructed by the self-organization principle of plant communities can be self-renewed in the process of vegetation succession is directly related to whether there is a dynamic and balanced relationship between revegetation and local environmental conditions (Lenton *et al*., 2003; Das *et al*., 2008; Lin *et al*., 2012; Long *et al*., 2014). During vegetation restoration, the transition from seedlings to saplings is the bottleneck stage of tree planting and re-vegetation construction, which is considered as the most vulnerable stage for individual growth and the most sensitive stage to environmental changes (Martens *et al*., 2004; Queenborough *et al*., 2007; Svenning *et al*., 2008; Madejon *et al*., 2009; Mao *et al*., 2017; Shao *et al*., 2017). Therefore, exploring the ecological characteristics and impacting factors such as light factor for regenerated seedlings and saplings at different stages of artificially restored plant communities facilitates the understanding for the new approaches of species synchronization in the process of vegetation restoration to reveal the root cause affecting the dynamics of artificial re-vegetation communities, which is of great significance for the reasonable evaluation of the adaptability of artificial re-vegetation (Volkov *et al*., 2005; Lin *et al*., 2012; Xu *et al*., 2014).

Materials and Methods

General information of the experimental sites: The experimental sites are located in the south dump of Antaibao coal mine in Pinglu District, Shuozhou City of northern Shanxi, 39°24'N～39°38'N, 112°11'E～113°32'E.The region belongs to temperate semi-arid continental monsoon climate with the average annual precipitation of 428.2mm, the average annual temperature 5.5℃, the ≥10℃ accumulated temperature 2300~2500 ℃, and the frost free period of 117d. The local vegetation in mining area was grassland type.The south dump of Antaibao coal mine was an outer dump with the final elevation of 1465m, the capacity of 116 million m^3 and the dumping height of 150m. It started to dump in 1985 until 1989, and re-vegetation process was initiated in 1993. It is one of the earliest areas for ecological restoration in Antaibao mine. Other than watering during tree planting, no other management practices were applied. At present, the re-vegetation restoration areas showed rich biodiversity with main locust (*Robinia pseudoacacia)* and elm (*Ulmus pumila)*, and have basically covered the bare surface of the dump, so the ecological environment has been effectively regenerated (Shibata *et al*., 2010). To the east of the region are mount Taihang and mount Wutai, both of which are over 2800m above sea level, preventing the ocean monsoon from blowing inland. Its western regions are Inner Mongolia, so that the region has become the only way of the cold wave southward invasion.Therefore, the continental monsoon climate is very typical, with cool in summer, strong wind in spring and winter. The maximum sunshine period of Pingshuo mine is 2883.1h, and the minimum annual sunshine period is 2444.5h, with an average of 2693.3h, humidity minimum 0, and maximum 80%.

Sample site setup and survey: Method of reference CTFS, in Ann, south fort too mine ecological FuKen District fixed monitoring sample area, and select two piece as the research object. The specific recovery mode for the locust, elm and ailanthus mixed Ⅰ(S) (100 m by 100 m) and acacia pure forest Ⅱ (S) (100 m by 100 m), 1 hm^2 sample area is divided into 100 10 m x 10 m as the measuring unit, respectively, in July 2010 and July 2014, investigating samples within all woody plants: All species identification of woody plants within the quadrat, positioning and quotation marks; tree height and diameter at breast height measurement and other basic information(trees with a diameter of < 3cm were seedlings, trees with a diameter of 3cm or less and a diameter of < 7cm were saplings, (Fig. 1).

Data collection of optical environment: Method of measurement: refer to the methodology as Xu *et al*., (2014) and Lin *et al*., (2012). Collection time: mid-September 2014, before sunrise; Shooting unit: each 10m x 10m sample square is used as shooting unit; Equipment: AF Fisheye Nikkor 16 mm f12.8D Fisheye lens (NIKON D700 camera), horizontal tripod; Method of collection: the shooting height was 1.5m, and three photos were taken at each position. Parameter selection: incidence rate of direct light (%Trans. Direct) and incidence rate of scattered light (%Trans. Diffuse); Digital processing: the parameters of the canopy structure were digitized (Frazer, 1999) and averaged using the Gap Light Analyser software (version2.0). During the operation, parameters such as longitude, latitude and altitude of the sample area should be set, with the rest default values (Fig. 2).

Data analysis and important value parameters: The important values of tree layer, shrub layer and herbaceous layer were calculated as follow (Lin *et al*., 2012):

$$AI = \frac{Ab + Co + Hi}{3} \quad (1\text{-}1)$$

$$SH = \frac{Co + Hi}{2} \quad (1\text{-}2)$$

$$HE = \frac{Co + Hi}{2} \quad (1\text{-}3)$$

where, *AI*, *SH* and *HE* are the important values of tree layer, shrub layer and herbaceous layer, respectively; *Ab* is the relative abundance, *Co* indicates the relative coverage and *Hi* represents the relative height.

Size classification and spatial distribution: Akima, spatstat and spatial packages in the internationally recognized software R2.11.1 (http://www.r-project.org) were used for the analysis and map-making.

Correlation analysis of biological and non-biological factors and plant communities: The relative importance of biological and non-biological factors to the survival of seedlings and young trees has been a hot topic. We took the individual number of 100 or 2010 seedlings of sapling to the survival of the state in 2014, 1 (live) or 0 (dead) as the dependent variable, using generalized linear mixed models (GLMM), with seedlings of sapling height, biological factors and non-biological factors constructs four GLMM: (1) seedlings of sapling height model (seedlings of sapling samples and species as random effects, height as fixed effects);(2) non-biological factor model (based on the height model, only the light environment is considered as a fixed effect);(3) biological factor model (based on the height model, only seedling and tree neighbors are considered as the fixed effects);(4) the full-factor model (on the basis of the height model, taking all the above variables into consideration as the effects of fixed effects) examined the influence of seedling tree height, biological and non-biological factors on seedling tree survival and the relative importance of each factor at the community level and species level. The ratio Criterion (Akaike's Information Criterion, AIC) is used for the comparison between models. The smaller the value is, the better the model is, which the optimal model is. Biological factors for each seedling samples within each of the same species and number of seedlings, each of the same tree species and individual number, as well as the target seedlings as the center of the circle, with a radius of 10 m, calculated the range of the tree of a piece of chest high breaking an area the size of the tree and the ratio of the target seedling distance, and points the same tree species and calculate the ratio of the sum. Non-biological factors used direct light transmittance and scattering light transmittance to represent the light environment under forest.

Results

Relationship between light factor and seedling tree survival at community level: At the community level, the optimal model affecting seedlings survival was seedling height model, and the optimal model affecting seedlings survival was abiotic model.In the model of young tree survival, the non-biological factors of direct light transmission and scattered light transmission are closely related to young tree survival. However, the effects of seedlings height cannot be ignored.This indicates that in the two samples with differences, not only the seedlings height, but also the non-biological factors have a certain influence on the re-vegetation and distribution of the whole seedlings in the sample plot (Tables 1-4).

Table 1 SI. Seedlings survival model of AIC value community level.

The alternative model	Community level
Seedling height model	5799.124
Non-biological factor model	5803.048
Biological factor model	**5786.543**
Total factor model	5790.504

Table 2 SI. Community level of sapling AIC value of the survival model.

The alternative model	Community level
Seedling height model	556.1387
Non-biological factor model	558.0331
Biological factor model	**553.0740**
Total factor model	554.6653

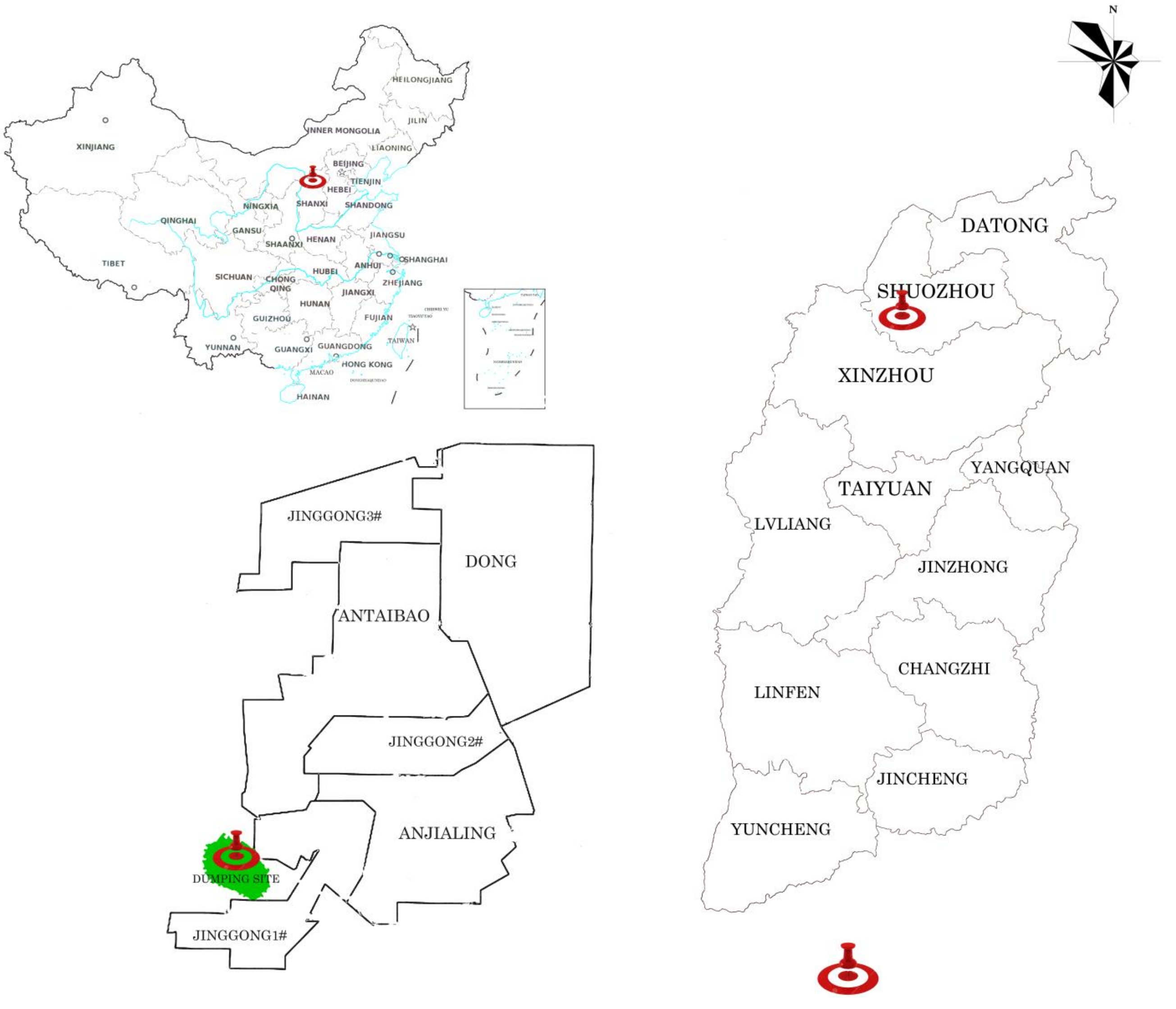

Fig. 1. Sampling sites of Antaibao coal mine in Pinglu District, Shuozhou City/

Before digitization After digitization

Fig. 2. Examples of light digital hemisphere photograph.

Table 3 SII. Seedlings survival model of AIC value for community level.

The alternative model	Community level
Seedling height model	1898.898
Non-biological factor model	1901.720
Biological factor model	**1893.469**
Total factor model	1895.917

Table 4 SII. Community level of sapling AIC value of the survival model.

The alternative model	Community level
Seedling height model	**110.1082**
Non-biological factor model	112.4039
Biological factor model	115.7801
Total factor model	118.5858

Relationship between light factors and seedling tree survival at the level of species: At the species level (elm), and the optimal model of locust seedling are biological model; at the same time, the same trees chest high area, the same trees individual number, species trees chest high breaking area of tree species, biological factors such as individual numbers also in different degree of influence.The survival and distribution are listed Tables 5-7.

Discussions

The results showed that under two different patterns of plant allocation, both at the community level and at the species level, the optimal models affecting seedlings and sapling survival were height model and biological factor model. In non-biological models, the light did not affect the survival of seedlings and sapling trees.In the optimal height model and the model of biological factors, the seedlings height is closely related to the seedlings survival, and the survival of seedlings and sapling shows a significant positive correlation with the overall height, that is, the higher the height, the easier it is to survive (Das *et al*., 2008; Shao 2014; Xu *et al*., 2014).

The influencing factors of seedlings and sapling of different species are also very different.The seedlings of the two sites were all elms and acacia, but the biological factors affecting the two species were different in the optimal biological model. In addition to seedlings height, the biological factors affecting the survival of elm seedling were the thoracic height of the same tree and the number of individuals of the same tree.The biological factors influencing the seedlings survival of *Robinia pseudoacacia* were the number of individuals with different species and the number of individuals with different species. The main factor affecting the survival of young trees was the height of young trees, and showed a significant positive correlation (Svenning *et al*., 2008; Shibata *et al*., 2010; Mao, *et al*., 2014; Shao *et al*., 2017; Hamayun *et al*., 2019).

In flat back open-pit coal mine, different plant configuration mode of engraftment in the process, the height of the seedlings of sapling and biological factors on the seedlings of sapling survival are more important than abiotic factors, and there is an obvious density effect, but there is no obvious niche differentiation, namely restrict common seedlings height, density affects the survival of the seedlings of sapling (Mahar *et al*., 2019). Light factor is one of the important abiotic factors that play important roles in re-vegetation process in the mining areas. More wok is still needed to do including collecting soil quality parameters.

Table 5 SI. Seedlings survival model of AIC value for species level.

	Seedlings height model	Non-biological factor model	Biological factor model	Total factor model
Locust	**608.3882**	609.7257	615.0555	616.9202
Elm	5012.960	5015.920	**5012.489**	5015.178

Table 6 SI. Species level of sapling AIC value of the survival model.

	Seedlings height model	Non-biological factor model	Biological factor model	Total factor model
Locust	**154.8690**	158.1091	161.9599	164.9411
Elm	315.0783	318.5791	**311.6675**	313.9067

Table 7 SII. Seedlings survival model of AIC value for species level.

	Seedlings height model	Non-biological factor model	Biological factor model	Total factor model
Locust	**1789.154**	1791.477	1792.555	1793.889
Elm	105.6160	106.5410	106.5232	**103.9382**

Conclusions

Light factor is one of the important abiotic factors that play important roles in re-vegetation process in the mining areas. This study is based on the survey data of two sample sites, which is not sufficient for monitoring the update status of artificial forest and the influence of light factors on the survival of seedlings and sapling trees. In addition, when analyzing the factors affecting the survival of seedlings and sapling trees, the evaluation factors we selected were not comprehensive, such as micro-topography. Therefore, more long-term localization monitoring and more factors should be taken into account to fully reveal the re-generation mechanism of species in the re-vegetation recovery area.

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