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Natural Regeneration of an Artificial *Platycladus orientalis* Stand in Beijing

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ABSTRACT

The study of the natural regeneration of an artificial *Platycladus orientalis* stand is important in order to reflect the potential trend of the stand. This field investigation was carried out in the Shisanling forest farm in Beijing. We analysed the factors that influenced the natural regeneration using the gray correlation method. The results showed that the regeneration status was bad in height classes of 0-30 cm and 30-50 cm, while it was moderate in the height class of >50 cm; the overall regeneration status was moderate. Eight factors that affected the natural regeneration, in a descending order, are: altitude, aspect, soil depth, slope position, stand density, gradient, shrub-herb cover and litter thickness. It was difficult to satisfy the demand of stand self-replacement because the natural regeneration of artificial *P. orientalis* stands was poor.

INTRODUCTION

Platycladus orientalis is an evergreen coniferous tree species that originated in China and is also naturalized in Korea, Japan and Iran (Lei et al. 2010). Considering its high resistance to cold, drought and nutrient deficiency, *P. orientalis* has become one of the dominant evergreen tree species in north China. Natural regeneration is the self-production and restoration of the forest ecology system and is a crucial component of the community dynamics of a forest (Ma et al. 2009). Because natural regeneration can reach an ecosystem balance through the cultivation of stands that grow naturally from seeds, it is considered very important and the key to modern silviculture based on principals of sustainable forest development. Natural regeneration is a complicated ecological process, and every step of seed production, dispersal, germination, seedling establishment and growth of the seedlings is influenced by various biotic and abiotic factors.

Presently, numerous studies have discussed the factors that influence natural regeneration, including terrain conditions (e.g., aspect, slope position, altitude, soil depth), stand conditions (e.g., canopy density, understory cover, tree composition, stand density), and anthropogenic disturbance (e.g., logging, forbidding cutting, forest tending) (Grassi et al. 2004, D'Alessandro et al. 2006, O'Brien et al. 2007). Because artificial *P. orientalis* is a significant soil and water conservation species planted in Beijing, the health and sustainable development of this forest type play an important role in the entire forest. Research on the natural regeneration of artificial *P. orientalis* is a crucial part of stand structure analysis and it reflects the potential development trend of stands. In this paper, our work can be summarized by the following three aspects: 1) the study of the natural regeneration status from the aspects of a holistic stand and the different species; 2) an analysis of the factors that influence natural regeneration; and 3) the advancement of some sustainable management strategies for artificial *P. orientalis* stands on the basis of the results.

MATERIALS AND METHODS

Study Area and Field Inventory

This study was conducted on the Shisanling forest farm (40°442 N, 116°352 E), in northwest Beijing, China (Fig. 1). It is located in low hills, with altitudes ranging from 68.0 m to 954.2 m. It is a monsoon climatic region with a dry, windy spring and a warm, wet summer. The mean annual temperature is 11.8°C, the lowest mean monthly temperature is -4.1°C (January), and the highest mean monthly temperature is 25.7°C (July). The mean annual rainfall is 631.0 mm.

We established thirteen sample plots with areas of 400 m^2. In each plot, the diameter at breast height (DBH) ≥ 4 cm was investigated, and some indicators were recorded, such

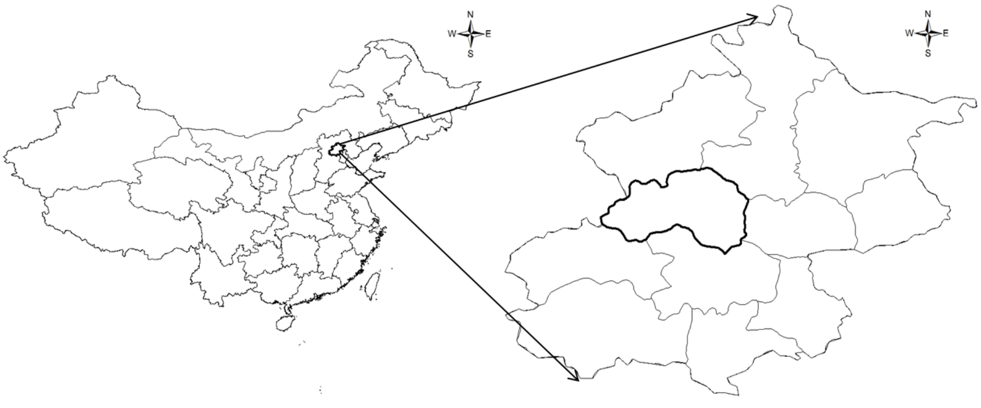

Fig. 1: The location of sample plots in Beijing, China.

as altitude, aspect, gradient, species, height, *DBH*, crown breadth, under branch height and so on. One shrub quadrat (5 m×5 m) and one herb quadrat (1 m×1 m) were established in the corners and centre of each plot. In the shrub quadrat, the shrub species, height, ground diameter and the number of every species were investigated and recorded, while herb species, height, coverage, abundance, and growth status were investigated and recorded in the herb quadrat. The height, ground diameter, and number of every species were recorded in the regeneration quadrat. A soil profile in each sample plot was dug, and the soil depth and litter thickness was surveyed.

Analytical Methods

Gray correlation analysis: The correlation analysis of the gray system is used as a method to study the relationship between forest regeneration and environmental factors. Tree regeneration density and the measured influence indicators were regarded as a whole, according to the requirements of the gray system theory. The number of regenerating seedlings was granted as X_{0j}, altitude X_{1j} (m), aspect X_{2j} (divided into 1-8 levels, east, south, west, north, northeast, southeast, northwest and southwest aspect, given as 1, 2, 3, 4, 5, 6, 7, 8, respectively), slope position X_{3j} (divided into 1-5 levels, upper, middle-upper, middle, middle-lower and lower slope position, given as 1, 2, 3, 4, 5, respectively), gradient X_{4j} (°), soil depth X_{5j} (cm), litter thickness X_{6j} (cm), shrub-herb cover X_{7j} (%), and stand density X_{8j} (seedlings/ha) (Table 1).

Because natural regeneration is influenced by eight factors in the form of different units, which would hamper the evaluations of their effect, we adopted the dimensionless method of equalization to conduct raw data (Liu & Zhang 2009, Bao et al. 2011) for the purpose of eliminating the unit effect, and the formula is expressed as follows:

$$x_i'(k) = \frac{x_i(k) - \overline{x_i}}{s_i}$$

Where $x_i(k)$ is raw data, $\overline{x_i}$ is the mean value of the same character, and S_i is the standard deviation of the same character.

Calculation of correlation coefficient and correlation degree: The formulas are expressed as follows:

Correlation coefficient $\xi_i(k)$

$$\xi_i(k) = \frac{\min i \min k \left|x_0(k) - x_i(k)\right| + \zeta \max i \max k \left|x_i(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \zeta \max i \max k \left|x_0(k) - x_i(k)\right|}$$

Where min*i* min*k* $|x_o(k)-x_i(k)|$ is the secondary minimum differential, max*i* max*k* $|x_o(k)-x_i(k)|$ is the secondary maximum differential, and ζ is the resolution coefficient with the value range [0,1], while usually the value is 0.5 (Liu & Zhang 2009, Bao et al. 2011).

Correlation degree R_i:

$$R_i = \frac{1}{n}\sum_{k=1}^{n} x_i(k)$$

Where *n* is the number of sample plots.

RESULTS

Stand natural regeneration status: Referring to "The main technical requirements of the forest resource planning and design survey in China" (Table 2) and following the seedling height at three classes (i.e., 0-30 cm, 30-50 cm and >50 cm), the seedlings were divided into three groups (Table 3). At the height classes of 0-30 cm and 30-50 cm, the natural regeneration status was bad, while it was moderate at the classes of >50 cm. Obviously, the overall stand self-restoration could not satisfy the requirement of natural regenera-

Table 1: Influence factor data.

Plot No.	X_{0j}	X_{1j}	X_{2j}	X_{3j}	X_{4j}	X_{5j}	X_{6j}	X_{7j}	X_{8j}
1	1000	221	6	3	21	9.8	1.9	58	1175
2	500	222	7	4	24	17.5	2.6	60	1475
3	3000	226	7	3	4	16.0	2.2	65	1050
4	2500	197	2	1	14	16.5	1.5	63	1000
5	5500	180	8	2	18	18.5	2.1	56	1320
6	2000	174	8	4	19	12.9	1.8	40	1160
7	6000	166	8	4	18	17.0	2.2	26	1280
8	5000	140	8	5	18	19.5	1.7	21	1160
9	2500	148	3	4	18	16.5	1.9	15	1160
10	500	273	2	1	25	10.0	3.2	51	2040
11	500	252	1	4	35	36.0	4.3	84	1480
12	1500	181	8	5	18	28.0	3.3	47	1320
13	2500	204	2	4	20	23.0	2.8	58	1360

Table 2: Natural regeneration level (seedlings/ha).

Height level	Good	Moderate	Bad
0-30 cm	> 5000	3000-4999	< 3000
30-50 cm	> 3000	1000-2999	< 1000
> 50 cm	> 2500	500-2499	< 500

Table 3: The natural regeneration status of the *P. orientalis* stand.

Height classes	Regeneration number (seedlings/ha)	Regeneration grade
0-30 cm	615	Bad
30-50 cm	538	Bad
> 50 cm	1385	Moderate

tion, and it is hard for stands to finish self-renewal by solely depending on natural regeneration. The number of seedlings were 615, 538, 1385 seedlings/ha at the height classes of 0-30 cm, 30-50 cm and >50 cm, respectively, showing that there were fewer seedlings at smaller heights than seedlings at larger heights. Both the density and frequency of the natural regeneration of the seedlings were relatively small, and the natural regeneration was weak (Table 4). Among seven tree species, the magnitude of density and frequency for *Quercus dentate* were the largest, which were 692 seedlings/ha and 21.5%, respectively. *P. orientalis* was dominant species, accounting for 68.55% relative abundance in the stand (Table 5). Nevertheless, its seedling density and frequency were merely 538 seedlings/ha and 13.8%, which illustrated that the natural regeneration status of *P. orientalis* was poor. The amount of seedlings of coniferous trees (i.e., *P. orientalis*, *Pinus tabulaeformis*) was far less than that of broad-leaved trees (i.e., *Quercus dentate*, *Quercus variabilis*, *Cotinus coggygria* and *Amygdalus davidiana*), the ratio of which was 0.32, which elucidated that the natural regeneration ability of broad-leaved trees was far better than that of coniferous trees.

Regeneration status is not only connected with seedling density and frequency, but is also connected with seedling height and ground diameter, which could reflect the growing and health conditions of seedlings, and these two factors could represent seedling quality to some extent. It is not difficult to understand that the seedlings of slightly greater height and ground diameter could better survive than the smaller seedlings due to better resistance to the environment. *P. orientalis* seedlings had the largest mean height and mean ground diameter, the values of which were 1.41 m and 0.90 cm (Table 4), respectively. The *P. orientalis* adult trees had reached a near-mature age. However, the mean diameter and mean height were only 11.30 cm and 6.81 m, far lower than normal standards. In addition, the mean *DBH* and height of the other tree species were also not large (Table 5), which might influence fruit bearing and seed quality to some extent, and could correspondingly hinder seed germination and growth, especially for *P. orientalis*, which relies mainly on seed propagation.

Gray correlation analysis: A dimensionless method was used to conduct the raw data, and a gray correlation analysis was utilized to compute the correlation degree of eight influence factors (Table 6). The rank was listed by descending order (Table 6): R_{1j}, R_{2j}, R_{5j}, R_{3j}, R_{8j}, R_{4j}, R_{7j}, R_{6j}, namely altitude, aspect, soil depth, slope position, stand density, gradient, shrub-herb cover and litter thickness.

The influence of altitude on natural regeneration: The correlation degree between the altitude and the number of seedlings was 0.742, which was the largest factor affecting the stand natural regeneration. The altitudes range from 140 m to 272 m, belonging to a low mountain landform. The altitude deviations of the sample plots were small, but the corresponding correlation coefficients fluctuated. In Table 1, it is shown that the relationship between altitude and the

Table 4: Seedling density and frequency of tree species.

Tree species	Density (seedlings/ha)	Frequency (%)	Mean height (m)	Mean ground diameter (cm)
Platycladus orientalis	538	13.80	1.41 (± 0.57)	0.90 (± 0.79)
Quercus dentate	692	21.50	0.46 (± 0.30)	0.46 (± 0.58)
Quercus variabilis	462	12.30	0.63 (± 0.47)	0.56 (± 0.66)
Cotinus coggygria	423	10.80	0.88 (± 0.30)	0.30 (± 0.20)
Ailanthus altissima	231	7.70	0.56 (± 0.69)	0.18 (± 0.15)
Amygdalus davidiana	115	4.60	0.78 (± 0.31)	0.27 (± 0.05)
Pinus tabulaeformis	77	3.10	0.24 (± 0.16)	0.20 (± 0.15)

Note: numbers in brackets are standard deviation

Table 5: Main tree species information of *P. orientalis* stands.

Tree Species	Mean *DBH* (cm)	Mean height (m)	Mean crown breadth (m)	Relative abundance (%)
Platycladus orientalis	11.30 (± 3.50)	6.81 (± 1.35)	2.99 (± 0.84)	68.55
Quercus dentate	8.34 (± 3.02)	5.02 (± 1.40)	3.82 (± 1.45)	2.52
Quercus variabilis	12.61 (± 4.45)	6.87 (± 1.44)	4.78 (± 1.90)	6.92
Cotinus coggygria	9.52 (± 3.38)	5.86 (± 1.79)	2.92 (± 0.74)	2.31
Ailanthus altissima	9.45 (± 5.57)	5.88 (± 2.51)	2.93 (± 1.75)	0.84
Amygdalus davidiana	6.70 (± 1.05)	4.41 (± 0.57)	3.80 (± 0.90)	1.89
Pinus tabulaeformis	9.89 (± 2.74)	4.13 (± 1.28)	2.98 (± 0.85)	14.68

Note: numbers in brackets are standard deviation

Table 6: The correlation coefficients and correlation degrees of influence factor.

Plot No.	L_{1j}	L_{2j}	L_{3j}	L_{4j}	L_{5j}	L_{6j}	L_{7j}	L_{8j}
1	0.681	0.656	0.792	0.652	0.828	0.930	0.606	0.864
2	0.623	0.544	0.559	0.528	0.679	0.596	0.549	0.532
3	0.950	0.863	0.788	0.441	0.767	0.779	0.785	0.731
4	1.000	0.628	0.523	0.722	0.884	0.635	0.737	0.624
5	0.542	0.752	0.427	0.525	0.554	0.502	0.618	0.564
6	0.926	0.621	0.724	0.899	0.796	0.799	0.902	0.701
7	0.496	0.682	0.589	0.490	0.488	0.476	0.389	0.530
8	0.553	0.838	0.967	0.566	0.627	0.471	0.413	0.725
9	0.902	0.708	0.804	0.920	0.884	0.757	0.528	0.775
10	0.578	0.955	0.731	0.508	0.946	0.487	0.629	0.335
11	0.595	0.815	0.559	0.368	0.356	0.359	0.406	0.530
12	0.811	0.572	0.524	0.852	0.510	0.545	0.820	0.767
13	0.983	0.628	0.804	0.952	0.754	0.815	0.818	0.901
Correlation degree *R*	0.742	0.712	0.676	0.648	0.698	0.627	0.631	0.660
Rank	1	2	4	6	3	8	7	5

number of seedlings presented a certain negative correlation, namely, when the altitude was relatively low, the number of seedlings increased.

The influence of aspect, slope position and gradient on natural regeneration: The correlation coefficients of aspect, slope position and gradient were 0.712, 0.676, and 0.648, respectively. Plots with relatively more seedlings were mostly distributed in the south and southwest aspects, which belonged to sunny slopes and semi-sunny slopes. As all investigated seedlings in this paper were shade-intolerant species, sunny and semi-sunny slopes were conducive to seed germination and seedling growth due to their fine light condition. The regeneration status in middle-low and low slope positions were better than that at upper and middle-upper slope positions, revealing that seedlings were prone to appear in woodlands located at the foot of the hills because of the better water and soil conditions compared to hilltops. Table 1 indicates that the gradient was greater, and accordingly, the correlation coefficient was smaller, with the relationship between gradient and the number of regeneration seedlings showing a certain negative correlation. If the slope is too steep, it will increase the difficulty for seeds to settle down and germinate.

The influence of soil depth on natural regeneration: The correlation degree of soil depth and the number of seedlings was 0.698, which exhibited great relevance. Generally, the thicker the soil, the better the regeneration. The range of soil depth of the plots was between 9.8 cm and 36.0 cm, while most were less than 30 cm (Table 1). The soil is too thin to provide enough nutrition and water for regeneration, so it is also a reason for the poor natural generation status.

The influence of stand density, shrub-herb cover, and litter thickness on regeneration: The correlation coefficients of stand density, shrub-herb cover and litter thickness were 0.660, 0.631, and 0.627, respectively, and there was no significant differentiation among them. Stand density, to a certain extent, can reflect the forest canopy density, and stand canopy density affects light conditions, temperature, humidity and the growth of ground cover. In this study, when the canopy density is 0.7-0.8, the forest stand density is suitable for natural regeneration. Appropriate shrub-herb cover can improve the micro environment of the forest, increase soil fertility, and protect the seedlings of shade tolerant species. In Table 1, when the shrub-herb cover of the artificial *P. orientalis* stand is between 40% and 55%, natural regeneration will be better. By preventing seeds from reaching the soil surface, the litter layer reduces the possibility of germination and seedling establishment. The litter shading has the functions of heat preservation, moisturization and mechanical obstruction, having a dual effect for regeneration. The artificial *P. orientalis* stand of the Shisanling forest farm in Beijing has a low thickness, which has little unfavourable effect on the natural regeneration. In the dry and cold winter of Beijing, it has the positive effects of heat preservation and moisturization, but these positive effects were offset by the negative effect mentioned above, and it is not hard to understand why the correlation degree was the smallest among the eight factors.

DISCUSSION

There are many factors that affect natural regeneration. Meanwhile, factors are interrelated and interact with each other, jointly affecting the natural regeneration process. Other factors, such as substrate and microsite characteristics, also determined regeneration success. Likewise, parent trees may promote or hinder germination and the growth of juveniles and alter conditions for subsequent recruitment by modifying habitat characteristics such as light, vegetation composition, soil nutrients and water availability (Battaglia et al. 2002, Kunstler et al. 2005, Stancioiu & O'Hara 2006, Petritan et al. 2007, Wagner et al. 2010, Ligot et al. 2013). The relationship between recruitment success and the presence of shrub vegetation has previously been highlighted in the literature (Smith 1980, Garcia et al. 2000, Farris & Filigheddu 2008). Shrubs may provide shaded conditions required for the growth of some seedlings of coniferous species, which can be subject to photoinhibition (Ball et al. 1991, Oquist & Huner 1991). Some studies have indicated that understory vegetation can limit natural regeneration through direct and indirect effects, such as competition and habitat impacts on seed predation (MacLean & Morgan 1983, Caccia & Balleré 1998, Roberts et al. 2005, O'Brien et al. 2007, Yildiz et al. 2007, Dodet et al. 2011, Sarr et al. 2011). In the study area, the main shrub and herb species are native species and possess the characteristics of cold and drought resistance.

Numerous studies have demonstrated that the regeneration and cover of conspecific canopy were negatively correlated, namely, the tree species might not naturally regenerate well under the canopy of the same species, and a number of reasons for a lack of regeneration beneath conspecific canopy cover have been proposed (Rodwell 1991, Svenning & Magárd 1999, Devaney et al. 2014). Some reasons are due to the potential for autotoxic mechanisms to operate in species populations (Smith 1980, Appendino et al. 1992, Svenning & Magárd 1999, Iszkulo & Boratynski 2006). Our study found that *P. orientalis* seedlings also did not tend to appear in conspecific trees, in accordance with the results above. The influence of gaps on regeneration in stands have been discussed in many studies (Pelt & Franklin 2000, Nabel et al. 2013), and their size and direction affect the process of natural regeneration (Page & Cameron 2006, Pröll et al. 2015). Gaps are more likely to occur in natural forests, especially old-growth forests, which have some gaps with a large litter area due to the thinning of trees and other factors (e.g., windthrow, plant diseases and insect pests), and downed logs can promote the formation of gaps. Furthermore, studies have indicated that downed logs play an important role in the regeneration of coniferous tree species because they can supply nutrition and safe habitat for seedlings (Nakamura 1992, Takahashi 1997, Narukawa & Yamamoto 2003). Our paper focused on an artificial *P. orientalis* stand under near-mature age where tree mortality was rarely observed. Therefore, gaps were relatively small and downed logs scarcely existed in the stands, so the influence of gaps and downed logs on natural regeneration were not obvious.

Recently, managing stands to improve natural regeneration has become a concern for foresters because of its importance in ecology and the economy. Some biotic factors that influence regeneration, such as shrub-herb cover and stand density, can be controlled in management activities. Some abiotic factors, such as aspect, gradient, and slope, are hard to change or are not worth changing to improve regeneration compared to the required expenditure of energy and money. It is productive to adjust the controlled factors to make the area suitable to regeneration. In management strategies, trees with weak growth and bad trunk shape should be cut to improve the stand conditions by reducing the stand density to a suitable range and increasing the mingling of tree species, and thus improving forest productivity. In view of the poor natural regeneration status, it is worth protecting seedlings associated with planting appropriate saplings, protecting the diversity of the understory vegetation, and maintaining the stability of the ecosystem. However, due to the complicated process of regeneration and the characteristics of every species, further study is necessary.

CONCLUSION

Stand seedling regeneration in the 0-30 cm and 30-50 cm height classes were bad and was moderate in the >50 cm height class. Overall, the restoration was not good, and it was difficult to complete the natural regeneration of the forest. The correlation degree rank of the eight impact factors listed in descending order are: altitude, aspect, soil thickness, slope position, stand density, gradient, shrub-herb coverage, and litter thickness. Fine natural regeneration usually occurred in stands at a lower altitude and south and southwest aspects.

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