Research Article
Response of Natural Recruitment to Gap Size in Chinese Pine Plantation

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Abstract: Building the stratified uneven-aged mixed forest and promoting the natural recruitment is an important way to realize the sustainable management of forest. This study is to characterize the variation discipline of growth of natural recruitment in different size gaps in 50 years old Chinese pine Plantation as well as its community structure and spatial pattern. All recruitment individuals were measured and stem-mapped in plots and the growth indexes were quantified in different size gaps and under the canopy as well as spatial pattern of recruitment. Ripley's K-function was selected to analyze spatial pattern of recruitment and spatial association between recruit cohorts in different development stages. Results were showed as following: (1) the proportion of Chinese pine in the natural recruitment community was all higher than 95% in gaps and under the canopy. (2) With the increase of gap size, the recruit density dropped off, whereas the average height, basal stem and age of recruit increased. Gaps enhanced the recruit density and improved the growth of recruit. However, gaps improvement will not fundamentally solve the problem of slow growth speed, low lifetime and maladjusted age structure. (3) The recruitment of Chinese pine was exhibited aggregation at research scales. Intraspecific competition and adult trees were showed with little effort on recruitment. The role of improving the recruitment by gaps was limited under the existing management technology system. Therefore, it is necessary to apply human disturbance to promote the recruitment. To introduce other tree species by human should be attempted. The effort of gaps created by more intensify disturbance and various disturbance frequency ought to be explored so as to find out the most effective interference measurements.

Keywords: Gaps, plantation, recruitment, Ripley's K, spatial pattern

INTRODUCTION

As an important part of the North China mountain vegetation, Chinese pine Plantation is considered to be one of the suitable afforestation tree species in mountain areas of North China for its strong adaptability. From 1950s, for the purpose of timber wood production and soil and water conservation, Chinese government started to plant Chinese pine in the northern mountainous region of Hebei province. So, there is a large area of artificial Chinese pine pure Plantation in Hebei province now. Currently the forest operation units in this region make extensive use of natural recruitment to achieve sustainable management. With the existing management system, Chinese pine Plantation is thinned for several times during the cultivation process. Thinning is an important forest cultivation measure to promote forest recruitment (Zhu et al., 2003). Gaps created by thinning are important for forest community dynamics (Coates and Burton, 1997; Otto et al., 2012) and usually are not large (Childs,

1970). More and more attention was paid with small gap disturbance in the research of forest dynamic and recruitment in the world (Coates and Burton, 1997; Dorota and Veblen, 2008; Elias and Dias, 2009; Garbarino et al., 2012).

Forest gap dynamics is thought as a key role in the forest site evolution process. Gap recruitment is a key puzzle of forest sustainable management. The recruitment was strongly influenced by gaps through intensifying the environmental heterogeneity (Canham et al., 1990). At present, the research of gaps recruitment mainly focus on the effect of gaps on recruitment discipline, especially on seedling density, seedling growth and species composition in nature or secondary forest, whereas only few involved plantation (Nakamura et al., 2005). Artificial gap involved are mostly showed gaps with different size grades designed for experiment (Parsons et al., 1994; D'oliveira and Ribas, 2011; Robert et al., 2011). The effect of gaps generated from the management system on recruitment, especially on the spatial pattern was less involved.

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Table 1: Gap area

Area classes	4-10 m² gaps	10-20 m² gaps	20-30 m² gaps	30-40 m² gaps
Average area (m²)	8.3±1.81	14.4±3.81	27.8±1.02	32.0±1.65
Area of selected gap (m²)	8.8	14.8	27.0	31.9

*: Selected gap means the gap selected for spatial pattern analysis

In the life history of plant, seedling stage is the most sensitive stage to the habitat. Seedling stage will determine the fortune of recruitment of population. The adaptive capacity of Chinese pine recruitment to gaps microhabitat and recruitment potential will be reflected by population density, growth situation and population distribution pattern. One particular attention was paid to the recruitment spatial pattern in gaps of this study. If the spatial interaction is ignored, dynamic of a simple ecosystem cannot be effectively predicted no matter how precisely calculate the community underlying demographic rates (Hastings, 1993). Therefore the research of the effect of gaps on natural recruitment discipline of Chinese pine Plantation is of important significance to promoting advance recruitment and implementing near natural management. This study is to:

- Explore the association between gap size and natural recruit density and growth in Chinese pine Plantation
- To analysis the effect of gap size on the natural recruitment spatial pattern and spatial association between recruit cohorts in different development stages in Chinese pine Plantation

MATERIALS AND METHODS

Study site: The study was conducted with a managed, even-aged 50 years old Chinese pine (*Pinus tabulaeformis*) Plantation at the Pingquan County, approximately 350 km north of Beijing, CA (41°13'N 118°41'E) in the North China. Elevation within the study area is 620 to 660 m. Soil is mountain brown earth containing gravel more. The climate is the temperate continental arid monsoon climate with annual precipitation of 54 cm and a mean annual temperature of 7.4°C. The forest is planted pure Chinese pine in 1962 at an initial stocking density of approximately 4950 stems/ha. It was thinned in 1977 and 1997; the density was adjusted to 1650 and 850 ha⁻¹, respectively. In 2012, average height of trees was 10.49 m, average Diameter at Breast Height (DBH) was 16.37 cm, average crown breadth was 3.80 m, average height of living branches was 4.66 m and canopy density was 0.7. Understory shrub coverage and herb coverage was about 30 and 60%, respectively. The mainly shrub species were *Elsholtzia stauntonii* Benth., *Berberis amurensis* Rupr. and *Lespedeza bicolor* Turcz.

Data collection: Field experiment was carried out from August to October 2012. Natural recruitment in different size gaps (4-10, 10-20, 20-30 m² and 30-40 m², respectively) and under the canopy was investigated. Each gaps sizes class was with three gaps

(Table 1) and a 15×15 m quadrat was set up under the canopy. The number, height, basal stem and age of recruit in gaps and under the canopy were measured. One gap was extracted from each size levels (Table 1). All recruits were mapped in these gaps and quadrat under the canopy. The quadrat under the canopy was not set larger was due to a larger quadrat will inevitably include gaps. The age of recruit of Chinese pine was measured based on branch number in a whorl. The Chinese pine recruits between 1-15 years were derived into five age classes (1-3, 4-6, 7-9, 10-12 and 13-15). In each gaps size class and under the canopy, five and three recruits were extracted from the first three and last two age classes respectively. Age, height, basal stem, crown width, crown length and current increment of the recruit were measured. The crown rate (a high percentage of crown length) was calculated. According to the height the recruits could be divided into two grades: seedlings as 0.1 m≤ stems ≤0.5 m tall, saplings as stems >0.5 m tall and ≤2.5 cm DBH. The seedlings defined as tall more than 0.1 m since this study involved the established seedlings survived at least two full years since germination (Ignacio *et al.*, 2009).

Spatial pattern analysis: Univariate and bivariate version of Ripley's K-function were used to examine the spatial patterns of recruitment in the gaps and under the canopy. Ripley's K was used to analysis the distribution type and intensity of points at a range of distances (Ripley, 1981). Univariate test was used to assay the spatial pattern of total recruitment (seedlings and saplings), seedlings and saplings. Brivariate test was supplied to test the spatial relationship between seedlings and saplings as well as total recruitment and canopy trees. The square root transformation L (t) and $L_{1.2}$ (t) (Moeur, 1993) were suggested here. The L-function and $L_{1.2}$ (t) -function are estimated as:

$$L(t) = \sqrt{(K(t)/\pi)} - t \tag{1}$$

$$L_{1.2(t)} = \sqrt{(K_{1.2}(t)/\pi)} - t \tag{2}$$

Significance was evaluated with 99% Monte Carlo confidence intervals (100 simulations) with a 0.1-m step. Spatial pattern statistics were calculated with the sds software package in the R (version 2.15.2) statistical environment.

RESULTS

The quantitative characteristic and growth situation: It was found that all of the canopy gap area was less than 40 m², thinning was the main forming reason and other factors include diseases and pests. Chinese pine was the predominant species in natural

Table 2: Recruit density and growth situation in different size gaps

Locations	Density (/m²)			Height (cm)			Basal diameter (mm)			Age (a)		
	Total	Seedling	Sapling	Total	Seedling	Sapling	Total	Seedling	Sapling	Total	Seedling	Sapling
4-10 m² gaps	14.2	8.0	6.3	30.2	20.0	43.2	4.7	3.2	6.6	4.7	4.0	5.7
10-20 m² gaps	8.0	3.5	4.5	37.3	21.7	49.2	6.2	3.7	8.1	5.2	3.9	6.2
20-30 m² gaps	6.7	3.3	3.4	41.9	20.1	62.7	6.7	3.2	10.0	5.5	3.7	7.2
30-40 m² gaps	5.4	2.0	3.4	51.1	22.3	67.9	8.2	3.7	10.8	6.4	4.2	7.7
Under the canopy	2.0	1.4	0.6	29.8	19.7	53.9	5.0	3.4	8.8	4.9	4.2	6.8

*: Total means total recruitment (seedlings and saplings)

Table 3: Growth situation of recruit in different age groups

Age classes (a)	Locations	Height (cm)	Basal diameter (mm)	Rrown breadth (cm)	Canopy length (cm)	Crown ratio	Current growth (cm)
1-3	4-10 m² gap	22.1	2.8	17.3	16.2	0.7	6.0
	10-20 m² gap	36.4	4.3	24.0	26.8	0.7	9.7
	20-30 m² gap	24.0	3.5	16.4	16.6	0.7	4.5
	30-40 m² gap	26.2	3.7	21.0	18.0	0.7	6.9
	Under the canopy	22.2	2.6	18.0	18.0	0.8	4.8
4-6	4-10 m² gap	48.2	7.2	28.8	34.2	0.7	9.8
	10-20 m² gap	47.5	7.6	34.4	31.8	0.7	11.7
	20-30 m² gap	54.3	8.4	42.3	39.6	0.7	12.0
	30-40 m² gap	48.5	7.5	31.2	37.6	0.8	10.6
	Under the canopy	44.3	6.8	35.3	31.0	0.7	9.0
7-9	4-10 m² gap	59.7	11.3	56.9	44.5	0.8	11.9
	10-20 m² gap	66.8	10.4	42.3	51.4	0.8	16.7
	20-30 m² gap	66.6	12.8	61.1	56.7	0.9	14.0
	30-40 m² gap	64.1	9.9	45.2	50.8	0.8	13.4
	Under the canopy	57.9	11.1	49.9	44.4	0.8	10.9
10-12	4-10 m² gap	103.0	28.1	102.0	82.0	0.8	18.0
	10-20 m² gap	94.0	14.4	75.0	84.2	0.9	11.7
	20-30 m² gap	100.3	19.3	89.9	88.0	0.9	17.3
	30-40 m² gap	138.5	22.5	103.0	124.3	0.9	22.7
	Under the canopy	91.7	14.7	65.5	74.7	0.8	10.3
13-15	4-10 m² gap	100.0	11.5	62.0	83.0	0.8	10.0
	10-20 m² gap	119.0	16.1	97.0	104.7	0.9	12.8
	20-30 m² gap	117.8	17.8	86.3	105.7	0.9	12.5
	30-40 m² gap	143.7	21.5	94.2	82.0	0.6	15.5
	Under the canopy	115.3	19.1	122.7	103.7	0.9	10.2

recruitment community in 50 years old Chinese pine Plantation. The total proportion of other tree species was less than 5% in all gaps and under the canopy. Other tree species included *Quercus mongolica*, *Populus davidiana*, *Armeniaca sibirica* (L.), *Ulmus pumila* L. and *Crataegus pinnatifida* and height were generally less than 0.5 m. So this paper only studies the natural recruitment of Chinese pine. In gaps the density of recruit decreased with the increase of gap area and all were higher than that under the canopy (Table 2). The average height, basal diameter and age of recruit were increased with the increase of gap area. Three indexes above in gaps larger than 10 m² were notably higher than that in 4-10 m² gaps and under the canopy (Table 2).

Height, basal diameter, crown breadth, canopy length and the current growth were used as indexes to evaluate the growth situation of Chinese pine recruit. Generally, growth of recruit in gaps was superior to that under the canopy. The optimal microhabitat for growth of recruit in the age classes of 1-3, 4-6, 7-9, 10-12 and 13-15 were 10-20, 20-30, 20-30, 30-40 and 30-40 m² gaps, respectively (Table 3). The area of gap suitable for growth was gradually amplified with the increase of recruit age. As to 1-3 years old seedlings, the crown ratio had the highest value under the canopy and decrease with the increase of gap area (Table 3). For 4-12 years old seedlings and saplings, variation tendency of crown ration was not significant (Table 3). The crown ratio of 12-15 years saplings suddenly became

small in 30-40 m² gaps (Table 3). However, the growth of recruit was still slow even in gaps (e.g., the average height of 12-15 years saplings was all below 1.5 m). The fact indicates that the effect of gaps on promoting recruitment was very limited.

Age structure: The age structures of Chinese pine recruitment populations were similar in different microhabitats (Fig. 1). All of them were characterized by unimodal type translating to irregularity with the age increase (Fig. 1). The population was mainly composed of 2 to 7 years old seedlings (Fig. 1). The three ages accounting for the largest proportion were all 3, 4 and 5. The recruitment populations distributed in each age class only in 20-30 and 30-40 m² gaps (Fig. 1). The age structure of recruitment population was maladjusted. The number of 2 years seedlings in recruitment populations was seriously insufficient (Fig. 1). The average lifetime was short and the population was mainly consisted of low age seedlings. The mortality peak appeared in the seventh year (Fig. 1). The results above indicate that whether in gaps or under the canopy process of recruitment layer translating in to canopy was uniformly severely hindered.

Spatial pattern: In addition to the 20-30 m² gaps, the overall spatial patterns of total recruitment (seedlings and saplings) were similar in all microhabitats (Table 4). The fact presents a spatial aggregation at all scales. The aggregation intensity firstly increased then
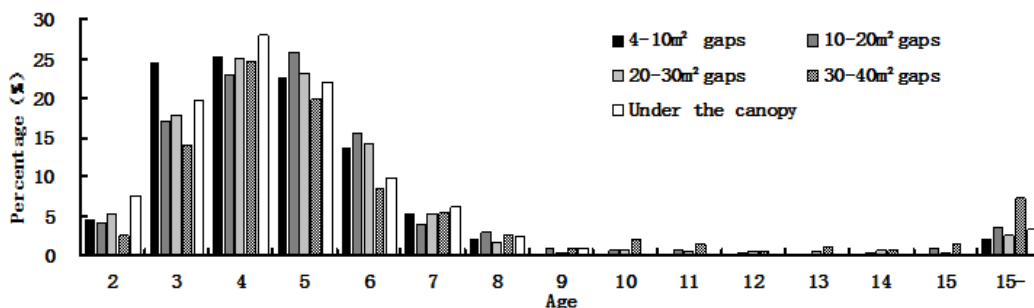
Fig. 1: Age distribution of recruitment populations

Table 4: Spatial patterns based on the univariate L-function for Chinese pine recruitment

		Distance (m)							
Types	Locations	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
Total	4-10 m^2 gap	c c	c c	c c	e e	e e	e e	e e	e
	10-20 m^2 gap	c c	c c	c c	c c	c e	e e	e e	e
	20-30 m^2 gap	c c	c c	c			e e	e e	e
	30-40 m^2 gap	c c	c c	c c	c c	c c	e e	e e	e
	Under the canopy	c c	c c	c c	c c	c c	c c	c c	c
Seedlings	4-10 m^2 gap	c c	c c	c c	e e	e e	e e	e e	e
	10-20 m^2 gap	c c	c c	c c	c c	c e	e e	e e	e
	20-30 m^2 gap	c c	c c				e e	e e	e
	30-40 m^2 gap	c	c c		c c	c	e e	e e	e
	Under the canopy	c c	c c	c c	c c	c c	c c	c c	c
Saplings	4-10 m^2 gap	c c	c c	c c	e e	e e	e e	e e	e
	10-20 m^2 gap	c c	c c	c c	c c	c c	e e	e e	e
	20-30 m^2 gap		c c	c c	c c	c e	e e	e e	e
	30-40 m^2 gap	c c	c c	c c	c c	c c	e e	e e	e
	Under the canopy	c c	c c	c c	c c	c c	c c	c	

*: Total means total recruitment (seedlings and saplings); The symbol 'c' means significant clustering at distance, based on the L-function function; An empty cell indicates random distribution; Significance is using a 99% simulation envelope (100 simulations) with a 0.1-m step; The symbol 'e' indicates that exceeding the analysis scales

Table 5: Patterns of conspecific spatial association based on the bivariate L$_{12}$-function between recruit cohorts in different development stages

		Distance (m)							
Types	Locations	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
Seedlings vs. saplings	4-10 m^2 gap				e e	e e	e e	e e	e
	10-20 m^2 gap						e e	e e	e
	20-30 m^2 gap						e e	e e	e
	30-40 m^2 gap	+					e e	e e	e
	Under the canopy	+	+ +	+ +	+ +	+			
Total vs. canopy trees	Under the canopy	-							

*: Total means total recruitment (seedlings and saplings); The symbol '+' means significant positive association; The symbol '-' means significant negative association; An empty cell indicates independent association; Significance is using a 99% simulation envelope (100 simulations) with a 0.1-m step; The symbol 'e' indicates that exceeding the analysis scales

decreased with the scale increase (Table 4). The scale values corresponding to peak value of aggregation intensity increased with the increase of gap area and were lower than that under the canopy. The maximum clustering intensity of recruitment in 4-10, 10-20 and 30-40 m^2 gaps and under the canopy occurred at scales of 2.4, 2.7, 3.1 and 3.4 m, respectively. Recruitment was exhibited clumped distribution up to 2.9 m in 20-30 m^2 gaps (Table 4). Distribution pattern of seedlings and saplings were generally similar to total recruitment, besides saplings in 20-30 m^2 gaps and under the canopy

(Table 4). The saplings was clumped at scales of greater than 2 m in 20-30 m^2 gaps and at scales of up to 6.6 m under the canopy (Table 4).

Spatial associations: Seedlings were spatially independent of saplings in all gaps, whereas positively associated with saplings at scales up to 4.2 under the canopy (Table 5). Results indicate that although there was competition, seedlings and saplings were showed consensus on biological characteristics and the requirement to environment conditions. The total

recruitment was generally spatially independent of canopy trees.

DISCUSSION

Density and growth situation: The area of canopy gaps were no more than 40 m² for the reason that the gaps produced by conventional thinning, diseases and pests were usually small (Childs, 1970). That the recruitment species in gaps under the canopy were nearly only Chinese pine may be related to the fact that the surrounding of the experimental field was only distributed Chinese pine without other species seed resource (Sousa, 1984). In this study it was found that the recruit density in gaps was notably higher than that under the canopy. In previous studies, it was also found that the recruits usually had higher density in gaps (Dale and Powell, 2001; Coates, 2002; Wolf, 2005). The fact that few seedlings would develop into saplings under the canopy compared with in gaps was similar to the research of Coates (2002). Compared to under the canopy, the small gaps were promoted the germination of Chinese pine seed. Therefore recruit density was markedly higher than under the canopy. Because of the character of shade tolerance in early stage and shade intolerance in later stage of Chinese pine, the microhabitat in small gaps cannot meet the requirement of later stage growth of seedling. For the reason above, the seedlings in small gaps were short and small. As the weak competition between seedlings, small gaps accommodate more than 10 seedlings per square meter. Micro habitat in lager gaps was more suitable for sapling growth. The lower recruit density suggests that the habitat intensified the interspecific competition and accelerated the natural selection. The microhabitat suitable for seed germinant and seedling establishment were not conducive to seedling growth (Coates, 2002; Messier *et al.*, 1999). The trend that both seedling and sapling density declined with the increase of gap area was inconsistency with the hypothesis that the recruit density of intolerance species positively associated with the gap area (Brokaw, 1987; Whitmore, 1989). In the mass, the proportion of sapling in recruitment community was lower in small gaps and under the canopy than that in larger gaps. It indicated that seedlings are visible but not saplings. The crown ratio of 1-3 year old seedlings tended to decrease from under the canopy to lager gaps. The fact indicated that the seedlings applied plasticity strategy of amplifying the crown ratio as far as possible to capture the photo-synthetically active radiation. The small scale heterogeneity of illumination condition is generally considered to be the important factor influencing the spatial variability of renewal process (Diaci *et al.*, 2008).

Age structure: The age structure of dominant species reveals the persistence of the species establishment and the ability of continuation in the recruitment community (Moktan *et al.*, 2009). The recruits between 2-10 years showed unimodal distribution type similar to the research of Larsen and Lawrence (1998). The recruitment population mainly composed of recruits below 10 years and appeared death peak in the seventh year. The thinning in the experimental field was carried out in the fifth and thirty-fifty year. The fact means that most of the gaps had been formed at lest 15 years. The means indicated that the most of the recruits emarginated after the form of gaps. The phenomenon above suggests that under the existing management technology system, before final felling, the nature recruitment population had the problem of low average age, high mortality and unreasonable age structure so the habitat in gaps could not support natural recruitment. Most often the small gaps mean the interspace only exit in canopy layer, due to the lush understory vegetation, intertwining grassroots and intensify underground competition, so the resource and space released by gaps is limited (Thomas *et al.*, 1989). As the experimental stand was characterized by the even-aged and single-layer structure and understory vegetation with low height and density, the gaps will release more resource and space for recruitment compared to gaps in natural forest. However, the improvement was limited when compared with habit under the closed canopy. Without other positive disturbance, it was unable to realize the positive succession of ecosystem and closed to nature management.

Spatial pattern: Recruit pattern is the result of organic and inorganic environment factors and their interaction and to a large extent determines the future structure and composition of stand (Clark *et al.*, 1998, 1999; Rozas, 2003). The dispersal type, seedlings establishment and survival of seedlings are the main factors affecting the recruitment pattern. In this study, generally Chinese pine recruitment presents spatial aggregation at the whole scale. The spatial aggregation of recruitment had been discussed in many reports (Debski *et al.*, 2000; Call and Nilsen, 2003; Camarero *et al.*, 2005; Fajardo *et al.*, 2006). The spatial aggregation of recruitment was usually caused by the dispersal limitations of the species and the spatial pattern of the optimal niche (Palmiotto *et al.*, 2004). Due to the gravity the seed of Chinese pine often scatters around the tree. That the seedlings present dense situation after germination in the next year caused the spatial aggregation of recruitment. The result is in favor of mutually protection of seedlings and resisting to adverse environment and enhances the survival probability. Generally saying, that there was no association was detected between seedlings and saplings in gaps indicates the gradual establishment of recruitment (Ignacio *et al.*, 2009). That the recruitment was

independent of canopy-layer suggests that density-dependent mortality (i.e., the recruits near the adult tree had a higher mortality) had limited effort on recruitment (Condit *et al.*, 2000). The phenomenon seedlings and saplings showed different spatial patterns may be caused by natural thinning process, disturbance pattern and environment variation (Smith, 1983).

CONCLUSION

Under the current management technology system, after final felling the stand would become multi-layer uneven-age Chinese pine stand in future, the heterogeneity of vertical structure and age structure would be enhanced. However, the stand will still have the difficulty of low tree species diversity. Therefore to enhance the tree species diversity and to establish stratified uneven-aged mixed forest should be considered to induce other tree species. The effort of gaps small than 40 m^2 on improving advance regeneration was limited. The problem of the slow growth speed, unreasonable age structure, high mortality and being unable to reach the canopy layer had not been fundamentally solved. The effect of intraspecific competition was limited as well as canopy layer trees on recruitment. So, the main factors influencing recruitment were inorganic habitat factors. Therefore, it is necessary to explore the effect of more open habitats on recruitment and feasibility of introducing other tree species by human in future. Consequently the effort of gaps lager than 40 m^2 and clear tapes created by various disturbance intensity and frequency ought to be study to find out the most effective interference measurements.

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