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ORIGINAL ARTICLE

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Comparison of tree growth and undergrowth development in aerially seeded and planted *Pinus tabulaeformis* forests

Abstract Direct seeding is a less expensive practice than planting and has the potential to become a viable alternative to transplanting for afforestation and regeneration purposes. As an effective and a less costly regeneration method, aerial seeding has been applied with several tree species. As early as 1956, Chinese people engaged in aerial seeding and stands with a total of 2.97×10^7 hm^2 have been developed up to 2004. Our study tested whether the growth of planted Chinese pine (*Pinus tabulaeformis* Carr.) seedlings and its undergrowth development in northwest aspects differ from that of aerially sown seedlings on the northern and northwestern aspects of slopes. In 2007, we collected data such as height, diameter at breast height (DBH), clear bole height and canopy widths of trees, abundance, coverage, and frequency of shrubs and herbs from 21-year-old planted Chinese pine stands on a northwestern aspect (PNW), aerially sown stands in a northwest aspect (ANW) and aerially sown stands in a northern aspect (AN). Results showed that the relation of crown area and mean DBH was best fitted by a double inverse model for the ANW and AN forests and by a quadratic model for the PNW forest. There was no difference in the growth between ANW and AN forests, while growth was significantly higher in the PNW forest than in the ANW and AN forests. That was consistent with the Sorenson diversity indices in the shrub and herb layers, indicating that there was a large number of the same species in both aerially seeded stands, although their locations were different. Both the number of species in the undergrowth and the Shannon-Wiener index in the shrub layer were higher in the PNW stands than in the ANW and AN stands. Dominant families for all three stands were Rosaceae and Compositae in the shrub and herb layer, respectively. The dominant species for all three stands was *Spiraea pubescens* in the shrub layer, while the dominant species was different from each other in the three stands. The discrepancy in diversity and composition of species in the herb layer show that herbs are sensitive to shrubs in the three forests. High mortality and skewed diameter distributions reflect severe competition and too high a density in the aerially seeded forests. Thus, aerial seeding is a viable and effective regeneration technique, but management practices, such as thinning, should be applied to these forests.

Keywords *Pinus tabulaeformis*, growth, undergrowth, aerial seeding, planting, slope, aspect

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1 Introduction

Direct seeding and planting are the common techniques for artificial vegetation rehabilitation. During the last decade, direct seeding, which has been the common method of achieving artificial regeneration up to the middle of the 19th century, has once again been advocated for regeneration and reforestation purposes (Ammer and Mosandl, 2007). As a particularly cheap and viable technique, direct seeding has been successfully applied to European beech (*Fagus sylvatica* L.) (Löf, 1999; Löf et al., 2003; Coll et al., 2004; Ammer and Mosandl, 2007), pedunculate oak (*Quercus robur* L.) (Nisson et al., 1996; Löf et al., 2003), wild cherry (*Prunus avium* L.), and hawthorn (*Crataegus mongyna* Jacq.) (Löf et al., 2003) in recent years. Specifically, aerial seeding is an effective operational silvicultural technique. This broadcast seeding by plane is becoming the predominant regeneration method in remote hills or for large areas. For example, aerial seedling has been a common practice after severe wildfires in an attempt to reduce soil erosion, despite the uncertainty about how much the potential impact of post-wildfire, rapidly growing nonnative grasses has on the recovery of native plant communities (Conard et al., 1991; Ott et al., 2003; Keeley et al., 2003). Moreover, a viable and less costly regeneration method has been proven in several tree species, such as jack pine (*Pinus banksiana* Lamb.) (Morris et all, 1994), lodgepole pine (*P. contorta* Dougl.) (Faulkner et al., 1990), masson pine (*P. massoniana* Lamb.), and Chinese pine (*P. tabulaeformis* Carr.) (Li et al., 2006; 2007a), indicating that the adverse ecological impact, caused by the introduction of seed of these dominant species, might be negligible.

As early as 1956, China engaged in aerial seeding, and up to 2004, a total area of 2.97×10^7 hm^2 of forest stands have been developed (Li et al., 2007b). Aerial seeding has succeeded for a substantial number of species such as slenderbranch sweetvetch (*Hedysarum scoparium* Fisch.) (Shen, 1999), yunnan pine (*P. yunnanensis* Franch.) masson pine, Japanese black pine (*P. thunbergii* Parl.), and Chinese pine and korshinsk peashrub (*Caragana korshinkii* Kom.) (Li et al., 2007). Of these species, Chinese pine and masson pine were predominant and occupy large areas in the north and south of China, respectively. Techniques of species selection, seeding time, seeding rate, and shrub and herb control have been well documented for more than 50 years and especially in the early years. Given this 50-year project, the increase in area of middle-aged stands has made its management more prominent. Thus, much concern was expressed over the thinning intensity of aerially seeded stands, which were too dense. Related studies involved the correlation of Chinese pine growth (Mo et al., 2003; Guo et al., 2004) and undergrowth (Li et al., 2007a) development with initial density, response of soil enzyme activity to thinning in different seasons (Li et al., 2008), and soil depth (Guo et al., 2007) in Chinese pine stands. The impact of thinning on soil microorganisms (Zhou et al., 2002) and soil fertility (Li et al., 2004) in masson pine stands has also been of concern. These studies only dealt with aerial seeding of the stands themselves. There is no overall comparison of the development of planting and aerial seedlings. Even less information is available to evaluate the effect of regeneration in middle-aged, aerially seeded forests. Given these premises, the main objectives of this study were i) to compare the differences of tree growth among Chinese pine plantations, aerially seeded stands in the northern and northwestern slopes; ii) to examine the undergrowth development for biological diversity and species composition of the stands; iii) to check if tree growth is consistent with undergrowth development for multiple function purposes; and iv) to provide value strategies for the management of aerially seeded stands.

2 Study area

Our study area was located in the Luojiatai Aerial Seeding Center, Yanqing County, Beijing (40°30′N, 116°14′E). This area is a typically hilly region and ranges in elevation from 700 to 1240 m. The site has slopes of 20–38° and soil depth ranged 30–55 cm. The site is characterized by a warm temperate continental monsoon climate with a mean annual temperature of 6.7°C and an average annual precipitation of 519.6 mm. The main soil type is a leached brown soil developed on weathered granite. As described by Jiang (1998), the original vegetation is typical of the flora of northern China. Historically, this area was densely forested, with Chinese pine and deciduous liaotung oak (*Quercus liaotungensis* Mayr. Koidz.) as dominant species. Beginning in the Yuan Dynasty, the primary and secondary forests in the area were drastically cut and degraded into abandoned coppice forests, characterized by three-lobe spiraea (*Spiraea trilobata* L.), pubescent spiraea (*S. pubescens* L.), lespedeza (*Lespededeza bicolor* Turcz.), and prunus armeniaca (*Prunus sibirica* Lam.). Since the 1980s, plantations, predominantly of Chinese pine and north china larch (*Larix principis-rupprechtii* Mayr.), have been established at a small scale. Particularly, in 1986, an area of 2386 hm^2 of an abandoned coppice forest was cleared and Chinese pine stands were sown by seeding from a plane. Closing of the hillsides was implemented to facilitate afforestation, and artificial disturbance was slight. Up to 2007, 1920 hm^2 of this abandoned forests have developed and are now middle-aged stands.

Given the experience in neighboring areas of similar elevation and slope gradient, three kinds of Chinese pine stands were selected. The first two areas originated from aerial seeding and are located on the northern and northwestern aspects. The third stand, a plantation, was planted by hand. A total of 12 hm^2 of 3-year-old Chinese pine seedlings spaced, 1.5 m$\times$2.0 m, were planted in April 1989. The survival rate is approximately 75%. Site conditions of these stands are shown in Table 1.

Table 1 Site conditions of Chinese pine stands

	aerial seeding stands in the north aspect (AN)	aerial seeding stands in the northwest aspect (ANW)	planting stands in the northwest (PNW)
elevation/m	720–740	700–730	715–750
slope gradient	32–36	30–35	29–33
slope aspect/°	8–12 W-N	30–38 S-N	26–36 S-N
depth of soil/cm	46–50	43–48	42–46
age in 2007	21	21	21

3 Materials and methods

Four almost contiguous plots of 20 m$\times$20 m were laid out at the center of each forest to avoid any edge effects caused by differences in neighboring forests (1600 m^2 each; 4800 m^2 total area). As described by Meng (2006), the initial diameter grade was equal to 0.4 times the average diameter at breast height (DBH). All living trees in these plots were identified as having a DBH greater than 2 cm for aerial seeding and 4 cm for planted stock. Their DBH, height, crown widths, and clear bole height were measured. DBH distribution curves were modeled using SPSS software (Lu, 2005; Zhang et al., 2007). Models were applied to study the relations between mean stand height and DBH and between crown area and mean DBH (Li, 1992; Meng, 2006). Height of living and dead seedlings was recorded. Crown area (C_w) was calculated by the following formula:

$$C_w = 3.14 \times \left(\frac{a}{4} + \frac{b}{4}\right)^2 \tag{1}$$

where a and b are the crown width in an east-west and north-south orientation, respectively.

At each corner of the plot, a 5 m×5 m subplot was established for a survey of the presence of flora and shrubs. A total of 16 shrub plots of 400 m^2 were established in each forest. In each subplot, two 1 m×1 m sub-subplots were randomly established for a survey of flora and herbs. A total of 32 herb quadrates of 32 m^2 were established for each stand. Abundance and coverage of shrub and herbal quadrates were estimated. Importance value indices (IVI) of Curtis and McIntosh (1951) were calculated per unit of stands. The Shannon-Wiener (H'), Simpson (D'), and Pielow (J') indices were calculated from the frequency of occurrence (1-16 for shrub plots and 1-32 for herb plots) of each species in each plot (Zhang, 2004). The H', D', and J' indices were obtained from the following formulas:

$$H' = -\sum_{i=1}^{m}(p_i \ln p_i) \tag{2}$$

$$D = 1 - \sum_{i=1}^{m} P_i^2 \tag{3}$$

$$J' = H'/\ln m \tag{4}$$

where p_i is the relative frequency of occurrence of each species in each stand and m is the number of species occurring in each stand.

The Sorenson index (C_s) was calculated from species among stands (Li et al., 2007c) and obtained from the following formula:

$$C_s = 2j/(a+b) \tag{5}$$

where j is the number of species coexisting in the two stands and a and b are the number of species in stands A and B, respectively.

4 Results and analysis

4.1 Tree growth in aerially seeded and planted stands

The height and mean DBH of ANW were higher than those of the AN stands but lower than PNW (Table 2). The results could be explained by the density that represents the discrepancy of competition intensity among the three types of stands. Another explanation is that the differences in crown areas imply varying ability of photosynthesis. The differences in mean DBH were larger than that of height among the three forest types, indicating that the growth of the mean DBH was more intensive than that of height. There are differences in clear bole height (CBH) among the forests, although no significant differences were found in the ratio of CBH to height of the forests. Interestingly, there were no differences in density, height, mean DBH, crown width, and area among the AN and ANW forests, while significant differences were observed in these variables between the aerially seeded forests and PNW forest.

4.2 Tree mortality in aerially seeded and planted stands

High mortality occurred in aerial seeding stands. The number of dead or dying seedlings were 3128 and 1806 tree/hm^2 in the AN and ANW forests (Table 3). A similar trend was shown in live seedlings, i.e., the number of live seedlings in the AN was higher than in the ANW forest. As well, the height of both dead and live seedlings was larger in the AN than in the ANW forests. It should be noted that the height of dead or dying seedlings was lower than that of live seedlings in both aerially seeded forests. These results indicate that a substantial number of live seedlings were on the point of dying from intense competition pressure. Specifically, variation was shown neither in density nor in height for the seedlings of the AN and ANW forests according to their Student's t values.

Table 2 Parameters of stand structure for the three forest types

stand	density /(tree·hm^{-2})	height /m	mean DBH/cm	CBH/m	CBH/height	crown width/m		crown area/m^2
						E-W	N-S	
AN	5175±1220a	4.17±0.29a	5.35±0.34a	1.57±0.12a	0.376a	1.67±0.08a	1.77±0.05a	2.54±0.16a
ANW	5750±728a	4.67±0.31a	5.97±0.41a	1.78±0.15ab	0.381a	1.82±0.11a	1.81±0.13a	2.83±0.34a
PNW	1825±179b	5.82±0.85b	9.29±1.13b	2.20±0.42b	0.378a	3.14±0.19b	3.05±0.31b	8.34±0.42b

Note: Density, mean diameter at breast height (DBH), clear bole height (CBH), crown width, and canopy area were compared using one-way ANOVA. Different letters indicate significant difference among forest types at $p < 0.05$ according to Tukey's b test. Values in parentheses represent the standard error ($n = 4$). AN, aerial seeding stands in the north aspect; ANW, aerial seeding stands in the northwest aspect; PNW: planting stands in the northwest aspect; E-W, east-west; N-S, north-south.

Table 3 Parameters of seedlings of aerially seeded stands

stands	density/(tree·hm^{-2})				height/m			
	dead seedlings	*t*	live seedlings	*t*	dead seedlings	*t*	live seedling	*t*
AN	3128±640		2025±1050		0.61±0.20		0.77±0.22	
ANW	1806±744	1.904	706±447	1.634	0.58±0.17	0.164	0.64±0.25	0.554

Note: Density and height of mortal and alive seedling were compared using independent-samples *t* tests. Values in parentheses represent the standard error ($n = 4$). Seedlings were rarely found in the PNW forests and relevant information of seedlings is not presented in this table.

4.3 DBH distribution in aerially seeded and planted Chinese pine forests

The DBH distributions were all partially skewed to the left (Fig. 1). The skewness ($SK = 0.553$) of the PNW forest was less than that of the ANW forest ($SK = 0.677$) and higher than that of the AN forest ($SK = 0.372$), indicating that ANW forest has a relatively large stand density followed by the PNW and AN forests. The kurtosis (K) of AN was -0.429, showing that its DBH distribution was lower than a normal curve. The DBH distribution of ANW ($K = 0.309$) was over a normal curve and that of PNW ($K = 0.017$) approximately coincided with a normal curve.

4.4 Coefficients of tree growth parameters in aerially seeded and planted Chinese pine forests

4.4.1 Relation between mean diameter at breast height and height in the stands

As shown in Fig. 2, the height and mean DBH could be almost perfectly modeled by logarithmic functions at all three types of stands ($p < 0.01$ in every case). The functions were $H = 1.81\ln(D) + 1.19$ ($R^2 = 0.941$), $H = 1.23\ln(D) + 2.29$ ($R^2 = 0.939$), and $H = 1.93\ln(D) + 1.56$ ($R^2 = 0.953$) for AN, ANW, and PNW forests, respectively.

4.4.2 Relation between mean diameter at breast height and crown area in the stands

As shown in Table 4, a double inverse model, a power model, and a quadratic model were capable of representing the relation of crown area and mean DBH at the three forests types ($p < 0.01$ in every case). Based on the coefficient of determination R^2, the aerially seeded stands were best estimated by double inverse models. The optimum models for AN and ANW forests were $1/C_w = -0.2002 + 3.2554/D$ ($R^2 = 0.990$) and $1/C_w = -0.1432 + 2.9171/D$ ($R^2 = 0.995$). A quadratic model was fitted to represent the relation of crown area and mean DBH at the PNW forest. The best model for the PNW type of forest was a quadratic function: $C_w = -2.5359 + 1.3951D - 0.0241D^2$ ($R^2 = 0.995$).

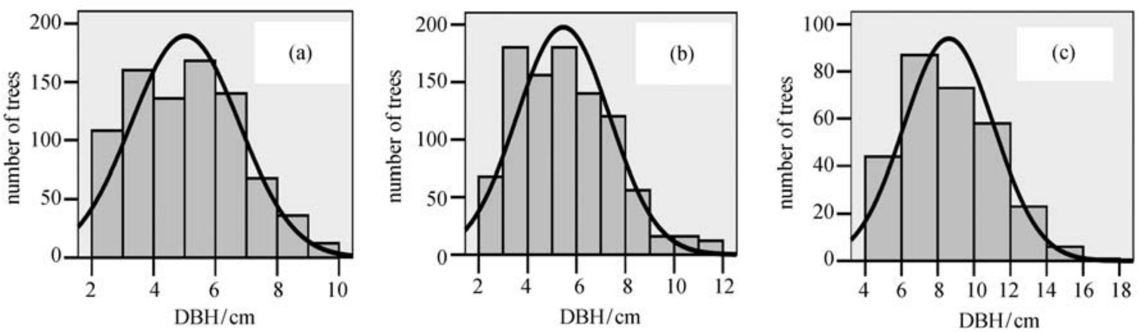

Fig. 1 Diameter at breast height (DBH) distribution for each stand. (a) AN; (b) ANW; (c) PNW.

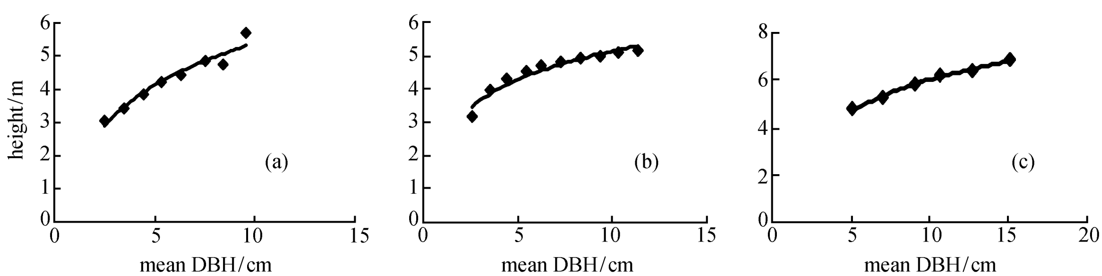

Fig. 2 Height as a function of mean diameter at breast height (DBH) for three types of stands. H and D indicate mean height and mean DBH for each forest type. (a) AN $H = 1.81\ln(D) + 1.19$, $R^2 = 0.941$; (b) ANW $H = 1.23\ln(D) + 2.29$, $R^2 = 0.939$; (c) PNW $H = 1.93\ln(D) + 1.56$, $R^2 = 0.953$.

Table 4 Model parameters for crown area as a function of mean DBH

stands	$1/C_w = a + b/D$			$C_w = aD^b$			$C_w = a + bD + cD^2$			R^2	n
	a	b	R^2	a	b	R^2	a	b	c		
AN	−0.2002	3.2554	0.990**	0.2364	1.4299	0.981**	−0.721	0.573	0.021	0.950**	8
ANW	−0.1432	2.9171	0.995**	0.2284	1.4610	0.984**	0.8802	−0.0759	0.0677	0.975**	10
PNW	−0.025	1.4073	0.945**	0.6768	1.1078	0.954**	−2.5359	1.3951	−0.0241	0.957**	6

Note: Double inverse model, power model, and quadratic model were fitted for forest types where the optimum models were based on the highest R^2 value. Small letter a, b, and c indicate regression coefficients. Independent variable D indicates mean DBH at a given diameter grade. The dependent variable C_w indicates mean crown area at the corresponding diameter grade. R^2 indicates coefficients of determination based on the regression of C_w on DBH. $^{**}p < 0.01$.

4.5 Composition of undergrowth in aerially seeded and planted stands

4.5.1 Composition of families, genera, and species of spermatophytes in forest under-storey

As shown in Table 5, no monocotyledons were observed in the shrub layer in all three types of stands and their numbers were 6, 6, and 9 in the AN, ANW, and PNW herb layers, respectively, indicating that no significant differences of shrub layers between the different stands were found. In contrast to monocotyledons, there were 8, 25, and 73 dicotyledons in the herb layers of the stands. The results suggest, as an explanation, that species differences in the undergrowth mainly derive from dicotyledons in the herb layer. In a 1600 m^2 sampling area, the number of spermatophytic plants, with 96 species, was greatest in the PNW, including 9 monocotyledon species and 87 dicotyledon species followed by ANW with 40 species including 6 monocotyledon species and 34 dicotyledon species. The lowest number of species was found in the AN type with 27, of which 6 monocotyledons and 21 dicotyledon species.

4.5.2 Dominant families and their components in the undergrowth of aerially seeded and planted forests

The shrub and herb layers in the stands were dominated by Rosaceae and Compositae, respectively (Table 6). Although there were no differences in the dominant families in either shrub or herb layers, variation in the components of families was evident. Rosaceae comprising of 4, 3, and 2 genera accounted for 57.1%, 37.5%, and 18.2% of the total number of genera in the shrubs of the AN, ANW, and PNW, respectively. From the Rosaceae family, 5, 4, and 3 species were represented and accounted for 41.7%, 44.4%, and 21.4% of the total number of shrub species, respectively. An opposite trend was found in the dominant herb families. This result was reflected by the increase in the number of genera and species of dominant families in the stands. For example, there were 3, 7, and 17 genera of Compositae family, which made up for 23.1%, 23.3%, and 27.4% of the total number of herb species, respectively.

Table 5 Composition of families, genera, and species of spermatophytes in the under-storey among the forest types

stands	shrub									herb									under-storey								
	D			M			A			D			M			A			D			M			A		
	F	G	S	F	G	S	F	G	S	F	G	S	F	G	S	F	G	S	F	G	S	F	G	S	F	G	S
AN	7	12	13	0	0	0	7	12	13	4	7	8	4	6	6	8	13	14	10	19	21	4	6	6	14	25	27
ANW	6	8	9	0	0	0	6	8	9	14	24	25	5	6	6	19	30	31	18	31	34	5	6	6	23	37	40
PNW	9	11	14	0	0	0	9	11	14	22	53	73	5	9	9	27	62	82	28	64	87	5	9	9	33	73	96

Note: D, dicotyledon; M, monocotyledon; A, angiosperm; F, family; G, genus; S, species.

Table 6 Dominant families, genera, and species in the shrub and herb layers of stands

stands	shrub					herb				
	family	genus		species		family	genus		species	
		no.	%	no.	%		no.	%	no.	%
AN	Rosaceae	4	57.1	5	41.7	Compositae	3	23.1	4	28.6
ANW	Rosaceae	3	37.5	4	44.4	Compositae	7	23.3	8	25.8
PNW	Rosaceae	2	18.2	3	21.4	Compositae	17	27.4	26	31.7

4.5.3 Dominant species in the undergrowth of aerially seeded and planted stands

The shrub layers in the stands were all dominated by *Spiraea pubescens* belonging to the Rosaceae family with importance value indices of the shrub species of 82.0%, 86.5%, and 73.3%, respectively (Table 7). The herb layers in the stands were dominated by *Spodiopogon sibiricus*, *Atractylodes lancea*, and *Carex lanceolata* of the Gramineae, Compositae, and Cyperaceae families, respectively (Table 8). We speculate that the species composition in the herb layer was sensitive to the environment.

Table 7 Importance values of shrub species based on 16 (5 m×5 m) sampling plots for each forest type

species	importance value index/%		
	AN	ANW	PNW
Spiraea pubescens	82.0	86.5	73.3
Spiraea trilobata	45.0	85.5	49.2
Corylus heteropylla	41.9	79.4	44.6
Quercus mongolica	36.6	10.8	25.4
Lespedeza bicolor	31.9	2.6	7.6
Campylotropis macrocarpa	25.7	/	/
Berberis poiretii	13.5	2.9	/
Crataegus pinnatifida var. *major*	9.5	3.4	/
Salix phylicifolia	4.2	/	4.6
Prunus sibirica	3.4	26.1	52.9
Broussonetia papyrifera	2.4	/	/
Pyrus betulifolia	2.0	/	/
Populus davidiana	1.8	/	/
Deutzia grandiflora	/	2.9	2.8
Ostryopsis davidiana	/	/	16.2
Elsholtzia stauntoni	/	/	11.5
Ulmus macrocarpa	/	/	4.6
Fraxinus bungeana	/	/	2.5
Fraxinus rhynchophylla	/	/	2.2
Lespedeza floribunda	/	/	1.8

4.6 Diversity index and plant coefficient in the undergrowth of aerially seeded and planted stands

The Shannon-Wiener diversity index was higher in the PNW shrubs than in the AN forest shrubs and lowest in ANW shrubs (Table 9). The Shannon-Wiener diversity index was highest in the ANW herb layer followed by PNW and AN herb layers. The Simpson diversity index showed an opposite trend compared with the Shannon-Wiener index. We conclude that the highest species diversity occurs in the shrub layer of PNW and in the herb layer of ANW for the stands. All the same, the highest Jealow index is shown in the shrub layer of AN and in the herb layer of the ANW forests.

Table 8 Importance values of herb species based on 32 (1 m×1 m) sampling plots for each forest type

species	importance value index/%		
	AN	ANW	PNW
Spodiopogon sibiricus	95.6	/	/
Carex lanceolata	74.4	13.8	69.2
Saussurea nivea	55.9	12.5	/
Pinellia ternate	21.9	/	/
Agrimonia pilosa	18.5	/	/
Bupleurum chinense	7.1	/	/
Heteropappus altaicus	6.2	17.3	/
Rubia cordifolia	5.8	/	/
Smilacina japonica	4.9	/	/
Doellingeria scaber	3.2	/	/
Atractylodes lancea	/	42.5	/
Poa annua	/	26.2	/
Sanguisorba officinalis	/	20.4	7.6
Saussurea japonica	/	16.6	/
Ampelopsis humulifolia	/	15.0	/
Cirsium setosum	/	14.2	/
Achnatherum pekinense	/	14.2	/
Dendranthema chanetii	/	/	25.9
Iris ruthenica var. *nana*	/	/	22.0
Viola selkirkii	/	/	11.2
Leibnitzia anandria	/	/	10.3
Aster tataricus	/	/	9.6
Rabdosia japonica	/	/	8.9
Ixeris denticulate	/	/	7.6
Potentilla fragarioides	/	/	7.6

Table 9 Diversity indexes based on 16 (5 m×5 m) sampling shrub plots and 32 (1 m×1 m) sampling herb plots for each forest type

	AN		ANW		PNW	
	shrub	herb	shrub	herb	shrub	herb
Shannon-Wiener index	1.957	1.743	1.453	2.978	2.063	2.805
Simpson index	0.180	0.224	0.267	0.0667	0.156	0.138
Jealow index	0.763	0.660	0.661	0.867	0.762	0.636

The Sorenson diversity index was highest in both shrub and herb layers of AN and ANW forests followed by ANW and PNW forests and lowest among AN and PNW forest types (Table 10). This shows that there is a large number of the same species in the aerially seeded stands, although their locations are different.

5 Conclusions and discussion

Lower height growth was found from sowing than from transplanting broad-leaved species such as *F. sylvatica*

Table 10 Sorenson diversity index of shrub and herb among the forest types

shrub	AN	ANW	PNW	herb	AN	ANW	PNW
AN	1			AN	1		
ANW	0.73	1		ANW	0.36	1	
PNW	0.44	0.61	1	PNW	0.08	0.30	1

(Löf et al., 2004; Ammer and Mosandl, 2007), *Q. robur*, *Prunnus avium*, and *C. monogyna* (Löf et al., 2004). This viewpoint coincides with that of the coniferous Chinese pine species studied in our project. Because the provenance and site class were the same for the Chinese pine forest types, neither differences in genetic nor growing conditions can serve as an explanation for the variation in height growth between ANW and PNW seedlings. The reason must be found in the fact that 1- to 2-year-old pine seedlings were planted. These were carefully cultivated in the nursery for 2 years and have absorbed plenty of nutrients. These were then transplanted to another nursery and cultivated with little water and without fertilizer application for 1 year to improve their resistance. When replanted in the hills, the 3-year-old seedlings adapted rapidly to the environment, while the aerially seeded Chinese pine lacked any kind of cultivation. Probably, the amount and type of nutrients in the seedlings were insufficient to resist the adverse environment. That meant that sown seedlings needed more time to catch up with the planted seedlings. Another explanation lies in the discrepancy of competition pressure from its neighboring plants that were much tall for the seedlings. As suggested by Shainsky and Radosevich (1992), competition occurs when adjacent plants are forced to share the limited resources of a restricted area. Owing to highly clustered distribution patterns, aerially seeded Chinese pine seedlings were exposed to more intense competition inter- and intra-populations (Liu et al., 1991). High mortality (Table 3) and a skewed diameter distribution (Fig. 1) of aerial seedlings also reflected this competition. Thus, the height growth of the ANW was inhibited more severely than that of PNW forest stands.

Compared with *F. sylvatica*, mentioned by Ammer and Mosandl (2007), there were significant differences in the mean DBH among ANW and PNW forests. That can be explained as follows. It is well known that height growth dominates in the early years for most trees. The *F. sylvatica* forest used in their experiment was no more than 9 years old at that time when its DBH growth was less than its height growth. In 2007, our Chinese pine was 21 years old when its DBH started to increase rapidly about 12 years ago (Yang, 1996). On the other hand, no difference in density was found between the sown and the planted *F. sylvatica* forests. However, in our study, the density was higher in the ANW stands with 5750 stem/hm^2 than in the PNW with 1825 stem/hm^2. As described by Shen (2001), DBH is affected more heavily than height by density in the same site class. To some extent, the significant difference in DBH resulted from the large difference in density between ANW and PNW forests.

The formation of a plantation is a process of invasion, competition, and rehabilitation. Once the plantations investigated by us were closed, they have an overwhelming effect on the coppice forest. How much the development of the undergrowth was affected by the introduction of Chinese pine depended on the density. These results can be derived from the fact that, for the species of the undergrowth (Table 5), the Shannon-Wiener and Pilou indices of the shrub layer (Table 9) were higher in the ANW than in the PNW forest. The dominant family in the shrub and herb layers (Table 6) and dominant species in the shrub layer (Table 7) were the same in the ANW as in the PNW forest. Moreover, our results indicate that species diversity is sensitive to species composition in the shrub layer and species diversity, and composition in the herb layer is sensitive to shrubs in both ANW and PNW forests.

Although development of the trees and undergrowth in the ANW was inferior to that of the PNW forest, the lower costs and higher afforestation efficiency of aerial seeding should be taken into consideration. Given the discussion above, high density was thought to be a limitation for the aerially seeded forests. A substantial number of aerial seedlings consume too many nutrients, which exceed the carrying capacity of the forest soil. Management practices such as thinning should be adopted. Specifically, aerially seeded forests are located in remote hills with large areas, with little manpower and material resources available. Thus, appropriately strong thinning intensity should be considered to prolong the intervals between thinnings. However, too large an intensity should be avoided because the relative small stems are vulnerable to wind throw. Additionally, tree growth and undergrowth development have to be weighed against one another for multifunction purposes. We conclude that thinning-related topics should be further discussed.

Distribution of aerial seedlings is affected most by slope aspect followed by position and slope gradient (Liu et al., 1983). The total number of seedlings on shady slopes was the largest, that of semi-shaded slopes was the second largest, and that of sunny slopes was the least. The results of our investigation are consistent with Liu's (1983). More seedlings were found in the north than in the northwest. The total number of seedlings was 3128 and 1806 stem/hm^2 in the AN and ANW forests (Tables 2 and 3), respectively. Interestingly, the number of trees in the ANW stand was larger than in the AN when the seedlings were 21 years old (Table 2). The fact that more dead seedlings were found in the AN might account for its low survival rate (Table 3). Young forest stands that are naturally regenerated are characterized by high mortality rates (Collet and Moguedec, 2007). Mortality can be affected by already established ground vegetation. For example, the pioneer species such as *Rubus* sp. often excludes direct seeding (Balandier et al., 2006). Additionally, mortality of aerial sown seedlings is dominated by vegetation types, including *Artemisia capillaris* Thunb., *Spodiopogon sibiricus* Trin., and *Heteropappus altaicus* (Wild.) Novopokr. (Liu et al., 1986). The relationships between the probability of mortality and ecological factors such as the already established ground vegetation, soil water content, and soil organic matter merits further study. It should be noted that there were no significant differences in both density and height among trees, dead seedlings, and live seedlings of the AN and ANW forests.

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