SPATIAL DISTRIBUTION PATTERN AND ECOLOGICAL NICHE CHARACTERISTICS OF *P. SYLUESTRIFORMIS* POPULATION IN CHANGBAI MOUNTAIN AREA, CHINA

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Abstract. *P. syluestriformis* is an endemic plant in Changbai Mountain area of China. Some sample plots were set up in natural distribution communities of *P. syluestriformis*. Based on the survey data of the plots, the spatial distribution pattern of *P. syluestriformis* population was studied by the aggregation index. The niche breadth of Levins, Hurlbert and the Pianka niche overlap methods were used to analyze the niche characteristics of *P. syluestriformis* population in different communities. The results showed that in the pure forest of *P. syluestriformis* at about 700 m above sea level, *P. syluestriformis* population was in an aggregate distribution state, and in the scattered community of *P. syluestriformis*, *P. syluestriformis* population was randomly distributed in different forest stands under natural conditions, *P. syluestriformis* population had obvious advantages in each resource location. The maximum niche breadth of Levins was 5.3094. In the aspect of niche overlap index, there was a large niche overlap between the population of *P. syluestriformis* and *U. japonica*, which had obvious sharing advantages. Followed by *L. olgensis*, *A. tegmentosum*, *Q. mongolica*, *A. nephrolepis*. *P. syluestriformis* population and the above-mentioned associated species had the same or similar requirements for the same resource, and competition would occur when the resources were insufficient. The succession dynamics of *P. syluestriformis* populations were mainly characterized by narrow geographical distribution and narrow habitat, few populations, no individual seedlings and saplings, and lack of self-renewal ability, so they belonged to the recession-type populations.
Keywords: *P. syluestriformis, aggregation degree, niche overlap, niche breadth*

Introduction

The niche is the smallest unit of species distribution. Since Grinnell J proposed niche conception in 1917. The study of niche theory has been one of the research hotspots in the field of world ecology (Grinnell, 1917). Niche theory is widely used in species relations, biodiversity, community structure and function, community succession dynamics, intraspecific and interspecific competition studies.

To analyze the status and relationship of target species in communities, Chinese and foreign scholars used multiple niche breadth and niche overlap formulas to measure the niche characteristics of main populations of different communities. Seen from the existing results, the plant communities that developed on different types of landforms in different regions have different manifestations of their population niche characteristics (Chang et al., 2015; Chen et al., 2010). Among them, Chinese scholars have made relatively successful attempts to study the niche of plant populations in Changbai Mountain, China (Chen et al., 2009; Ye et al., 2011). The research on the population niche characteristics of rare and endangered plants is of great significance for further exploring the utilization of space resources and the interrelationships between other

endangered plants and other populations, and revealing the mechanism of endangered plants.

P. syluestriformis, is an evergreen tree of *Pinus* L. and a rare and endangered tree species in Changbai Mountain area of China. The natural population is relatively narrow and is located at N 42°06' - 42°32', E 128°07' - 128°21', scattered on the northern slope of Changbai Mountain, China (Jin et al., 2015).

Due to population increase, economic development and environmental destruction, the distribution area of natural population of *P. syluestriformis* have gradually narrowed and it has reached the edge of extinction. At present, the number of existing plants of *P. syluestriformis* is less than 110000 (Wang, 2007).

Since the 1980s, some Chinese scholars began to pay attention to the special species of *P. syluestriformis*. Aiming at the ecological characteristics, the growth pattern, the introduction and afforestation techniques, the biomass, diversity of interspecific seed traits in population, and so on (Lu et al., 2004; Cheng et al., 2013; Zou et al., 1995), and research cases on the niche characteristics of the rare population of *P. syluestriformis* have not been reported so far. Therefore, in this paper, the field survey data of community of *P. syluestriformis* population distribution as the data source were used to quantitatively measure the niche characteristics of the dominants to reveal the function and status of *P. syluestriformis* population in the community and analyze the interrelation between various groups. It will provide scientific support for judging the stability of *P. syluestriformis* population and theoretical basis for revealing its endangered mechanism.

Material and methods

Regional survey of research

The research area is located in the Changbai Mountain Nature Reserve in Jilin, China. The zonal climate belongs to the continental mountain climate with monsoon influence. Winter is cold and dry; summer is warm and humid. The precipitation is mostly concentrated in July-August, with an average annual temperature of 4.4 °C, extreme minimum temperature of -40 °C, the extreme maximum temperature of 37.5 °C, annual precipitation of 600-1340 mm, relative humidity of more than 70%, and the frost-free period of 90-100 days. The soil in the distribution area of *P. syluestriformis* is mostly formed dark brown soil on volcanic ash. The soil layer is thin, the pH is 4.2-4.9, the content of humus is low, and the water holding capacity is poor.

The plant in the area belongs to floristic plant of Changbai Mountain. The upper part of the natural distribution area of *P. syluestriformis* is mixed with coniferous forest, and the lower part is interlaced with coniferous and broad-leaved mixed forest belt, forming a unique mixed forest and a small piece of pure forest of *P. syluestriformis*.

Sampling method

In 2015, one sample plots of 30m × 30m were set up in the pure forest of *P. syluestriformis*, two sample plots of 30m × 30m were set up in the scattered forest of *P. syluestriformis* in Changbai Mountain Nature Reserve. The species, crown width, coverage and diameter at breast height (DBH) of woody plants with DBH ≥ 1.3 cm were investigated and recorded in detail. The sample area was summarized in *Table 1*. The distribution map of *P. syluestriformis* is shown in *Figure 1*.

Table 1. *Community habitat and vegetation status in the survey area*

| Sample number	Forest type	Altitude/m	Falling gradient	Aspect	Crown density	Geographic coordinates	Dominant species of Arbor layer
P1	The pure forest of *P. syluestriformis*	700-740	<1	Northeast, near the plains	70	N 42°25' E128°07'	*P.syluestriformis, Q.mongolica, A.mono, U.japonica, A.pseudosieboldianum, F.mandshurica, T.mandschurica*
P2	The scattered forest of *P. syluestriformis*	890-984	3	Southeast	75	N 42°18' E128°06'	*P.syluestriformis, Q.mongolica, A.nephrolepis, L.olgensis, A.mono, T.amurensis, P.koraiensis, A. kalkora, P jezoensis*
P3	The scattered forest of *P. syluestriformis*	1100-1180	<3	North	80	N42°10' E128°08'	*P.syluestriformis, T.amurensis, A.nephrolepis, L.olgensis, A. mono, B.platyphylla, P.davidiana, T.amurensis, P.jezoensis, A.tegmentosum*
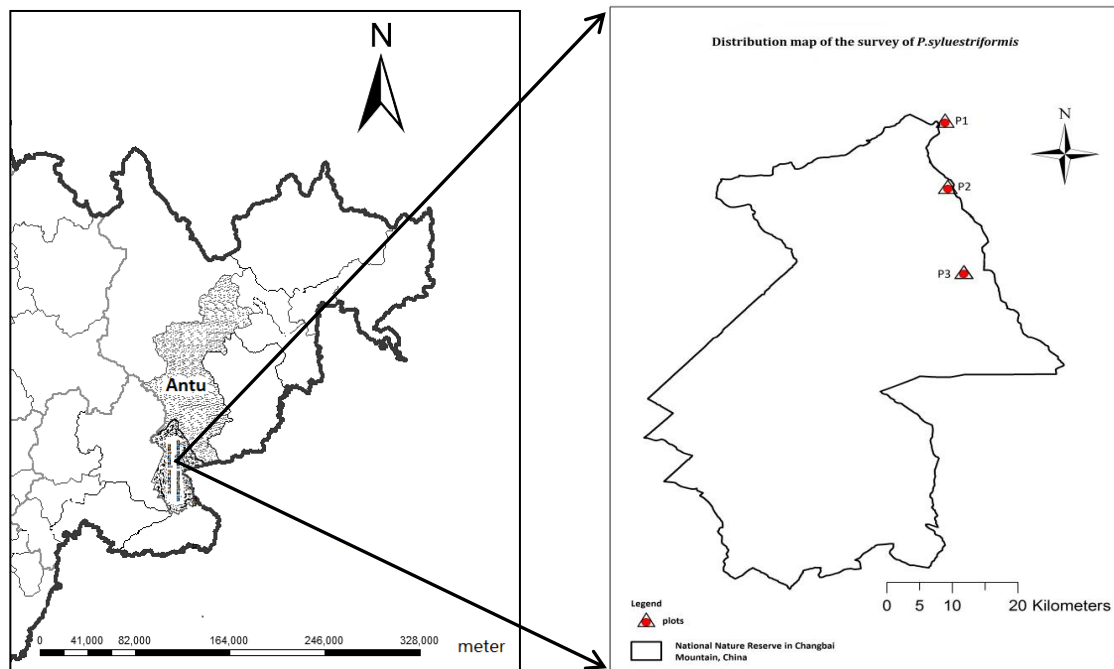
Figure 1. *Distribution map of the survey of P. syluestriformis*

Data processing

Population distribution pattern measurement method

There are many mathematical models for determining the types of distribution patterns of biological populations. In practical applications, each model has its adaptive application effect and the method is simple and effective. This paper combines with five kinds of aggregation index, such as the diffusion coefficient (C), aggregation index (I), average congestion (M^*), convergence index (M^*/x) and M index (C_A). The distribution pattern is determined by means of t test of mean variance and F test of deviation degree of random distribution, and the population aggregation is determined by negative binomial parameters (K) (Wang, 2012; Guo, 2004).

Niche breadth (Hurlbert, 1978; Li et al., 2003)

$$Bi = \frac{1}{r\sum_{j=1}^{r} P_{ij}^2}$$
(Eq.1)

Equation 1 of Levins (1968) is quantitatively calculated, γ is the number of resource bits, P_{ij} is the proportion of the species is using the j-th resource for all resources and is the population number; the niche breadth range is [1/γ, 1].

$$B_a = \frac{1}{\sum_{j=1}^{n} \frac{p_j^2}{a_j}}$$
(Eq.2)

Equation 2 stands for Hurlbert niche breadth index. P_j is the proportion of the species i that uses the j-th resource to the total resource bit used by the species, a_j is the number of items available in resources $j(\Sigma a_j = 1.0)$, B_a is the standardized Hurlbert niche breadth index.

Niche overlap (Hurlbert, 1978)

$$O_{ik} = \left. \sum_{j=1}^{r} P_{ij}P_{kj} \middle/ \sqrt{\left(\sum_{j=1}^{r} P_{ij}\right)^2 \left(\sum_{j=1}^{r} P_{kj}\right)^2} \right.$$
(Eq.3)

Pianka (1973) overlap index was used for analysis. In *Equation 3*, O_{ik} value is between 0 and 1.

Age class division of P. syluestriformis

For the classification of age class of *P. syluestriformis*, this paper takes 30 years as an age class, altogether divides into 8 age classes, which are I grade, II grade, III grade, IV grade, V grade, VI grade, VII grade, VIII grade. Those over 240 years old are classified as VIII grade.

Data statistical analysis

The original data is input into Excel table, and the data format can be read by R software according to the need of analysis. The spatial distribution pattern is analyzed, using the Riplely correlation function in the Spatstat library of R software.

Results

Spatial distribution pattern of P. syluestriformis population

According to the survey sample data, the indexes mentioned above of aggregation were measured by distribution (*Table 2*). It could be seen from the results in the table that the maximum diffusion coefficient of P2 sample plot was 2.243, which was greater than 1, and the diffusion coefficient of other sample plots was less than 1. After comparing *t* and *t*0.05(36-1), both reached significant level of difference. According to the analysis of sample plots, the pure forest community of *P. syluestriformis* presented a clustered distribution. While in the scattered forests, the distribution state showed random and scattered in various forest communities. The *M*/x* index was greater than 1 in P2 sample plots, the indexes in the other samples were all less than 1. To more accurately reflect the spatial pattern of a natural population of *P. syluestriformis* in different habitats, the regression analysis of 6 plots *M*/x* of scattered forests was carried out. The regression equation was as follows: $M* = -0.05161 + 0.43806x$ $R = 0.6927$. In the regression relationship, the α value was -0.05161, which was approximately 0, indicating that the basic component of the distribution was a single individual. The space β used to explain the basic component, the β value was 0.43806, and the value β was < 1, which was a uniform distribution. Using the statistical method of Taylor's power law, the regression equation was: $lgS^2 = -0.16858 + 0.88407lgx$ $R = 0.9959$, further confirmed that the populations of *P. syluestriformis* were scattered in the communities in the scattered state.

Table 2. *Spatial distribution and aggregation index of P. syluestriformis population*

Sample number	$\bar{x}$	S^2	Diffusion coefficient C	I index	Average congestion $M*$	$M*/x$ index	C_A index	Distribution pattern
P1	1.750	2.243	2.4933**	1.4933	2.0317	1.1610	0.1610	C
P2	0.278	0.201	0.7221**	-0.2779	-0.0001	-0.0004	-1.0004	R
P3	0.056	0.052	0.9437**	-0.0563	-0.0007	-0.0128	-1.0128	R

C: cluster distribution, *R:* random

The spatial distribution pattern of a natural population of *P. syluestriformis* was analyzed by using *C, M*, C_A* index. The results showed in *Table 3* that in pure forest there was no individual of *P. syluestriformis* in addition to VIII age-class, and there were distributions at all other levels, of which III and IV age-classes were clustered, and other age-classes were random. It also showed that the population had a certain diffusivity from young to mature individuals, and *C, C_A* had the same result of judgment. In pure forest community, the spatial distribution pattern of *P. syluestriformis* population changed from young to mature, which was a general trend from random type to clustered type and then to random type.

Table 3. *Aggregation degree of distribution pattern of different age classes of P. syluestriformis population*

Sample number	Age-class	Diffusion coefficient C	Average congestion M*	M*/x index	C_A index	Distribution pattern
P1	I	0.9306	0.0000	0.0001	-0.9999	R
	II	0.8472	0.2222	0.5926	-0.4074	R
	III	1.0708	0.9180	1.0836	0.0836	C
	IV	1.0853	0.5714	1.1755	0.1755	C
	V	0.9722	-0.0000	-0.0005	-1.0005	R
	VI	0.9583	0.0000	0.0001	-0.9999	R
	VII	0.9722	-0.0000	-0.0005	-1.0005	R
	VIII	-	-	-	-	N
P2	I	1.0000	0.0069	1.0000	0.0000	R
	II~III	-	-	-	-	N
	IV	0.9930	0.0069	0.4972	-0.5028	R
	V	0.9650	0.0067	0.1608	-0.8392	R
	VI	0.9720	0.0068	0.1946	-0.8054	R
	VII	0.9720	0.0068	0.1946	-0.8054	R
	VIII	0.9510	0.0066	0.1187	-0.8813	R
P3	I~V	-	-	-	-	N
	VI	0.9444	-0.0000	-0.0002	-1.0002	R
	VII	0.9167	0.0000	0.0001	-0.9999	R
	VIII	0.9861	-0.0000	-0.0005	-1.0005	R

C: cluster distribution, *R:* random, *N:* lack of this type

However, aggregation index of *P. syluestriformis* population of the scattered community below 1000 m above sea level showed that only one individual of I age-class was present in the investigated community, the individuals of II-III age-classes were missing, and the individuals of IV-VIII age-classes were randomly distributed.

Aggregation index of *P. syluestriformis* population of the scattered community above 1000 m above sea level showed that there were no individuals of I-V age-classes in the community, and only individuals of VI-VIII age-classes had the spatial distribution pattern of random distribution.

Analysis of niche breadth measurement results

Niche breadth is an indirect measurement of the scale and population dynamics of the population's ability to use environmental resources. The niche breadth depends on the quantitative expression of species' position and role in the community, which can better explain the environmental adaptability and resource utilization ability of the population during the succession process. The greater the niche breadth of the population, the stronger its ability to adapt to the environment, the fuller the utilization of various resources, and the more dominant position it often plays in the community. To overcome the impossibility of comparing the niche of different communities and within the same community, levins index and Hurlbert index were used to study the niche breadths of major populations. Comprehensive analysis of survey plots, niche

breadths were calculated of 12 species with relatively high important value and wide distribution range by using *Equations 1* and *2*.

It could be seen in *Table 4* that the order of the levins niche breadth index was P. syluestriformis > A. nephrolepis>L. olgensis>B. platyphylla>T. amurensis>U. japonica >A. tegmentosum>Q. mongolica>P. jezoensis> A. mono>S. pohuashanensis>P. koraiensis. The maximum of Levins niche breadth of P. syluestriformis population was 5.3094, indicating that P. syluestriformis had obvious superiority in each resource location. As one of the community species, it was distributed in 8 resource locations. The second was A. nephrolepis, and the Levins niche breadth was 4.1782, and it also occupied a wide range of niches. It was distributed in all six resource locations except for pure forests. B. platyphylla and T. amurensis had wide niche amplitude and wide distribution, the Levins niche breadth was 3.3196 and 3.1864, respectively. L. olgensis and P. koraiensis were the main associated tree species in the arbor layer of scattered communities, and the Levins niche breadth was 3.4050 and 2.3611, respectively.

Table 4. Niche breadth of main species in arbor layer of P. syluestriformis community

Species number	Pi1	Pi2	Pi3	Pi4	Pi5	Pi6	Pi7	Pi8	Bi	Ba
P. syluestriformis	0.265	0.273	0.083	0.083	0.040	0.130	0.021	0.106	5.3094	0.6637
Q. mongolica	0.034	0.009	0.134	0.505	0.000	0.000	0.000	0.318	2.6626	0.5325
T. amurensis	0.048	0.018	0.000	0.462	0.242	0.000	0.197	0.034	3.1864	0.5311
U. japonica	0.314	0.228	0.456	0.000	0.000	0.000	0.000	0.000	2.7771	0.9257
P. jezoensis	0.000	0.016	0.000	0.299	0.000	0.011	0.534	0.139	2.5296	0.5059
L. olgensis	0.000	0.000	0.339	0.290	0.000	0.299	0.072	0.000	3.4050	0.8513
B. platyphylla	0.049	0.004	0.383	0.054	0.000	0.035	0.370	0.104	3.3196	0.4742
A. mono	0.001	0.000	0.208	0.000	0.000	0.103	0.580	0.108	2.4885	0.4977
P. koraiensis	0.000	0.000	0.011	0.034	0.572	0.021	0.302	0.059	2.3611	0.3935
A. nephrolepis	0.000	0.000	0.001	0.355	0.090	0.141	0.205	0.209	4.1782	0.6964
S. pohuashanensis	0.000	0.000	0.026	0.061	0.000	0.061	0.270	0.583	2.3638	0.4728
A. tegmentosum	0.029	0.000	0.107	0.126	0.000	0.555	0.184	0.000	2.7089	0.5418

Taking full account of the fact that the resource status was highly variable under actual circumstances, the Hurlbert niche breadth value was calculated. The index took into account the magnitude of each resource's state. The analysis data showed that the Hurlbert niche breadth was the largest due to *U. japonica,* it had a larger important value in the *P. syluestriformis* pure forest, its utilization of resources and space in forest was similar to that of *P. syluestriformis*. The Hurlbert niche breadth of other species were basically the same as the Levins niche breadth, which reflected the status and the distribution range of major arbor populations determined the niche breadth.

Analysis of niche overlap measurement results

Niche overlap is the similarity between two species in relation to ecological factors. Niche overlap occurs when two species use the same resource or share one resource (food, nutrients, space, etc.). Niche overlaps make connections between species, and the niche overlap value can explain the competition or coexistence between species.

Calculation of niche overlap index by *Equation 3,* as shown in *Table 5,* the maximum niche overlap occurred between *A. mono* and *B. platyphyll*, followed by *A. Nephrolepis* and *T. amurensis*, indicating that there may be higher niche overlap among species with narrow niche breadth. There was a large niche overlap between *P. syluestriformis* and *U. japonica* population, with an overlap index of 0.704, followed by *L. olgensis*, *A. tegmentosum*, *Q. mongolica*, *L. olgensis* and *A. nephrolepis*, with niche overlap indices of 0.395, 0.392, 0.369, 0.368 and 0.367, respectively.

In the communities of natural *P. syluestriformis* population, the degree of niche overlap of various populations was great, the relationship between species was complex, the trend of resource sharing was obvious, and the utilization of resources by species was similar. The niche overlap of populations with large importance value and wide niche breadth was greater than that of other populations. On the contrary, the niche overlap of populations with small importance value and narrow niche breadth was smaller than that of other populations.

Table 5. *Niche overlaps of main species in arbor layer of P. syluestriformis community*

Species	*P. syluestriformis*	*Q. mongolica*	*T. amurensi*	*U. japonica*	*P. jezoensis*	*L. olgensis*	*B. platyphylla*	*A. mono*	*P. koraiensi*	*A. nephrolepis*	*S. pohuashanensis*	*A. tegmentosum*
P. syluestriformis	1	0.368	0.302	0.704	0.206	0.395	0.310	0.198	0.148	0.367	0.291	0.392
Q. mongolica		1	0.716	0.201	0.507	0.578	0.337	0.161	0.094	0.820	0.550	0.212
T. amurensis			1	0.058	0.703	0.488	0.337	0.331	0.590	0.849	0.276	0.280
U. japonica				1	0.007	0.477	0.583	0.251	0.013	0.002	0.029	0.160
P. jezoensis					1	0.377	0.664	0.820	0.440	0.801	0.602	0.371
L. olgensis						1	0.614	0.416	0.118	0.604	0.178	0.765
B. platyphylla							1	0.888	0.349	0.454	0.493	0.409
A. mono								1	0.450	0.504	0.563	0.482
P. koraiensis									1	0.442	0.284	0.183
A. nephrolepis										1	0.651	0.539
S. pohuashanensis											1	0.235
A. tegmentosum												1

Discussion

The niche breadth of the populations in each community depends on the adaptability of the species to the environment, the intensity of interspecific competition, and the distribution of environmental factors (Chen et al., 2014).

This research found that the niche breadth of *P. syluestriformis* was large in the community, indicating that the species had strong adaptability to the environment. Wei Zhiqin and others thought that rare and endangered plants were mostly inhibited in the community, and the niche was very narrow (Wei et al., 2004). The conclusion of this study is contrary to it. The reason may be that, on the one hand, it is possible that the purpose of the study is to use *P. syluestriformis* as the target tree. When selecting the

plots, the gathering community of *P. syluestriformis* was artificially selected as the survey site, but this did not affect the community structure and its status in the community. On the one hand, it may be because *P. syluestriformis* itself had a special habitat requirement, and the population had a widening niche breadth to obtain sufficient resources (Zhang, 2011).

This research reflects that the view is consistent with Liu Wei's research on the niche of main plant species of the Spruce-fir forests in Changbai Mountain, that is, the greater niche breadth, the greater overlap (Liu and Cao, 2011). However, due to the individual niche breadth, the species' biological and ecological characteristics are unnecessarily the same, and the niche overlap between them is unnecessarily high. It is considered that the decrease in the degree of overlap reflects the differentiation of inter-species resource utilization (Du et al., 2015). Therefore, for species pairs with large niche overlap in the community, it is considered that there are two possibilities: one is that there is a competitive relationship while sharing resources among the species, and the other is that the resources are similarly used while promoting the relationship between the species (Xu et al., 2014). Vannette proposed the niche construction hypothesis, which held the view that if the niche of species was divided into three parts: niche overlap between species, the environmental impact niche and the requirement niche of environmental resources, the prediction of community construction based on niche would be more accurate (Vannette and Fukami, 2014).

Field investigations showed that there were fewer young seedlings of *P. syluestriformis* under the forest, indicating that the habitat of *P. syluestriformis* was higher than the interaction between the species. This paper only explored the resource utilization status between *P. syluestriformis* and the current community dominant species from the perspective of community science. The resource utilization ability of *P. syluestriformis* under different growth conditions was not compared, and further research would be needed. Besides, the distribution of two communities of *P. syluestriformis* could be regarded as the key protection habitat, and the difference of population dynamics caused by the difference of their habitats needed to be further explored.

Conclusions

The research showed that populations with similar habitat requirements could form a good symbiotic relationship under the condition of sufficient resources, which supported the theory that niche overlap and competition were not related. There were relatively few individuals in each resource location of *P. syluestriformis*, and most of them were older, occupying the absolute superiority in the height niche of the arbor layer, and occupying the upper layer of the forest canopy and occupying the absolute dominant position in the community.Therefore, this advantage of *P. syluestriformis* was temporary, and the succession dynamics of *P. syluestriformis* populations were mainly characterized by narrow geographical distribution and narrow habitat, few populations, no individual seedlings and saplings, and lack of self-renewal ability, so they belonged to the recession-type populations. After a certain period of succession, it would probably be replaced by other arbor species, which had many saplings, and had relatively large niche overlap with its *P. syluestriformis,* such as *P. koraiensis, A. nephrolepis,* and so on.

The reason for the rarity of *P. syluestriformis* was mainly caused by the combination of internal and external factors. The internal factors were the defects of ecological and biological characteristics of *P. syluestriformis*. The ecological adaptability of *P. syluestriformis* was relatively narrow and the distribution area was limited; the seed regeneration was difficult, and the ability of self-regeneration was extremely lacking; the resources for the growth of seedlings and saplings were limited. External factors included historical overuse and habitat destruction, and natural communities were largely absent. Therefore, the community resources of Changbai Mountain area were very rare. The protection of wild populations and their habitats of *P. syluestriformis* was the most effective protection measure. With establishment of a different forest for further implementation of *P. syluestriformis* by local conservation and artificial cultivation, the artificial cultivated individuals were transplanted into their original habitats. In this way, they could be naturalized into the natural environment, could develop normally and produce future generations, and consequently expand the size of natural populations.

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