COMPARATIVE ANALYSIS OF SPECIES COMPOSITION AND POPULATION DYNAMICS OF *PICEA JEZOENSIS* AND *PICEA WILSONII* IN AN URBAN PLANTATION, CHINA

YANG, S. L.* – YANG, X. Y. – ZHANG, R. H. – CUI, R. R. – SUN, K. X.

College of Landscape Architecture, Changchun University, Changchun 130012, Jilin, China

**Corresponding author*
e-mail: yangsl@ccu.edu.cn; phone: +86-135-6554-5417

(Received 28th Aug 2025; accepted 3rd Dec 2025)

Abstract. To assess the viability of spruce plantations, this study examined the species composition and population dynamics of *Picea jezoensis* and *Picea wilsonii* communities in Changchun Baimuyuan Park, Jilin Province, China, using quadrat surveys combined with TWINSPAN classification, static life tables, and population dynamic models. The main results are as follows: (1) The companion species in the *P. wilsonii* community were primarily from Ulmaceae and Berberidaceae, while those in the *P. jezoensis* community were dominated by Pinaceae species. (2) *P. jezoensis* showed a bell-shaped age structure, whereas *P. wilsonii* exhibited a pyramid-shaped distribution. Neither species showed signs of degeneration based on age structure. (3) The survival curve of *P. jezoensis* approximated Deevey-II, and that of *P. wilsonii* aligned with Deevey-III. *P. jezoensis* demonstrated more stable mortality rates across life stages compared to *P. wilsonii*. (4) Both populations showed expansion trends ($Vpi > 0$). However, external disturbances strongly suppressed their growth ($V'pi \rightarrow 0$), and resistance capacity was weak ($Pmax \approx 0$). Management efforts should focus on improving juvenile survival of *P. wilsonii* and enhancing the seedling conservation of *P. jezoensis*. This study provides a theoretical basis for sustainable management and optimization of mixed spruce plantations in urban settings.
Keywords: *Picea, time series model, static life table, survival analysis, quantitative population dynamics*

Introduction

Urban forest parks play a vital role in urban ecosystems by providing substantial ecological and social benefits. As essential components of these parks, plants form diverse communities through species combinations within defined spatial scales. The composition of such plant communities not only influences structural stability and ecological functionality but also significantly shapes their aesthetic and landscape value. These communities reflect the interactions among plant species and between plants and their environment, providing critical habitats that support biodiversity (Hou et al., 2019, 2021). The composition, structure, function, and dynamics of plant communities offer valuable insights into community succession patterns and contribute to understanding underlying ecological mechanisms (Zhen et al., 2024; Huang et al., 2025). Species diversity-a fundamental attribute of biodiversity and a key feature of community structure-serves as an indicator of both species composition and habitat condition. It is determined by the number of species and their abundances within a community and is closely linked to community organization and stability. Research on species diversity is crucial for assessing ecosystem resilience and forest restoration dynamics (Chen, 2024a,b). Furthermore, the species composition of plant communities underpins ecosystem functioning and processes, offering important clues to the mechanisms governing species coexistence and biodiversity maintenance (Wang et al., 2018). A thorough understanding of forest plant community structure, coupled with the design of scientifically informed and well-constructed communities, is essential for optimizing

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_939958

the multifunctional performance of urban forests. Such efforts ensure that urban forest parks maximize their ecological and social functions.

Building on the community-level perspective, the population-defined as a collection of conspecific individuals occupying a specific space over a certain period-serves as the fundamental unit for the survival, development, and evolution of a species. It represents a critical link connecting individual organisms, communities, and ecosystems (Zhao et al., 2020; Zhang et al., 2022a). Core research areas in population ecology include population structure and population dynamics (He et al., 2024). Population structure, which determines long-term developmental trends, encompasses size-class structure, height structure, and age structure (Shang et al., 2025). It reflects the age, size, and abundance of individuals within the population, thereby revealing population dynamics and trends (Hu et al., 2023). Life tables and survival curves are instrumental in illustrating the survival status of populations and their interactions with the environment. For populations with overlapping generations, the use of static life tables and survival curves to analyze natural population viability represents an important methodology for studying population structure and developmental trends. These tools help assess the current survival status of plant populations, evaluate historical disturbances, and predict future population trajectories (Wang et al., 2021). The structure and dynamics of populations lie at the heart of population ecology. In-depth research in this field can elucidate the survival potential and mechanisms of species, provide a robust scientific basis for the conservation of plant resources, facilitate the rational planning of resource utilization, and ultimately contribute to their sustainable development (Gui et al., 2025).

Among the ecologically significant tree species suited to such studies, the genus *Picea* (Pinaceae) comprises important evergreen conifers distributed across temperate to boreal regions of the Northern Hemisphere. Of the approximately 40 recognized species worldwide, 16 species and 9 varieties are native to China, primarily inhabiting high-altitude areas of the northeast, north, northwest, southwest, and Taiwan. Based on ecological adaptations, these can be classified into three types: cold-moist, cold-arid, and warm-moist (Feng, 2016). *Picea* forests represent major terrestrial carbon sinks, containing several highly efficient carbon-sequestering species. Their carbon storage capacity is closely correlated with vegetation indices, net radiation, and humidity, underscoring the importance of species selection in optimizing carbon sequestration (Kong, 2022; Cao, 2022; Pei et al., 2024). Soils in spruce forests typically exhibit high organic matter content and near-neutral pH, which facilitate nutrient cycling and microbial activity. Management practices such as appropriate mixed-species planting and thinning can balance ecological benefits with biodiversity conservation, while also mitigating soil acidification and nutrient loss often associated with monospecific pine invasions (Rao, 2022; Du, 2022). Studying the population dynamics of *Picea* species helps refine forest management and harvesting strategies. The dynamics of these communities reflect the combined effects of climate change and anthropogenic disturbance, reveal the ecological adaptability of Pinaceae species, and provide a scientific basis for formulating ecological compensation policies.

Focusing on two representative species, *Picea wilsonii* and *Picea jezoensis* serve as key components in cold temperate and high mountain ecosystems (Yuan, 2022; Ni, 2022; Zhu, 2023; Fu, 2023). As a unique species of *Picea* in China, *P. wilsonii* displays strong cold tolerance but drought sensitivity with summer-precipitation-dependent radial growth vulnerable to heat-enhanced evapotranspiration, though its mixed stands

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enhance soil nutrients and ecological functions; conversely, *P. jezoensis* dominates humid montane Northeast China, improving soil erosion resistance yet constrained by topographic-climatic limits and significant thermotolerance thresholds (Xie et al., 2020; Hong et al., 2022; Zhang et al., 2022b; Han, 2022; Qi, 2024). This study investigates both species in Changchun Baimuyuan Park (Jilin Province) through integrated methodologies-species composition/richness analysis, TWINSPAN community stability assessment, and size-class-structured life table construction-to quantify population dynamics, thereby establishing theoretical foundations for optimizing urban plantation configurations of *Picea* species. Based on the survey results, the following hypotheses are proposed: (1) The species richness of both communities is relatively low due to the absence of shrub and herb layers; (2) *P. wilsonii* population, with a higher proportion of young individuals and a lack of mature ones, represents an expanding population.

Materials and methods

Study area

The research area is located in Baimuyuan Park (44°02'N, 125°19'E), Changchun City, Jilin Province, China (

Figure 1.). It is the only botanical garden in Jilin Province with the theme of tree gardening. The average annual temperature is 4.6-5.6 ℃, the annual precipitation is 570-670 mm, and the precipitation is concentrated from June to August. The frost free period is about 140-150 d. The soil is mainly composed of black calcareous soil, with a pH value of 6.8-7.2 and an organic matter content of ≥ 3%. The park covers an area of about 18 hectares, with an altitude of 180-210 m. There are currently more than 154 species of artificial forest trees in 30 families. Baimuyuan Park was established in 2012 through the conversion of a former tree nursery. Both the *P. jezoensis* and *P. wilsonii* stands originated from the nursery period. The study area is located within a designated protected zone where human activities and forest thinning are strictly prohibited. The investigation was conducted with prior approval from the management authorities.

Study plot

We established a total of 18 plots (15 m × 15 m): four mixed and four pure *P. jezoensis* plots, alongside six mixed and four pure *P. wilsonii* plots. The canopy closure of the sample plots, measured using the tree crown projection method, ranged from 60% to 85%, with a mean ± standard deviation of 72.29% ± 7.57% (Brūmelis et al., 2020).

Community characteristics

Quadrat sampling recorded species identity, abundance, height, and diameter at breast height (DBH, 1.3 m) for all woody plants (Yigeremu and Woldearegay, 2022; Dada et al., 2024). Statistical analyses quantified tree species' importance value (Eq.1) (McKenna et al., 2019; Cong et al., 2023), relative abundance (Eq.2) (D'amato et al., 2004), and relative dominance (Eq.3) (Oliveira Feitosa et al., 2022) using the following formulas:

$$IV = (\text{Relative Density} + \text{Relative Frequency} + \text{Relative Dominance}) / 3 \quad \text{(Eq.1)}$$

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RA = (Number of individuals of a species / Total individuals) × 100% (Eq.2)

RD = (Basal area of a species / Total basal area) × 100% (Eq.3)

Species Richness (Gleason's index): R = S / lnA (Wang et al., 2023c) (Eq.4)

where S = species number per plot; A = plot area (m²); Gleason's index measures species richness per unit area.

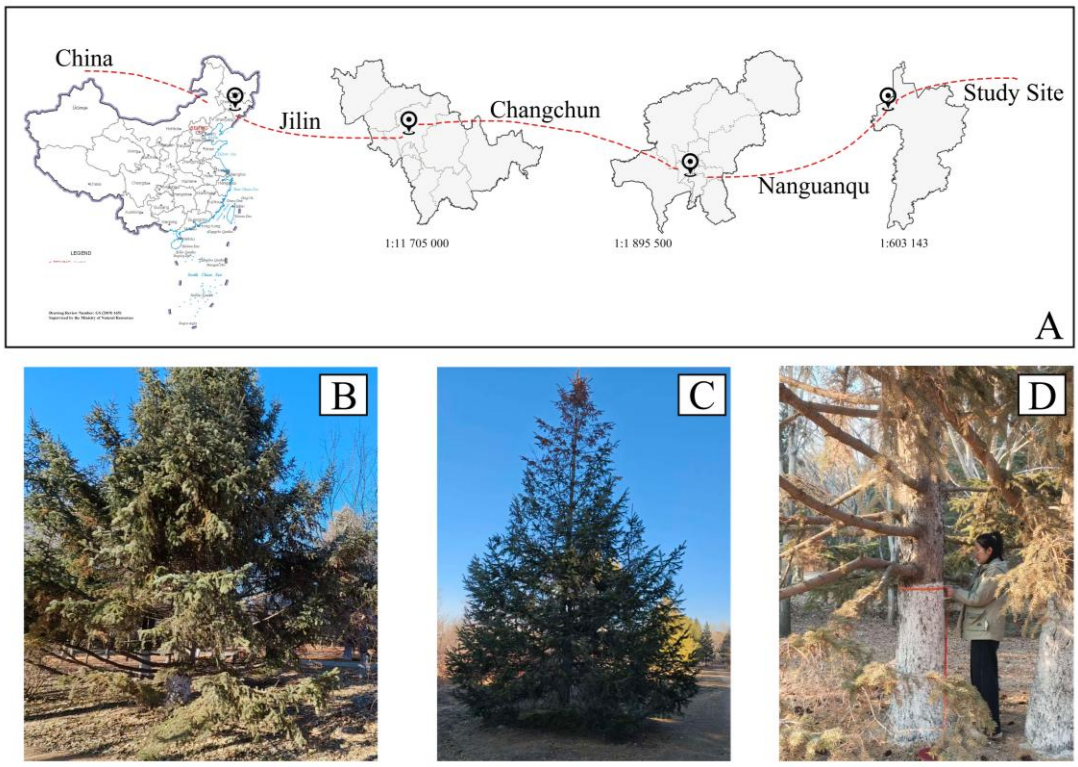

Figure 1. *Geographical location of the study area. Note: A: The map of study area. B: Picea jezoensis (Siebold & Zucc.) Carrière. C: Picea wilsonii Mast. D: experimental process. This map utilizes a standard base map obtained from the Standard Map Service website (http://bzdt.ch.mnr.gov.cn/) administered by the National Bureau of Surveying, Mapping and Geographic Information, with approval numbers GS(2019)1651. The base map remains unaltered*

Age-class classification

Age-class of *P. jezoensis* and *P. wilsonii* were defined based on DBH size structure to infer population age dynamics (Song et al., 2023). Trees were categorized into seven stages with stem counts tallied by age-class (*Table 1.*).

Static life table construction

Static life tables (Eq.5-Eq.12) were compiled using DBH/height as size-class proxies for developmental stages, based on censuses of age-class survival status at a specific time (Luan et al., 2023). Key parameters, including mortality rate (q_x), survival rate (S_x),

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and killing power (K_x), were calculated directly from the census data. The process involved smoothing the raw age-class counts (A_x) to obtain (a_x), from which the standardized survivors (Eq.5) were derived. Mortality rate (Eq.7) and survival rate (Eq.11) were then computed as the proportion dying and surviving between age-classes, respectively, while killing power (Eq.12) was determined from the logarithmic decline in l_x. This approach estimates stage-specific mortality(Eq.7) to analyze long-term population dynamics in *P. jezoensis* and *P. wilsonii*. Age-class distributions were converted to temporal sequences using the following key metrics (Gao et al., 2022; Lv et al., 2024):

$$l_x = a_x / a_0 \times 1000 \quad \text{(Eq.5)}$$

$$d_x = l_x - l_{x+1} \quad \text{(Eq.6)}$$

$$q_x = d_x / l_x \times 100\% \quad \text{(Eq.7)}$$

$$L_x = (l_x + l_{x+1})/2 \quad \text{(Eq.8)}$$

$$T_x = L_x + L_{x+1} + L_{x+2} + \ldots \quad \text{(Eq.9)}$$

$$e_x = T_x / l_x \quad \text{(Eq.10)}$$

$$S_x = l_{x+1} / l_x \quad \text{(Eq.11)}$$

$$K_x = ln(l_x) - ln(l_{x+1}) \quad \text{(Eq.12)}$$

where x = age-class; a_x = smoothed individuals in class x (reference: a_0 = class I); l_x = standardized survivors at x; d_x = deaths in [x, x+1]; q_x = mortality rate; L_x = stationary equivalent in [x, x+1]; T_x = total stand-time beyond x; e_x = life expectancy; S_x = survival rate; K_x = killing power.

Table 1. *Age-class stage division*

Age-class \ Population	***Picea jezoensis***	***Picea wilsonii***
I	seedlings, DBH<5 cm, H≤6.0 m	seedlings, DBH<3 cm, H≤2 m
II	sapling, 5 cm<DBH<10 cm, 6 m<H<8 m	sapling, 3 cm<DBH<5 cm, 3 m<H<4 m
III	Saplings, 10 cm<DBH<15 cm, 8 m<H<10 m	saplings, 5 cm<DBH<8 cm, 5 m<H<5 m
IV	dominant poles, 15 cm<DBH<20 cm, 10 m<H<12 m	saplings, 8 cm<DBH<12 cm, 5 m<H<6 m
V	suppressed poles, 20 cm<DBH<25 cm, 12 m<H<14 m	saplings, 12 cm<DBH<15 cm, 6 m<H<8 m
VI	mature trees, 25 cm<DBH<30 cm, 14 m<H<16 m	pole-stage trees, 15 cm<DBH<18 cm, H≥8 m
VII	mature trees, DBH＞30 cm, H≥16 m	

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Population survival curves

Survival curves depict age-specific survivorship patterns, with age-class on the x-axis and log-transformed standardized survivors [ln(l_x)] on the y-axis (Peng et al., 2022b). Curve typology was assessed via the Hett and Loucks (1976).

Quantitative population dynamics

Population structure dynamics were quantified using the *size-class transition matrix model* (Eq.13-Eq.16) following Chen (1998) methodology (Chen, 1998; Shang et al., 2025). Key metrics were computed as:

$$V_x = \frac{A_x\text{-}A_{x+1}}{max(A_x, A_{x+1})} \times 100\% \quad \text{(Eq.13)}$$

$$V_{pi} = \frac{1}{\sum_{x=1}^{K\text{-}1} A_x} \times \sum_{x=1}^{K\text{-}1} (A_x \times V_x) \quad \text{(Eq.14)}$$

$$V'_{pi} = \frac{\sum_{x=1}^{K\text{-}1} A_x \times V_x}{K \times min(A_1, A_2, \ldots A_k) \sum_{x=1}^{K\text{-}1} A_x} \quad \text{(Eq.15)}$$

$$P_{\max} = \frac{1}{K \times min(A_1, A_2 \ldots A_k)} \quad \text{(Eq.16)}$$

where A_x, A_{x+1} = abundance in classes x, x+1; K = terminal age-class; V_x = transition flux (A_x - A_{x+1}); V_{pi} = intrinsic dynamics index; V'_{pi} = disturbance-mediated dynamics index.

Time series model

The time-series model (Eq.17) predicting population dynamics was constructed based on actual survival counts of individuals across age cohorts, employing the single moving average method to infer age structure trajectories (Xiao et al., 2004).

$$M_t^{(1)} = \frac{1}{n} \sum_{k=t\text{-}n+1}^{1} X_k \quad \text{(Eq.17)}$$

In the formula: n denotes the prediction horizon (measured in age-class units, equivalent to n age-class intervals in this study), t represents the current age-class index, X_k is the abundance of individuals within age-class k, $M_t^{(1)}$ indicates the projected population size at age-class t after n future age-class transitions.

Survival analysis

To gain deeper insights into population dynamic patterns, this study introduces four key functions from survival analysis: Survival rate function (S_x), Cumulative mortality function (F_x), Mortality density function (f_x), Hazard rate function (λ_x). These functions were calculated following the formulas established by Yang et al. (1991).

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Data analysis

Data analysis of species composition, number, importance values, relative abundance, and relative dominance was performed with Excel 2019; TWINSPAN and DCA were performed with PCORD v5.0; and graphs were made with PhotoShop 2025 and Origin 2024.

Results

Comparison of community characteristics between the two Picea communities

Comparison of species composition characteristics between the two Picea communities

The two communities comprised a total of 13 species, with *Larix gmelinii* and *Pinus sylvestris* common to both the *P. wilsonii* and *P. jezoensis* communities (DBH>1cm). *P. wilsonii* community comprised 10 species (5 families, 8 genera), dominated by Pinaceae (6 species) and Ulmaceae (2 species). *P. jezoensis* community contained 4 species (2 families, 4 genera) with Pinaceae (3 species) predominant (*Table 2.*). Pinaceae dominated both communities (75% species composition).

Table 2. *Floristic composition of the two Picea communities*

Community	Family	Genus	Species
Picea jezoensis	Pinaceae	*Picea*	*Picea jezoensis*
		Larix	*Larix gmelinii*
		Pinus	*Pinus sylvestris*
	Celastraceae	*Euonymus*	*Euonymus alatus*
Picea wilsonii	Pinaceae	*Pinus*	*Pinus sylvestris*
			Pinus massoniana
			Pinus thunbergii
		Picea	*Picea wilsonii*
		Abies	*Abies fabri*
		Larix	*Larix gmelinii*
	Ulmaceae	*Ulmus*	*Ulmus pumila L.*
			Ulmus pumila L. cv. Tenue
	Berberidaceae	*Nandina*	*Nandina domestica*
	Fagaceae	*Quercus*	*Quercus mongolica*
	Salicaceae	*Salix*	*Salix babylonica*

Among 13 shared species, 8 had importance values (IV) >1% (

Figure 2.). In *P. jezoensis* community, *P. jezoensis* showed the highest IV and RA, while *Pinus sylvestris* had maximal relative dominance. In *P. wilsonii* community, *P. wilsonii* achieved peak IV and RA, with *Ulmus pumila* exhibiting greatest relative dominance. These were identified as constructive species in their respective communities.

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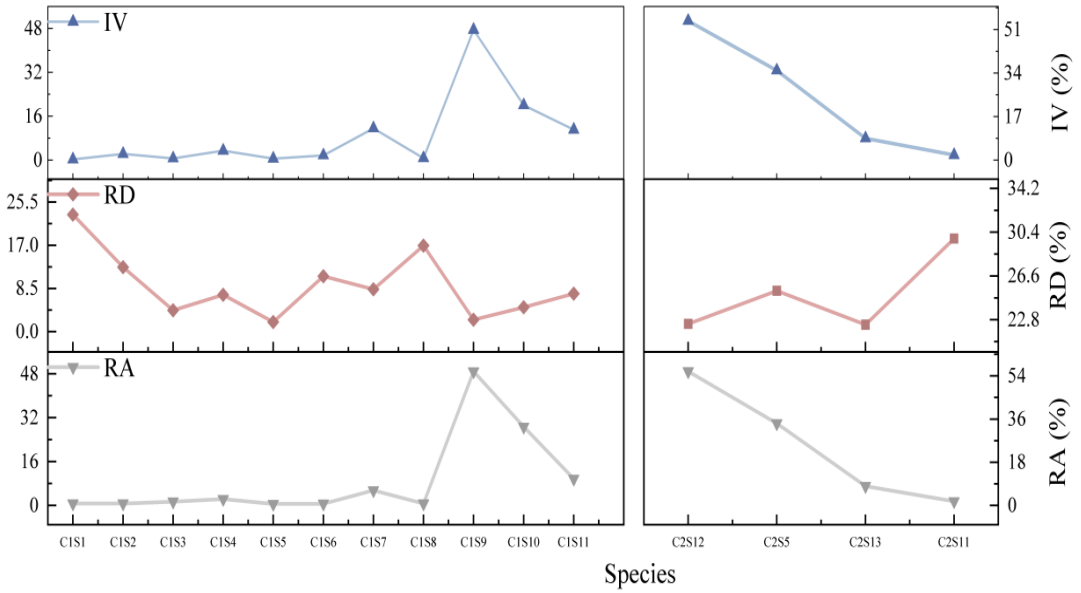

Figure 2. *Quantitative structural metrics of the two Picea communities. Note: C1 Picea wilsonii, C2 Picea jezoensis, S1 Ulmus pumila L. cv. Tenue, S2 Pinus thunbergii, S3 Abies fabri, S4 Salix babylonica, S5 Larix gmelinii, S6 Pinus massoniana, S7 Quercus mongolica, S8 Nandina domestica, S9 Picea wilsonii, S10 Ulmus pumila L., S11 Pinus sylvestris, S12 Picea jezoensis, S13 Euonymus alatus*

TWINSPAN classification of the two Picea communities

TWINSPAN divided 10 mixed forest plots into four associations co-dominated by *Picea* species:(I) *P. jezoensis* + *Larix gmelinii*; (II) *P. wilsonii* + *Pinus thunbergii* + *Nandina domestica*; (III) *P. wilsonii* monodominant; (IV) *P. wilsonii* + *Abies nephrolepis* (

Figure 3.). Species richness indices were R=0.588 (*P. jezoensis*) and R=1.468 (*P. wilsonii*), indicating higher diversity in *P. wilsonii* communities (

Figure 4.).

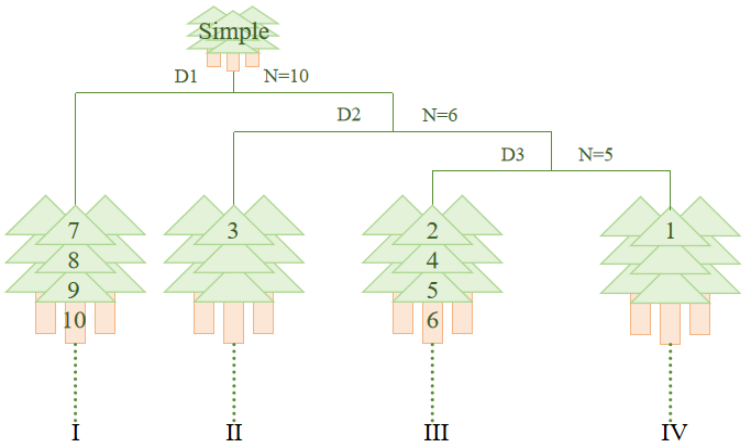

Figure 3. *TWINSPAN dendrogram of mixed forest plots. (Plots 1-6: P. wilsonii; Plots 7-10: P. jezoensis)*

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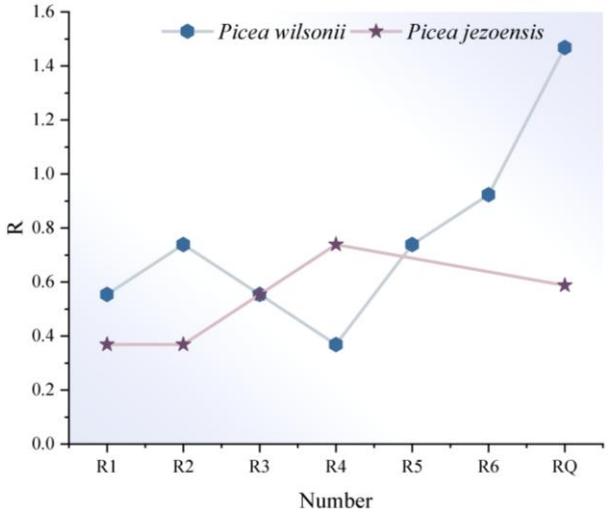

Figure 4. *Species richness of forest plots. (R: Species richness per plot; RQ: Community-level species richness)*

Comparison of characteristics of the two Picea populations

Comparison of age structure between the two Picea populations

A total of 251 *P. jezoensis* individuals and 247 *P. wilsonii* individuals were recorded within the 18 quadrats. The population size of *P. jezoensis* initially increased then decreased with increasing age-class (

Figure ***5.***). Within the *P. jezoensis* population, middle-aged individuals (age-class III-V) accounted for 48.21%, followed by young individuals (age-class I-II) at 41.83%, while old individuals (age-class VI-VII) constituted only 9.96%. In contrast, the *P. wilsonii* population was dominated by young individuals (age-class I-III), which accounted for 72.47%, followed by middle-aged individuals (age-class IV-V) at 27.53%. Notably, no old individuals were present in the *P. wilsonii* population.

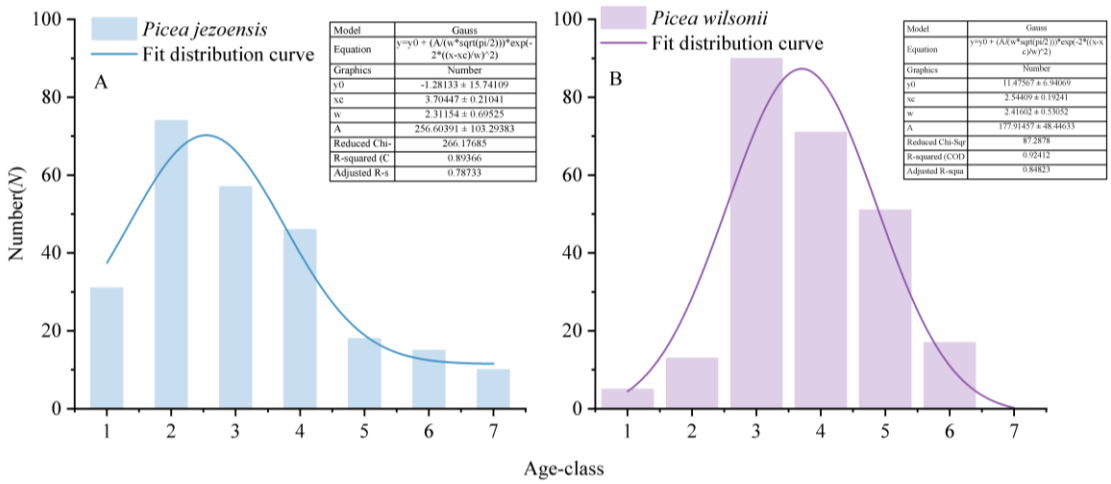

Figure 5. *Age structure of the two Picea populations*

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Comparison of static life tables between the two Picea populations

The number of surviving individuals (A_x) in both *P. jezoensis* and *P. wilsonii* fluctuated with an "increase-decrease" pattern as age-class increased. The life expectancy (e_x) of the *P. jezoensis* population exhibited a "decrease-increase-decrease" trend, while that of *P. wilsonii* showed an overall decreasing trend. Both species reached their peak e_x values (4.37 and 4.39, respectively) in age-class I. Furthermore, the mortality rate (q_x) and disappearance rate (k_x) of the two spruce populations followed identical trends, each reaching their maximum values in age-class IV and age-class V, respectively. This indicates that both populations experienced mass mortality during their middle developmental stages (*Table 3.*).

Table 3. *Static life table of the two Picea populations*

Age-class		A_x	a_x	l_x	ln (l_x)	d_x	q_x	L_x	T_x	e_x	S_x	K_x
Picea jezoensis	I	31	57	1000	6.91	70	0.07	965	4368	4.37	0.93	0.07
	II	74	53	930	6.84	53	0.06	904	3368	3.62	0.94	0.06
	III	57	50	877	6.78	70	0.08	842	2438	2.78	0.92	0.09
	IV	46	46	807	6.69	491	0.61	562	1561	1.93	0.39	0.93
	V	18	18	316	5.76	53	0.17	290	754	2.39	0.83	0.19
	VI	15	15	263	5.57	88	0.33	219	438	1.67	0.67	0.41
	VII	10	10	175	5.16	-	-	88	175	1.00	-	5.16
Picea wilsonii	I	5	54	1000	6.91	93	0.09	954	4389	4.39	0.91	0.1
	II	13	49	907	6.81	92	0.10	861	3389	3.74	0.90	0.11
	III	90	44	815	6.70	93	0.11	769	2482	3.05	0.89	0.12
	IV	71	39	722	6.58	92	0.13	676	1667	2.31	0.87	0.13
	V	51	34	630	6.45	315	0.50	473	945	1.50	0.50	0.7
	VI	17	17	315	5.75	-	-	158	315	1.0	-	5.75

Comparison of survival curves between the two Picea populations

Both spruce populations exhibited survival curves that initially increased then decreased (

Figure ***6.***). This indicates *P. jezoensis* approximates Deevey-II, while *P. wilsonii* aligns with Deevey-III (*Table 4.*).

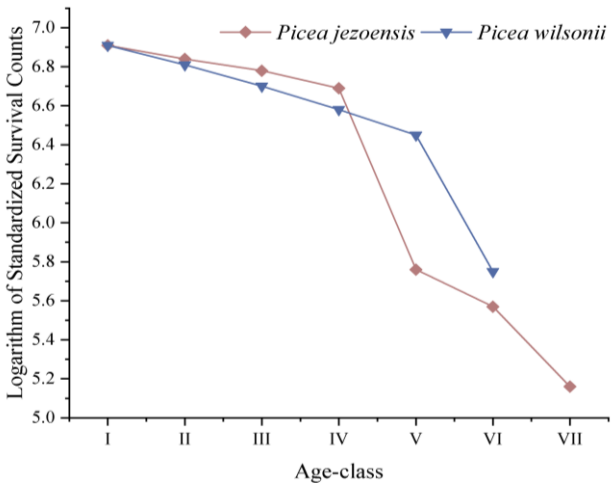

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Figure 6. *Survival curves of the two Picea populations*

Table 4. *Test models of survival curves of P. jezoensis and P. wilsonii*

Population	Equation	R^2	F
Picea jezoensis	$N_x = 8.0412e^{-0.052x}$	0.8751	35.03
	$N_x = 8.5223x^{-0.209}$	0.7428	14.44
Picea wilsonii	$N_x = 7.5123e^{-0.031x}$	0.7853	14.63
	$N_x = 7.6885x^{-0.116}$	0.6607	7.79

Population dynamics comparison of the two Picea populations

Positive V_{pi} values for age-class III-VI (*P. jezoensis*) and III-V (*P. wilsonii*) indicate expansion phases, while negative values for I-II denote decline. Natural growth indices (V_{pi}) were 0.191 (*P. jezoensis*) and 0.256 (*P. wilsonii*). With stochastic disturbances, these (V'_{pi}) dropped to 0.003 and 0.009, respectively, demonstrating significant growth suppression. The relationship $V_{pi} > V'_{pi} > 0$ confirms both are expanding populations. Near-zero P_{max} values indicate high disturbance sensitivity and weak resistance (*Table* ***5.***).

Time series model of the two Picea populations

After a period of 2 age classes, the number of individuals in age-class I to III declined in both populations, while the numbers in the remaining age-classes generally increased. Both populations exhibited a consistent growth trend in the number of intermediate-sized trees. Collectively, however, both populations demonstrate a declining trajectory in total abundance over progressive age-class transitions (*Table 6.*).

Table 5. *Dynamic indices of the two Picea populations*

Population \ Dynamic indices(%)	V1	V2	V3	V4	V5	V6	V_{pi}	V'_{pi}	P_{max}
Picea jezoensis	-58	23	19	61	17	33	0.191	0.003	0.014
Picea wilsonii	-62	-86	21	28	67	-	0.256	0.009	0.033

Table 6. *Time series analysis of P. jezoensis and P. wilsonii population dynamics changes*

Age-class \ Population	*Picea wilsonii*				*Picea jezoensis*			
	Raw data	$M_2^{(1)}$	$M_4^{(1)}$	$M_6^{(1)}$	Raw data	$M_2^{(1)}$	$M_4^{(1)}$	$M_6^{(1)}$
I	31				5			
II	74	15			13	2		
III	57	52			90	9		
IV	46	81	7		71	54	1	
V	18	104	26		51	89	4	
VI	15	113	40	5	17	135	27	1
VII	10	120	52	17	-	-	-	-

Survival analysis of the two Picea populations

The survival rate and cumulative mortality rate of *P. jezoensis* and *P. wilsonii* populations reached equilibrium at age-class III and age-class IV, respectively. The *P. jezoensis* population entered the decline phase earlier than that of *P. wilsonii*. The mortality rate and mortality density curve peaked at age-class IV for *P. jezoensis* and age-class V for *P. wilsonii*, respectively. The disappearance rate and hazard rate curves exhibited trends consistent with the respective mortality curves (

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Figure 7.).

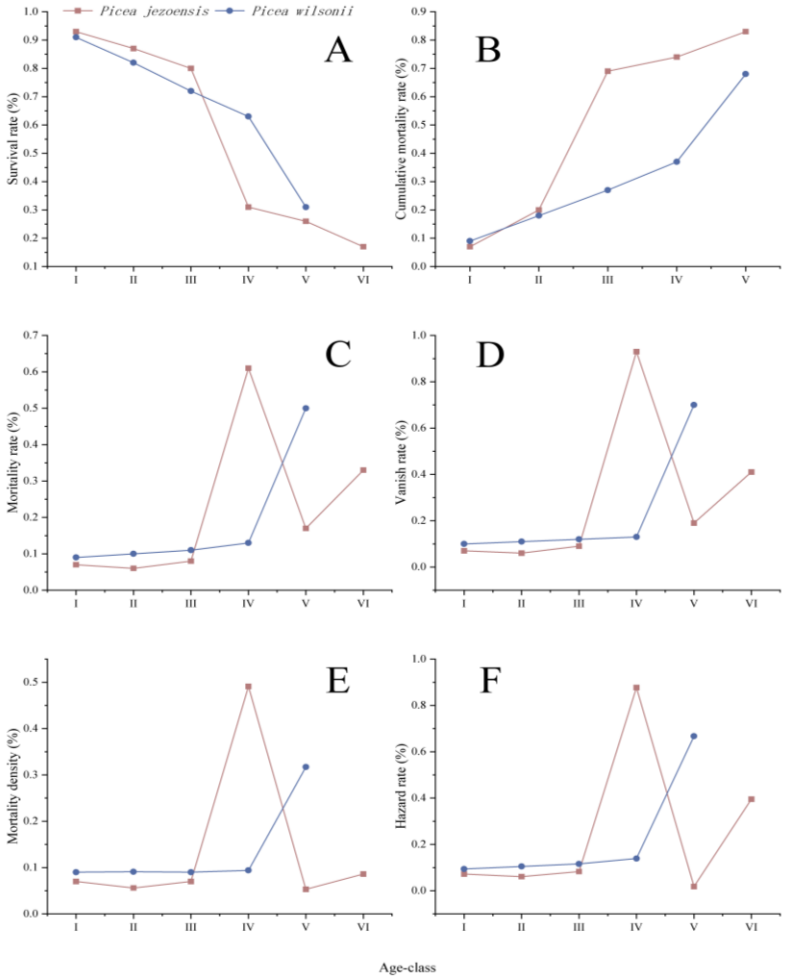

Figure 7. *P. jezoensis and P. wilsonii population survival rate (A), cumulative mortality rate (B), moritality rate (C), vanish rate (D), mortality density (E) and hazard rate (F)*

Discussion

Composition of the two Picea communities

Species diversity within a community influences its stability and determines the ecological service functions of the ecosystem (Zhou et al., 2024). Investigating community species composition and the distribution characteristics of dominant species aids in biodiversity conservation and maintaining ecosystem stability (Jiang et al., 2024). The Pinaceae family constitutes the primary dominant species in both warm-temperate and cold-temperate coniferous forests (Li et al., 2023). In this study, both *Picea* communities were predominantly composed of Pinaceae plants, which held a dominant position and exhibited high competitiveness within this plantation ecosystem. *P. sylvestris* and *U. pumila* served as the constructive species in the *P. jezoensis* community and the *P. wilsonii* community, respectively, playing significant roles within their communities. Compared to surveys of other *Picea* communities (He et al., 2020; Fan et al., 2022; Gao et al., 2023), these two *Picea* communities lacked distinct

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stratification; no plants were recorded in the shrub or herb layers. Furthermore, compared to studies on species composition in urban plantations such as those in forest parks (Zhou et al., 2021; Qian et al., 2024; Wang et al., 2024a; Yang et al., 2025; Long et al., 2025), these two *Picea* communities possessed a lower number of species, families, and genera. This indicates a lower ecological stability within the *Picea* communities, highlighting the critical role of Pinaceae plants in maintaining their structure. The species richness of the *P. wilsonii* community was higher than that of the *P. jezoensis* community. The *P. wilsonii* community included companion species from families such as Ulmaceae and Berberidaceae, whereas the *P. jezoensis* community exhibited Pinaceae monoculturalization. This study reveals differences in species coexistence mechanisms within Pinaceae-dominated communities, providing a theoretical basis for optimizing mixed plantation models.

Population structure and dynamics of two Picea species

The method of using basal diameter and height as proxies for age to analyze population structure is widely applied. Reflecting the age-class structure of a population through the breast-height diameter (DBH) of individual plants simplifies the study process in population ecology (Peng et al., 2022a). It intuitively displays the population's dynamic changes and adaptation to the environment, revealing information about population dynamics. This is one of the important approaches to uncovering the survival status and regeneration strategies of populations (Zhang et al., 2021). A large number of young seedlings forms the basis for the increase of individuals across all age-class; the higher the proportion of young seedlings, the greater the population's growth potential (Zhao et al., 2020). In this study, the *P. jezoensis* population exhibited a bell-shaped age structure characterized as "large in the middle and small at both ends". This indicates that the population maintains relatively stable recruitment and replacement during natural regeneration, classifying it as a stable population type. In contrast, the overall age structure of the *P. wilsonii* population displayed a pyramid-shaped age-class distribution pattern. It featured a high number of saplings and intermediate-aged trees, with a complete absence of mature individuals. This suggests the population is currently in a phase of rapid expansion, classifying it as an increasing population type. This pattern resembles the age structures observed for the *Aegiceras corniculatum* and *Kandelia obovata* populations in studies of Guangxi mangrove structural characteristics (Liang et al., 2022). During forest regeneration, the seedling and sapling stages are the most sensitive and critical phases (Ma et al., 2023). The bell-shaped age structure of the *P. jezoensis* population reflects its adaptive equilibrium within this specific ecological environment. However, the relatively low number of seedlings suggests potential regeneration constraints.

Population dynamics reflect the life-history characteristics of populations and their interactions with the environment (Tian et al., 2022; Wang et al., 2023a). Quantification of population structure dynamics revealed that $V_{pi} > V'_{pi}$ and $V'_{pi} \approx 0$, indicating both *Picea* populations are currently in a growth phase. Analysis of population dynamic indices showed negative values for V1 and V2 in *P. wilsonii* and V1 in *P. jezoensis*, signifying declines in age-class I for *P. jezoensis* and age-class I-II for *P. wilsonii*. In contrast, positive values were found for V2-V6 (*P. jezoensis*) and V3-V5 (*P. wilsonii*), indicating growth in age-classes II-VII (*P. jezoensis*) and III-VI (*P. wilsonii*). This reveals that both *Picea* populations exhibit a regressive trend in some age classes, with recruitment impeded, thereby slowing the overall population growth rate and

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manifesting a fluctuating developmental pattern, which aligns with the findings of Yang et al. (2025). Furthermore, the P_{max} index for both populations approached 0, indicating low resilience to stochastic disturbances, vulnerability to external threats, yet high responsiveness to environmental change - a pattern similar to the *Chunia bucklandioides* population structure reported (Gui et al., 2024).

Static life tables and survival curves of the two Picea species populations

Static life tables are key indicators for assessing the development trajectory of plant populations. Combined with survival curves, they can reveal the current status and dynamic characteristics of plant populations, and predict their future growth trends (Wang et al., 2021; Tian et al., 2022). Survival curves intuitively reflect the survival strategies of a population by quantifying changes in survival rates across different age classes (He et al., 2020; Wu et al., 2021). They can indicate a plant species' sensitivity to environmental changes and help assess the impact of human activities or climate change on plant populations (Wang et al., 2023b). The survival curve of the *P. jezoensis* population aligns more closely with the Deevey-II pattern. This is consistent with the survival curve types observed in extremely small populations of *Acer miaotaiense* and *Camptotheca acuminata* (Ma et al., 2021; Wang et al., 2024b). This indicates that environmental disturbances are relatively stable across all growth stages of this population, resulting in relatively consistent mortality rates among individuals of different diameter classes. In contrast, the *P. wilsonii* population exhibits a survival curve more characteristic of Deevey-III. This finding is consistent with research results on populations of *Sinomanglietia glauca* and *Berchemiella wilsonii* (Zhang et al., 2023, 2024; Pang et al., 2025), although the underlying mechanisms for high mortality may differ. This pattern indicates that the population experiences high early-stage vulnerability and exhibits signs of decline during intermediate and late stages. Furthermore, it exhibits large fluctuations in population size and low resistance to disturbances. Analysis of survival curves aids in identifying the proportions of seedlings, saplings, and mature individuals within a population. This provides a basis for formulating appropriate management practices and helps optimize planting and management planning in agriculture and forestry.

Time-series prediction and survival analysis

Time series analysis serves as an important tool for investigating the variation patterns of time series data (Young et al., 1972). The analysis integrating survival functions with time series forecasting models can reveal the mechanisms of population decline (Zhang et al., 2008). Predictions from time series models indicate that both spruce species exhibit insufficient sapling recruitment, leading to constrained natural regeneration capacity. This may result in an aging population structure and an overall decline in population size. The lack of seedlings combined with high mortality rates among saplings and small trees represents a major factor endangering the populations (Li et al., 2011). These predictions are consistent with the high mortality observed in intermediate age classes in static life tables, indicating a significant bottleneck during population development. While the populations currently rely on middle-aged individuals, intense competition contributes to high mortality (Zhang et al., 2004). Analysis of the cumulative mortality function (F_x) and hazard rate function (λ_x) shows that *P. jezoensis* and *P. wilsonii* reach their mortality peaks at age class IV and V, respectively, coinciding with the stages where stand competition is most intense and

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individual demand for environmental resources is highest. The time series forecasts highlight a potential crisis of inadequate sapling renewal in both spruce populations, while survival analysis further reveals their vulnerability across different life stages.

Protective measures

Given the simplified structure and low species richness of these artificial *Picea* communities, we recommend implementing mixed-species planting strategies to enhance ecological stability and functional diversity. Introducing native understory shrubs and herbaceous layers could improve microhabitat conditions, facilitate nutrient cycling, and support pollinators, thereby strengthening ecosystem resilience. For *P. wilsonii*, which exhibits high juvenile mortality, protective measures such as shading, irrigation during dry periods, and reduced competition through selective thinning are advised. For *P. jezoensis*, focus should be placed on conserving existing seedlings and promoting natural regeneration through canopy gap creation. Additionally, long-term monitoring and adaptive management are essential to respond to climate change impacts and anthropogenic pressures, ensuring the sustainability of these urban forest plantations.

Conclusion

In conclusion, this study provides a detailed ecological assessment of two *Picea* species within an urban plantation context, revealing significant differences in community structure and population dynamics. While both populations are currently expanding, their high sensitivity to disturbances and low resilience underscore the fragility of monoculture-dominated urban forests. The absence of understory layers and low species diversity further exacerbate their vulnerability to environmental changes. Future research should integrate genetic diversity assessments, soil health monitoring, and climate resilience modeling to develop more robust conservation frameworks.

Funding. This work was supported by Science and Technology Development Plan Project of Science and Technology Department of Jilin Province (YDZJ202201ZYTS468).

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