

Article

Changing Dynamic of Tree Species Composition and Diversity: A Case Study of Secondary Forests in Northern China in Response to Climate Change

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Abstract: Climate warming is believed to have irreversible effects on biodiversity and ecosystem functions. Secondary forests are non-negligible ecosystems in northern China that have attracted much attention because of their instability and sensitivity to global change. However, there is no consensus on the impact of warming on secondary forest succession. In this study, we explored the response of tree species diversity to climate warming in northern secondary forests in China using a series of field surveys combined with annual meteorological data from 2015 to 2021. Our results indicate that the temperature in the study area increased in spring and autumn, while the precipitation increased in spring, summer, and autumn from 2015 to 2021. Changes in species composition in the study area and climate warming were significant in the northern region of China. The importance values of many broadleaf tree species increased, whereas those of local coniferous and broadleaf tree species decreased. The Shannon–Wiener, Simpson, and Margalef indices for the pure forest were significantly lower than those for the broadleaf mixed forest and the conifer–broadleaf mixed forest ($p < 0.05$) in 2015 and 2021. The highest value for the Pielou index was in the conifer–broadleaf mixed forest ($p < 0.05$), whereas it was not significantly different between the pure forest and broadleaf mixed forest in 2021. Surprisingly, the secondary broadleaf mixed forest in northern China showed an unfavorable degradation trend under the influence of climate change, just the same as the secondary pure forest. Our work provides an experimental data source for research on secondary forests under various climate change scenarios and is an important reference for predicting and dealing with the impact of global climate change on the adaptive management and protection of secondary ecosystems.

Keywords: climate warming; secondary ecosystem; high latitude; species composition; tree diversity



Citation: Liu, B.; Liao, C.; Chang, Y. Changing Dynamic of Tree Species Composition and Diversity: A Case Study of Secondary Forests in Northern China in Response to Climate Change. *Forests* **2024**, *15*, 322. <https://doi.org/10.3390/f15020322>

Academic Editors: Tiziana Danise and Antonietta Fioretto

Received: 1 January 2024

Revised: 26 January 2024

Accepted: 1 February 2024

Published: 8 February 2024



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1. Introduction

Extensive experiments by many scientists have long demonstrated the issue of global climate change. There is a consistent trend of rising temperatures with climate change from the current trend and the predictions of climate change. The global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 °C higher than in 1850–1900 [1]. While the unprecedented changes in global temperatures due to increased greenhouse gases affect the terrestrial ecosystem, which is highly sensitive to temperature changes [2,3], humans are increasingly altering the diversity of life on Earth through activities that drive climate change, e.g., the overexploitation of resources, severe pollution, and habitat fragmentation [4–6]. However, various arguments have been made regarding the decrease or increase in species diversity and richness caused by climate warming [7–11].

This indicates that the response of plants to climate warming varies depending on the characteristics of the site conditions and functional groups of plants, which profoundly influence their growth, distribution, and reproduction. Kazakis et al. [12] and Pickering et al. [13] found that the distribution of shrubs adapted to warm temperatures, and invasive plants gradually migrated towards high-altitude areas. Klanderud et al. [14] investigated the dominant shrubs in the mountainous areas of southern Norway and showed that they were gradually replaced by suitable herbs owing to climate change. Rafferty et al. [15] noted that the phenological period of flowering plants is affected by climate change, which leads to the extinction of other related species. Wehn et al. [16] studied the impact of climate change on plant diversity. They reported that species richness increased with increasing temperature; however, it did not correlate with changes in precipitation gradients. Extensive studies have shown that one of the critical driving forces of changes in global plant diversity in forest ecosystems is climate change, which will replace different forest ecosystems, especially in the coniferous forests of frigid zones, shrubby areas, and northern forests [17]. Therefore, understanding the interaction between climate change and plant diversity is of great theoretical and practical significance for protecting biodiversity and maintaining ecosystem stability.

The acceleration of warming in China from 1960 to 2019, reaching $0.27^{\circ}\text{C}/10\text{ a}$, was greater than the global trend for the same period, and there was an obvious regional difference [18]. That is, the increasing temperature value in the northern region was greater than in the southern region [19]. The Heilongjiang River Basin is crucial for biodiversity conservation, the functional maintenance of carbon sinks, and the protection of black soil productivity [20]. Climate warming is most pronounced in Heilongjiang Province, the first northernmost province of China to react to climate change [21]. In addition, in an area that, through human activities, had lost the structure, function, species composition, and productivity normally associated with a natural forest type expected on the site, a large area of secondary forest formed from natural regeneration in the Xiaoxing'an Mountain forest region [22]. Under the dual pressures of future climate change and human disturbances, the restoration and succession of secondary forests will become more severe [23]. So far, the main body of forest resources in China is secondary forests, of which research has received increasing attention, mainly focusing on the growth and regeneration of secondary forests [24–27]; the composition, structural characteristics, and distribution pattern of secondary communities [28,29]; the degradation characteristics of secondary forests [30]; the impact of foster management on secondary forests [31,32]; and the changes or impacts of soil and soil microbes during secondary succession [33–35]. However, little information is available regarding the succession patterns of secondary forests in northern China under the influence of climate warming.

Studying the succession for secondary communities contributes to the restoration and reconstruction of ecosystems, as species diversity is closely related to community succession. The dynamic characteristics of community succession are reflected in species diversity, which is important for community information. Therefore, researching the species diversity of communities is more beneficial for understanding the composition, structure, function, and dynamics of communities and for grasping their general rules [36]. Yan et al. [37], Xiao et al. [38], and Yuan et al. [39] explored the effects of plant diversity in secondary forests on the physical and chemical properties of soil. Li et al. [40] studied the effects of plant diversity and soil properties on microbial communities in secondary broadleaf forests under different management densities. Many scholars have analyzed the plant diversity of secondary forests for different tree species in tropical and subtropical regions [36,41–45]. However, the responses of secondary communities to climate change in the high-latitude northern regions of China are still unclear.

In our study, a series of field surveys were performed to investigate the growth, species composition, richness of trees, and changes in tree species diversity in the Xiaoxing'an mountain forest region, Heilongjiang province, northern China, from 2015 to 2021. Our study specifically aimed to address two research questions: (1) How does species com-

position change in different types of secondary forests in northern China during climate warming? (2) What is the response of tree species diversity to climate warming in northern secondary forests in China?

2. Methods

2.1. Study Area

The experimental field was located in Heihe City and Yichun City, between the mountains of Daxing'an and Xiaoxing'an in China (Figure 1). The geomorphic type is primarily mountainous and hilly, approximately 400 m above sea level, and belongs to the transitional zone between temperate and frigid temperatures. The annual precipitation is 550–620 mm, mainly in summer and autumn. The study site was considered one of the regions with the most obvious climate warming in Heilongjiang Province, with an annual mean temperature of $-2\text{ }^{\circ}\text{C}$ (from $-40\text{ }^{\circ}\text{C}$ in January to $36\text{ }^{\circ}\text{C}$ in July). The zonal soil is dark brown forest soil, whereas nonzonal soil includes meadow, swamp, and peat soils. The vegetation shows interlaced and transitional flora characteristics because it is located between the mountains of Daxing'an and Xiaoxing'an. The most common broadleaf tree species is birch, including *Betula platyphylla*, *Betula costata*, and *Betula dahurica*. Other broadleaf trees include *Tilia amurensis*, *Populus davidiana*, *Quercus mongolica*, *Alnus sibirica*, *Acer ukurunduense*, *Ulmus laciniata*, *Acer pictum*, etc. The main coniferous species are *Pinus koraiensis* and *Larix gmelinii*, and some cool-temperature tree species in the coniferous forests of Eurasia, such as *Abies nephrolepis*, *Picea koraiensis*, *Picea jezoensis* var. *microsperma*, etc.

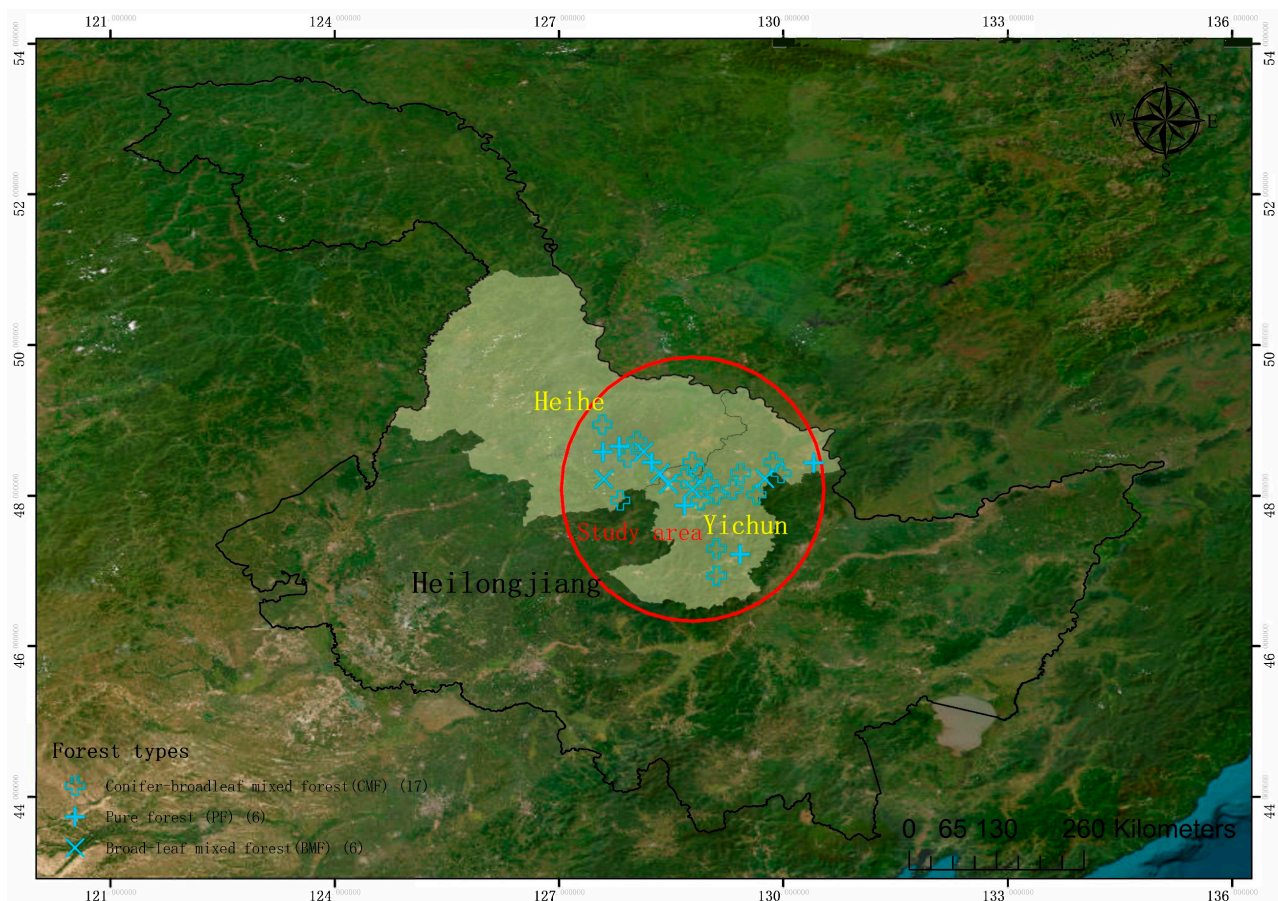


Figure 1. Location of permanent quadrats used in the analysis of diversity for pure forest, broadleaf mixed forest, and conifer–broadleaf mixed forest. (Each blue symbol represents the location of one permanent quadrat; numbers represent the numbers of permanent quadrats for each type of forest).

2.2. Experimental Design

The experiment was initiated in 2015 in Heihe City and Yichun City, between the mountains of Daxing'an and Xiaoxing'an. Twenty-nine fixed quadrats measuring 0.6 ha (20 m × 30 m) each were selected separately in areas far from roads less affected by human activity. In addition, according to our investigation, they were not disturbed by fires, pests, or diseases from 2015 to 2021. The quadrats were divided into three types: pure forest, broadleaf mixed forest, and conifer–broadleaf mixed forest. The pure forest included coniferous pure forests (quadrats No. 2 and 7) and broadleaf pure forests (quadrats No. 4, 5, 6, and 20), of which the main tree species were *L. gmelinii*, *B. platyphylla*, *A. sibirica*, etc. The broadleaf mixed forest included quadrats No. 3, 11, 12, 13, 14, and 15, and the main tree species included *B. platyphylla*, *Populus davidiana*, *Q. mongolica*, etc. Moreover, the conifer–broadleaf mixed forest includes quadrats No. 1, 8, 9, 10, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, and 29. The species and number of trees in each plot are given in Table 1.

Table 1. Basic information for the experimental sites of different forest types in northern China in 2015.

ID of Quadrat	Vegetation Information					Topography			
	Dominant Species	Number of Trees	Average DBH/cm	Average Height/m	Crown Density	Coverage/%	Elevation/m	Slope/°	Aspect
1	<i>L. gmelinii</i> , <i>B. platyphylla</i>	11	23.1	18.8	0.2	95	420	2	—
2	<i>L. gmelinii</i>	30	15.0	12.8	0.3	85	270	1	—
3	<i>B. platyphylla</i> , <i>Populus davidiana</i>	88	12.5	15.6	0.7	80	470	2	—
4	<i>B. platyphylla</i>	113	8.9	12.3	0.6	95	450	1	—
5	<i>A. sibirica</i>	103	7.1	6.2	0.7	95	240	3	—
6	<i>Q. mongolica</i>	70	16.6	8.0	0.7	85	400	38	South
7	<i>Picea koraiensis</i>	71	17.8	12.9	0.7	90	400	6	Southeast
8	<i>Picea koraiensis</i> , <i>A. ukurunduense</i> , <i>Pinus koraiensis</i>	60	12.7	15.3	0.5	90	630	6	Northeast
9	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>P. jezoensis</i> var. <i>microsperma</i>	42	17.6	16.9	0.4	90	450	2	—
10	<i>Picea koraiensis</i> , <i>Pinus koraiensis</i> , <i>Ulmus davidiana</i> var. <i>Japonica</i>	75	15.1	14.9	0.7	85	350	7	Southeast
11	<i>Syringa reticulata</i> , <i>Betula costata</i> , <i>Ulmus macrocarpa</i>	89	10.6	18.3	0.7	90	460	2	—
12	<i>B. platyphylla</i> , <i>Populus davidiana</i> , <i>Fraxinus</i> <i>mandshurica</i>	56	13.2	16.5	0.5	95	494	5	South
13	<i>B. platyphylla</i> , <i>Populus davidiana</i> , <i>A. pictum</i>	126	13.9	17.5	0.8	85	473	4	—
14	<i>B. platyphylla</i> , <i>U. macrocarpa</i> , <i>A. sibirica</i>	74	11.3	15.4	0.5	65	340	2	—
15	<i>B. platyphylla</i> , <i>Populus davidiana</i>	146	10.5	12.7	0.6	80	549	2	—
16	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>A. sibirica</i>	99	11.7	14.8	0.7	95	444	5	Northwest
17	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>Picea koraiensis</i> , <i>A. sibirica</i>	64	16.8	13.9	0.6	95	352	2	—

Table 1. Cont.

ID of Quadrat	Vegetation Information					Topography			
	Dominant Species	Number of Trees	Average DBH/cm	Average Height/m	Crown Density	Coverage/%	Elevation/m	Slope/°	Aspect
18	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>A. sibirica</i>	52	10.1	12.1	0.4	95	480	1	—
19	<i>B. costata</i> , <i>A. nephrolepis</i>	73	17.8	16.7	0.7	95	534	4	—
20	<i>B. platyphylla</i>	37	16.3	14.8	0.5	85	430	3	—
21	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>B. dahurica</i> , <i>T. amurensis</i>	54	13.3	14.2	0.5	95	373	3	—
22	<i>B. platyphylla</i> , <i>A. nephrolepis</i>	148	12.6	14.4	0.7	90	520	5	Northwest
23	<i>B. platyphylla</i> , <i>B. costata</i> , <i>A. nephrolepis</i>	79	17.3	15.7	0.7	80	442	14	North
24	<i>B. platyphylla</i> , <i>P. jezoensis</i> var. <i>microsperma</i> , <i>B. costata</i> , <i>A. nephrolepis</i>	122	10.5	13.9	0.8	95	540	6	Northwest
25	<i>A. ukurunduense</i> , <i>B. costata</i> , <i>A. nephrolepis</i> , <i>Acer tegmentosum</i>	48	19.8	16.3	0.7	90	458	15	East
26	<i>Picea koraiensis</i> , <i>A. ukurunduense</i> , <i>B. costata</i> , <i>A. nephrolepis</i>	74	12.6	13.9	0.6	90	666	5	Northwest
27	<i>Pinus koraiensis</i> , <i>B. costata</i> , <i>A. nephrolepis</i>	66	14.2	12.6	0.7	95	365	4	—
28	<i>B. platyphylla</i> , <i>L. gmelinii</i> , <i>T. amurensis</i>	65	13.6	14.4	0.7	95	318	4	—
29	<i>B. costata</i> , <i>A. pictum</i> , <i>A. nephrolepis</i> , <i>A. tegmentosum</i> , <i>U. laciniata</i>	67	13.4	17.5	0.6	95	517	10	Northeast

Detailed field surveys were conducted from July 2015 to July 2020. All tree species that appeared in the quadrats were recorded, and the surveyed characteristics included species name, diameter at breast height (DBH), height, coverage, and abundance. The importance values and species diversity indices were calculated using the characteristic values. The DBH ruler measured the DBH of each tree in all quadrats. The altimeter measured the heights of three to five trees of each species in their natural states. The average value was considered to be the community height. Abundance was defined as the number of trees in each quadrat. Community and species coverage was visually estimated by taking the percentage of the maximum projected area of each species in the entire plot area as the measurement result [46].

2.3. Climatic Data

The annual meteorological data (NCEP reanalysis datasets) were obtained from the National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research as a reference for regional climate change. The temperature and precipitation data are derived from the NCEP reanalysis datasets (downloaded from <ftp://ftp.cdc.noaa.gov> and <https://www.psl.noaa.gov>), with a spatial resolution of $2.5^{\circ} \times 2.5^{\circ}$. Temperature data include the global monthly average surface temperature from 1948 to 2021, mainly

produced by combining upper atmospheric information with land surface process models, which can better reflect large-scale climate change caused by increases in greenhouse gases and atmospheric circulation [47]. Precipitation data include the global monthly average precipitation from 1979 to 2022, mainly estimated by five satellites. This data type has been widely used in many domestic and international studies. In addition, Xu et al. [47] showed that the NCEP data were consistent with the measured values in their study of short-term climate change and interannual variability and have a high level of credibility.

2.4. Data Analysis

The α -diversity indicators selected in this study include the Margalef index (R), Shannon–Wiener index (H), Simpson index (H'), and Pielou index (E) to estimate the diversity of the community structure, and the calculation formulas are as follows [46,48]:

$$ra = \frac{a_i}{a_{total}} \quad (1)$$

$$IV = \frac{ra + rh + rc}{3} \quad (2)$$

$$R = S \quad (3)$$

$$H' = 1 - \sum_{i=1}^S p_i^2 \quad (4)$$

$$H = - \sum_{i=1}^S p_i \ln(p_i) \quad (5)$$

$$E = \frac{H}{\ln(S)} \quad (6)$$

$$p_i = \frac{IV_i}{IV_{total}} \quad (7)$$

where ra is the relative significance, a is the basal area of the breast height, IV is the importance value, rh is the relative abundance, and rc is the relative frequency. The importance value (IV) was calculated according to the ra , rh , and rc of each species, i is the tree species, p_i is the relative importance value of species i in each quadrat, and S is the total number of tree species in each quadrat.

The data were organized and summarized using the Excel 2010 software and processed, analyzed, and plotted using R language, version 4.13. A one-way ANOVA with Duncan's multiple range test was conducted in R language, version 4.13, to test the statistical significance of the mean values of the types of significant differences in the vegetation structure among forest types.

3. Results

3.1. Analysis of Regional Climate Change

3.1.1. Temperature

The four seasons of spring (March to May), summer (June to August), autumn (September to November), and winter (January, February, and December) were divided according to the characteristics of the seasonal distribution in northern China. The spatial variation in seasonal temperature differences between 2015 and 2021 is shown in Figure 2. There was an obvious trend in temperature differences throughout the four seasons in Heilongjiang Province of China from 2015 to 2021. The temperature of the entire province significantly increased in autumn. In contrast, the temperature difference in spring increased with latitude, which was opposite to the distribution characteristics of the latitude zonality of temperature. During summer, the temperature increased slightly in the northeast and decreased slightly in the southwest. The rate of temperature decrease gradually increases from north to south during winter.

It was found that the temperature increased most obviously in autumn, reaching over 1 °C, and it increased by about 0.5 °C in spring from the spatial variation of seasonal temperature differences in the study area. On the contrary, there was a slight cooling in summer, and the temperature dropped by about 0.5 °C in winter in the study area. However, the temperature in the study area showed an overall upward trend from 2015 to 2021.

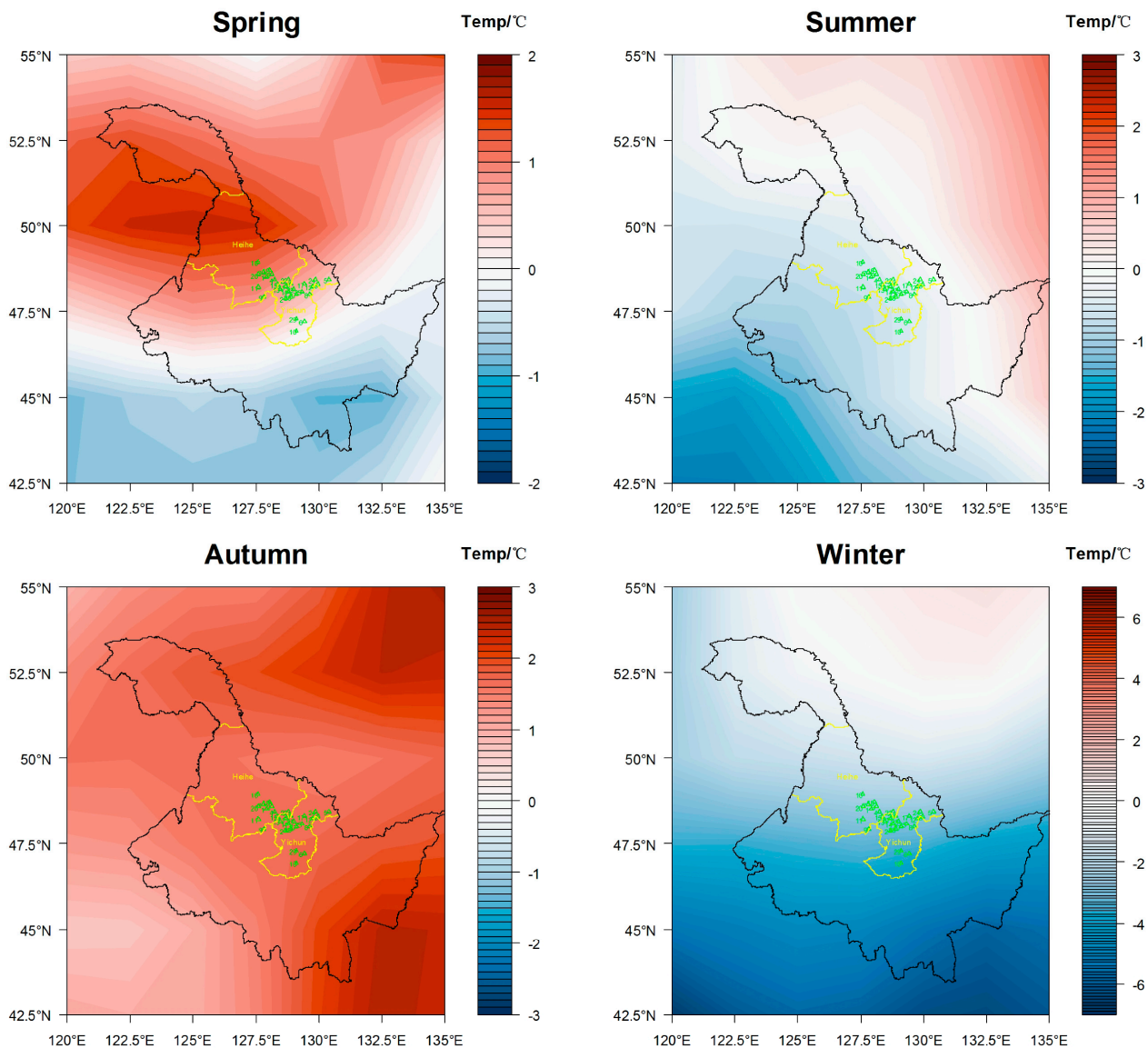


Figure 2. The spatiotemporal variation of temperature in the four seasons. (Each green element represents the location of one permanent quadrat; the yellow line represent the urban boundaries).

3.1.2. Precipitation

The spatial variation in seasonal precipitation differences between 2015 and 2021 is shown in Figure 3. Precipitation increased slightly in the south, but decreased in the northern part of Heilongjiang Province from 2015 to 2021. There was an obvious increase in precipitation across the entire province during summer, except in the eastern region. In contrast to the rising precipitation levels throughout the province in autumn, they remained relatively stable or decreased slightly in winter.

The precipitation in spring, summer, and autumn increased in the following order: summer (1.5 mm) > autumn (1.0 mm) > spring (0.5 mm), whereas it decreased slightly in winter.

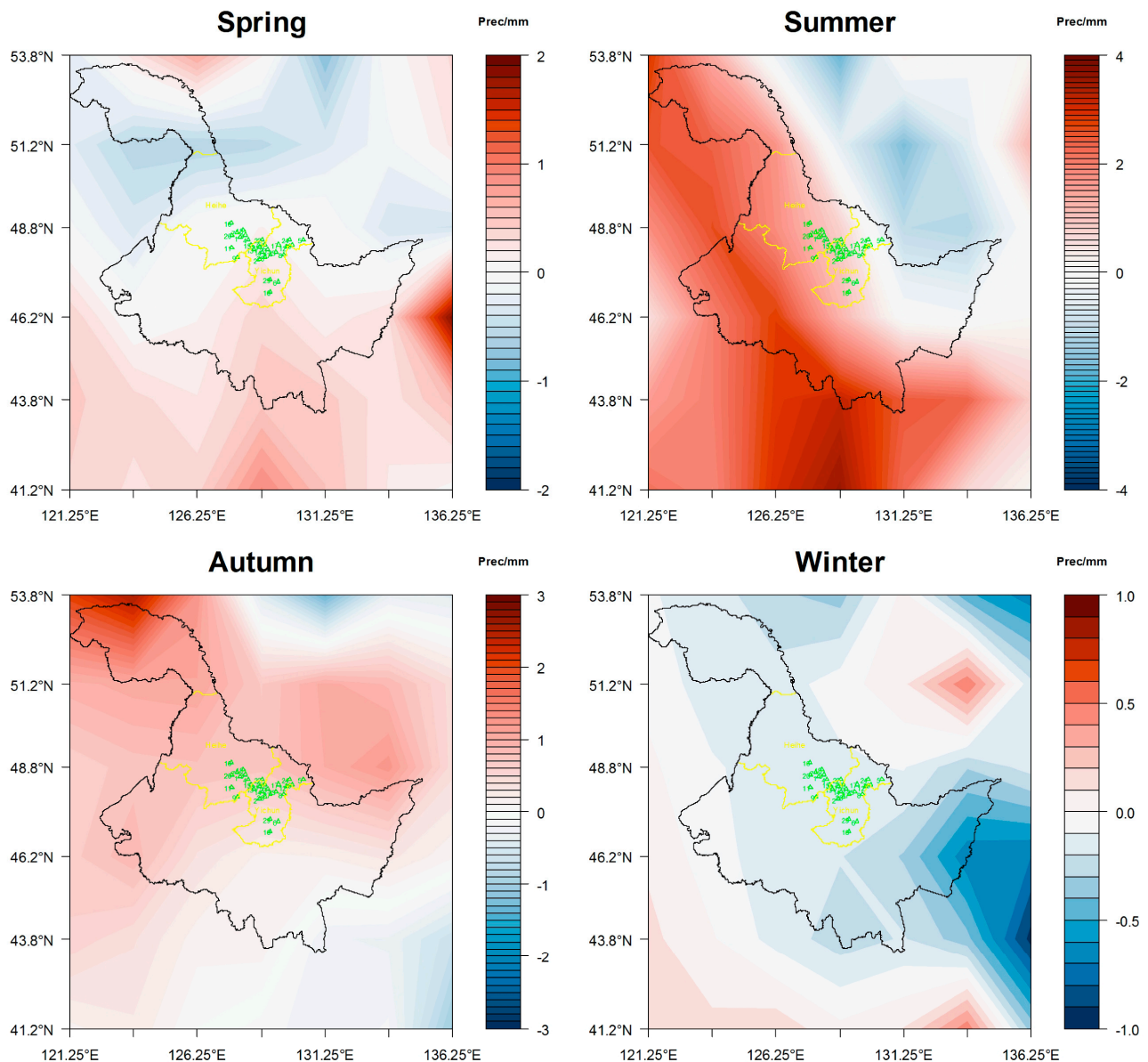


Figure 3. The spatiotemporal variation of precipitation in the four seasons. (Each green element represents the location of one permanent quadrat; the yellow line represent the urban boundaries).

3.2. Changes in the Composition of Tree Species

The changes in the IV of each tree species in the study area are presented in Table 2. The principal tree species was *B. platyphylla*, with an IV of approximately 20.0%, followed by *L. gmelinii* and *A. nephrolepis* with an IV of approximately 10.0%, followed by *B. costata*, *Picea koraiensis*, *Populus davidiana*, *Pinus koraiensis*, *T. amurensis*, *Q. mongolica*, *A. sibirica*, *A. pictum*, *A. ukurunduense*, *P. jezoensis* var. *microsperma*, *Acer tegmentosum*, *B. dahurica*, *Syringa reticulata*, *U. laciniata*, *Prunus davidiana*, *Salix taraikensis*, *Fraxinus mandshurica*, and *Ulmus macrocarpa*, which were all below 7.0%. There were 29 tree species in these quadrats in 2015 and 34 in 2021. The five newly emerged tree species were *Alnus japonica*, *Acer tataricum*, *Salix matsudana*, *Sorbus alnifolia*, and *Malus baccata*. In addition, there was no obvious difference between 2015 and 2021 in the changes in the IV of each tree species, except for *S. taraikensis*, where the IV increased from 1.1% to 3.1%.

Table 2. Changes in the composition of tree species in the study area from 2015 to 2021.

Tree Species	2015				2021			
	<i>rh</i>	<i>ra</i>	<i>rc</i>	<i>IV</i>	<i>rh</i>	<i>ra</i>	<i>rc</i>	<i>IV</i>
<i>Betula platyphylla</i>	29.2	21.1	12.2	20.8	26.0	20.5	11.2	19.2
<i>Larix gmelinii</i>	7.5	14.1	7.1	9.6	6.2	13.9	7.0	9.0
<i>Abies nephrolepis</i>	9.5	13.2	5.6	9.4	8.8	12.6	5.1	8.8
<i>Betula costata</i>	5.5	9.5	5.6	6.9	4.7	8.6	5.6	6.3
<i>Picea koraiensis</i>	6.8	6.8	5.1	6.2	6.3	7.0	5.6	6.3
<i>Populus davidiana</i>	7.3	6.8	2.5	5.5	6.0	6.7	2.8	5.2
<i>Pinus koraiensis</i>	2.7	5.1	5.1	4.3	2.7	5.0	4.7	4.1
<i>Tilia amurensis</i>	2.5	3.6	6.6	4.2	2.7	3.6	6.1	4.1
<i>Quercus mongolica</i>	4.6	5.7	2.0	4.1	4.1	4.9	2.3	3.8
<i>Alnus sibirica</i>	4.5	2.0	5.1	3.9	4.0	2.1	4.7	3.6
<i>Acer pictum</i>	2.8	2.5	5.6	3.6	2.6	2.3	5.6	3.5
<i>Acer ukurunduense</i>	3.4	0.9	5.6	3.3	4.8	1.2	5.6	3.9
<i>Picea jezoensis</i> var. <i>microsperma</i>	2.0	1.9	5.6	3.2	1.9	2.1	5.1	3.0
<i>Acer tegmentosum</i>	1.9	1.0	4.1	2.3	2.5	1.2	3.7	2.5
<i>Betula dahurica</i>	1.5	1.3	3.6	2.1	1.3	1.3	3.3	2.0
<i>Syringa reticulata</i>	2.1	0.5	2.0	1.5	2.7	0.8	1.9	1.8
<i>Ulmus laciniata</i>	0.6	1.3	2.5	1.5	0.6	1.1	2.3	1.3
<i>Prunus davidiana</i>	0.9	0.5	2.5	1.3	0.9	0.8	2.3	1.3
<i>Salix taraikensis</i>	0.6	0.2	2.5	1.1	5.2	1.1	2.8	3.1
<i>Fraxinus mandshurica</i>	0.9	0.6	1.5	1.0	1.1	0.8	1.4	1.1
<i>Ulmus macrocarpa</i>	1.2	0.7	1.0	1.0	1.8	1.1	0.9	1.3
<i>Salix raddeana</i>	0.5	0.3	1.0	0.6	0.4	0.3	0.9	0.5
<i>Padus racemosa</i>	0.2	0.03	1.5	0.6	0.2	0.03	1.4	0.5
<i>Ulmus davidiana</i> var. <i>japonica</i>	0.8	0.3	0.5	0.5	0.9	0.5	0.9	0.8
<i>Phellodendron amurense</i>	0.2	0.1	1.0	0.4	0.2	0.1	1.4	0.6
<i>Sorbus pohuashanensis</i>	0.2	0.1	1.0	0.4	0.2	0.1	0.9	0.4
<i>Ulmus pumila</i>	0.1	0.02	0.5	0.2	0.1	0.04	0.5	0.2
<i>Rhamnus davurica</i>	0.1	0.01	0.5	0.2	0.1	0.02	0.5	0.2
<i>Aralia elata</i>	0.1	0.01	0.5	0.2	0.1	0.02	0.9	0.4
<i>Alnus japonica</i>	—	—	—	—	0.9	0.2	0.5	0.5
<i>Acer tataricum</i>	—	—	—	—	0.1	0.01	0.5	0.2
<i>Salix matsudana</i>	—	—	—	—	0.1	0.01	0.5	0.2
<i>Sorbus alnifolia</i>	—	—	—	—	0.1	0.01	0.5	0.2
<i>Malus baccata</i>	—	—	—	—	0.1	0.01	0.5	0.2

Note: *rh*—the relative abundance; *ra*—the relative significance; *rc*—the relative frequency; *IV*—the importance value.

However, differences in the abundance of principal tree species were observed at the quadrat scale from 2015 to 2021 (Table 3). Except for quadrat No. 2, where the forest type changed from pure forest, mainly composed of *L. gmelinii*, to a coniferous and broadleaf mixed forest, mainly composed of *L. gmelinii* and *B. platyphylla*, the forest types in the remaining 28 quadrats remained unchanged. However, there were 14 quadrats (including quadrat No.2) with obvious changes in the composition or relative abundance of the principal tree species among all 29 quadrats. Although the composition of the principal tree species in quadrats No. 10, 12, 14, 21, and 27 did not change, obvious differences were observed in the relative abundance of each principal tree species between 2015 and 2021. The dominant tree species in quadrat No. 5 changed from *A. sibirica* to *S. taraikensis*, with significant changes in tree species composition. *A. tegmentosum* and *A. japonica*, which were not found in 2015, appeared in quadrats No. 8 and 18 and became one of the principal tree species, indicating that the proportion of broadleaf tree species had significantly increased in both quadrats. While *Picea koraiensis* became one of the principal tree species in 2021, it changed the composition of tree species in quadrat No. 28, resulting in a difference in the proportion of coniferous and broadleaf tree species between 2015 and 2021. In addition, the relative abundance of the principal tree species *U. macrocarpa* decreased to below 10.0% in quadrat No. 11, with an obvious increase from 43.9% to 54.7% for the relative abundance of

S. reticulata. Similarly, the relative abundance of *Picea koraiensis*, the principal tree species in quadrat No. 26, decreased, while the relative abundance of *A. ukurunduense* increased from 39.1% to 53.8%. The principal tree species, *B. costata* in quadrat No. 24 and *U. laciniata* in quadrat No. 29, both decreased to below 10.0%, while the other principal tree species did not change obviously and even decreased synchronously, indicating a balanced increase in the relative abundance of nondominant tree species.

Table 3. Changes in the composition and abundance of principal tree species in the quadrats from 2015 to 2021.

ID of Quadrat	2015	2021	Changes
1	<i>L. gmelinii</i> + <i>B. platyphylla</i> (63.6% + 27.3%)	<i>L. gmelinii</i> + <i>B. platyphylla</i> (63.6% + 27.3%)	No
2	<i>L. gmelinii</i> (81.3%)	<i>B. platyphylla</i> + <i>L. gmelinii</i> (59.3% + 40.7%)	Yes
3	<i>B. platyphylla</i> + <i>Populus davidiana</i> (62.0% + 30.4%)	<i>B. platyphylla</i> + <i>Populus davidiana</i> (61.7% + 29.6%)	No
4	<i>B. platyphylla</i> (82.2%)	<i>B. platyphylla</i> (81.4%)	No
5	<i>A. sibirica</i> (77.8%)	<i>S. taraiensis</i> (89.3%)	Yes
6	<i>Q. mongolica</i> (100.0%)	<i>Q. mongolica</i> (100.0%)	No
7	<i>Picea koraiensis</i> (72.4%)	<i>Picea koraiensis</i> (72.4%)	No
8	<i>Picea koraiensis</i> + <i>A. ukurunduense</i> + <i>Pinus koraiensis</i> (47.8% + 15.2% + 13.0%)	<i>Picea koraiensis</i> + <i>A. ukurunduense</i> + <i>A. tegmentosum</i> + <i>Pinus koraiensis</i> (38.3% + 28.3% + 11.7% + 10.0%)	Yes
9	<i>L. gmelinii</i> + <i>B. platyphylla</i> + <i>P. jezoensis</i> var. <i>microsperma</i> (43.2% + 37.8% + 10.8%)	<i>L. gmelinii</i> + <i>B. platyphylla</i> + <i>P. jezoensis</i> var. <i>microsperma</i> (40.0% + 37.5% + 12.5%)	No
10	<i>Picea koraiensis</i> + <i>U. davidiana</i> var. <i>Japonica</i> + <i>Pinus koraiensis</i> (20.6% + 20.6% + 17.5%)	<i>U. davidiana</i> var. <i>Japonica</i> + <i>Picea koraiensis</i> + <i>Pinus koraiensis</i> (23.5% + 19.1% + 16.2%)	Yes
11	<i>S. reticulata</i> + <i>B. costata</i> + <i>U. macrocarpa</i> (43.9% + 15.2% + 10.6%)	<i>S. reticulata</i> + <i>B. costata</i> (54.7% + 11.6%)	Yes
12	<i>B. platyphylla</i> + <i>F. mandshurica</i> + <i>Populus davidiana</i> (27.5% + 25.0% + 17.5%)	<i>F. mandshurica</i> + <i>B. platyphylla</i> + <i>Populus davidiana</i> (29.6% + 20.4% + 13.0%)	Yes
13	<i>Populus davidiana</i> + <i>B. platyphylla</i> + <i>A. pictum</i> (50.5% + 20.4% + 15.5%)	<i>Populus davidiana</i> + <i>B. platyphylla</i> + <i>A. pictum</i> (48.6% + 19.6% + 15.0%)	No
14	<i>B. platyphylla</i> + <i>U. macrocarpa</i> + <i>A. sibirica</i> (50.0% + 28.6% + 19.0%)	<i>U. macrocarpa</i> + <i>B. platyphylla</i> + <i>A. sibirica</i> (44.4% + 33.3% + 19.0%)	Yes
15	<i>B. platyphylla</i> + <i>Populus davidiana</i> (62.5% + 25.0%)	<i>B. platyphylla</i> + <i>Populus davidiana</i> (59.1% + 23.6%)	No
16	<i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>A. sibirica</i> (46.7% + 28.0% + 25.3%)	<i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>A. sibirica</i> (46.4% + 26.2% + 22.6%)	No
17	<i>Picea koraiensis</i> + <i>L. gmelinii</i> + <i>A. sibirica</i> + <i>B. platyphylla</i> (45.7% + 23.9% + 19.6% + 10.9%)	<i>Picea koraiensis</i> + <i>L. gmelinii</i> + <i>A. sibirica</i> + <i>B. platyphylla</i> (45.7% + 23.9% + 19.6% + 10.9%)	No
18	<i>L. gmelinii</i> + <i>B. platyphylla</i> + <i>A. sibirica</i> (46.2% + 26.9% + 26.9%)	<i>A. japonica</i> + <i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>A. sibirica</i> (35.3% + 27.5% + 23.5% + 13.7%)	Yes
19	<i>A. nephrolepis</i> + <i>B. costata</i> (56.3% + 15.6%)	<i>A. nephrolepis</i> + <i>B. costata</i> (56.3% + 15.6%)	No
20	<i>B. platyphylla</i> (77.1%)	<i>B. platyphylla</i> (77.1%)	No

Table 3. Cont.

ID of Quadrat	2015	2021	Changes
21	<i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>B. dahurica</i> + <i>T. amurensis</i> (31.4% + 28.6% + 14.3% + 14.3%)	<i>T. amurensis</i> + <i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>B. dahurica</i> (23.1% + 21.2% + 21.2% + 11.5%)	Yes
22	<i>B. platyphylla</i> + <i>A. nephrolepis</i> (38.3% + 25.0%)	<i>B. platyphylla</i> + <i>A. nephrolepis</i> (37.4% + 24.4%)	No
23	<i>B. costata</i> + <i>A. nephrolepis</i> + <i>B. platyphylla</i> (30.3% + 27.3% + 22.7%)	<i>B. costata</i> + <i>A. nephrolepis</i> + <i>B. platyphylla</i> (29.4% + 26.5% + 22.1%)	No
24	<i>B. platyphylla</i> + <i>A. nephrolepis</i> + <i>P. jezoensis</i> var. <i>microsperma</i> + <i>B. costata</i> (27.3% + 20.5% + 15.9% + 10.2%)	<i>B. platyphylla</i> + <i>A. nephrolepis</i> + <i>P. jezoensis</i> var. <i>microsperma</i> (24.6% + 20.3% + 11.9%)	Yes
25	<i>A. nephrolepis</i> + <i>B. costata</i> + <i>A. ukurunduense</i> + <i>A. tegmentosum</i> (28.6% + 23.8% + 11.9% + 11.9%)	<i>A. nephrolepis</i> + <i>B. costata</i> + <i>A. ukurunduense</i> + <i>A. tegmentosum</i> (27.3% + 22.7% + 13.6% + 11.4%)	No
26	<i>A. ukurunduense</i> + <i>B. costata</i> + <i>A. nephrolepis</i> + <i>Picea koraiensis</i> (39.1% + 26.1% + 17.4% + 13.0%)	<i>A. ukurunduense</i> + <i>B. costata</i> + <i>A. nephrolepis</i> (53.8% + 18.5% + 15.4%)	Yes
27	<i>A. nephrolepis</i> + <i>B. costata</i> + <i>P. koraiensis</i> Sieb. et Zucc. (30.4% + 10.0% + 8.9%)	<i>A. nephrolepis</i> + <i>Pinus koraiensis</i> + <i>B. costata</i> (27.4% + 12.9% + 9.7%)	Yes
28	<i>B. platyphylla</i> + <i>L. gmelinii</i> + <i>T. amurensis</i> (48.8% + 23.3% + 11.6%)	<i>B. platyphylla</i> + <i>Picea koraiensis</i> + <i>L. gmelinii</i> + <i>T. amurensis</i> (36.8% + 21.1% + 17.5% + 10.5%)	Yes
29	<i>B. costata</i> + <i>A. tegmentosum</i> + <i>A. nephrolepis</i> + <i>U. laciniata</i> + <i>A. pictum</i> (25.6% + 16.3% + 11.6% + 11.6% + 11.6%)	<i>A. nephrolepis</i> + <i>B. costata</i> + <i>A. tegmentosum</i> + <i>A. pictum</i> (25.8% + 16.7% + 16.7% + 12.1%)	Yes

Note: The first row shows the composition of species, while the second row shows the proportion of tree species in this quadrat.

3.3. Analysis of Diversity of Tree Species

Significant differences were observed in the Margalef, Shannon–Wiener index, Simpson, and Pielou indices among the forest types in both 2015 and 2021 (Figures 4 and 5). In 2015, the Shannon–Wiener, Simpson, and Margalef indices were significantly lower for the pure forest compared to the broadleaf mixed forest and the conifer–broadleaf mixed forest ($p < 0.05$), whereas there was no significant difference between the broadleaf mixed forest and the conifer–broadleaf mixed forest. Otherwise, there were no significant differences between the pure forest and the mixed broadleaf forest or between the mixed broadleaf forest and the mixed conifer–broadleaf forest in terms of the Pielou index, which was remarkably lower in the pure forest than in the mixed conifer–broadleaf forest ($p < 0.05$). The significant differences in the Shannon–Wiener index, Simpson, and Margalef indices among the different forest types in 2021 were consistent with those in 2015, except for the Pielou index. The highest value for the Pielou index was in the conifer–broadleaf mixed forest ($p < 0.05$), whereas it was not significantly different between the pure forest and broadleaf mixed forest in 2021.

Although there was no obvious difference between 2015 and 2021 in changes in tree diversity for the same forest type, the trend of change for each index was interesting (Figure 6). For the pure forest, the Shannon–Wiener index, Simpson, and Pielou indices decreased from 2015 to 2021, and the upper and lower limits fluctuated because of the single tree species with poor stability. In the broadleaf mixed forest, the fluctuations in all indices showed a state of contraction, which was characterized by a decrease in the upper limit and an increase in the lower limit. In contrast to the pure forest, the Shannon–Wiener, Simpson, and Pielou indices showed an upward trend in the conifer–broadleaf mixed forest, regardless of the upper limit, lower limit, or mean value.

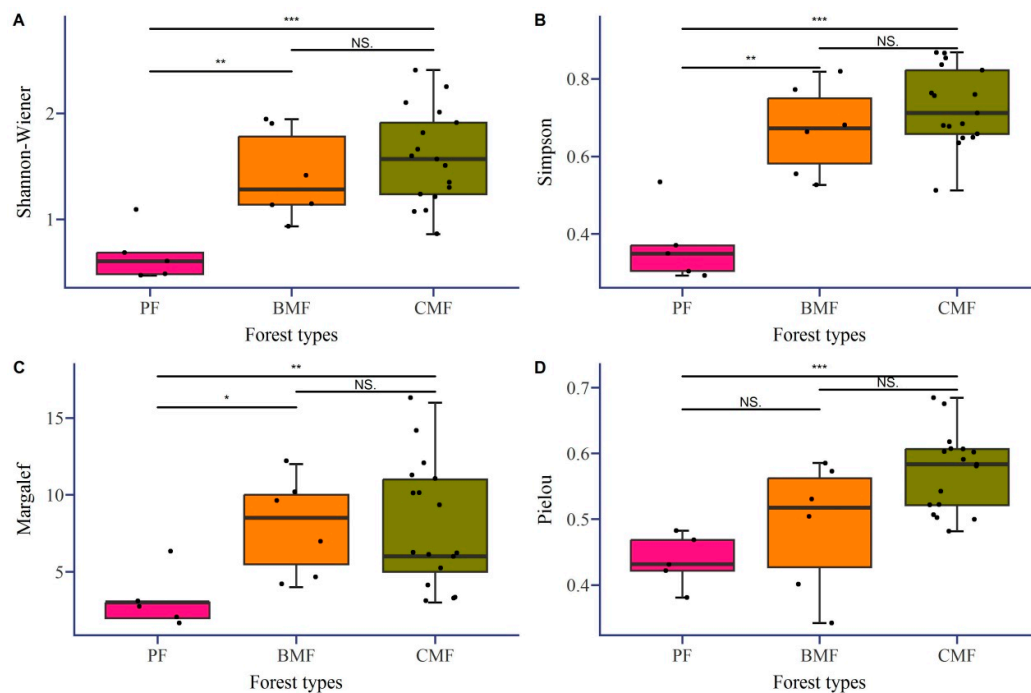


Figure 4. Changes in tree species diversity of different forest types in 2015 (A–D). * is significantly different at $p < 0.05$; ** is significantly different at $p < 0.01$; *** is significantly different at $p < 0.001$; NS indicates nonsignificant. PF—pure forest; BMF—broadleaf mixed forest; CMF—conifer–broadleaf mixed forest.

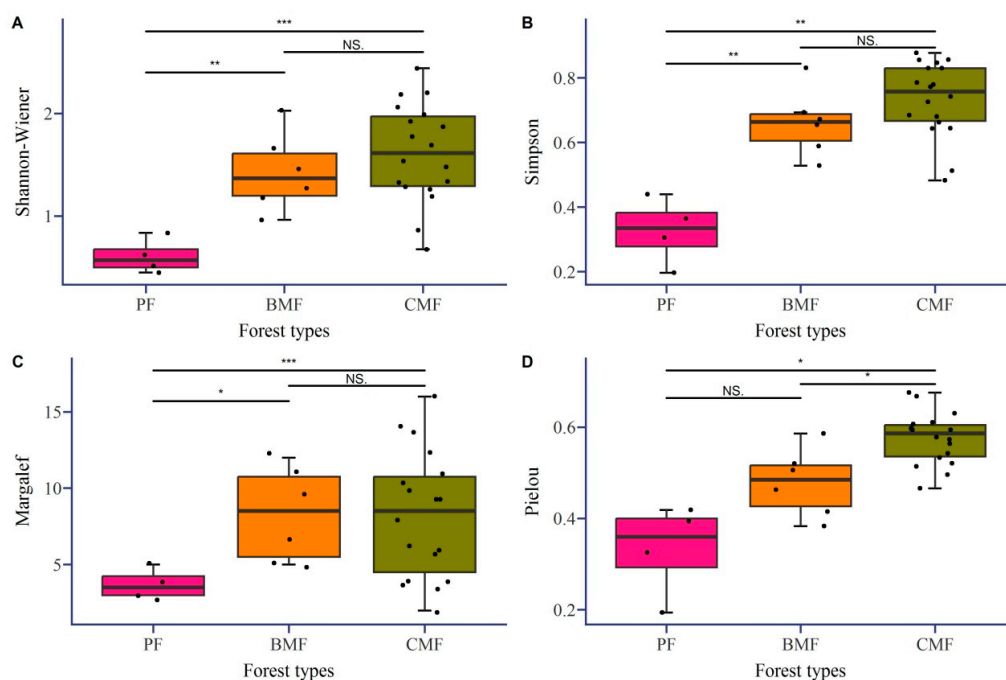


Figure 5. Changes in tree species diversity of different forest types in 2021 (A–D). * is significantly different at $p < 0.05$; ** is significantly different at $p < 0.01$; *** is significantly different at $p < 0.001$; NS indicates nonsignificant. PF—pure forest; BMF—broadleaf mixed forest; CMF—conifer–broadleaf mixed forest.

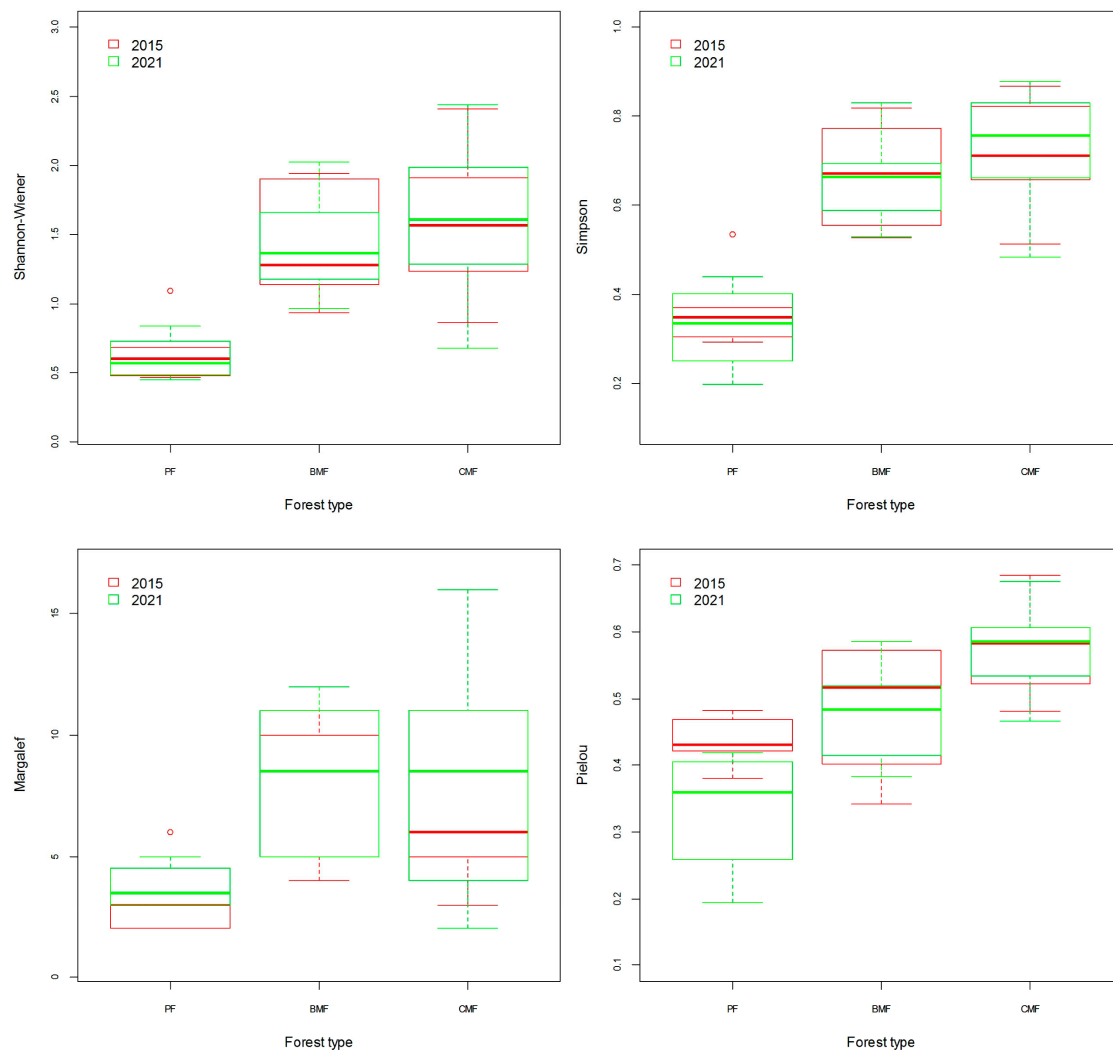


Figure 6. The fluctuation in tree species diversity for different forest types from 2015 to 2021. PF—pure forest; BMF—broadleaf mixed forest; CMF—conifer–broadleaf mixed forest.

4. Discussion

Animals and plants adapt to climate change by changing their distributional ranges and altering the periods of growth or reproduction [49]. Therefore, one of the most important indices for explaining the distribution of species and changes in diversity is climate heterogeneity, among which changes in temperature and precipitation are extremely critical for plant diversity and ecosystem diversity. From 2015 to 2021, the temperature of the study area increased in spring and autumn, whereas precipitation also increased in spring, summer, and autumn. Yang et al. [50] stated that temperature is a key climatic factor constraining changes in the phenological period of deciduous trees in Xi'an Province, China. The faster the temperature returns in spring, the earlier the tree leaf blooming period. Similarly, an increase in temperature in autumn delays leaf browning. As the northernmost province in China, Heilongjiang Province responds more significantly to climate warming. The important values of coniferous tree species in the study area, such as *L. gmelinii*, *A. nephrolepis*, *Pinus koraiensis*, and other species, showed a decreasing trend from 2015 to 2021. However, the important values of many broadleaf tree species increased, such as *A. ukurunduense*, *A. tegmentosum*, *S. reticulata*, *S. taraiensis*, *U. macrocarpa*, *U. davidiana* var. *japonica*, *P. amurense*, *A. elata*, etc. Moreover, five tree species, *A. japonica*, *A. tataricum*, *S. matsudana*, *S. alnifolia*, and *M. baccata*, were found in the quadrats until 2021, and all were broadleaf tree species. The range of suitable habitats for broadleaf tree species expanded within the study area. This result is consistent with the research of Zhang et al. [51], who

simulated the effects of climate change on eastern Eurasian forests, and Li [52], who studied the vulnerability of six typical deciduous broadleaf tree species to future climate change in China, which indicates that the range of suitable habitats for broadleaf tree species will gradually expand under the effect of future climate warming. However, the decrease in the importance values of coniferous tree species or some local broadleaf tree species in the study area showed that the distribution of coniferous tree species or broadleaf tree species in the unique region will be reshaped. The limiting factors for some local tree species that require stricter climate conditions will be more stringent with global climate change [53,54].

According to the FAO (2010), 57% of the forests worldwide result from natural regeneration. Angela et al. [55] presented that secondary forests play an important role in biodiversity conservation. Changes in species composition inevitably lead to changes in community structure, affecting plant diversity and ultimately leading to completely different directions of secondary succession. Although there was no significant difference in the annual variation of diversity for each secondary forest community type in the study area from 2015 to 2021, the trend of variation for the three secondary forest types (pure forest, broadleaf mixed forest, and conifer–broadleaf mixed forest) was interesting. For the secondary pure forests, the upper and lower limits fluctuated significantly, and the diversity showed a further downward trend because of the single structure of the tree species and the poor overall stability of the stand. Numerous studies have shown that mixed forests have a high species diversity and can significantly improve ecosystem stability [56–60]. This study also found that the species richness, Shannon–Wiener index, and Simpson index of conifer–broadleaf mixed forests were significantly higher than those of pure forests in different years, with smaller fluctuations between 2015 and 2021. Moreover, the Pielou index showed a higher level of convergence with annual changes, indicating that the distribution of various tree species in the quadrats of conifer–broadleaf mixed forests tended to be average under conditions of climate change, and the overall structure of the forest stand was complete and stable. However, it is interesting to note that, for both types of mixed forests, the diversity of broadleaf mixed forests significantly differed from the conifer–broadleaf mixed forests, showing a downward trend with obvious fluctuations between 2015 and 2021 (Figure 6). The Pielou index of the broadleaf mixed forest was significantly lower than that of the conifer–broadleaf mixed forest in 2021. This might be because of the positive response of broadleaf tree species to northern climate warming, leading to the encroachment of the living space of coniferous tree species in the original secondary broadleaf mixed forest by broadleaf tree species. Similarly, Rajesh et al. [61] reported that the vegetation shift from coniferous forest to broadleaf forest is seen as more dominant.

In summary, the changes in species composition in the study area were significant based on investigating changes in species composition and tree diversity of different types of secondary forests in the northern region of China, along with climate warming. First, there was an increase in the importance values of many broadleaf tree species, whereas the importance values of local coniferous and broadleaf tree species such as *B. platyphylla* and *L. gmelinii* et al., decreased. Second, there were significant differences in the succession characteristics of different types of secondary forests in northern China in response to climate change. The secondary conifer–broadleaf mixed forest had the highest stability, a clear direction of secondary succession, and the lowest degree of disturbance under the effect of climate warming. In contrast, the composition of the tree species was single, and stability was the worst in the secondary pure forest. However, the secondary broadleaf mixed forest in northern China, which was most easily overlooked, exhibited an unfavorable degradation trend due to the influence of climate change.

5. Conclusions

Our comparative study of different forest types for the secondary communities in the high-latitude northern regions of China from 2015 to 2021 revealed both similarities and differences in the changing dynamics of species composition and α -diversity under the influence of climate change, helping us to understand responses to climate change during

the restoration process of secondary forests. The temperature and precipitation in the study area showed an overall upward trend from 2015 to 2021. The importance values of local coniferous and broadleaf tree species, such as *B. platyphylla* and *L. gmelinii*, decreased, while those of other broadleaf tree species, such as *A. ukurunduense* and *A. tegmentosum*, increased. Moreover, five new tree species were found in the quadrats during the experiment, and all were broadleaf tree species. The Margalef index, Shannon–Wiener index, and Simpson index of conifer–broadleaf mixed forests were significantly higher than those of pure forests in different years, with smaller fluctuations between 2015 and 2021. Although there was no significant difference in the annual variation of diversity for each secondary forest community type in the study area from 2015 to 2021, the trend of variation for the three secondary forest types was different. The diversity showed a further downward trend for both the pure forest and the broadleaf mixed forest. Our results indicate that the changing dynamics of tree species composition and diversity for the secondary forests in northern China in response to climate change is completely different. These findings might facilitate a favorable succession trend for the secondary communities under the influence of climate change and improve the positive succession of secondary communities to produce ecological benefits of high value.

Author Contributions: Y.C. conceived and designed the research; B.L. wrote the paper; C.L. helped to improve the hypothesis; B.L. and C.L. carried out the fieldwork and the analysis. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by Priority Academic Program Development of Jiangsu provincial universities (PAPD).

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lee, H.; Calvin, K.; Dasgupta, D.; Krinner, G.; Mukherji, A.; Thorne, P.; Trisos, C.; Romero, J.; Aldunce, P.; Barret, K.; et al. Summary for Policymakers. In *Climate Change 2023: Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Lee, H., Romero, J., Eds.; Synthesis Report; IPCC: Geneva, Switzerland, 2023; pp. 1–34.
2. Jonathan, A.P.; Diarmid, C.; Tracey, H.; Jonathan, A.F. Impact of regional climate change on human health. *Nature* **2005**, *438*, 310–317.
3. Pan, S.A.; Li, X.H.; Feng, Q.H.; Liu, X.L.; Sun, J.X. Response of *Abies faxoniana* to future climate change and its potential distribution patterns in Sichuan Province. *Acta Ecol. Sin.* **2022**, *42*, 4055–4064.
4. Gaston, K.J. Global patterns in biodiversity. *Nature* **2000**, *405*, 220–227. [[CrossRef](#)] [[PubMed](#)]
5. MacDougall, A.S.; McCann, K.S.; Gellner, G.; Turkington, R. Diversity loss with persistent human disturbance increases vulnerability to ecosystem collapse. *Nature* **2013**, *494*, 86–89. [[CrossRef](#)] [[PubMed](#)]
6. Liao, Z.; Chen, Y.; Pan, K.; Dakhil, M.A.; Lin, K.; Tian, X.; Zhang, F.; Wu, X.; Pandey, B.; Wang, B.; et al. Current climate overrides past climate change in explaining multi-site beta diversity of Lauraceae species in China. *For. Ecosyst.* **2022**, *9*, 100018. [[CrossRef](#)]
7. Klein, J.A.; Harte, J.; Zhao, X.-Q. Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau. *Ecol. Lett.* **2004**, *7*, 1170–1179. [[CrossRef](#)]
8. Fonty, E.; Sarthou, C.; Larpin, D.; Ponge, J. A 10-year decrease in plant species richness on a neotropical inselberg: Detrimental effects of global warming? *Glob. Chang. Biol.* **2009**, *15*, 2360–2374. [[CrossRef](#)]
9. Yang, H.; Wu, M.; Liu, W.; Zhang, Z.; Zhang, N.; Wan, S. Community structure and composition in response to climate change in a temperate steppe. *Glob. Chang. Biol.* **2010**, *17*, 452–465. [[CrossRef](#)]
10. Yang, Y.; Wang, G.; Klanderud, K. Plant community responses to five years of simulated climate warming in an high altitude fen of the Qinghai-Tibetan Plateau. *Plant Ecol. Divers.* **2015**, *8*, 211–218. [[CrossRef](#)]
11. Wangchuk, K.; Darabant, A.; Nirola, H.; Wangdi, J.; Gratzner, G. Climate Warming Decreases Plant Diversity but Increases Community Biomass in High-Altitude Grasslands. *Rangel. Ecol. Manag.* **2021**, *75*, 51–57. [[CrossRef](#)]
12. Kazakis, G.; Ghosn, D.; Vogiatzakis, I.N.; Papanastasis, V.P. Vascular plant diversity and climate change in the alpine zone of the Lefka Ori, Crete. *Biodivers. Conserv.* **2006**, *16*, 1603–1615. [[CrossRef](#)]
13. Pickering, C.; Hill, W.; Green, K. Vascular plant diversity and climate change in the alpine zone of the Snowy Mountains, Australia. *Biodivers. Conserv.* **2008**, *17*, 1627–1644. [[CrossRef](#)]

14. Klanderud, K.; Birks, H.J.B. Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. *Holocene* **2003**, *13*, 1–6. [[CrossRef](#)]
15. Rafferty, N.E.; Ives, A.R. Effects of experimental shifts in flowering phenology on plant pollinator interactions. *Ecol. Lett.* **2011**, *14*, 69–74. [[CrossRef](#)] [[PubMed](#)]
16. Wehn, S.; Taugourdeau, S.; Johansen, L.; Hovstad, K.A. Effects of abandonment on plant diversity in semi-natural grasslands along soil and climate gradients. *J. Veg. Sci.* **2017**, *28*, 838–847. [[CrossRef](#)]
17. Bellard, C.; Bertelsmeier, C.; Leadley, P.; Thuiller, W.; Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **2012**, *15*, 365–377. [[CrossRef](#)] [[PubMed](#)]
18. Qingchen, C.; Rouke, L.; Tong, C. Scientific progress and future prospects in climate change: An interpretation of Part 1 of China's Fourth National Assessment Report on Climate Change. *China Popul. Resour. Environ.* **2023**, *33*, 74–79.
19. He, Y.L.; Zhang, Y.P.; Yang, X.B. Climate change in tropical area of southwestern china since 1950s. *Sci. Geogr. Sin.* **2007**, *27*, 499–505.
20. Peng, C.; Zhou, X.; Zhao, S.; Wang, X.; Zhu, B.; Piao, S.; Fang, J. Quantifying the response of forest carbon balance to future climate change in Northeastern China: Model validation and prediction. *Glob. Planet. Chang.* **2009**, *66*, 179–194. [[CrossRef](#)]
21. Ren, G.; Ding, Y.; Zhao, Z.; Zheng, J.; Wu, T.; Tang, G.; Xu, Y. Recent progress in studies of climate change in China. *Adv. Atmospheric Sci.* **2012**, *29*, 958–977. [[CrossRef](#)]
22. Wang, R.S.; Zhang, B.S.; Liu, H.P.; Li, G.S.; Li, X.A.; Zhang, H.L.; Zhang, Q.G. Diversity of tree species for broadleaf secondary forests in Yichun. *For. Science Technol.* **2010**, *35*, 14–17.
23. Deng, L.P.; Bai, X.J.; Qin, S.J.; Wei, Y.W.; Bin Zhou, Y.; Li, L.L.; Niu, S.S.; Na Han, M. Spatial distribution and scale effect of species diversity of secondary forests in montane region of eastern Liaoning Province, China. *J. Appl. Ecol.* **2016**, *27*, 2197–2204.
24. Wang, J.; Xu, S.; Yan, T.; Ma, W.J.; Yan, Q.L. Effects of soil nutrients on seeding growth of major tree species in montane region of eastern Liaoning Province, China. *Chin. J. Ecol.* **2017**, *36*, 3148–3159.
25. Zong, G.; Bai, X.J.; Zhang, S.Y.; Cai, J.Q. Spatial pattern and interspecific spatial association of tree seedlings in a secondary forest in montane region of eastern Liaoning Province, China. *J. Appl. Ecol.* **2018**, *29*, 18–24.
26. Liu, X.L.; Li, X.H.; Liu, S.; Li, W.; Cai, L.; Zhang, L.; Pan, H.; Feng, Q.; Xu, Z.; Li, H.; et al. Effects of human disturbance on natural secondary forests in China: I. Tree growth, regeneration and community structure. *J. Sichuan For. Sci. Technol.* **2022**, *43*, 1–12.
27. Liu, F.; Tan, C.; Yang, Z.; Li, J.; Xiao, H.; Tong, Y. Regeneration and growth of tree seedlings and saplings in created gaps of different sizes in a subtropical secondary forest in southern China. *For. Ecol. Manag.* **2022**, *511*, 120143. [[CrossRef](#)]
28. Liu, H.M.; Xing, Z.K.; Gu, Y.S.; Gao, Y.X.; Han, Y.Z. Spatial structure of natural secondary broad-leaved mixed forest in eastern mountainous area of Liaoning Province. *J. Northwest For. Univ.* **2012**, *27*, 150–154.
29. Ye, N.N.; Shen, N.P.; Shang, T.Q.; Gao, H.; Guan, J.; Yi, L. Vegetation structure and internal relationship between distribution patterns of vegetation and environment in ecological service forest of Rui'an city in Zhejiang Province. *Chin. Bull. Bot.* **2017**, *52*, 496–510.
30. Zhang, H.D.; Wang, R.Z.; Mao, Y.X.; Yan, T.; Wei, W.; You, W. Characteristics and quantitative classification of natural secondary forests in the mountainous area of eastern Liaoning Province, China. *Ecol. Environ. Sci.* **2020**, *29*, 1953–1960.
31. You, W.Z.; Zhao, G.; Zhang, H.D.; Guo, Y.T.; Yan, T.W.; Wei, W.J.; Mao, Y.X. Effects of thinning on growth of Mongolian oak (*Quercus mongolica*) secondary forests. *Acta Ecol. Sin.* **2015**, *35*, 56–64.
32. Liu, Y.; Zhang, D.-P.; Ji, L.; Xu, L.-Y.; Dong, L.-B.; Yang, L.-X. Effects of selective cutting on the distribution pattern and inter-specific association of arbor seedlings in *Tilia amurensis* secondary forest. *Chin. J. Appl. Ecol.* **2020**, *31*, 3296–3304.
33. Yan, B.; Sun, L.; Li, J.; Liang, C.; Wei, F.; Xue, S.; Wang, G. Change in composition and potential functional genes of soil bacterial and fungal communities with secondary succession in *Quercus liaotungensis* forests of the Loess Plateau, western China. *Geoderma* **2020**, *364*, 114199. [[CrossRef](#)]
34. Zhang, X.; Zhao, W.; Liu, Y.; He, H.; Kou, Y.; Liu, Q. Dominant plant species and soil properties drive differential responses of fungal communities and functions in the soils and roots during secondary forest succession in the subalpine region. *Rhizosphere* **2022**, *21*, 100483. [[CrossRef](#)]
35. Zhang, X.; Huang, J.; Chen, J.; Li, G.; He, H.; Huang, T.; Ding, J. Changes in diversity patterns and assembly processes of soil nematode communities during forest secondary succession on the Loess Plateau. *For. Ecol. Manag.* **2023**, *529*, 120734. [[CrossRef](#)]
36. Wang, J.F.; Zheng, X.X. Species diversity and community succession of evergreen broad-leaved secondary forests in Sanming. *J. Northwest For. Univ.* **2015**, *30*, 39–45.
37. Yan, W.M.; Sun, B.; Pei, N.; Wang, X.; Li, F.; Luo, X.; Zou, B. Correlation analyses on plant diversity and soil physical-chemical properties between evergreen broad-leaved plantations and natural secondary forests in North Guangdong, China. *Ecol. Environ. Sci.* **2019**, *28*, 898–907.
38. Xiao, S.H.; Zhang, W.Q.; Huang, Y.H.; Cai, J.; Gao, C.J.; Sun, H.B.; Wang, Z.L. Species diversity and soil chemical properties of typical secondary forest in Tiegang-Shiyan natural reserve in Shenzhen. *For. Environ. Sci.* **2020**, *36*, 35–40.
39. Yuan, Z.; Guan, Q.; Chen, X.; Zou, P.; Gu, Y.; Wu, Q.; Niu, Y.; Meshack, A.O. Tree diversity increases soil C and N stocks of secondary forests in subtropical China. *CATENA* **2023**, *222*, 106812. [[CrossRef](#)]
40. Li, J.; Li, S.; Huang, X.; Tang, R.; Zhang, R.; Li, C.; Xu, C.; Su, J. Plant diversity and soil properties regulate the microbial community of monsoon evergreen broad-leaved forest under different intensities of woodland use. *Sci. Total. Environ.* **2022**, *821*, 153565. [[CrossRef](#)]

41. Li, X.Y.; Pan, P.; Zang, H.; Ning, J.; Ouyang, X.; Li, X.; Gui, Y.; Wu, Z. Study on factors affecting natural regeneration of natural secondary *Phoebe bournei* forest. *For. Res.* **2017**, *30*, 701–708.
42. Wang, P.; Gou, Z.H.; Nong, S.Q.; Huang, C.T.; Lin, L.; Yu, X.B. Species diversity and floristic components tropical secondary forests in hilly areas of central Hainan. *Chin. J. Trop. Crops* **2018**, *39*, 802–808.
43. Nong, Y.; Lu, L.H.; You, J.H.; Lei, L.Q.; Wang, Y.N.; Li, H.; Yang, G.F. The plant diversity and biomass of trees in different successional stages of secondary forest of south subtropical. *J. Cent. South Univ. For. Technol.* **2018**, *38*, 83–88.
44. Wu, Q.Z. Species diversity analysis of natural secondary forest of *Castanopsis fargesii* in Mingxi, Fujian. *Subtrop. Agric. Res.* **2019**, *15*, 217–222.
45. Zhang, H.; Chen, S.; Zheng, X.; Ge, X.; Li, Y.; Fang, Y.; Cui, P.; Ding, H. Neighborhood diversity structure and neighborhood species richness effects differ across life stages in a subtropical natural secondary forest. *For. Ecosyst.* **2022**, *9*, 100075. [\[CrossRef\]](#)
46. Ma, L.; Zhang, Z.; Shi, G.; Su, H.; Qin, R.; Chang, T.; Wei, J.; Zhou, C.; Hu, X.; Shao, X.; et al. Warming changed the relationship between species diversity and primary productivity of alpine meadow on the Tibetan Plateau. *Ecol. Indic.* **2022**, *145*, 109691. [\[CrossRef\]](#)
47. Xu, Y.; Ding, Y.H.; Zhao, Z.C. Confidence analysis of NCEP/NCAR 50-year global reanalyzed data in climate change research in China. *J. Appl. Meteor. Sci.* **2001**, *12*, 337–347.
48. Wang, L.; Chang, J.L.; Zhou, S.B.; Wang, X.Y.; Zhang, J.Q.; Yan, S.K.; Zhang, J.M.; Chen, X.; Zhao, X.; Wang, Z. Species diversity and interspecific association of trees in the Yaoluoping Nation Nature Reserve. *Acta Ecol. Sin.* **2019**, *39*, 309–319.
49. Sinervo, B. Erratum: Erosion of lizard diversity by climate change and altered thermal niches (science (894)). *Science* **2010**, *328*, 1354. [\[CrossRef\]](#)
50. Yang, Q.; Li, S.; Li, J.; Du, J.; Wang, J. Response of phenology phases of four deciduous trees to climate change in Xi'an. *Acta Ecol. Sin.* **2022**, *42*, 1462–1473. [\[CrossRef\]](#)
51. Zhang, N.; Shugart, H.H.; Yan, X. Simulating the effects of climate changes on Eastern Eurasia forests. *Clim. Chang.* **2009**, *95*, 341–361. [\[CrossRef\]](#)
52. Li, J. Vulnerability of Six Typical Deciduous Broad-Leaved Tree Species to Future Climate Change in China. Master's Thesis, Northwest A & F University, Xianyang, China, 2020.
53. Chen, Y.H.; Lu, Y.W.; Yin, X.J. Predicting habitat suitability of 12 coniferous forest tree species in southwest China based on climate change. *J. Nanjing For. Univ. Nat. Sci. Ed.* **2019**, *43*, 113–120.
54. Wang, X.; Bao, Y. Divergent tree radial growth at alpine coniferous forest ecotone and corresponding responses to climate change in northwestern China. *Ecol. Indic.* **2020**, *121*, 107052. [\[CrossRef\]](#)
55. Angela, M.V.; Juan, F.B.; Gabriel, J.C.; Francisco, E.F. The importance of old secondary forests for understory birds in the tropical Andes. *Glob. Ecol. Conserv.* **2023**, *47*, e02658.
56. Carnevale, N.J.; Montagnini, F. Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species. *For. Ecol. Manag.* **2002**, *163*, 217–227. [\[CrossRef\]](#)
57. Kelty, M.J. The role of species mixtures in plantation forestry. *For. Ecol. Manag.* **2006**, *233*, 195–204. [\[CrossRef\]](#)
58. Vaz, A.S.; Honrado, J.P.; Lomba, A. Replacement of pine by eucalypt plantations: Effects on the diversity and structure of tree assemblages under land abandonment and implications for landscape management. *Landsc. Urban Plan.* **2019**, *185*, 61–67. [\[CrossRef\]](#)
59. Yu, Q.; Rao, X.; Chu, C.; Liu, S.; Lin, Y.; Sun, D.; Tan, X.; Hanif, A.; Shen, W. Species dominance rather than species asynchrony determines the temporal stability of productivity in four subtropical forests along 30 years of restoration. *For. Ecol. Manag.* **2019**, *457*, 117687. [\[CrossRef\]](#)
60. Wang, Y.J.; Lu, H.F.; Lin, Y.B.; Zhou, L.; Cai, H.; Zhou, D. Plant community structure and health development dynamics of different restoration modes in Guangdong-Hong Kong-Macao Bay Area. *Acta Ecol. Sin.* **2021**, *41*, 3669–3688.
61. Rajesh, M.; Prem, R.N.; Michael, K. Climate change impacts: Vegetation shift of broad-leaved and coniferous forests. *Trees For. People* **2023**, *14*, 100457.

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