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Effect of thinning intensity on understory herbaceous diversity and biomass in mixed coniferous and broad-leaved forests of Changbai Mountain

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Abstract

Background: Herbs are an important part of the forest ecosystem, and their diversity and biomass can reflect the restoration of vegetation after forest thinning disturbances. Based on the near-mature secondary coniferous and broad-leaved mixed forest in Jilin Province Forestry Experimental Zone, this study analyzed seasonal changes of species diversity and biomass of the understory herb layer after different intensities of thinning.

Results: The results showed that although the composition of herbaceous species and the ranking of importance values were affected by thinning intensity, they were mainly determined by seasonal changes. Across the entire growing season, the species with the highest importance values in thinning treatments included *Carex pilosa*, *Aegopodium alpestre*, *Meehanian urticifolia*, and *Filipendula palmata*, which dominated the herb layer of the coniferous and broad-leaved mixed forest. The number of species, Margalef index, Shannon-Wiener index and Simpson index all had their highest values in May, and gradually decreased with months. Pielou index was roughly inverted “N” throughout the growing season. Thinning did not increase the species diversity. Thinning can promote the total biomass, above- and below-ground biomass. The number of plants per unit area and coverage were related to the total biomass, above- and below-ground biomass. The average height had a significantly positive correlation with herb biomass in May but not in July. However, it exerted a significantly negative correlation with herb biomass in September. The biomass in the same month increased with increasing thinning intensity. Total herb biomass, above- and below-ground biomass showed positive correlations with Shannon-Wiener index, Simpson index and Pielou evenness index in May.

Conclusions: Thinning mainly changed the light environment in the forest, which would improve the plant diversity and biomass of herb layer in a short time. And different thinning intensity had different effects on the diversity of understory herb layer. The findings provide theoretical basis and reference for reasonable thinning and tending in coniferous and broad-leaved mixed forests.

Keywords: Selective thinning, Mixed coniferous and broad-leaved forests, Herbaceous plants, Diversity, Biomass

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Background

Understory herbaceous plants are an important part of the species diversity of forest ecosystems (Han et al. 2016). In temperate forests, more than 80 % of vascular plants are herbaceous plants (Whigham 2004), and herbaceous plants are of great significance for maintaining the species diversity of forest ecosystems. Compared with trees and shrubs, understory herbs are more sensitive to disturbances and are the most adaptable to the environment. If the disturbance severely destroys the original forest ecosystem, herbaceous plants will usually recover fast, thereby quickly improving the soil site conditions, reducing the intensity of solar radiation on the ground, and providing important protection for the regeneration of trees and shrubs and the growth of seedlings (Huang et al. 2016). Therefore, the species diversity and biomass of the herb layer can reflect the vegetation restoration status after forest disturbance.

Forest thinning is an important disturbance in the forest managements. Thinning can have an important impact on the stability of the forest ecosystem, and even destroy the balance of the forest ecosystem (Lei et al. 2005). As an important disturbance in the forest managements, thinning has long attracted people's attention (Zhou et al. 2012). Reasonable thinning can maintain the stability and structure of the forest ecosystem while obtaining timber, and achieve sustainable forest management (Zhou et al. 2015). Thinning can affect forest growth, understory vegetation regeneration, forest spatial structure, forest species diversity (Rong et al. 2014; You et al. 2015; Gong et al. 2015; Huang 2016). Some studies have reported that thinning can not only promote the growth of tree height and diameter at breast height, increase forest stock and improve wood quality (An et al. 2012), but also improve the understory environment, reduce understory competition among species, and promote the increase in the growth and diversity of understory species, especially the understory herb layer (Li et al. 2012).

Due to long-term human disturbance, the original broad-leaved Korean pine forests in Northeast China have been severely damaged, and now there are a large number of secondary coniferous and broad-leaved mixed forests (Zhang et al. 2009). Reasonable thinning can accelerate the succession rate of this forest type, realize its sustainable management, and play an important role in maintaining the stability of timber yield and species diversity (Liu et al. 2014). Through thinning of different intensities in the near-mature secondary coniferous and broad-leaved mixed forest in the State-owned Forest Protection Center of the Jilin Province Forestry Experimental Zone, this study investigated the species diversity and the seasonal changes of biomass of the understory herb layer after thinning, and evaluated the influence of thinning on herbaceous plants. The study aims to provide a theoretical basis for reasonable tending and

thinning for secondary coniferous and broad-leaved mixed forests in Northeast China.

Materials and methods

Study area

The study site was located at Dapo Forest Farm (43°57' N, 127°43' E), the state-owned forest protection center of Jilin Province Forestry Experimental Zone. In July 2011, 4 permanent monitoring plots with an area of 1 ha (100 m × 100 m) were set up in the near-mature forest. Each plot was divided into 25 plots of 20 m × 20 m and the forest stand survey was conducted. In December 2012, 4 plots were thinned with actual intensity of 0, 17.2 %, 32.7 %, and 50.8 % respectively, which were defined as unthinning (CK), light thinning (LT), moderate thinning (MT) and heavy thinning (HT) (Liu et al. 2019).

Herbaceous plant diversity

At the beginning of May 2015, 4 herbal plots of 1 m × 1 m were randomly set up in each 20 m × 20 m plot, and a total of 100 herbal plots were set up. From early May to early October 2015, the species name, abundance, average height, and coverage of the herb plots in the four plots were investigated, and the total coverage was also recorded. The relative abundance (RA), relative coverage (RC), relative height (RH), and importance value (IV) of herbaceous plants based on the obtained data were calculated. Furthermore, the Margalef index (R), Shannon-Wiener index (H'), Simpson index (D) and Pielou index (J_{sw}) were also calculated as follows:

$$\text{Importance value: IV} = \frac{(RA + RC + RH)}{3} \quad (1)$$

$$\text{Margalef index: } R = \frac{(S - 1)}{\ln N} \quad (2)$$

$$\text{Shannon - Wiener index: } H' = - \sum_{i=1}^S (P_i \times \ln P_i) \quad (3)$$

$$\text{Simpson index: } D = 1 - \sum_{i=1}^S P_i^2 \quad (4)$$

$$\text{Pielou index: } J_{sw} = \frac{- \sum_{i=1}^S (P_i \times \ln P_i)}{\ln S} \quad (5)$$

where IV is the importance value, RA is the relative abundance, RC is the relative coverage, RH is the relative height, S is the total number of species in the sample plot, N is the total individuals of species in the sample plot, and N_i is the individual of the i -th species Number,

P_i is the relative value of i , and the calculation formula of P_i is:

$$P_i = \frac{N_i}{N} \quad (6)$$

Herbaceous plant biomass

In early May, mid-July, and early September 2015, the understory herbaceous biomass was sampled and surveyed three times. Specifically, two 1 m × 1 m subplots were randomly set up in each 20 m × 20 m plot. We investigated all species names, abundance, height, coverage, total coverage, and finally harvested the whole plant for all the herbs in the subplot. The samples were taken back to the laboratory to clean the soil at the roots with water. The above- and belowground parts were cut with scissors, and weighed their fresh weight (MA for aboveground part and MB for belowground part). Then the sample was first quenched at 105 °C for 30 min, adjusted to 85 °C and dried to a constant weight. After drying, weigh the dry weight of the aboveground and belowground parts and record them as WA and WB. The herb biomass of the entire subplot was calculated based on the coverage, the dry weight of the herbaceous plants, and the area of the entire subplot (Sun et al. 2017).

Data analysis

Correlation analysis and one-way analysis of variance (one-way ANOVA) were performed to test thinning effects on herbaceous diversity and biomass. A total of 100 1 m × 1 m herbal plots in each thinning treatment was defined as replicates. Multiple comparisons were performed using the least significant difference method (LSD) once the thinning effects were significant. All data analysis was performed using SPSS18.0 software. The significance level was set at $\alpha < 0.05$.

Results

Effect of thinning on plant diversity

Species composition

During the whole growing season, a total of 87 species of herbaceous plants were investigated in 4 plots, belonging to 37 families and 74 genera. From the distribution of each family, the number of species belonging to Ranunculaceae, Liliaceae, Umbelliferae and Compositae was the largest, with 11, 7, 7 and 5 species respectively. There were 19 families containing only one species and 8 families including 2 species. Only 2 families (Rosaceae and Papaveraceae) included 3 species. Four families (Cyperaceae, Rubiaceae, Caryophyllaceae and Urticaceae) included 4 species, accounting for 10.8 % of all families.

From the distribution of the genera, there are 64 genera with 1 species, accounting for 86.5 % of the total number of genera. There are 10 genera with more than

2 species, accounting for 13.5 % of the total number of genera. Among them, there are 7 genera (*Lilium*, *Viola*, *Geranium*, *Hippochaete*, *Cimicifuga*, *Arisaema* and *Anemone*) containing 2 species and 3 genera (*Rubia*, *Carex*, and *Urtica*) containing 3 species. In summary, a single family and a single genus had an absolute advantage in the survey plots, and the phenomenon of few families and few genera was obvious, which was a typical species distribution of temperate forest herbs.

Compared with the control, thinning increased the number of species and genera of herbaceous plants. Light thinning, moderate thinning and heavy thinning increased 2 species and 3 genera, 8 species and 9 genera, 1 species and 1 genus, respectively. For the family, moderate thinning increased 1 family, while light thinning and heavy thinning both decreased by 1 family compared with the control (Table 1).

The number of species, genera and families of herbaceous plants in each thinning treatment showed seasonal variations. In May, the number of species, genera and families in the thinning were higher than those of the control, and the number of species, genera and families in the heavy thinning plot was the largest. In June, the number of species, genera and families in the thinning were all low compared with the control, and light thinning had the smallest number of species, genera and families. In July, August and September, moderate thinning had the largest number of species, genera and families while heavy thinning was opposite. In October, the number of herbaceous species in each plot decreased sharply, with little difference among thinning treatments. The number of species in the control and moderate thinning was slightly higher than that of light thinning and heavy thinning.

Seasonal variation of importance values

The importance values of herbaceous plants in different thinning in each month are shown in Table 2. In May, the top 5 importance values of herbaceous plants in the control were *Anemone raddeana*, *Hylomecon japonica*, *Aegopodium alpestre*, *Meehanian urticifolia* and *Corydalis ambigua*. The sum of the importance values of these plants was 51.38 %, dominating in the plot. Among them, there were 15 species with importance values greater than 1 %, and the sum of their importance values accounted for 93.54 % of all herb species. *Carex pilosa*, *Anemone raddeana*, *Filipendula palmata*, *Meehanian urticifolia*, and *Cardamine leucantha* were the top 5 importance values of herbaceous plants in the light thinning, with the sum of the importance values of 51.21 %. There are 14 species of herbs with importance value greater than 1 %, and the sum of their importance values accounted for 88.35 % of all herb species. *Carex*

Table 1 Changes in the number of families, genera and species of herbaceous plants in each thinning treatment in different months

Month	CK			LT			MT			HT		
	Species	Genus	Family	Species	Genus	Family	Species	Genus	Family	Species	Genus	Family
May	36 ± 2	34 ± 0	18 ± 0	43 ± 3	39 ± 1	24 ± 0	44 ± 3	40 ± 1	21 ± 0	44 ± 3	41 ± 1	25 ± 0
June	37 ± 2	36 ± 1	25 ± 0	32 ± 3	30 ± 0	21 ± 0	35 ± 2	32 ± 1	22 ± 0	33 ± 2	32 ± 1	23 ± 0
July	38 ± 3	36 ± 1	22 ± 0	39 ± 2	36 ± 1	25 ± 0	46 ± 3	40 ± 1	27 ± 0	36 ± 3	31 ± 1	21 ± 0
August	33 ± 2	27 ± 0	20 ± 0	29 ± 1	25 ± 0	22 ± 0	36 ± 3	30 ± 0	20 ± 0	30 ± 1	26 ± 0	19 ± 0
September	23 ± 1	21 ± 0	15 ± 0	21 ± 0	19 ± 0	15 ± 0	25 ± 1	22 ± 0	15 ± 0	14 ± 0	13 ± 0	13 ± 0
October	10 ± 0	10 ± 0	8 ± 0	8 ± 0	7 ± 0	7 ± 0	10 ± 0	8 ± 0	7 ± 0	9 ± 0	8 ± 0	7 ± 0
Total	65 ± 2	53 ± 1	31 ± 0	67 ± 2	56 ± 1	30 ± 0	73 ± 3	62 ± 1	32 ± 0	66 ± 2	54 ± 1	30 ± 0

pilosa, *Anemone raddeana*, *Filipendula palmata*, *Meehaniania urticifolia* and *Poa annua* were the top 5 importance values of herbaceous plants in the moderate thinning. The sum of the importance values of these plants was 49.36 %, and there were 18 species with the importance value greater than 1 % and the sum of their importance values accounted for 89.56 % of all herbaceous species. *Filipendula palmata*, *Aegopodium alpestre*, *Anemone raddeana*, *Anemone amurensis*, and *Meehaniania urticifolia* were the top 5 herbaceous plants in the heavy thinning plots. The sum of the important values of these plants was 46.09 %. There were 17 species of herbaceous plants with the importance value greater than 1 %, and the sum of their importance values accounted for 89.93 % of all herb species. The proportion of important value of early spring herbs (including *Anemone raddeana*, *Anemone amurensis*, *Hylomecon japonica*, *Gagea lutea*, *Corydalis ambigua*, *Adonis amurensis*, etc.) in the control was relatively high (42.64 %), while that of light thinning, moderate thinning and heavy thinning were 24.90 %, 18.64 % and 22.09 % respectively, which was significantly lower than that of the control, indicating that the phenological period of herbs after thinning was advanced. Some early spring herbs in early May had completed the whole life cycle and died.

In June, the top 5 important values of herbaceous plants in the control were *Carex pilosa*, *Poa annua*, *Meehaniania urticifolia*, *Aegopodium alpestre* and *Filipendula palmata*. The sum of the importance values of these plants was 50.88 %. There were 18 species with the importance value greater than 1, and the sum of their importance values accounted for 92.57 % of all herbaceous species. The top 5 important values of herbaceous plants in the light thinning were *Carex pilosa*, *Athyrium multidentatum*, *Aegopodium alpestre*, *Filipendula palmata* and *Brachybotrys paridiformis*. The sum of the importance values was 59.92 %, and there were 16 species with the importance value greater than 1. The top 5 importance values of herbaceous plants in the

moderate thinning and heavy thinning plots were *Carex pilosa*, *Meehaniania urticifolia*, *Carex remotiuscula*, *Aegopodium alpestre* and *Filipendula palmata*, but their importance values were different. The order of importance values in the moderate thinning was *Carex pilosa* > *Meehaniania urticifolia* > *Carex remotiuscula* > *Aegopodium alpestre* > *Filipendula palmata*. The importance values of the heavy thinning were *Carex pilosa* > *Filipendula palmata* > *Aegopodium alpestre* > *Carex remotiuscula* > *Meehaniania urticifolia*. In the moderate thinning and heavy thinning, the sum of the importance values of these plants was 58.10 % and 56.22 %, respectively. Herbs with importance values greater than 1 % were 20 and 17, and accounted for 91.30 % and 91.49 % of all herb species, respectively. The number of species in the control was large, because the poor light conditions in the control led to late plant phenology, and there were more early spring herbs in the control, which led to the existence of early summer herbs and early spring herbs at the same time, resulting in a large number of species; while in the thinning plot, due to the better light conditions caused by thinning, most of the early spring herbs had died, resulting in the number of species has declined.

In July, the top 5 importance values of herbaceous plants in the control were *Carex pilosa*, *Laportea bulbifera*, *Filipendula palmata*, *Cardamine leucantha*, and *Meehaniania urticifolia*. The sum of the importance values of these plants was 56.33 %, there were 16 species with the importance value greater than 1 %, and the sum of their importance values accounted for 90.20 % of all herb species. The top 5 important values of herbaceous plants in the light thinning were *Carex pilosa*, *Filipendula palmata*, *Aegopodium alpestre*, *Matteuccia struthiopteris* and *Anemone amurensis*. The sum of the importance values of these plants was 60.67 %, and there were 19 species with the importance value greater than 1 %. The sum of their importance values accounted for 90.52 % of all herb species. The top 5 important values of herbaceous plants in the moderate thinning and heavy thinning plots were *Carex pilosa*, *Meehaniania urticifolia*,

Table 2 The top 5 herbs with relative importance value in different months

Month	CK		LT		MT		HT	
	Species	Importance value (%)	Species	Importance value (%)	Species	Importance value (%)	Species	Importance value (%)
May	<i>Anemone raddeana</i>	18.11	<i>Carex pilosa</i>	18.93	<i>Carex pilosa</i>	17.53	<i>Filipendula palmata</i>	12.92
	<i>Hylomecon japonica</i>	9.96	<i>Anemone raddeana</i>	14.47	<i>Anemone raddeana</i>	12.04	<i>Aegopodium alpestre</i>	12.32
	<i>Aegopodium alpestre</i>	9.47	<i>Filipendula palmata</i>	8.89	<i>Filipendula palmata</i>	8.35	<i>Anemone raddeana</i>	9.38
	<i>Meehanian urticifolia</i>	7.23	<i>Meehanian urticifolia</i>	4.48	<i>Meehanian urticifolia</i>	7.35	<i>Anemone amurensis</i>	6.84
	<i>Corydalis ambigua</i>	6.61	<i>Cardamine leucantha</i>	4.44	<i>Poa annua</i>	4.09	<i>Meehanian urticifolia</i>	4.63
	Others	48.62	Others	48.79	Others	50.64	Others	53.91
June	<i>Carex pilosa</i>	14.39	<i>Carex pilosa</i>	28.14	<i>Carex pilosa</i>	26.63	<i>Carex pilosa</i>	19.29
	<i>Poa annua</i>	9.87	<i>Athyrium multidentatum</i>	8.92	<i>Meehanian urticifolia</i>	9.26	<i>Filipendula palmata</i>	10.94
	<i>Meehanian urticifolia</i>	9.87	<i>Aegopodium alpestre</i>	8.90	<i>Carex remotiuscula</i>	8.68	<i>Aegopodium alpestre</i>	10.33
	<i>Aegopodium alpestre</i>	8.73	<i>Filipendula palmata</i>	8.07	<i>Aegopodium alpestre</i>	8.18	<i>Carex remotiuscula</i>	8.42
	<i>Filipendula palmata</i>	8.02	<i>Brachybotrys paridiformis</i>	5.89	<i>Filipendula palmata</i>	5.35	<i>Meehanian urticifolia</i>	7.24
	Others	49.12	Others	40.08	Others	41.90	Others	43.78
July	<i>Carex pilosa</i>	16.27	<i>Carex pilosa</i>	35.84	<i>Carex pilosa</i>	27.52	<i>Carex pilosa</i>	27.76
	<i>Laportea bulbifera</i>	10.98	<i>Filipendula palmata</i>	9.67	<i>Filipendula palmata</i>	8.42	<i>Filipendula palmata</i>	15.34
	<i>Filipendula palmata</i>	9.77	<i>Aegopodium alpestre</i>	5.62	<i>Carex remotiuscula</i>	7.35	<i>Aegopodium alpestre</i>	7.96
	<i>Cardamine leucantha</i>	9.74	<i>Matteuccia struthiopteris</i>	5.21	<i>Meehanian urticifolia</i>	5.92	<i>Meehanian urticifolia</i>	5.55
	<i>Meehanian urticifolia</i>	9.57	<i>Anemone amurensis</i>	4.33	<i>Aegopodium alpestre</i>	5.73	<i>Carex remotiuscula</i>	3.64
	Others	43.67	Others	39.33	Others	45.06	Others	39.75
August	<i>Milium effusum</i>	14.43	<i>Carex pilosa</i>	24.45	<i>Carex pilosa</i>	22.99	<i>Carex pilosa</i>	16.56
	<i>Meehanian urticifolia</i>	13.26	<i>Aegopodium alpestre</i>	10.54	<i>Meehanian urticifolia</i>	10.69	<i>Aegopodium alpestre</i>	10.99
	<i>Carex pilosa</i>	11.93	<i>Filipendula palmata</i>	10.20	<i>Aegopodium alpestre</i>	10.26	<i>Filipendula palmata</i>	10.59
	<i>Aegopodium alpestre</i>	10.30	<i>Brachybotrys paridiformis</i>	7.34	<i>Filipendula palmata</i>	9.67	<i>Carex callitrichos</i>	9.64
	<i>Filipendula palmata</i>	10.25	<i>Meehanian urticifolia</i>	5.73	<i>Brachybotrys paridiformis</i>	5.81	<i>Meehanian urticifolia</i>	6.38
	Others	39.83	Others	41.74	Others	40.58	Others	45.84
September	<i>Carex pilosa</i>	17.66	<i>Carex pilosa</i>	33.06	<i>Carex pilosa</i>	27.94	<i>Carex pilosa</i>	22.89
	<i>Aegopodium alpestre</i>	16.34	<i>Aegopodium alpestre</i>	11.01	<i>Meehanian urticifolia</i>	11.90	<i>Filipendula palmata</i>	16.76
	<i>Milium effusum</i>	12.75	<i>Filipendula palmata</i>	10.79	<i>Aegopodium alpestre</i>	10.64	<i>Aegopodium alpestre</i>	16.64
	<i>Meehanian urticifolia</i>	12.46	<i>Athyrium multidentatum</i>	7.93	<i>Filipendula palmata</i>	9.67	<i>Urtica angustifolia</i>	16.28

Table 2 The top 5 herbs with relative importance value in different months (Continued)

Month	CK		LT		MT		HT	
	Species	Importance value (%)	Species	Importance value (%)	Species	Importance value (%)	Species	Importance value (%)
October	<i>Cardamine leucantha</i>	8.76	<i>Carex remotiuscula</i>	6.88	<i>Athyrium multidentatum</i>	5.61	<i>Meehanian urticifolia</i>	5.67
	Others	32.03	Others	30.33	Others	34.24	Others	21.76
	<i>Carex pilosa</i>	40.12	<i>Carex pilosa</i>	58.27	<i>Carex pilosa</i>	47.63	<i>Carex pilosa</i>	39.57
	<i>Meehanian urticifolia</i>	21.20	<i>Aegopodium alpestre</i>	15.78	<i>Aegopodium alpestre</i>	19.20	<i>Aegopodium alpestre</i>	17.47
	<i>Aegopodium alpestre</i>	17.57	<i>Meehanian urticifolia</i>	10.89	<i>Carex remotiuscula</i>	14.91	<i>Carex callitrichos</i>	13.60
	<i>Milium effusum</i>	8.08	<i>Carex callitrichos</i>	5.38	<i>Meehanian urticifolia</i>	10.24	<i>Meehanian urticifolia</i>	8.86
	<i>Cardamine leucantha</i>	5.68	<i>Filipendula palmata</i>	4.20	<i>Carex callitrichos</i>	2.93	<i>Carex remotiuscula</i>	8.60
	Others	7.35	Others	5.48	Others	5.09	Others	11.90

Carex remotiuscula, *Aegopodium alpestre* and *Filipendula palmata*. The order of importance values in the moderate thinning was *Carex pilosa* > *Filipendula palmata* > *Carex remotiuscula* > *Meehanian urticifolia* > *Aegopodium alpestre*, and the importance values of the plots with heavy thinning were *Carex pilosa* > *Filipendula palmata* > *Aegopodium alpestre* > *Meehanian urticifolia* > *Carex remotiuscula*. In the moderate and heavy thinning, the sum of the importance values of these plants was 54.94 % and 60.25 %, respectively. The herb plants with importance values greater than 1 % were 21 and 22 species and accounted for 92.47 % and 93.50 % of all herb species, respectively. 38, 39, 46 and 36 species of herbs were found in control, light thinning, moderate thinning and heavy thinning respectively. Compared with the control, moderate thinning significantly increased the number of herbs. This is due to the good light under the forest and the invasion of light loving herbs species after moderate thinning, and there are more shade environment under the forest and more shade loving herbs are retained, which makes the light loving and shade loving species co-exist, resulting in a relatively large number of species. After heavy thinning, the shade environment under the forest is less and the light condition is excellent, which is especially suitable for the survival of photophilous herbs, but the loss of photophilous species.

In August, the top 5 importance values of herbaceous plants in the control were *Milium effusum*, *Meehanian urticifolia*, *Carex pilosa*, *Aegopodium alpestre* and *Filipendula palmata*. The sum of the importance values was 60.17 %, and there were 15 species with the importance value greater than 1, accounting for 90.59 % of all herb species. The top 5 importance values of herbaceous plants in the light thinning were *Carex pilosa*, *Aegopodium alpestre*, *Filipendula palmata*, *Brachybotrys*

paridiformis and *Meehanian urticifolia*, with the sum of the important values of 58.26 %. There were 19 species with the importance value greater than 1 %, accounting for 94.23 % of all herb species. The top 5 important values of herbaceous plants in the moderate thinning were *Carex pilosa*, *Meehanian urticifolia*, *Aegopodium alpestre*, *Filipendula palmata* and *Brachybotrys paridiformis*. The sum of the important values was 59.42 %, and there were 16 species with the importance value greater than 1 %, accounting for 87.55 % of all herb species. The top 5 important values of herbaceous plants in the heavy thinning were *Carex pilosa*, *Aegopodium alpestre*, *Filipendula palmata*, *Carex callitrichos* and *Meehanian urticifolia*. The sum of the importance values was 54.16 %, and there were 21 species with the importance value greater than 1 %, accounting for 95.51 % of all herb species. Among the top 5 species of herbs in different thinning plots, there are 4 common species, namely *Carex pilosa*, *Meehanian urticifolia*, *Aegopodium alpestre* and *Filipendula palmata*. From the important values of these 4 species, the important values of *Carex pilosa* increased significantly after thinning, while that of *Meehanian urticifolia* decreased. *Aegopodium alpestre* and *Filipendula palmata* were relatively consistent in different plots, and there was no significant change.

In September, the top 5 importance values of herbaceous plants in the control were *Carex pilosa*, *Aegopodium alpestre*, *Milium effusum*, *Meehanian urticifolia*, and *Cardamine leucantha*, the sum of the important values was 67.97 %. There were 11 species of herbs with importance values more than 1 %, accounting for 94.00 % of all herb species. The top 5 important values of herbaceous plants in the light thinning were *Carex pilosa*, *Aegopodium alpestre*, *Filipendula palmata*, *Athyrium multidentatum* and *Carex remotiuscula*. The sum of the important values was 69.67 %. There were 15

species with importance values greater than 1 %, accounting for 96.65 % of all herb species. The top 5 importance values of herbaceous plants in the moderate thinning were *Carex pilosa*, *Meehanian urticifolia*, *Aegopodium alpestre*, *Filipendula palmata* and *Athyrium multidentatum*. The sum of the important values was 65.76 %. There were 16 species with importance value more than 1 %, accounting for 92.82 % of all herb species. The top 5 importance values of herbaceous plants in the heavy thinning were *Carex pilosa*, *Filipendula palmata*, *Aegopodium alpestre*, *Urtica angustifolia* and *Meehanian urticifolia*. The sum of the important values was 78.24 %. There were 13 species with the importance value greater than 1 %, accounting for 99.14 % of all herb species. 23, 21, 25 and 14 species of herbs were found in the control, light thinning, moderate thinning and heavy thinning, respectively. This is due to the fact that more photophilous species, such as *Impatiens noli-tangere*, have invaded the plots after heavy thinning. The earlier invasive species will occupy a wide area in the sample plot, and prevent the invasion of other species. Consequently, the number of species will decrease after heavy thinning. With the coming of autumn, the number of photophilous species in the heavy thinning plots in September was lower because of their higher individuals and more easily withered and died.

In October, the top 5 importance values of herbaceous plants in the control were *Carex pilosa*, *Meehanian urticifolia*, *Aegopodium alpestre*, *Milium effusum* and *Cardamine leucantha*, the sum of the importance value was 92.65 %. There are 8 species with importance value greater than 1 %, accounting for 98.60 % of all herb species. The top 5 importance values of herbaceous plants in the light thinning were *Carex pilosa*, *Aegopodium alpestre*, *Meehanian urticifolia*, *Carex callitrichos* and *Filipendula palmata*. The sum of the important values was 94.52 %, and there were 7 species with the importance value greater than 1 %, accounting for 99.32 % of all herb species. The top 5 importance values of herbaceous plants in the moderate thinning were *Carex pilosa*, *Aegopodium alpestre*, *Carex remotiuscula*, *Meehanian urticifolia* and *Carex callitrichos*. The sum of the important values of was 94.91 %. There were 6 species with importance value greater than 1 %, accounting for 97.38 % of all herb species. The top 5 importance values of herbaceous plants in the heavy thinning were *Carex pilosa*, *Aegopodium alpestre*, *Carex callitrichos*, *Meehanian urticifolia*, and *Carex remotiuscula*. The sum of the important values was 88.10 %. There were 8 species with important value greater than 1 %, accounting for 99.34 % of all herb species. There were 10, 8, 10 and 9 species of herbs in the control, light thinning, moderate thinning and heavy thinning, respectively. There was no significant difference in the

number of species in different plots, and the species in different plots were almost the same.

Seasonal changes in diversity index

Calculation of diversity index showed that there were significant variations ($P < 0.05$) in different thinning. Except for the control, which showed an increasing trend from May to June, the Margalef index showed a similar trend in all plots in other months (Fig. 1a). It gradually decreased from May to July, increased from July to August, and then fell rapidly from August to October. The Margalef index of different treatments showed various patterns in different months with moderate thinning > heavy thinning > light thinning > control in May, and control > moderate thinning > light thinning > heavy thinning from June to August. From August to October, the Margalef index of the four plots all showed a significant decreasing trend with control > light thinning > moderate thinning > heavy thinning.

In the four treatments, the Shannon-Wiener index and Simpson index had similar patterns (Fig. 1b and c). The Shannon-Wiener index and Simpson index gradually decreased from May to July, increased gradually from July to August, and then decreased sharply. In June, July and September, the Shannon-Wiener index and Simpson index in the control were higher than the other three thinning treatments. In May, August and October, the Shannon-Wiener index and Simpson index of the four plots were relatively the same.

Throughout the growing season, the Pielou index was roughly in the shape of an inverted “N” (Fig. 1d), namely it had a high value at the beginning of growth, a low value in June or July, and the second peak in August, and then it decreased sharply. The Pielou index of the control was generally higher than that of the other thinning treatments. The control plot and the heavy thinning showed the first decrease in June, while the light and moderate thinning showed the first decrease in July.

Effect of thinning on biomass

Seasonal changes in biomass

In May, thinning can promote the increase of total biomass, above-ground biomass and belowground biomass of herbaceous plants, but there were no significant differences among thinning treatments. Total biomass and above-ground biomass were the largest in light thinning, and the belowground biomass was the largest in moderate thinning. In terms of root-to-shoot ratio, the moderate thinning was significantly higher than the other three treatments, and the light and heavy thinning were not significantly different from the control. Compared with the control, the number of herbaceous plants decreased after light thinning, but the difference was not obvious.

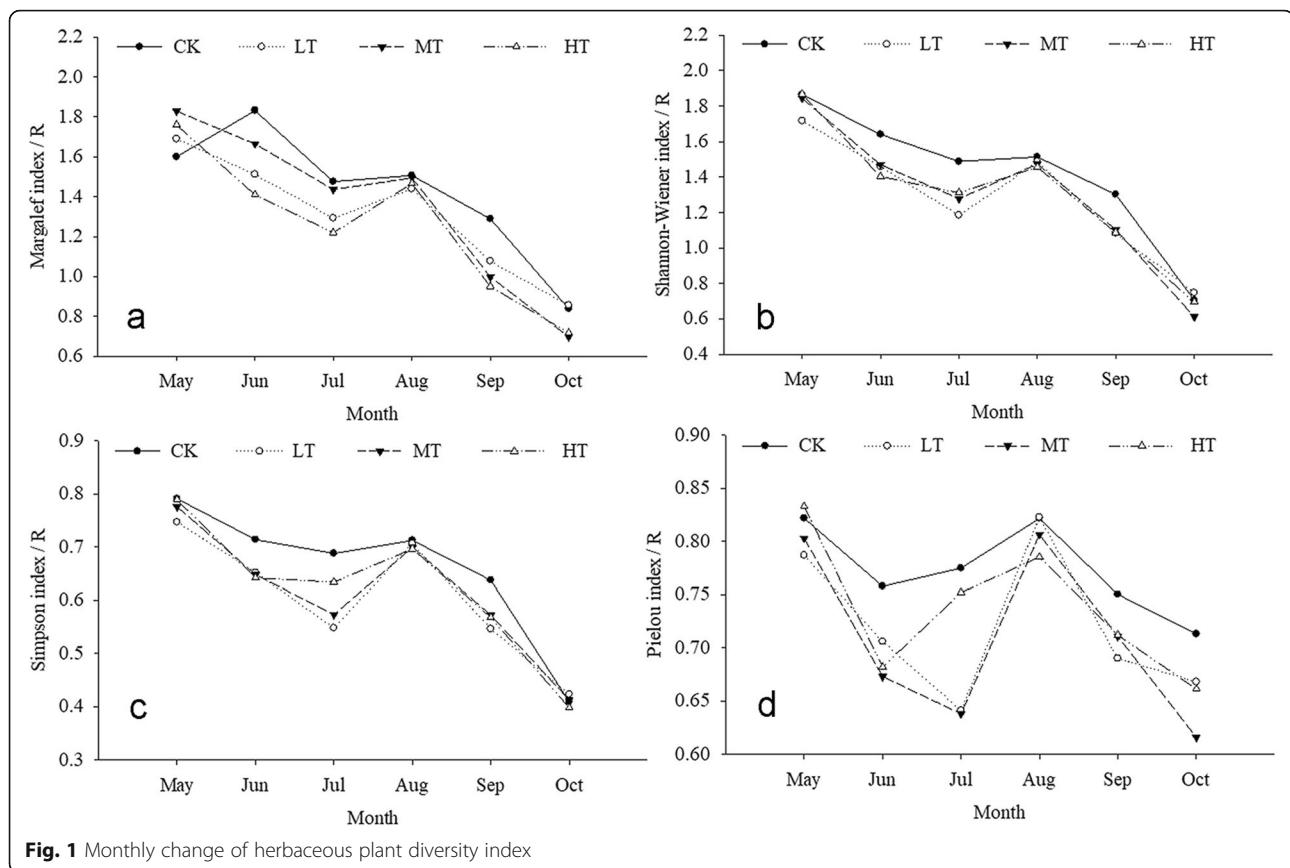


Fig. 1 Monthly change of herbaceous plant diversity index

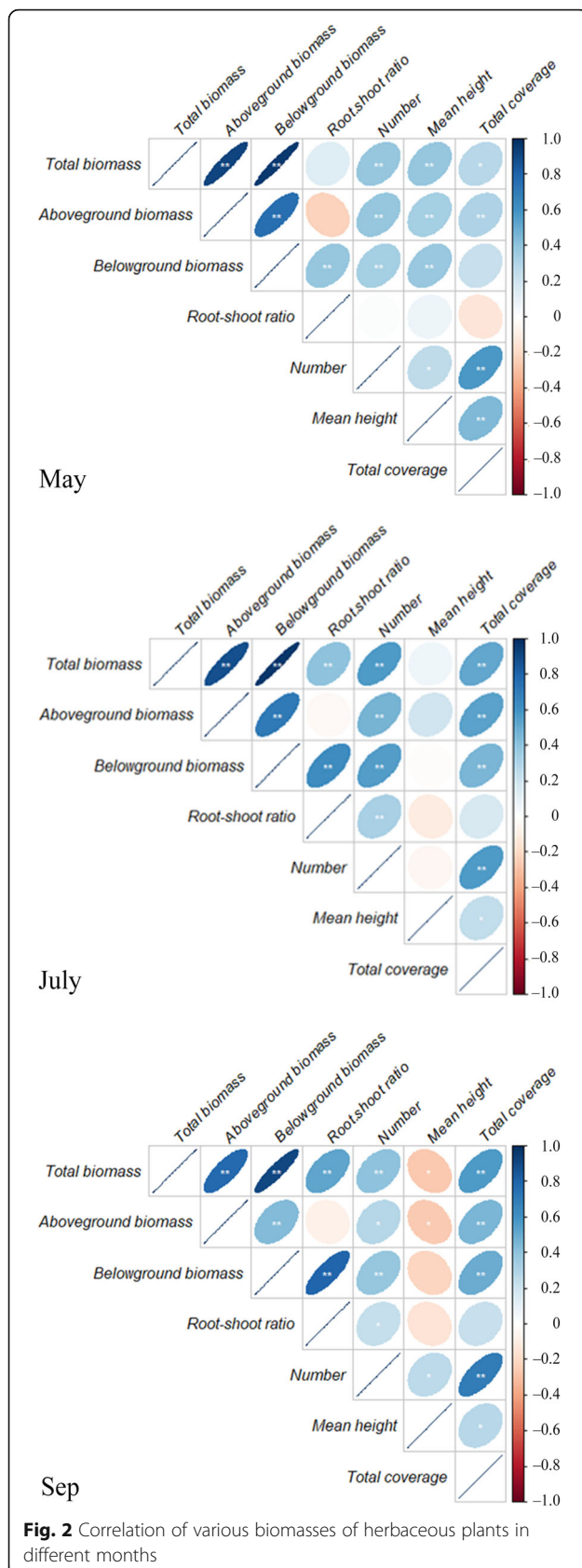
Moderate and heavy thinning significantly increased the number of herbaceous plants. In terms of average height and total coverage, moderate thinning was significantly higher than that of light thinning.

The biomass of herbaceous plants increased in July compared with May. Compared with the control, thinning promoted the increase of total biomass, above- and belowground biomass. Among them, the total biomass, above- and belowground biomass were significantly higher in heavy thinning than those of the control. The difference between moderate thinning and the control was not significant. In terms of root-shoot ratio, the difference between the four treatments was not significant, indicating that thinning intensity did not change the biomass allocation between the above- and belowground parts. Thinning increased the number of plants, and the number increased with increasing thinning intensity. The average height of herbaceous plants after thinning decreased, but the difference was not significant. In addition, thinning increased the total coverage of herbaceous plants. The coverage was significantly higher in the heavy thinning than that in the control, while the light and moderate thinning were not significantly different from the control.

Compared with the control, thinning significantly increased the total herb biomass and belowground

biomass in September. Heavy thinning rather than light thinning and moderate thinning significantly increased above-ground biomass. After thinning, the root-shoot ratio increased significantly, but the difference in the root-shoot ratio was not significant among light, moderate and heavy thinning, indicating that thinning changed the distribution of above- and belowground biomass of herbaceous plants. The nutrients were mostly allocated to the belowground part, but the thinning intensity did not change the distribution of plant biomass between above- and belowground parts. Thinning increased the number of herbaceous plants, and the number of herbaceous plants in the moderate and the heavy thinning was significantly higher than that in the control. The average height of herbs decreased after thinning, which was evident in light thinning. Thinning significantly increased the total coverage of herbs, but there were no significant differences among light, moderate and heavy thinning.

The correlation analysis of the biomass in different months is shown in Fig. 2. In May, the total biomass significantly correlated with the number, average height, and the total coverage, but it did not significantly correlate with the root-shoot ratio. Above-ground biomass was positively correlated with the number, average height and total coverage, but not correlated with the



root-shoot ratio. Belowground biomass was positively correlated with root-shoot ratio, the number and average height, but did not change with the total coverage.

In July, the number and total coverage of herbaceous plants were positively correlated with total biomass, above- and belowground biomass. The average height of herbaceous plants did not correlate with total biomass, above- and belowground biomass. The root-shoot ratio significantly correlated with total biomass and belowground biomass.

In September, the root-shoot ratio positively correlated with total biomass and belowground biomass. The number of herb plants had a significantly and positively correlation with total biomass and belowground biomass. The average height of herb plants was significantly and negatively correlated with the total biomass and above-ground biomass. The total coverage of herb plants was positively related to the total biomass, above- and belowground biomass.

It was found that the herb biomass was different over time (Table 3). In the control, the total biomass, above- and belowground biomass all showed their maximum in July. After thinning, the total biomass, above- and belowground biomass all gradually increased over time and reached their maximum in September. In the thinning treatments, the total biomass, above- and belowground biomass in September were significantly higher than those in May.

Correlations between diversity and biomass

The correlation analysis between herb biomass and diversity index in different months is shown in Fig. 3. In May, total herb biomass, above- and belowground biomass were significantly and positively correlated with Shannon-Wiener index, Simpson index, and Pielou index. The correlation between herb biomass and diversity index in July and September was not significant. Compared with May, the relationship between species diversity and biomass were changed, indicating that seasonal changes will change the relationships.

Discussion

Importance values variation

Forest thinning, as an important forest management practice, is an important way to change the composition and structure of the forest, adjust forest density, and improve the understory environmental conditions. It will directly affect the composition and diversity of understory vegetation, and influence tree growth and community stability (Zhang and Tang 2008). The importance values of each species varied significantly among

Table 3 Biomass of herbaceous plants in different months

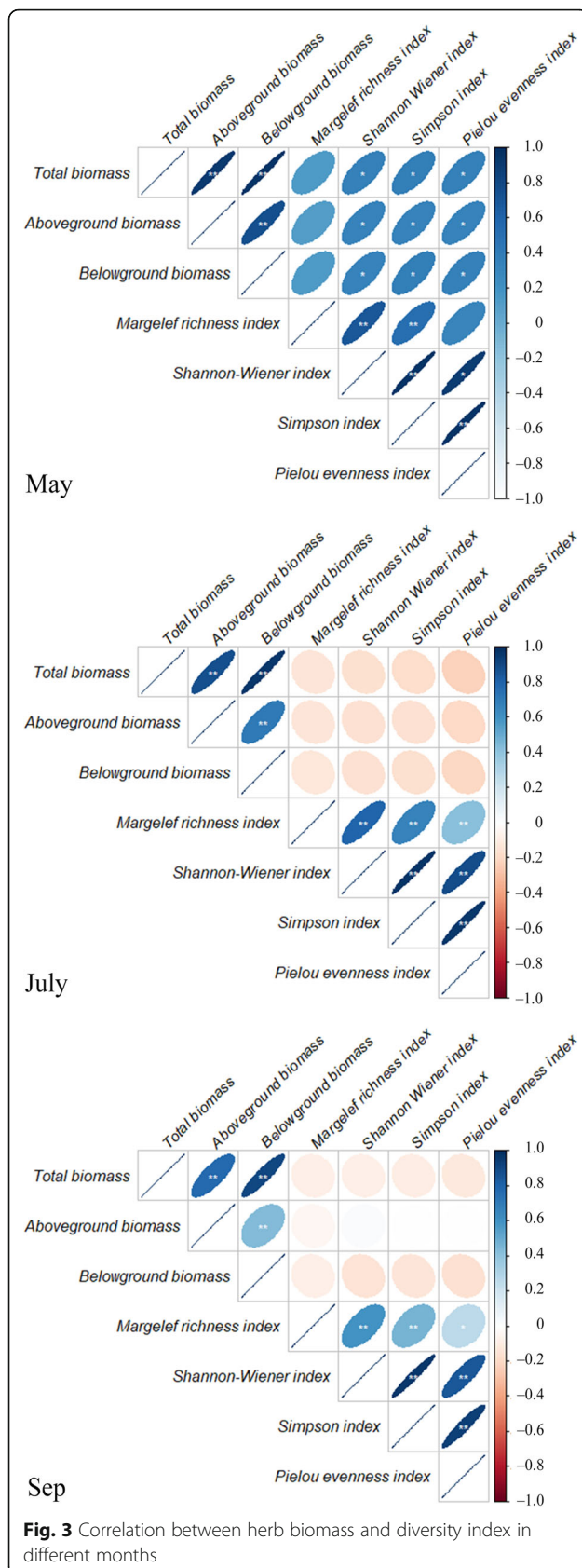
Month	Treatments	Total biomass (g·m ⁻²)	Aboveground biomass (g·m ⁻²)	Belowground biomass (g·m ⁻²)	Root-shoot ratio	Number per m ²	Mean height (cm)	Total coverage (%)
May	CK	113 ± 10a	53 ± 4a	59 ± 7a	1.11 ± 0.10a	216 ± 12a	11.95 ± 0.36ab	68.75 ± 3.70ab
	LT	194 ± 12b	86 ± 5b	109 ± 8bc	1.29 ± 0.06a	198 ± 11a	11.14 ± 0.36a	59.60 ± 2.77a
	MT	188 ± 21b	71 ± 10ab	117 ± 12b	1.86 ± 0.17b	275 ± 18b	12.44 ± 0.48b	72.75 ± 3.55b
	HT	163 ± 15b	76 ± 8b	88 ± 8c	1.18 ± 0.09a	265 ± 19b	12.09 ± 0.41ab	67.53 ± 4.46ab
July	CK	207 ± 16a	104 ± 11a	104 ± 8a	1.05 ± 0.08a	122 ± 14a	30.14 ± 1.18a	65.63 ± 3.13a
	LT	240 ± 13a	108 ± 6a	132 ± 9ab	1.24 ± 0.08a	175 ± 20ab	26.89 ± 1.88a	70.20 ± 3.70a
	MT	236 ± 19a	107 ± 9a	128 ± 12a	1.22 ± 0.09a	191 ± 18b	28.07 ± 1.20a	70.65 ± 2.98a
	HT	339 ± 53b	154 ± 16b	185 ± 39b	1.12 ± 0.13a	219 ± 29b	28.79 ± 1.34a	81.67 ± 3.89b
September	CK	161 ± 8a	85 ± 3a	76 ± 5a	0.89 ± 0.05a	109 ± 10a	25.12 ± 0.75a	58.30 ± 2.24a
	LT	273 ± 22b	112 ± 7a	161 ± 17b	1.43 ± 0.12b	134 ± 26ab	21.20 ± 1.90b	70.06 ± 3.96b
	MT	289 ± 30b	113 ± 8a	176 ± 23bc	1.51 ± 0.13b	181 ± 16b	24.62 ± 0.98ab	76.80 ± 3.28b
	HT	418 ± 43c	192 ± 28b	225 ± 31c	1.41 ± 0.25b	180 ± 43b	21.47 ± 1.36ab	78.13 ± 4.93b

different thinning treatments. The reason may be that the growth of overstorey changes with season, which in turn causes changes in the understory environment. The importance values of species in different treatments showed similar patterns with seasonal changes. The importance values of early spring plant were greater in May, and the top 5 importance values of various treatments were *Anemone amurensis*, *Hylomecon japonica*, *Anemone raddeana*, and *Corydalis ambigua*. Furthermore, these plants constitute the main body of herbaceous plants under the broad-leaved Korean pine forest in early spring. At this time, the overstorey has not yet reached canopy closure, the understory has sufficient sunlight, and the understory temperature continues to rise. In addition to early spring plants, other herbaceous plants have also sprouted in large numbers, so there are more species in May (Chen and Matter 2017; Kleinn et al. 2020). In June, the trees grow fast, but the overstorey is not completely closed. The light intensity of understory gradually decreases, and the plants wither and die in early spring. Except for the control, the number of species significantly decreased in other thinning treatments. At this time, *Carex pilosa*, *Aegopodium alpestre*, *Meehanian urticifolia*, and *Filipendula palmata* replaced early spring plants as the dominant species of understory herbs, and ferns also showed greater advantages due to their vigorous growth (Gao et al. 2019). The overstorey grows fast in July. The canopy density is relatively high, and the understory light intensity is low. At this time, the understory is mainly covered by shade-tolerant species such as *Carex pilosa*, *Carex remotiuscula*, *Carex callitrichos*, *Carex siderosticta*, *Meehanian urticifolia*, *Laportea bulbifera*, *Urtica angustifolia*. As precipitation begins to increase, understory wet plants grow quickly, leading to an increase in the number of

species (Hulík and Douda 2017). The overstorey reaches its growth peak in August, and the canopy closure continues to increase, resulting in a continuous decrease in understory light intensity. Early spring plants and some early summer plants withered and died, and the number of understory herbaceous species declined significantly, but the dominant species did not change (Gong et al. 2016). The temperature drops significantly in September, and the overstorey stops growing, some tall trees begin to defoliate, and the canopy closure is reduced. At this time, most of the herbaceous plants also stop the growth of the above-ground parts and enter the nutrient reserve period, which causes a significant decrease in the number of species. Understory herbaceous plants still consist of dominant species such as *Carex pilosa*, *Aegopodium alpestre* and *Meehanian urticifolia* (Wu et al. 2018). In October, the Changbai Mountain area has entered the end of autumn. Although most of the trees in the upper layer of the canopy have fallen leaves, there is sufficient sunlight understory. But due to the low temperature, most of the herbaceous plants have withered and died, causing the number of species to drop to the lowest value in the growing season (Dai et al. 2013). Based on the data of the entire growing season, the top herbaceous plants in the various treatments are mainly composed of *Carex pilosa*, *Aegopodium alpestre*, *Meehanian urticifolia* and *Filipendula palmata*, indicating that these species have strong adaptability and a wide ecological range.

Herbaceous plant species variation

The monthly changes in the number of herbaceous plant species in different thinning treatments indicate that the number of species in the thinning in May is higher than that in the control. This may be due to the increased



understory light intensity after thinning, which leads to the advance of plant phenology (Ye et al. 2015). The number of species in the thinning treatments decreased in June. This is due to the advance of the phenological period after thinning that causes some early spring short-lived plants to wither and die, resulting in a decrease in the number of species in the thinned treatments (Li et al. 2006). From July to September, the number of species in the four treatments gradually decreased. This is because July is the rainy season in this area. The soil under the forest is moist and the temperature is high, which is most suitable for plant growth. Therefore, the number of species in July reached the maximum. Although the enhancement of understory light intensity might have caused the death of some shade-tolerant species in moderate thinning, heliophile will quickly invade the site, leading to species reaching the maximum in the moderate thinning during this period. Although light thinning may not significantly increase light intensity, the thinning will form gaps, which will lead to the death of some rare shade-tolerant herbaceous plants, and the heliophile cannot invade the plot, resulting in the decrease of species numbers. In the heavy thinning treatment, the understory sunlight is significantly enhanced and there are more gaps, causing the death of most of the shade-tolerant herbaceous plants. Although the heliophile can invade the site, they cannot compensate for the death number of shade-tolerant plant, resulting in a significant decrease in species numbers (Ding et al. 2016). The understory temperature and light intensity of the four treatments are very low in October, and the understory environmental conditions are roughly the same. Most of the herbaceous plants withered and died, and only a few herbs with strong cold tolerance could survive (Small and McCarthy 2002).

Herbaceous plant individuals number variation

Throughout the growing season, the number of individual plants in the heavy thinning is the largest, indicating that thinning can promote the increase in the number of individual plants. This is due to the increase in the intensity of thinning, which leads to the increase of understory light intensity, subsequently promoting the increase of understory herb plants (Westerband and Horvitz 2017; Didion 2020). The number of individuals in the moderate thinning was higher than that in the heavy thinning in July. This is due to the presence of large herb plants in the heavy thinning, occupying a larger space under the forest, resulting in the death of some small one (Zhang et al. 2019). The number of individual plants in the control showed a decreasing trend. This was because most of the control in May were early spring plants. Although the early spring plants are small, there are more individuals on the same stem, so the

number of individuals was the largest. Early spring plants gradually die from June to August, early summer plants and late summer plants dominant the herbaceous plants. These plants are relatively large, occupying more space understory, resulting in a decrease in the number of individual plants. The overstory defoliate in September, the increase in understory light intensity increases the ground temperature, and the secondary growth of some plants leads to an increase in the number of individuals. The temperature gradually decreases in October, and most understory herbs are not cold-resistant, and will gradually wither and die, leading to a decrease in the number of individuals (Grant et al. 2019). The increase in the number of individual plants in May and June after thinning is due to the increase in understory light and the increase in understory temperature due to thinning, which advances the phenological period of plants. There are two types of plants including early spring plants and early summer plants in June (especially in heavy thinning). At this time, the plant individuals are small, and the understory space can meet the needs of plant growth. Therefore, the number of individual plants tends to increase. After June, the size of individual plants gradually increases after June, resulting in insufficient understory space and the competition causing the death of some individuals, which led to a decrease in the number of individuals (Li et al. 2017).

Herbaceous plant biomass variation

The total biomass, aboveground biomass and belowground biomass of the thinning treatments were greater than those in the control, indicating that thinning can promote the biomass growth of understory herbaceous plants. The greater the thinning intensity, the faster the plant biomass will grow. This is because thinning can significantly improve the understory light environment, thereby promoting biomass growth of understory herbs (Tinya and Ódor 2016). The plant heights of the light thinning and the control showed a peak curve, and the plant heights of the heavy and moderate thinning showed a double-peak curve. This is because July is the rainy season and the temperature is high, and the environmental conditions are moderate. Both overstory and understory entered the vigorous growth period, and the average height of the herbs reached the maximum. In August, as the stand canopy density increase, the understory light of the light thinning and the control was relatively poor, some tall herbs gradually withered and died due to insufficient growth. The light environment of the moderate and the heavy thinning improved significantly after thinning. After the highest canopy closure time in August, understory herbaceous plants have a significant high growth. For example, the heights of *Carex pilosa*, ferns, and *Impatiens noli-tangere*, *Veratrum nigrum* and

other plants in the moderate and heavy thinning were significantly higher than those in the light thinning and the control (Sun et al. 2017).

The diversity of herbaceous plants is an important indicator of the succession and development of forests. This study only studied four-intensity thinning in near-mature forests. In order to better reflect the effects of thinning on the understory environment, herbaceous plant diversity and biomass, therefore, it is necessary to further carry out relevant experiments in forest with different development stages and stand characteristics. It is also a necessity to analyze the impact of thinning on forest species diversity and biomass, guide forest management and accelerate the development of secondary forests to primary forests. In addition, this study also demonstrates that the species diversity and biomass of shrubs will also be affected by thinning. In the future, research can be conducted on the impact of thinning on the species diversity and biomass of shrubs.

Conclusions

The changes of biodiversity in the herb layer under the coniferous and broad-leaved mixed forest in Changbai Mountain were mainly affected by seasons. However, thinning changed the light environment in the forest, which could improve the plant diversity and biomass of herb layer in a short time. Moderate thinning had the most significant effect on the number of species, and the number of individual plants, average height and total coverage of plants increased significantly in all months of the growing season. With the increase of thinning intensity, the biomass of herb layer increased accordingly. Total herb biomass, above- and belowground biomass showed positive correlations with Shannon-Winner index, Simpson index and Pielou index in May. The findings provide theoretical basis and reference for reasonable thinning and tending in coniferous and broad-leaved mixed forests.

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Authors' contributions

Gerong Wang designed the study and developed the main hypotheses, Mo Zhou and Mengjia Wu collected and prepared the data, Naqian Guan, Yuwen Wang, Runhua Jiang and Zhiyu Liu analyzed the data, Fucai Xia and Yue Sun drafted the manuscript. All authors commented preliminary versions of the manuscript and contributed to improve the final version. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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