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RESEARCH ARTICLE

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Effects of thinning on plant species diversity and composition of understory herbs in a larch plantation

Abstract The effects of thinning on plant species diversity and composition of understory herbs in a larch plantation were investigated. The relationships between plant species diversity and composition of understory herbs and light conditions were established. Twenty-five 1 m × 1 m plots and fifteen 13 m × 1 m transects were set up in unthinned and thinned stands, respectively. All the transects in the thinned stands were set across the thinned rows and unthinned rows, and each of them was divided into nine 1 m × 1 m sub-plots. The herb diversity and light conditions were observed in each plot and sub-plot. The results show that there was a significant difference in herb diversity between the thinned and unthinned stands. All biodiversity indices except for evenness index in the thinned stand were higher than those of the unthinned stand, i.e., the herb diversity increased after thinning. According to the changes in herb densities and whether one species could be found in a stand or not before and after thinning, all herb species were classed into three types: positive, neutral and negative species, which referred to a species newly appeared and having an obviously increased density after thinning, with no obvious changes in its appearance and density after thinning, and disappeared and having an obviously decreased density after thinning, respectively. Many new species were found in the thinned stand like *Corydalis pallida*, *Prenanthes tatarinowii*, *Vicia unijuga* and *Sonchus brachyotus* etc. However, most species found in both the thinned and unthinned stands were negative species. In all nine sub-plots, only 11 and 10 species were found in spring and in autumn respectively, accounting for 17.74% and 15.15% of all the species in the thinned stand, respectively. All biodiversity indices were the highest in the center sub-plots and most of them tended to reduce from middle to side sub-plots. There was a close correlation between most of the three types of species and light conditions which was similar to each other in the thinned and unthinned stands.

Keywords thinning, light, herb, diversity, composition

1 Introduction

Thinning, as a means of the forest management, can not only increase the forest stock volume and improve the quality of the wood product, but it can also change the stand structure and successional process of the understory vegetation (Sullivan et al., 2002). Furthermore, thinning can also improve the conditions of temperature, nutrient and light regime of the understory (Yanai et al., 1998). Light, one of the most important environmental factors, can influence tree species composition and growth in forest ecosystems (Turner, 1990). The change in the utilizable quantity of light resources can also influence the species composition of undergrowth vegetation (Klinka et al., 1996). Generally, thinning can increase the biomass of undergrowth vegetation (Stone and Wolfe, 1996; Thomas et al., 1999; Sullivan et al., 2001). However, there are some disputes on the conclusions about the effects of thinning on the changes of plant species biodiversity (Duffy and Meier, 1992; Elliott et al., 1993; Ruben et al., 1999; Thomas et al., 1999). Therefore, it is necessary to carry out such studies in many different ecosystems (Nagaike et al., 1999).

There are various methods to classify species composition according to different objectives. For example, Ruben et al. (1999) divided the herbs after thinning into insensitive species, sensitive species, enhanced species and edge-enhanced species based on the change of herb density. In addition, according to life history, growth habit and bioclimatic characteristics of the species, they are divided into ferns, lycopodia, forbs (except spring ephemerals and weedy species), spring ephemerals, weedy species, graminoids, shrubs and trees (Thomas et al., 1999). In this study,

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Ruben's method was employed to classify the species into 1) positive species (the species whose density increases significantly and the newly appeared species after thinning), 2) neutral species (the species whose density changes insignificantly or does not change after thinning), 3) negative species (the species whose density decreases significantly and the disappeared species after thinning). Our specific objectives were to explore the effects of thinning on plant species diversity and the composition of herbs, to analyze the difference of understory light conditions between the thinned and the unthinned stands and to examine the effects of the changed light conditions on the plant species diversity and composition of understory herbs based on Ruben's classification method.

2 Materials and methods

2.1 Study site

The study was carried out at the Qingyuan Experimental Station of Forest Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, located at Dasuhe District, Qingyuan County, Liaoning Province, the northeast of China (41°51′6.1″N, 124°54′32.6″E), which belongs to the extension area of Changbai Mountain (42°01′15.33″N, 127°55′41.10″E). The altitude varies from 456 to 1116 m. The chief topography is montane. The climate is continental monsoon with a strong windy spring, a warm and humid summer, and a dry and cold winter. The mean annual air temperature is 3.9–5.4°C, with January as the coldest month at −37.6°C, and July the warmest at 36.5°C. The annual active accumulated temperature above 10°C is 2497.5–2943.0°C. The frost-free period is between 120 and 139 days, and the average sunshine time is 2433 h. Annual precipitation ranges from 700 to 850 mm, of which 80% falls in June, July and August. The growing season is from April to September (Zhu et al., 2007).

This observation was carried out in larch plantations, which were located at a slope of SE 23 degrees, and the altitude was at 824 m at Qingyuan Experimental Station. The larch plantation was planted in 1965 with 2 m apart between rows and trees. In spring of 2004, two rows were cut every three rows along the slope. After thinning, the average height of larch plantation was about 16.0 m and the average diameter at breast height was 19.5 cm with the maximum and minimum values 37.2 cm and 9.6 cm respectively, and the average height of first under branch was 8.5 m.

2.2 Methods

2.2.1 Sampling design

In thinned larch plantation, the sample plots were set up along the midline of the thinned rows, and had extension of 6.5 m to unthinned rows of two sides. Then transects, 13 m in length and 1 m in width, were set across the thinned rows and unthinned rows. Ten, two and three transects were selected on respective thinned rows. Each transect was divided into nine 1 m × 1 m sub-plots with 0.5 m apart from each other. The sub-plots were numbered from west to east. In sub-plots, the species name, number or cluster number, coverage, average height and the total coverage of herbs were recorded.

In the unthinned larch plantation with the same site conditions (control stand), five 25 m × 1 m transects with 2 m apart from each other were established. Each of them was divided into five 1 m × 1 m sub-plots, 5 m apart from each sub-plots. The investigation of herbs was conducted similar to that of the thinned stands.

2.2.2 Light

Eleven evenly distributed points were selected in the thinned and unthinned stands, respectively. The hemispherical photographs were taken by a digital hemispherical camera (Nikon, Coolpix 910, Japan, $f = 7–21$ mm) with a 180° fish-eye converter (Nikon, FC-E8, Japan, $f = 8–24$ mm). To get the vertical image, hemispherical photographs were taken at 16:30–17:00 of overcast days. The observed heights for the estimation of canopy openness were set at 1.0 m from the forest floor. LIA for Win32 software, developed by Kazukiyo Yamamoto, was applied for the image processing system, taking the area of circle in 60° of the hemispherical photograph as treatment area (Machado and Reich, 1999).

Two transects were selected randomly and the light of sub-point 1, 3, 5, 7 and 9 (Fig. 1) were investigated. The photosynthetic photon flux density (*PPFD*) at 1.0 m from the forest floor was measured by QMSW-SS, USA (in Spring), and Li-1400 data logger with sensors of LI-190, LI-COR, Nebraska, USA and 21 ×, Campbell Scientific, Utah, USA (in Autumn). In spring, the investigation was conducted during 9:00–16:00 in one day. The observation interval was 1 h with five records each time. But in autumn, records were taken every 5 min during 9:00–15:00. The

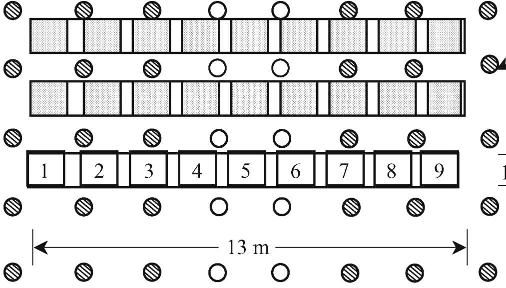

Fig. 1 Sketch map of belt transects for field investigation

investigation of light was conducted on sunny days. Field survey was conducted from May to September, 2005.

2.2.3 Species diversity indices

1) Importance value

$$IV=(D+C+F)/3,$$

where D is the relative density, C is the relative cover and F is the relative frequency.

2) Species richness index

$$\text{Margalef index}: R=(S-1)/\ln N,$$

where S is the number of species and N is the total number of individuals.

3) α-diversity indices

$$\text{Simpson index: } D'=1-\sum_{i=1}^{s} P_i^2$$

$$\text{Shannon-Wiener index: } H'=-\sum_{i=1}^{s} P_i ln P_i,$$

where P_i is the proportion of individuals belonging to species i (the ith species), $P_i=n_i/N$, and n_i is the number of the ith species.

4) Species evenness index

$$\text{Pielou's index: } J=(H')/(\ln S)$$

5) β-diversity indices

$$\text{Community dissimilarity: } CD=1-\frac{2j}{a+b}$$

where j is the number of species existing in both environments, a is the number of species in A condition and b is the number of species in B condition.

$$\text{Cody index: } \beta_r=\frac{g(H)+l(H)}{2},$$

where $g(H)$ is the number of species increasing along the habitat gradient (H) and $l(H)$ is the number of species decreasing along the habitat gradient (H).

3 Results and analysis

3.1 Comparison between thinned and unthinned stands

3.1.1 Light

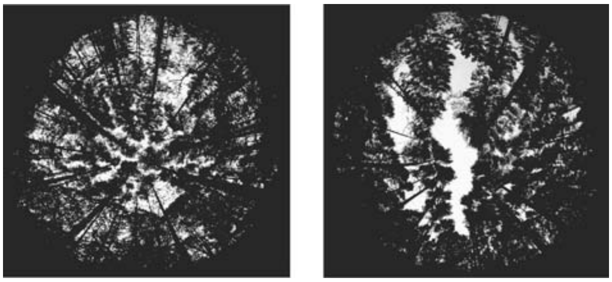

Fig. 2 Hemispherical silhouettes of unthinned stand (left) and thinned stand (right)

Eight hemispherical photographs of two stands taken in two observation periods (Fig. 2) were selected for this analysis. The canopy openness of the thinned and unthinned stands was 31.31% and 28.59%, respectively, in spring. In autumn it was 39.43% and 34.54% for thinned and unthinned stand, respectively. According to the results measured in the two observation periods, the canopy openness in the thinned stand was higher than that in the unthinned stand with the difference of 2.72% and 4.89%, respectively. The canopy openness of the two groups was analyzed by independent sample t-test. The results show that the two groups had significant differences (spring: $p=0.006$, autumn: $p=0.001$). The change of the canopy openness induced the different light conditions in the two stands and further caused the understory plants to differ by some extent.

3.1.2 Relationship between species diversity, composition of herbs and light

The species richness indices and biodiversity indices were higher in the thinned stand than those in the unthinned stand. This result might be caused by thinning, which could change the environmental conditions in the thinned stand. However, the variation of the plant species evenness indices was different in spring and autumn. This might be because thinning did not cause the direct or assured effects on the indices (Table 1).

Table 1 Comparison of indices of unthinned stand and thinned stand

		thinned stand	unthinned stand
species number	spring	61	24
	autumn	66	21
Margalef index	spring	6.7174	2.9904
	autumn	8.1387	3.0543
Simpson index	spring	0.8957	0.8523
	autumn	0.9241	0.8188
Shannon-Wiener index	spring	2.8300	2.1991
	autumn	3.0417	1.9806
Pielou's index	spring	0.6884	0.6920
	autumn	0.7260	0.6505

The changes of light conditions were the most important and direct reflections to environment variables. The light intensity and sunshine duration increased among the thinned rows. Meanwhile, the light intensity and sunshine duration nearby the unthinned rows also increased slightly. So it created conditions for some light-depending plant species. In spring, there were *Viola collina*, *Prenanthes tatarinowii*, *Vicia unijuga* and *Sonchus brachyotus* in the thinned stand, but these species never appeared in unthinned stand. Compared with the importance values of all species in the thinned stand, four species were ranked as the fourth, seventh, ninth and tenth, respectively. However, *Adoxa moschatellina*, whose importance value ranked at the third in the unthinned stand, did not appear in the thinned stand. Other herbaceous species were not found in the thinned stand, but they were found in the unthinned stand such as *Aclaea erythrocarpa, Equiselum hyemale*, *Brachybotrys paridiformis* and *Smilacina dahurica*. These results may be related to setting of the plots.

In autumn, some species had shown similar results with those in spring for both thinned and unthinned stands. For example, *P. tatarinowii* and *Vicia unijuga* were not found in the unthinned stand, but *E. hyemale* and *B. paridiformis* only occurred in the unthinned stand. In spring, *Cardamine leucantha* was a species with an importance value of 0.2928 and the total number of individuals (density 24.6 trees/m^2) was the largest in the unthinned stand (Table 2). But the importance value is 0.1279, and density is 7.4 trees/m^2 in the thinned stand. The result of decreasing density indicated that *C. leucantha* had strong responses to thinning. There were some other species such as *Corydalis ambigua, Hylomecon japonica* and *Meehania urticifolia* etc., which had a similar trend with *C. leucantha*. These plant species were defined as negative species. The number of negative species was thirteen in the thinned stand with eight species of these appearing in two stands, accounting for 61.5%. In contrast, *Artemisia igniaria* and *V. collina* were positive species. The density of *A. igniaria* greatly increased from 0.6 trees/m^2 in the control stand, to 10.9 trees/m^2 in the thinned stand. There were a total of 48 positive species, of which five species were found in both the thinned and unthinned stands, accounting for 10.4% of all the species. The variation of *Lamium album* and *Moehringia lateriflora* was not obvious between the thinned and control stands, which were defined as "neutral species". The result shows that it had six neutral species in the thinned stand. In autumn, *C. leucantha*, *M. urticifolia* and *B. paridiformis* etc. were negative reactions to thinning. But *A. igniaria*, *P. tatarinowii* and *Vicia unijuga* were the contrary. *L. album* was the only neutral specie (Table 2).

According to the change of importance value and density of common species, low light condition could meet requirements for herb species, i.e., the herb species needed a weak light environment in unthinned stand. The light conditions were relatively improved in the thinned stand. In this case, most species density would decrease, being negative reactions to light conditions, and some species of them were obvious, such as *C. leucantha*, *M. urticifolia*. Thinning could cause the change in light conditions, but plant species had different reactions to the changes and the same species had different reactions for various seasons. For examples, *Caraex leucochlora* was a positive species in spring, but in autumn it became negative. *Polygonatum inflatum* changed as a negative species in spring into a neutral species in autumn. *Laportea bulbifera* changed from a neutral species in spring into a positive species in autumn. The change of light conditions that caused by thinning would influence the appearance of species. The influences included the change of herb densities, whether one species could be found in a stand or not and the time of changes and being found. The complex reaction was due to some species which grew well in weak

Table 2 Importance values of herbaceous species

species	spring		autumn	
	thinned	unthinned	thinned	unthinned
Cardamine leucantha	0.1279	0.2928	0.1015	0.2770
Chelidonium majus	–	–	0.0072	0.0059
Pinellia ternate	0.0018	0.0096	0.0031	0.0256
Dioscorea nipponica	–	–	0.0030	0.0059
Allium monanthum	0.0958	0.0792	–	–
Carex leucochlora	0.0216	0.0031	0.0015	0.0201
Arisaema amurense	0.0011	0.0076	–	–
Corydalis ambigua	0.0230	0.1002	–	–
Heracleum moellendorffii	0.0039	0.0058	–	–
Polygonatum involucratum	0.0182	0.0164	–	–
Hylomecon japonica	0.0008	0.0480	–	–
Rubia cordifolia var. *pratensis*	–	–	0.0186	–
Actaea erythrocarpa	–	0.0039	–	–
Viola acuminata	0.0238	0.0081	0.0819	0.0041
Aquilegia oxysepala	0.0011	0.0037	–	–
Sonchus brachyotus	0.0257	–	–	–
Ixeris denticulate	–	–	0.0565	–
Artemisia stolonifera	–	–	0.1036	–
Carex siderosticta	–	–	0.0275	–
Astilbe chinensis	–	–	0.0056	0.0083
Pseudostellaria davidii	–	–	0.0122	0.0438
Chrysosplenium pilosum	–	–	0.0291	–
Polygonatum inflatum	0.0020	0.0040	0.0019	0.0059
Carex pilosa	–	–	0.0229	–
Moehringia lateriflora	0.0427	0.0623	–	–
Equisetum hyemale	–	0.0072	–	0.0359
Prenanthes tatarinowii	0.0411	–	0.0568	–
Artemisia igniaria	0.1592	0.0130	0.1119	0.0136
Meehania urticifolia	0.0109	0.1180	–	0.1825
Rorippa globosa	0.0165	–	–	–
Viola collina	–	–	0.0109	0.0045
Corydalis pallida	0.0595	–	–	–
Galium pseudoasprellum	–	–	0.0011	0.0073
Brachybotrys paridiformis	–	0.0120	–	0.0153
Impatiens noli-tangere	0.0300	0.0131	0.0320	–
Circaea quadrisulcata	0.0209	0.0024	–	–
Vicia unijuga	0.0284	–	0.0500	–
Adoxa moschatellina	–	0.1018	–	–
Smilacina dahurica	–	0.0032	–	–
Lamium album	0.0487	0.0749	0.0176	0.0443
Viola yezoensis	–	–	–	0.0050
Oenothera biennis	0.0134	–	–	–
Rubia chinensis	–	–	0.0030	0.0073
Laportea bulbifera	0.0121	0.0097	–	0.1429

light but was more sensitive to other micro-environments, most especially the change of relative humidity and the change of micro-environments was just caused by the change of incidental light (Qin et al., 2003).

3.2 Comparison between thinned rows and unthinned rows in thinned stand

3.2.1 Change of *PPFD*

The variations of the average *PPFD* in different points were plotted in Fig. 3. In the five points, average *PPFD* of the point 5 (spring) and point 7 (autumn) exhibited the largest values for spring and autumn, respectively. The *PPFD* at point 9 was completely different from point 1 because the unthinned rows were not just the three rows along the point 9 direction but with 4–6 rows. From point 1 to 9, the highest *PPFD* values appeared at 10:00, 11:00, 13:00, 14:00 and 9:00 in spring and at 11:00, 12:00, 11:00, 9:00 and 10:00 in autumn. There was no obvious regularity for the distributions of *PPFD* with the changing of time because of many influencing factors such as investigation location, season, investigation time, aspect, the direction of thinned rows, thinning intensity, species, height and the coverage of the tree layer, etc. (Elliott et al., 1993). The heterogeneous condition of light was induced by thinning in thinned stand, the increased light levels and the exposure time to light which were different in various locations.

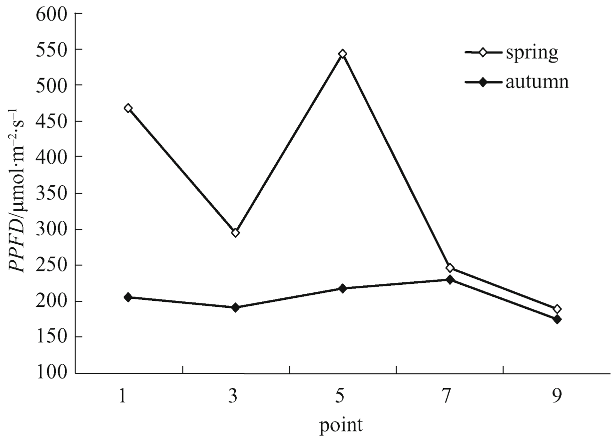

Fig. 3 Change of average *PPFD* in each point

3.2.2 Relationships between gradient change of herbs diversity and light conditions

Richness indices and diversity indices were the highest in the middle and decreased in both sides. Evenness indices were not obvious in spring (Figs. 4 and 5). In autumn, the tendency of all points, except point 2, was similar to the trend mentioned above. Only 11 and 10 species were found in all nine sub-plots, in spring and in autumn, respectively, accounting for 17.74% and 15.15% of all the species in the thinned stand, respectively. It was obvious that the common species in all points were few, i.e. there was a great difference in species composition of each point. The community dissimilarity and Cody indices were largest in point 4 and 5 (Fig. 6). The trend of all indices was in concordance with the average *PPFD* in different points, i.e. light conditions and the indices in different points decreased from thinned rows to unthinned rows. This shows that there were certain relationships between the changes of light conditions and plant species diversity gradient after thinning. Average *PPFD* of point 1 was significantly different from that of point 9, almost reaching the level of point 5. The diversity at point 1 was not as big as that at point 5. There were two reasons accounting for this. One was that the light changed differently with time all day. The other, more important of the two reasons was the locations of the two points, which was. One point was located on edge of unthinned row, while the other in the middle of thinned row, which might influence the biotic and abiotic environment.

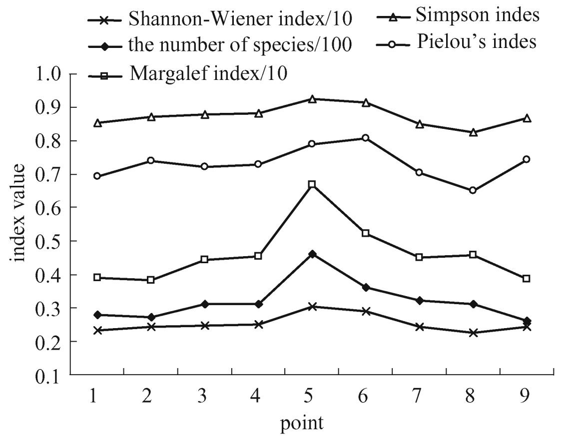

Fig. 4 Comparison of α-diversity indices in each point (spring)

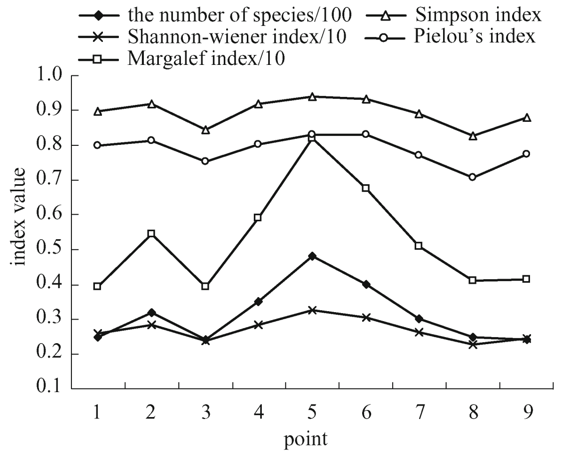

Fig. 5 Comparison of α-diversity indices in each point (autumn)

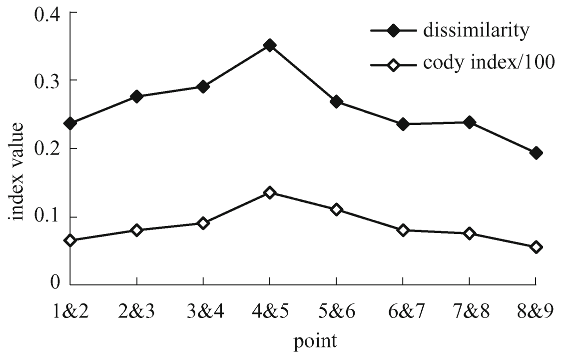

Fig. 6 Comparison of β-diversity indices in each point in spring

Comparing the thinned with the unthinned stand, the reactions to light conditions of three species types only represented two gradients. The density changes of three type species in different points (including the species that importance values were relatively larger) were analyzed to check the effect of light. Take the spring species for example. In spring, every positive species (*S. brachyotus*, *A. igniaria*, *P. tatarinowii*, *V. collina*, *Vicia unijuga*, *Impatiens noli-tangere*) had the same trend as the average *PPFD* except *I. noli-tangere*. In other words, they were related to light, with *P. tatarinowii* being the most obvious ($r = 0.886$, $p = 0.046$) (Fig 7). The density of each negative species (*C. leucantha*, *Corydalis ambigua*, *H. japonica*, *M. urticifolia*), except *Corydalis ambigua*, was small or did not exist at the points of large *PPFD* (Fig. 8). *A. moschatellina* was not considered because it was absent in the thinned stand. But the density of neutral species (*Moehringia lateriflora*, *L. album*, *Allium monanlhum*) fluctuated markedly, inconsistent with the trend of the changing light (Fig. 9). The results show that there was no significant difference in the density of *L. album* and *Moehringia lateriflora* before and after thinning. There were two reasons for that: 1) these two species were insensitive to the environmental changes caused by thinning; 2) these species had recovered before we investigated, i.e. the period of thinning was short. Some species was not sensitive in a certain environment, but might change a lot in another environment, and vice versa. Understory herbs were recovering constantly after disturbances. We regarded thinning as a disturbance. Ruben et al. (1999) studied the difference of understory herbs 25 and 60 years after clear-cutting of a stand. They found that the effects of clear-cutting on understory herbs still existed after 25 years later. But in the 60-year-old clear-cutting stand, this effect was smaller than the former. In addition, some earlier mentioned species showed different responses to thinning in spring and autumn. Therefore, the similar division of the species composition in different communities, different periods of resumption after disturbance and under different seasons was not completely identical.

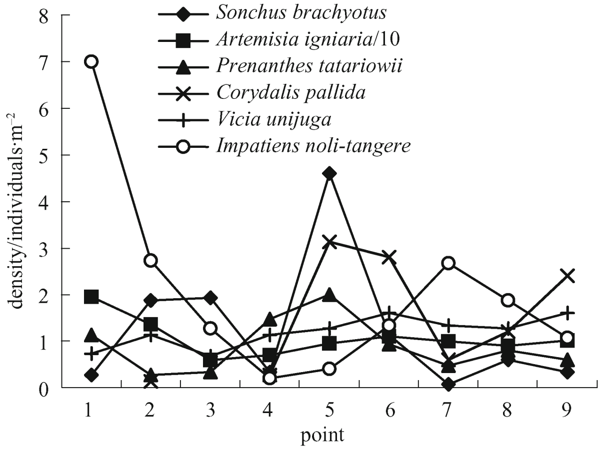

Fig. 7 Change of densities of positive species

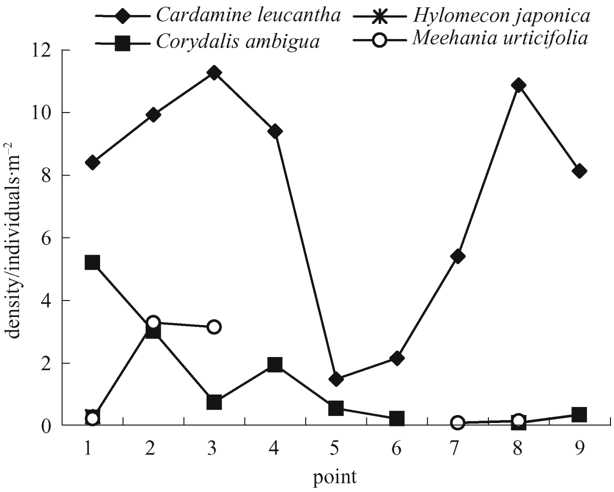

Fig. 8 Change of densities of negative species

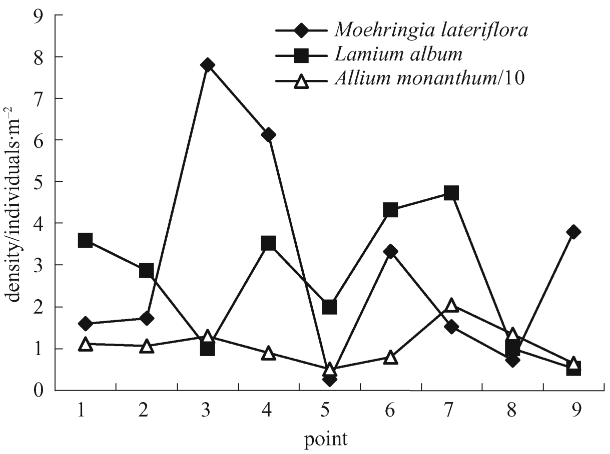

Fig. 9 Change of densities of neutral species

4 Discussion

According to the above analysis, we could conclude that all the indices and the changes of positive and negative species were associated strongly with the light conditions. It could be said that the light conditions influenced the diversity and composition of herbs significantly in the thinned stand. Since the light through the canopy of trees was related to species, height and coverage, etc. (Aubin et al., 2000; Brosofske et al., 1997), the impacts of different thinning intensities were also different based on the illumination conditions. Wetzel and Burgess (2001) explored the light conditions of stand at three different harvesting intensities and found that light levels changed from 14% of full illumination in an unthinned stand, to 62% in the stand of the largest thinning intensity during the whole growing season, i.e., the light levels gradually increased with the increased thinning intensity.

Thinning cannot only raise the degree of heterogeneity of the light intensity distribution, but can also make different parts receive light at different times. At the same time, thinning can also improve the intensity of scattering light, reflected light and transmitted light, leading to a great difference in light quality (Hu and Zhu, 1999). Therefore, different thinning intensities of forests may cause different species diversity and composition of understory. In addition, light conditions change rapidly in early periods after thinning, following with the appearance of newly light-loving herb species or the increased density of herbs under the forest. Accordingly, species composition changes because of competition for resources. Canopy density changes continuously due to the growth of trees after thinning, which may have an impact on the species diversity of understory herbs. Therefore, the diversity of understory herbs will fluctuate greatly for a longer period.

During the plantation management and recovery of a natural secondary forest, we should take special account of the effect of thinning on the diversity of understory plants. Thinning, viewed from a certain angle, is a useful method to change stand density. But the impact of stand density on biodiversity is more significant (Qin et al., 2003).

The improvement of plant species diversity plays an important role on improving soil water holding capacity and increasing organic content. At the same time, it can also effectively reduce the occurrence of forest pest and increase the stability of the ecosystem (Lin and Huang, 2001). As to the understory vegetation themselves, there are some medicinal and ornamental species which have economic values. The plantation management will be a concerning issue in the future. We should regulate the relationship between the wood volumes and plant diversity by different cutting methods and cutting intensities at each level, to create the maximum ecological and economic benefits. The resolution of this issue will make forest management develop in a reasonable, efficient and sustainable way.

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