EFFECT OF GAP DISTURBANCES ON SOIL PROPERTIES AND UNDERSTORY PLANT DIVERSITY IN A PINUS MASSONIANA PLANTATION IN HUBEI, CENTRAL CHINA

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ABSTRACT

The response of plant species composition, diversity and soil nutrient availability to different canopy sizes and age gaps in a Pinus Massoniana plantation were surveyed in Taizishan, Hubei province, central China. The soil chemical properties of 27 gaps and 3 non-gaps were measured and compared. The study objectives were: (a) confirm whether and when nutrient pulses emerged in small gaps; (b) determine the effects of gap sizes and ages on the soil properties and species diversity in gaps; and (c) determine the response of species diversity to soil nutrient variables in gaps. The understory plants of all canopy gaps and non-gaps were identified. Diversity indices were employed in this study, and the relationship between understory plant diversity and soil chemical properties were analyzed by detrended canonical correspondence analysis (DCCA). The results showed that soil properties and species diversity were significantly impacted by forest gaps, and the effects of the gap ages were more extensive than those of the gap sizes. The nutrient pulses occurred in gaps, but the emergence of nutrient indicators pulses in different age and size gaps was different.

Keywords: disturbance; gap size; gap age; soil properties; species diversity.

INTRODUCTION

China possesses the largest plantations in the world, and Pinus massoniana plantations comprise the largest area. Plantations generate many ecological problems due to their simplified vegetation structure, such as biodiversity loss, frequent outbreaks of plant diseases and insect damage. Therefore, enhancing the biodiversity and stability of plantations is an important objective for forest management, after implementing natural forest protection projects. Thinning is the most important method for adjusting the plantation structure and enhancing the productivity of forest stands, which has been widely used in plantation management in China. Artificial canopy gaps, with sizes ranging from 30 m² to 200 m², have been hypothesized to be important in providing frequent, small-scale disturbances in plantations after thinning. Therefore, small openings in forest canopies are common and important in providing spatial heterogeneity in forest ecosystems (Clintion, 2003). The changes in soil moisture (Runkle 1982; Ritter and Vesterdal, 2006) and nutrient (Denslowet al., 1998; Pettersson and Hogbom, 2004) occur in disturbed forests with thinning gaps. The heterogeneity habitats accompanied by edge habitats would therefore influence species composition and population dynamics in plantations with gaps.

The physiological and ecological habits of plants are dominant factors in the abundance and diversity of understory plant species. The different formation stage (Uhl et al., 1988; Spies et al., 1990) and sizes (Zhang and Zak, 1995; Bouchard et al., 2005; Heithecker and Halpern 2006; Muscolo et al., 2007; Griffiths et al., 2010) of gaps have various influential and intensive impacts on both the habitats and regeneration of understory plants (e.g., Dirzo et al., 1992; Schumann et al., 2003). Previous studies addressed paid the responses of tree species grown under canopy gaps (Frel chained Reich 1995), analyzed and simulated the gap dynamics (e.g., Vepakomma et al., 2008), as well as the regeneration characteristics under the gap (Gagnon et al., 2004; Kukkonen et al., 2008; Prévost and Raymond, 2012). However, a few studies have focused on the influence of thinning gap disturbances on soil properties in the gaps (Adele et al., 2007; Griffiths, 2010; Muscolo et al., 2010) and the correlations between soil properties and understory species diversity of plantations (Arunachalam and Arunachalam, 2000; Muscolo et al., 2007). Previous studies have shown that the effects on soil nutrients of forest gaps were significantly greater than in the understory, and these effects increased with the gap size (Denslowl et al., 1998); moreover, larger and older gaps increased species diversity, but diversity then decreased when the sizes or age increased to a certain extent (Fred et al., 2000). Some studies focus on the changes in nutrient availability for short intervals after gap creation, and it is poorly understood whether and how changes in nutrient availability for short intervals after gap creation, and it is poorly understood whether and how changes in nutrient availability for short intervals after gap creation, and it is poorly understood whether and how changes in nutrient availability for short intervals after gap creation, and it is poorly understood whether and how changes in nutrient
availability persist over longer periods of time (Denslow et al., 1998; Thiel and Perakis, 2009). Some results suggest that many treefall gaps may be too small to produce detectable changes in soil nutrient processes (Vitousek and Denslow, 1986; Denslow, 1987), but Denslow et al. (1998) presumed the nutrient pulses affecting the growth of seedlings and saplings would be found in small treefall gaps.

Here, we aim to: (1) measure the effects of different gap sizes and ages on gap soils, and (2) determine which are the primary factors controlling the gap composition of species and species diversity in a Pinus massoniana plantation. Thus, the authors hope to compiled direct evidence not only on our perception of ecological processes but also on the quality of management practices when gap dynamics are adopted as a template for ecosystem-based management.

**MATERIALS AND METHODS**

**Study Area:** The study site is located in Taizishan (112°48′-113°03′E, 30°48′-31°02′N), Hubei province, Central China. It has a typically subtropical humid monsoon climate with hot and rainy summer and cold winter. The annual average precipitation is 1090 mm, the annual average temperature is 16.4°C. The forest types in this region mainly are evergreen coniferous forests and coniferous broad-leaved mixed forests and evergreen broad-leaved forest. The three major soil types were yellow-brown soil, mountain yellow-brown soil and yellow-cinnamon soil.

*Pinus massoniana* is one of Chinese endemic species. Based on the results of felling age, thinning age and intensive of *Pinus massoniana* plantation (Ding et al., 2002; Yu et al., 2011), the optimum felling age of pulpwood plantation and building timber plantation were 14-20a and 18-28a, respectively. The first thinning disturbance starts from 7-10a in high density stand or 11-14a in low density stand, and Thinning interval is about 3-6a (Ding et al., 2002). The intensity of thinning is about 15% to 35%. Therefore, three sizes of canopy gap (S1 with an area of 50-70 m² for contractible gap, S2 with an area of 100-120 m² for central gap, and S3 with an area of 150-200 m² for extended gap), three ages of gap (A1 is after gap formation, A2 is 3a, A3 is 5a), and CK (Non-gap) were chosen in *Pinus massoniana* plantation. Nine gaps were chosen to every size gradient, every three of this nine gaps belong to different age gradient (A1, A2, and A3), respectively. Three samples were chosen to beon gap.

Since compass orientation of gaps might influence the diversity of species, the oriented north-south (N-S) and oriented east-west (E-W) transects in each expanded gap (EG) chosen for study overlap at the center of the canopy gap (CC). We placed five uniform 2 m × 2 m quadrants on each N-S and E-W transects with mean distance in each expanded gap (1 quadrat is overlapped between 2 transects in each gap) except area about 50-70 m² gaps in which three uniform 2 m × 2 m small quadrats on each transects were placed. Hence, a total of 27 gaps and 3 non-gaps samples, 60 belts transect and 468 small quadrats were surveyed.

**Data Collection:** In each canopy gap, three random soil profiles were excavated, and soil samples of every layer (0-20cm and 20-40cm) were obtained in each profile. The pH, soil organic matter (SOM), total nitrogen (TN), hydrolysable nitrogen (HN), total phosphorus (TP), available phosphorus (AP), total potassium (TK), and available potassium (AK) were measured using the cytomter method, soil bath potassium dichromate oxidation method, automatic Kjeldahl method, diffusion method, acid solution-molybdenum antimony resistance to colorimetric method, molybdenum antimony resistance to colorimetric method, acid solution-flame photometry, and ammonium acetate extraction-flame photometry, respectively. In each 2 m × 2 m quadrant, the height, coverage and number of each wood and herb species were measured. These factors (community characteristics, soil chemical property factors) were included in the DCCA ordination.

**Data Analysis:** The important value (IV) of the species is calculated using the following formulas (Li, 2012; Wang et al., 2012): IV shrub and herb = (relative height + relative coverage + relative frequency) ×100/3; Patric richness index $R = S$; Simpson index, $D = 1 - \sum P_{ij}$; Shannon-Wiener index, $H = -\sum P_i \ln P_i$; Pielou evenness index, $J = (\sum P_i) / \ln S$; $P_i$ is the relative IV of the species; and $S$ is the total species (Wang et al., 2012). The similarity among communities (β-diversity) is calculated using Jaccard’s index: $C_s = c / (a + b - c)$, where $C_s$ is the similarity index; $a$ and $b$ are the species number of community A and B, respectively; and $c$ is the number of common species between community A and B.

The effects of gap sizes, gap ages and soil layers, and the two-way interactions of gap sizes and gap ages on the soil properties were examined using an Analysis of Variance (SAS, 2005). All data were tested for homogeneity of variance before performing specific statistical procedures. A multiple comparison was used to determine any significant differences of thesoil properties index, and thediversity index among theses sizes or ages of the canopy gap was determined using SAS’s t-tests (SAS, 2005). Significant differences are reported at the P<0.05 probability levels. Detrended canonical correspondence analysis (DCCA) of CANOCO4.5 software was used to analyze the relationship between the species in sample plots (based on the importance values of species) and thesoil properties variables (0-20cm), as well as to discuss key influential factors (Wang et al., 2012). The
RESULTS

Different Size and Age Gaps Effect on Soil Chemical Properties: Tab. 1 reports the significant differences of the chemical properties of soils in different size age gaps. The results obtained showed that the soils' chemical and physical property measurements were significantly different among the different gap ages, and the pH, TP, AP, and TK of the soils were significantly different among the different gap sizes. With the interaction of size and age gaps, the SOM, TN, HN, and AK of the soils were significantly different among the size and age gaps.

Fig. 1 presents the data on the soil properties variability in the 1a, 3a, and 5a gaps, and the under canopy cover sites (CK), as well as in the 50-70m², 100-120m², and 150-200m² areas and the under canopy cover sites (CK). For the soil in the *Pinus massoniana* plantation, the pH, SOM, HN, TN, TK, AK, TP and AP levels varied significantly among the different gapages. Regardless of the soil in the 0-20cm or 20-40cm layers, the pH level was different between the age gap sites, and the 3a gap showed the highest value. The SOM, HN and TN levels all increased with the increasing age of the gaps.

The measured values of TK and AK in the 0-20 cm layer were significantly higher in the 3a-gaps than in the other age gap plots and the adjacent under canopy cover sites. The AP values of the 0-20cm layer also increased with the increasing age of the gaps. The amount of AP was highest in the 5a age gaps. A similar trend for the AP values of the 20-40cm layer was also observed (Fig. 1). The trend for the TP values of the different age gaps is similar to those of TK or AK. The highest values of TP for the 0-20 cm and 20-40 cm layers were both found in 3a-gaps.

In contrast to the results of the soil chemical properties to different age gaps, approximately half of the measured values of the soil chemical properties varied significantly among the different size gaps, such as the pH, TK, TP, and AP. The pH in both soil level layers was significantly higher in the 150-200m² gaps and non-gaps than in the 50-70m² gaps. The TK values of the 0-20 cm soil layer were significantly higher in the 150-200m² gaps than in about the 100-120m² gaps, and the TK values were slightly higher in the 50-70m² gaps and canopy cover sites adjacent to the gaps. The TK levels increased with increasing size of the gaps in the 20-40cm layer. The amount of AP in the 0-20cm layers was highest in the 50-70m² gaps (255.42 mg kg⁻¹ soil) and decreased with increasing gap size with a value of 221.75 mg kg⁻¹ in the 150-200m² gaps. The same results of the available phosphorus (AP) in the 20-40cm layer of different size gaps were observed. The total phosphorus (TP) values of the 0-20 cm layer were significantly higher in the 150-200m² gaps than in the canopy cover sites adjacent to the gaps.

The interaction effects of the gap size and age on the surface soil (0-20cm layer) chemical properties are presented in Fig. 2. The SOM and TN were significantly higher in the 5a-gaps and 50-70m² gaps than those of other gaps and non-gaps, respectively. Higher values of HN in the surface soil were found in the 5a-gaps of all size gaps. The values of AK were higher in the 3a-gaps of all size gaps than those of other gaps.

Different Size and Age Gaps Effect on Species Composition and Species Diversity of Plant: A total of 152 species were sampled in the study sites, including 31 arbor species, 57 shrub species, and 64 herb species. The results obtained showed that a significant difference existed in the primary woody and herb species composition among the different age gaps and non-gaps. A similar result was obtained when comparing the different size gaps with non-gaps (Fig. 3).

Fig. 3 presents the number of species in different size gaps, age gaps and non-gaps. The results showed that the numbers of total species in 3a or in 5a gaps were significantly higher than those in 1a gaps or non-gaps. The difference in the number of total species might due to the difference in the number of arbor species and shrub species, because no difference in the number of herb species was found among the different age gaps and non-gaps.

The Jaccard's index (β diversity) of shrub layer is the highest between the 100-120 m² and 50-70m² gaps, and its the lowest between the 50-70 m² gaps and non-gaps. However, the index of the herb layer is the highest between the 100-120 m² and 50-70m² gaps, and its the lowest between the 100-120 m² and non-gaps. Simpson diversity indices of arbor species, shrub species and herb species for different age gaps and size gaps are described in Fig. 3-B. The results show that 5a gaps have the highest Simpson diversity indices; the 100-120 m² gaps have the highest Simpson diversity indices of shrub species and are significantly higher than those of 50-70 m² gaps and non-gaps, but they are only slightly higher than those of other gaps.

The Shannon-Wiener diversity indices were the same as the three indices (Fig. 3-A, Fig. 3-D).
The interaction effects between the gap size and age on the species diversity are presented in Table 1. With respect to the arbor species of the sample plots, the 5a of the 100-120m² gaps had the highest Patrick richness index (6.33), highest Simpson’s diversity index (1.78) and highest Shannon-Wiener index (0.82) among the gaps and non-gap stands. The 1a of the 50-70m² and 100-120m² gaps had a lower Pielou evenness indices (J) than the other gaps and non-gap stands. With respect to the shrub species of the gaps and non-gap stands, a higher Patrick richness index (R) was found in 3a for the 100-120m² and 150-200m² gaps, which were significantly higher than those in the non-gap and 1a of all size gaps, except for the 100-120m² gap. The higher Simpson’s diversity indices (D) were found in 3a of the 100-120m² gap (3.16) and 5a of the 150-200m² gap (3.17), and the higher Shannon-Wiener indices (H) were found in 1a of the 100-120m² (0.95) and 5a of the 150-200m² gap (0.95). The highest Pielou evenness index (J) was found in 1a of the 100-120m² gap (0.93). However, no difference was found in the Patrick richness index (R) of the herb species among the combination of different size and age gaps and non-gap stands.

Table 1. Significant differences in the chemical properties of soils in different size or age gaps, and the interaction effects between gap size and gap age on species diversity

<table>
<thead>
<tr>
<th>Source</th>
<th>Soil characters</th>
<th>Species diversity</th>
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<tr>
<td></td>
<td>DF</td>
<td>PH</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>*</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>*</td>
</tr>
<tr>
<td>A*S</td>
<td>4</td>
<td>--</td>
</tr>
</tbody>
</table>

A: gap age; S: gap size; L: soil layer; DF: degree of freedom; pH: The pH value; SOM: soil organic matter; TN: total nitrogen; HP: hydrolyzable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium; R: Patrick richness index; D: Simpson’s diversity index; H: Shannon-Wiener index; J: Pielou evenness index; S1: area about 50-70m² gap; S2: area about 100-120m² gap; S3: area more than 150m² gap; A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: non-gaps; *: significantly different, statistically different at P = 0.05.
Fig. 1 The soil chemical properties in different age and size gaps

A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: Non-gap; pH: The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolyzable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium; bars refer to standard error; Values in the figure to the same factor and soil layer, followed by the same letter, are not statistically different at P = 0.05.
Fig. 2 The interaction of gap age and gap size on the soil chemical properties
A: gap age; S: gap size; L: soil layer; S1: area about 50-70m² gap; S2: area about 100-120m² gap; S3: area more than 150m² gap; A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: canopy cover sites adjacent to gaps; pH: The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolysable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium; bars refer to standard error; Values in the figure to the same factor and soil layer, followed by the same letter, are not statistically different at P = 0.05.
Fig. 3 The species diversity index in different age and size gaps
A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: Non-gap; bars refer to standard error; Values in the figure to the same factor, followed by the same letter, are not statistically different at P = 0.05

Table 2. The numbers of pioneer species and shade-tolerant species in different size gaps, age gaps and non-gaps.

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<tr>
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<th>%</th>
<th>Herb</th>
<th>%</th>
<th>total</th>
<th>%</th>
<th>Woody</th>
<th>%</th>
<th>Herb</th>
<th>%</th>
<th>total</th>
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<td>54.5</td>
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<td>54.3</td>
<td>1.89</td>
<td>7.6</td>
<td>2.89</td>
<td>19.3</td>
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<td>8.33</td>
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<td>25.55</td>
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<td>A3</td>
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<td>8.67</td>
<td>54.6</td>
<td>26.34</td>
<td>51.1</td>
<td>3.33</td>
<td>9.3</td>
<td>4.11</td>
<td>25.9</td>
<td>7.44</td>
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<td>52.2</td>
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<td>24.33</td>
<td>52.9</td>
<td>4.42</td>
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<tr>
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<td>28.6</td>
<td>7.33</td>
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</tr>
</tbody>
</table>

Table 3. Correlations of variables of soil chemical properties to the first two DCCA axes of woody(A) and herb(B) species.

<table>
<thead>
<tr>
<th>soil properties variables</th>
<th>chemical properties</th>
<th>Correlations Axis1</th>
<th>Correlations Axis2</th>
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<th>chemical properties</th>
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<tbody>
<tr>
<td>PH</td>
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<td>AK</td>
<td>0.057</td>
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</table>

A: The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolyzable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium.
DISCUSSION

Gap impacts on soil chemical properties: Most soil chemical properties were not significantly impacted by the different size gaps. However, we did find that the contents of the total phosphorus and total potassium in the gaps were higher than those under the canopy cover sites, except for the total potassium in the 0-20 cm layer. The same was true in the study addressed by Muscoco et al. (2007) in which they found that the amount of P was higher in the small gaps (380 m²) than in the canopy cover sites. We also found the larger gaps had higher contents of total phosphorus and total potassium in both the 0-20 cm and 20-40 cm soil layers. This result could be explained by the assumption of Denslow et al. (1998) in which the gap size effect was found to be higher primarily to greater leaf and fine root litter densities and lower uptake by vegetation in the larger gaps. However, opposite findings were reported by Scharenbroch and Bockheim (2007), who showed that the extractable base potassium was significantly greater in the forest compared to the gaps. It was assumed that the decrease in the exchangeable base cations in the gaps was a result of leaching losses as these cations were moved out of the upper profile. Scharenbroch and Bockheim (2007) speculated that an increased nutrient-leaching potential would occur in relatively large (300-2,000 m²) gaps, and Parsons et al. (1994) assumed that the same condition would occur with the removal of 15-30 tree clusters. This explanation is supported by our observation of the total potassium content at depth 20-40 cm, which was greater than the content at 0-20 cm both in the gaps and in the forest.

Vitousek and Denslow (1986) found no difference in the P and N pool sizes in 2-12 month-old gaps. They speculated that the effect of the high litter inputs would be masked by high N-mineralization rates and high P adsorption and that an early, ephemeral peak in N pools would have been missed in their study. Uhl et al. (1988) also found that soil nutrient levels in single-treefall gaps did not differ from gap size or age during the first 4a. However, most soil chemical properties measured were significantly impacted by different age gaps. We did find that the contents of soil organic matter, total nitrogen, hydrolysable nitrogen and total potassium in both the 0-20 cm and 20-40 cm soil layers were higher in the 5a gap than those in the other age gaps and the under canopy cover sites. We also found that the pH, total potassium, available potassium, and the total phosphorus of the surface soil (0-20 cm) were higher in the 3a gap than those in the other age gaps and under canopy cover sites. Muscoco et al. (2007) confirmed that there was a nutrient pulse in the small gaps, as speculated by Denslow et al. (1998), but they did not provide the schedule of nutrient pulse emergence after the gaps formation. Therefore, we speculated that soil nutrient pulses in gaps would appear after the gaps formation in 3-5 years, and the pulses of different nutrient type would occur in gap with a different specific area; for example, the pulse of soil organic matter, total nitrogen and available phosphorus would be found in smaller gaps (50-70 m² in our study), but hydrolysable nitrogen and total phosphorus in the surface soil would be found in larger gaps (greater than 100 m² in our study).

Gap impacts on species composition and diversity: Due to the different ecological conditions in gaps and non-gap stands, the generation and growth of different plant species were different in gaps and non-gap stands (Brown, 1993). We found a high diversity existed in the understory community as a whole (152 species found in 30 sites of approximately 4,000 m²). With respect to the species composition of different age gaps, approximately 63, 40, and 38 woody species and 41, 40, 37, and 27 herb species were found in the 5a, 3a, 1a gaps and non-gaps, respectively. With respect to the different size gaps, approximately 85, 65 and 68 woody species and 38, 46, and 44 herb species were found in the 150-200 m², 100-120 m² and 50-70 m² gaps, respectively. Our findings confirmed that gaps increase the possibility of multispecies coexistence by introducing heterogeneity into forest ecosystems (Grubb, 1977).

The size of the canopy opening has a direct effect on light levels, which could affect vegetation growth rates (Barton et al., 1989). Additionally, the small gap effects observed are likely primarily due to nutrient pulses, and the time of emergence of nutrient pulses was uncertain because it depended on the microhabitat and litter input. We found there were proportional similarities among the different size gaps and non-gaps. Because light availability is the primary limitation to growth in a forest, the species most likely able to take advantage of pulses in both light and nutrient availability are pioneer, highlight demanding species (Denslow et al., 1998). We did find that the 150-200 m² gap had alarger number and proportion of pioneer species (high-light demanding species), and the 50-70 m² gaps had more shade-tolerant species than any of the other gaps (Tab. 2). Our findings also confirmed that the pioneer species in small gaps were highly plastic to any variation in resources, exhibiting high dispersal rates and a persistence of seeds in the soil (Denslow et al., 1990; Dalling et al., 1997). We also found that the Simpson’s diversity index, Shannon-Wiener index and Evenness index in the shrub species different among the size gaps, and no difference in the size gaps was found.

Spies et al. (1990) found that the seedling density in Cascade Mountain Range forest gaps was more strongly related to the gap size than to gap age. Poulson and Platt (1989) also found that patterns of species composition in hardwood forest gaps changed over time
due to competition and morphological differences among species. The biotic and abiotic factors may interact with the mosaic of environments created by tree falls and gap-phase regeneration that contribute considerably to the variation in the occurrence of understory species (Dirzo et al., 1992). They also found that there was a low similarity between gaps and the large number of rare species and that intermediate-aged (3-5a) gaps tended to be more similar to one another than young sites (1-2a). We also found there were proportional similarities among the different age gaps and non-gaps. In addition, we found that the nutrient pulse in gaps was better related to the gap age than to gap size. Therefore, we postulated that germination and the survival of seeds and seedlings should vary with gap microhabitat (such as light, moisture, nutrient pulses, etc.). We found that the Simpson's diversity index, Shannon-Wiener index and Evenness index in arbor and shrub species are different among age gaps and that there is no difference in herb species. This finding is similar to the study by Dirzo et al. (1992), in which they also found no effect of age on density or on the number of herb species, but the young gaps had the highest evenness in herb species. Different from other studies' results, the lowest Simpson's diversity index and Shannon-Wiener index of arbor species were found in the 1a gaps in our study. Thus, we speculated the 1a gaps did not have enough dispersed or germinating seeds soon after thinning.

In addition, the decomposition of large amounts of fresh litter from fallen trees might result in an increase of soil nutrients, and the fortified available nutrients would significantly promote the growth of vegetation (Denslow et al., 1998). However, the relative indirect skylight and relative directly sunlight both increased remarkably with the gap size and decreased remarkably with the gap age, which were important to species composition and vegetation growth. Furthermore, intermediate-aged gaps were a critical 'building phase' for species composition in forest (Dirzo et al., 1992). Thus, the interaction of gap size and age plays a specific role in affecting soil properties and species diversity.

**Soil properties impacts on species composition and diversity:** Based on the species in the sample plots and the soil properties (0-20cm) matrix, the plots distribution was analysed using DCCA. For the woody species in the sample plots, the first axis is largely associated with the available phosphorus (correlations coefficient = -0.804), soil organic matter (-0.623), hydrolysable nitrogen (-0.592) and total phosphorus (-0.590), which represent the gradient of the N-P and SOM pulse that are primarily induced by the addition of leaf and fine root litter in the gap soil (Tab. 3). The second axis is primarily associated with the pH (-0.844), total potassium (-0.720) and available potassium (-0.538), which represents the cations leaching losses gradients. With respect to the herb species of the sample plots, the first axis is largely associated with the available potassium (correlations coefficient = -0.660) and total phosphorus (-0.545), which represent the P and K leaching losses gradients in the gap soil (Tab. 3). The second axis is largely associated with hydrolysable nitrogen (0.803) and SOM (0.702), which represent the N and SOM pulse gradients that are primarily induced by the addition of leaf and fine root litter in gaps.

**Conclusions:** Soil properties and species diversity are significantly impacted by forest gaps, and the effect of gap age was more extensive than gap size. Our results show that the 50-70m² and 3a gaps represent the silvicultural treatment capable of generating soil nutrient pulse in the surface soil, and this nutrient pulse would increase species diversity, especially pioneer species. Gap size and age are both important to the composition of species and diversity, but the impact of gap age is more pronounced. In addition, the interaction of the 50-70m² and 5a gaps represents the most significant influence on soil properties. Therefore, we believe that the addition of small thinning gaps may be important for developing a forestry management regime capable of balancing production and biodiversity preservation.

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