Research note

Effects of Clearcutting on the Tree Species Composition, Structure, and Diversity of a Mixed Broadleaf-Korean Pine (*Pinus koraiensis*) Forest on Changbai Mountain: Implications for Ecosystem Restoration

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【Summary】

Large areas of primary mixed broadleaf-Korean pine forests on Changbai Mt., on the border between China and North Korean have been replaced by secondary forests through clearcuting since the 1950s. How clearcutting impacts the mixed forest ecosystem still remains unclear. We compared the tree species composition, structure, and diversity of a primary and a secondary forest that had suffered clearcutting, 30 yr. previously. Results showed that the mean basal area of trees (≥ 10 cm diameter at breast height (DBH)) was markedly lower in the secondary forest than in the primary forest, whereas the density of seedlings (< 2 cm DBH, ≥ 50 cm tall), saplings (2~9.9 cm DBH), and trees were all significantly higher in the former. Values for the species richness and both Simpson's and Shannon's diversity indices for seedlings and saplings were greater in the secondary forest than in the primary forest, but the values of these 3 indices for trees were significantly lower in the former. These results indicate that clearcutting altered the forest structure by significantly decreasing the basal area of trees and increasing the numbers of seedlings and saplings. It also altered the species composition with the secondary forest having more pioneer species than the primary forest. The secondary forest has higher species diversity and abundant climax species of seedlings and saplings, and this potentially favorable situation offers an opportunity to develop restoration plans.

Key words: clearcutting, forest structure, tree species composition, species diversity, ecosystem restoration.

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研究簡報

皆伐對長白山闊葉紅松(*Pinus koraiensis*)林樹種組成、結構及多樣性的影響：對生態系統復育的啟示

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摘　要

20世紀50年代開始的皆伐作業，使長白山大面積的原始闊葉紅松林被次生林所取代。目前，皆伐對該混交林生態系統的生態學影響還不完全清楚。我們比較了原始林和次生林的樹種組成、結構及物種多樣性。該次生林是30年前原始林被皆伐而形成。結果顯示次生林中成樹(≥ 10 cm胸徑)的平均胸高斷面積要顯著低於原始林，而苗木(< 2 cm胸徑，≥ 50 cm高)、稚樹(2~9.9 cm胸徑)及成樹的密度都高於原始林。次生林中的苗木和稚樹的物種豐富度、Shannon多樣性指數和Simpson多樣性指數的值高於原始林，但是次生林中成樹的這3個指數的值則比原始林低。上述結果顯示皆伐改變了森林的結構，主要表現在成樹的胸高斷面積顯著降低，同時苗木和稚樹的數量大量增加。次生林中入侵了較多的先驅樹種，因此皆伐也改變了樹種組成。次生林中苗木和稚樹的多樣性較高，而且有豐富的極盛相樹種，這有利于森林更新，也有助制定合理的森林復育計劃。

關鍵詞：皆伐、森林結構、樹種組成、物種多樣性、生態系統復育。

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Many studies have focused on the structural and compositional aspects of temperate forests (e.g., Hara et al. 1995, Liu et al. 1998, Chen and Bradshaw 1999, Nakashizuka 2001, Hao et al. 2007), but few studies have focused on how a forest's dynamic feature may change in response to logging, burning, and other human impacts. Clearcutting is one of the most significant disturbances affecting forest ecosystems, and these effects are profound and prolonged (Bergstedt and Milberg 2001). Clearcutting of forests is frequently criticized, since the complete removal of vegetation severely alters the forest structure and functional attributes of forest ecosystems (De Grandpre et al. 2000). However, the full ecological consequences and long-term ecological sustainability of this cutting regime is still not fully understood.

Changbai Mt., located on the border of China and North Korea, is covered with a large area of mixed broadleaf-Korean pine (*Pinus koraiensis*) forests (Shao et al. 2003), which is the largest and most important forest area in Northeast China (Chen et al. 2003). It provides large amounts of timber and is well-known for its high species richness and distinctive species composition in temperate forests (Yang and Xu 2003, Stone 2006). However, due to nearly half a century of extensive exploitation, large areas of primary forests in the region have been degraded, timber resources are declining, and biodiversity is decreasing (Shao et al. 2005). From the 1950s to the 1980s, clearcutting was the most popular and most often employed approach for commercial timber production in the region, and now large areas of secondary forests have succeeded from the clear-cut areas in the region. To conserve the remaining primary forests and restore secondary forests in the region, it is essential to have a better understanding of how clearcutting affects these forest ecosystems.

In this paper, we focus on the impacts of clearcutting on the tree species composition, structure, and diversity of a mixed broadleaf-Korean pine forest on Changbai Mt., Northeast China. We compared these forest attributes between a primary and a secondary forest. The comparative nature of such information is essential for understanding how clearcutting impacts forest ecosystems. At the same time, the information obtained about the primary forest will allow us to develop ecosystem restoration projects because it provides the knowledge about the original composition and structure of the forests.

The study was conducted in 2008 at the Lu Shuihe Forestry Bureau (42°20'~42°40'N, 127°29'~128°02'E), located on a northwest-facing slope of Changbai Mt. The elevation of the study area ranges 450~1400 m. The area has a temperate, continental climate, with long, cold winters and warm summers. The mean annual precipitation is approximately 894 mm, most of which occurs from June to September. The mean annual temperature is 2.9℃, with a January mean of -16.3℃, and a July mean of 19.2℃. The soil is classified as dark-brown forest soil. The climax vegetation is a mixed broadleaf-Korean pine forest. Major species include *P. koraiensis*, *Tilia mandshurica*, *Quercus mongolica*, *Fraxinus mandshurica*, *Ulmus japonica*, and *Acer pseudo-sieboldianum*.

The 1st study site was a primary forest (PF) with no record of past logging. The 2nd study site was a secondary forest (SF) that was subjected to clearcutting 30 yr prior to this study. In total, sixteen 40×40-m plots (8 at each study site) were set up. Each plot was located at least 100 m from the forest edge and separated by at least 50 m from other plots. All plots were located on gentle slopes (< 5°) at around 750 m in elevation. Each plot was divided into four 20×20-m subplots. In each subplot, all free standing trees at least 2 cm in diameter at breast height (DBH, 1.3 m above the ground) were identified and measured. Within each plot, 2 random 5×5-m quadrats were used to record seedlings (< 2 cm DBH, ≥ 50 cm tall). Tree data were divided into 2 size classes: saplings (2~9.9 cm DBH) and trees (≥ 10 cm DBH).

The 2 forests were compared with respect to mean DBH, stem density, basal area, and 3 diversity indices (Magurran 2004): species richness (S), Shannon's diversity index (H'), and Simpson's diversity index (D). Comparisons were made between the 2 forest sites using t-tests with each plot considered an independent replicate. All statistical analyses were conducted with the software R (R Development Core Team 2005).

We found that the mean diameter, basal area, and density significantly differed between the primary and secondary forest sites (Table 1). The mean diameter for saplings and trees were significantly higher in the PF than the SF ($p < 0.01$). The mean basal area for trees was markedly lower in the SF (22.22 ±0.75 m^2 ha^{-1}) than in the PF (36.83±1.77 m^2 ha^{-1}) (t_{14} = 8.05, $p < 0.001$), whereas the mean basal area for saplings was significantly higher in the SF (2.08±0.22 m^2 ha^{-1}) than the PF (1.24±0.09 m^2 ha^{-1}) (t_{14} = -3.54, $p < 0.01$). Tree density in the SF (869±39 trees ha^{-1}) significantly exceeded that in the PF (435± 34 trees ha^{-1}) (t_{14} = -9.78, $p < 0.001$). Seedlings and saplings were also more abundant in the SF than the PF ($p < 0.001$). When all plots

Table 1. Structural characteristics (mean±S.E.) of the primary forest (PF) and secondary forest (SF)

Parameter	PF	SF	
Mean DBH (cm)			
Saplings	4.9±0.1	4.2±0.1	$t_{14} = 3.62, p < 0.01$
Trees	28.0±1.2	16.8±0.3	$t_{14} = 9.24, p < 0.001$
Overall trees	14.9±0.3	9.7±0.4	$t_{14} = 11.16, p < 0.001$
Basal area (m^2 ha^{-1})			
Saplings	1.24±0.09	2.08±0.22	$t_{14} = -3.54, p < 0.01$
Trees	36.83±1.77	20.22±0.75	$t_{14} = 8.55, p < 0.001$
Overall trees	38.06±1.79	22.3±0.79	$t_{14} = 8.05, p < 0.001$
Density (trees ha^{-1})			
Seedlings	6350±270	10650±400	$t_{30} = -8.70, p < 0.001$
Saplings	559±39	1171±137	$t_{14} = -4.28, p < 0.001$
Trees	435±20	869±39	$t_{14} = -9.78, p < 0.001$
Overall trees	994±34	2040±171	$t_{14} = -6.01, p < 0.001$

Seedlings: < 2 cm diameter at breast height (DBH), ≥ 50 cm tall; saplings: 2~9.9 cm DBH; trees: ≥ 10 cm DBH; overall trees: ≥ 2 cm DBH.

in each forest site were combined, a reverse-J diameter distribution curve was produced for the PF but a bimodal distribution was found for the SF (Fig. 1). Regarding the smaller size classes, 57% of trees in the SF were < 10 cm in DBH, and in the PF, the corresponding value was 56%. With respect to the larger size classes, 15% of overall trees were > 30 cm in DBH in the PF, but there were none in the SF.

In total, 30 tree species belonging to 22 genera and 14 families were found on the 2 forest sites. In the PF, 24 tree species were found, representing 17 genera and 11 families; in the SF, 29 species from 22 genera and 13 families were recorded. Of the overall number of tree species, 20 species were present at both forest sites. For overall trees in the PF, the top 5 species ranked in terms of basal area were *P. koraiensis*, *T. amurensis*, *F. mandshurica*, *Q. mongolica*, and *A. pseudo-sieboldianum*. In the SF, the top 5 species ranked in terms of basal area were *Betula platyphylla*, *Larix olgensis*, *F. mandshurica*, *P. koraiensis*, and *U. japonica* (Table 2).

Values for species richness (*S*), Simpson's diversity index (*D*), and Shannon's diversity index (*H*') for seedlings and saplings were significantly greater in the SF than in the PF ($p < 0.01$), whereas these 3 indices for trees were all lower in the SF than in the PF ($p < 0.01$) (Table 3). For overall trees, the value of *D* was higher in the PF (0.86±0.01) than in the SF (0.82±0.01) ($t_{14} = 2.85$, $p < 0.05$), whereas there were no significant differences among *S* and *H*' between the 2 forests ($p > 0.05$) (Table 3).

For the SF, values for both the mean diameter and basal area of saplings and trees were significantly lower than those in the PF, while numbers of seedlings, saplings, and trees were all significantly greater (Table 1). These results revealed that clearcutting had altered the forest structure by significantly decreasing the basal area of trees and increasing the numbers of seedlings and saplings. These results agree with those of many previous studies such as Hao et al. (1994). Tree density distribution across different diameter classes

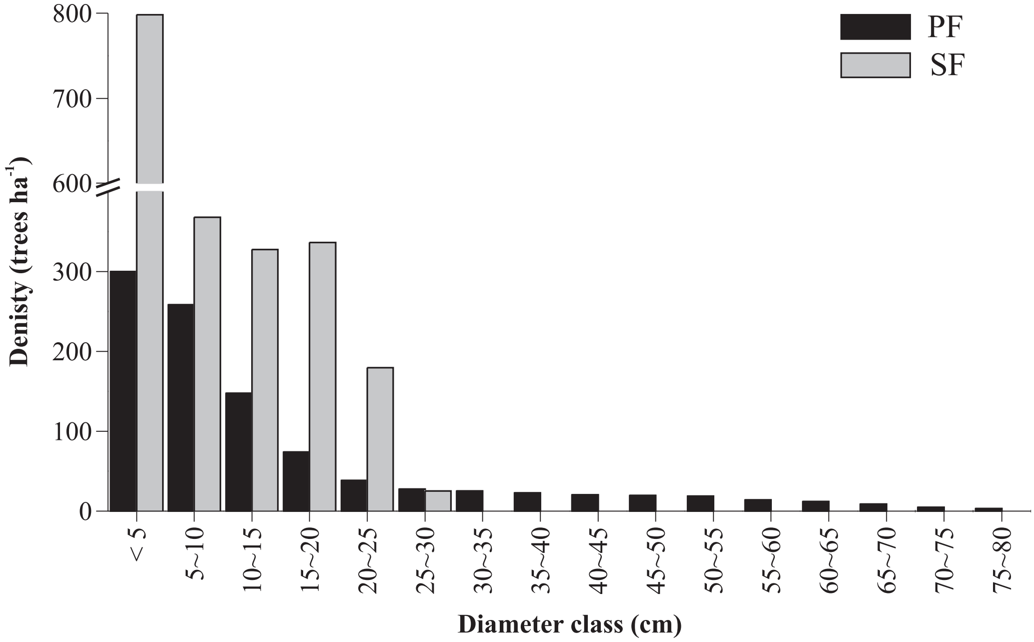

Fig. 1. Size class distributions of trees ≥ 2 cm diameter at breast height in the primary forest (PF) and secondary forest (SF).

Table 2. Tree species composition in the primary forest (PF) and secondary forest (SF), trees ≥ 2 DBH (percent of basal area and density in parentheses, respectively)

Site	Tree species	Family	Basal area (m^2 ha^{-1})	Density (trees ha^{-1})
PF				
	Pinus koraiensis	Pinaceae	15.26 (40)	113 (11)
	Tilia amurensis	Tiliaceae	6.62 (17)	75 (8)
	Fraxinus mandshurica	Oleaceae	4.49 (12)	23 (2)
	Quercus mongolica	Fagaceae	3.21 (8)	17 (2)
	Acer pseudo-sieboldianum	Aceraceae	2.01 (5)	228 (23)
	19 other speices		6.47 (18)	538 (54)
SF				
	Betula platyphylla	Betulaceae	15.15 (68)	683 (33)
	Larix olgensis	Pinaceae	3.03 (14)	170 (8)
	Fraxinus mandshurica	Oleaceae	1.24 (6)	241 (12)
	Pinus koraiensis	Pinaceae	0.76 (3)	308 (15)
	Ulmus japonica	Ulmaceae	0.61 (2)	159 (8)
	25 other speices		1.51 (7)	479 (24)

indicates how well a growing forest is utilizing site resources (Hitimana et al. 2004). In our study, the presence of a few smaller-sized (≤ 10 cm DBH) trees in the PF may imply that the land is not being fully utilized by the trees. In contrast, the density of seedlings and saplings of the SF had increased, confirming that tree regeneration after clearcutting had

Table 3. Species diversity indices (mean±S.E.) in the primary forest (PF) and secondary forest (SF)

Parameter	PF	SF	
Species richness (*S*)			
Seedlings	4.2±0.4	5.9±0.2	t_{30} = -3.85, p < 0.001
Saplings	10.9±0.6	14.6±0.6	t_{14} = -4.39, p < 0.001
Trees	11.8±0.4	9.4±0.7	t_{14} = 3.08, p < 0.01
Overall trees	14.9±0.5	15.4±0.7	t_{14} = -0.62, p = 0.547
Simpson (*D*)			
Seedlings	0.66±0.02	0.75±0.01	t_{30} = -3.46, p < 0.01
Saplings	0.80±0.01	0.84±0.01	t_{14} = -2.37, p < 0.05
Trees	0.83±0.02	0.46±0.05	t_{14} = 7.29, p < 0.001
Overall trees	0.86±0.01	0.82±0.01	t_{14} = 2.85, p < 0.05
Shannon (*H*')			
Seedlings	1.23±0.08	1.55±0.03	t_{30} = -3.56, p < 0.01
Saplings	1.88±0.05	2.16±0.06	t_{14} = -3.51, p < 0.01
Trees	2.0±0.07	1.03±0.1	t_{14} = 7.89, p < 0.001
Overall trees	2.20±0.05	2.06±0.05	t_{14} = 1.89, p = 0.079

Seedlings: < 2 cm diameter at breast height (DBH), ≥ 50 cm tall; saplings: 2~9.9 cm DBH; trees: ≥ 10 cm DBH; overall trees: ≥ 2 cm DBH.

been significantly stimulated, and indicating that the land is being effectively utilized.

Restoring the species composition of clear-cut forests to that of primary forests is difficult (Nagaike et al. 2005). Several authors suggested that shifts in species composition are related to logging intensity (Bergstedt and Milberg 2001, Zenner et al. 2006). In our study, the PF was dominated by *P. koraiensis*, *T. amurensis*, *F. mandshurica*, *Q. mongolica*, and *A. pseudo-sieboldianum*, which comprised 46% of all trees and 82% of the total basal area (Table 2). These percentages reflect the typical composition of the climax stage of the mixed broadleaf-Korean pine forest (Zhang et al. 2007). However, these 5 species comprised only 31% of all trees and 11% of the total basal area in the SF (Table 2). These results indicated that clearcutting significantly altered the species composition. Moreover, previous studies showed the forest succession dynamics following clearcutting of mixed broadleaf-Korean pine forests to be as follows: pioneer species, such as *B. platyphylla*, first colonize and dominate the site, and these are succeeded by forests dominated by broadleaf tree communities. Finally, the communities reach a climax stage dominated by Korean pine (Chen et al. 2003). In our study, the fact that the secondary forest was dominated by the 2 pioneer species (*B. platyphylla* and *L. olgensis*) in terms of basal area (Table 2) indicates that the forest was in the earlier stage of succession with a species composition significantly differing from that of the original forest.

Species diversity can be very dependent on the duration of forest recovery. For instance, Liu et al. (1998) reported that species richness and diversity in the mixed broadleaf-coniferous forest around the Changbai Mt. Biosphere Reserve were sharply reduced following clearcutting in the early stage of succession. The observed decrease in the diversity of the forest may be a short-term phenomenon, given that the species diversity in some other clear-cut forests was found to be even greater than that in the PF (Hao et al. 1994). In our study, the species richness for overall trees did not significantly differ between the 2 forest sites (Table 3), indicating that species richness can recover to pre-harvest levels in the earlier stage (here, in the 1st 3 decades) after clearcutting. In addition, the fact that Simpson's diversity index (*D*) and Shannon's diversity index (*H*') were significantly higher for seedlings and saplings, but considerably lower for trees in the SF (Table 3), indicates that the impact of clearcutting on species diversity differed for different diameter classes. Only 2 pioneer species (*B. platyphylla* and *L. olgensis*) dominated the overstory, reflecting lower diversity in this layer; but it is possible that diversity in the understory could increase as mid-tolerant species and shade-tolerant species become established. These results are consistent with those of Luo et al. (1997), who examined a forest that had been clearcut 25 yr previously on the north slope of Changbai Mt. and reported that the response after clearcutting in the understory reflected an increase in species diversity. Hao et al. (1994) reported that the species diversity in a forest adjacent to the Changbai Mt. Biosphere Reserve that had been clearcut 50 years previously was higher than that of the PF. But a higher diversity does not ensure the stability of the forest community, as mid-tolerant species and shade-tolerant species will replace pioneer species in the later stages of forest succession. Therefore, the impact of clearcutting on diversity seems to be more complicated.

In conclusion, clearcutting severely altered the species composition, structure, and diversity attributes of this forest ecosystem, and several centuries may be required for the SF to return to its original structure and composition. The results of this study have significant implications for forest restoration in the region. They show that the SF has a higher species diversity and abundant climax species (such as *P. koraiensis* and *F. mandshurica*) for seedlings and saplings, and this potentially favorable situation offers an opportunity to develop restoration plans. Since *P. koraiensis* can grow quickly in forest gaps (Chen et al. 2003), if appropriate methods are used such as thinning closed-canopy stories, we believe the restoration of the secondary forest to the climax (mixed broadleaf-Korean pine forest) could be accelerated.

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