Short Communication

Differences in the structure, species composition and diversity of primary and harvested forests on Changbai Mountain, Northeast China

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ABSTRACT: Broadleaved-Korean pine (*Pinus koraiensis*) mixed forest is a typical vegetation type in the eastern Eurasian continent. We compared the structure, composition and diversity of a primary forest and a logged forest for effective management and regeneration of a mixed forest ecosystem on Changbai Mountain, Northeast China. The logged forest was subjected to selective harvesting twenty years ago. The mean diameter and basal area for overall trees (≥ 2 cm dbh) were higher in the primary forest than in the logged forest, whereas overall tree density was significantly lower in the former (994 ± 34 trees·ha^{-1}) than in the logged forest (1921 ± 79 trees·ha^{-1}). The values of species richness and both Simpson's and Shannon's diversity indices for seedlings (< 2 cm dbh, ≥ 50 cm tall), saplings (2–9.9 cm dbh) and overall trees were greater in the primary forest. These results indicate that the selective logging had a lasting impact on the structural characteristics of the forest. There were major differences in species composition between the two forest sites, with the logged forest having more pioneer and mid-tolerant species than the primary forest. Diversity was more extensive in the logged forest due to the invasion of pioneer species. Twenty years is clearly an insufficient time for the logged forest to regain "primary" forest composition and structure. These two characteristics of the primary forest may serve as a reference for developing management plans for forest regeneration.

Keywords: broadleaved-Korean pine mixed forest; forest structure; species composition; species diversity

The broadleaf-conifer mixed forest occurs in the cooler region of the eastern Eurasian continent, extending across the coastal areas of eastern Russia, the Korean Peninsula, and the eastern portion of northeastern China (Nakashizuka, Iida 1995). Changbai Mountain, the core area of this vegetation zone, is covered with a large area of broadleaved–Korean pine (*Pinus koraiensis*) mixed forest (Shao et al. 2003). This is a typical vegetation type in the eastern Eurasian Continent, and it has provided large amounts of timber and is well-known for high species richness and distinctive species composition in temperate forests (Yang, Xu 2003; Stone 2006).

Forest harvesting in Changbai Mountain region began in the 1950s when state-owned forestry bureaus were established. Prior to the 1980s, clearcutting was the primary method for timber harvesting in the region, since then selective logging methods have been widely used. Due to nearly half a century extensive harvesting in the region, large areas of primary forests have been degraded, timber resources are declining and the age structure of the remaining

Supported by the National Natural Science Foundation of China, Projects No. 40873067 and 30800139 and 40601102, the National Key Technologies R&D Program of China, Project No. 2006BAD03A09 and the National Forestry Public Welfare Program of China No. 201104070.

forests has become unsuitable for sustainable forestry (Shao et al. 2001; Zhao, Shao 2002). In 1998, the Chinese government established the Natural Forest Protection Program (NFPP), the major purposes of which are to protect existing natural forests from excessive logging and to restore degraded forests (Zhang et al. 2000). While several studies on vegetation and flora have been conducted on Changbai Mountain (e.g. Liu 1997; Shao et al. 2003; Wu et al. 2004; Liu et al. 2005), there are few quantitative studies on differences in the structure, composition or diversity of primary and logged forests. The lack of knowledge regarding these quantitative characteristics of both primary and logged forests is one of the major problems encountered in developing plans for forest restoration.

A major objective of this study was to compare the structure, composition and diversity of an undisturbed primary forest with those of an adjacent forest that was subjected to selective logging twenty years ago. The comparative nature of such information is useful both for effective regeneration and management of logged forests and the development of ecosystem restoration projects. At the same time, comparing primary and logged forest sites allows us to examine how closely a logged forest may approach the structure and composition of a primary forest two decades after harvesting.

MATERIAL AND METHODS

The study was conducted on the northwest-facing slope of Changbai Mountain in the northeastern PR China (42°20'–42°40'N 127°29'–128°02'E, Fig. 1), where the Lu Shuihe Forestry Bureau, a typical state-owned forest enterprise, manages about 200,000 ha of forests. The altitude of the study area ranges from 450 to 1,400 m a.s.l. The area has a temperate, continental climate, with long, cold winters and warm summers. Mean annual precipitation is approximately 894 mm, most of which occurs from June to September. Mean annual temperature is 2.9°C, with a January mean of –16.3°C and a July mean of 19.2°C. The soil is classified as dark brown forest soil. The climax vegetation is the broadleaved-Korean pine mixed forest. Major species include: *Pinus koraiensis*, *Tilia mandshurica*, *Quercus mongolica*, *Fraxinus mandshurica*, *Ulmus propinqua*, *and Acer mono.*

The first study site was a primary forest with no record of past logging (PF). The second study site was an adjacent forest in which a timber harvest was conducted in 1988 with a harvesting intensity of 30% by volume (LF). In the summer of 2008, a total of sixteen 40 × 40 m plots were established, eight in each study site. 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 approximately 750 m of 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, two random 5 × 5 m quadrats were used to record seedlings (< 2 cm dbh, ≥ 50 cm tall). Tree data were divided into three size classes: saplings (2–9.9 cm dbh), poles (10–29.9 cm dbh) and large trees (≥ 30 cm dbh). Tree species were further grouped according to their shade tolerance: pioneer species, mid-tolerant species and shade tolerant species.

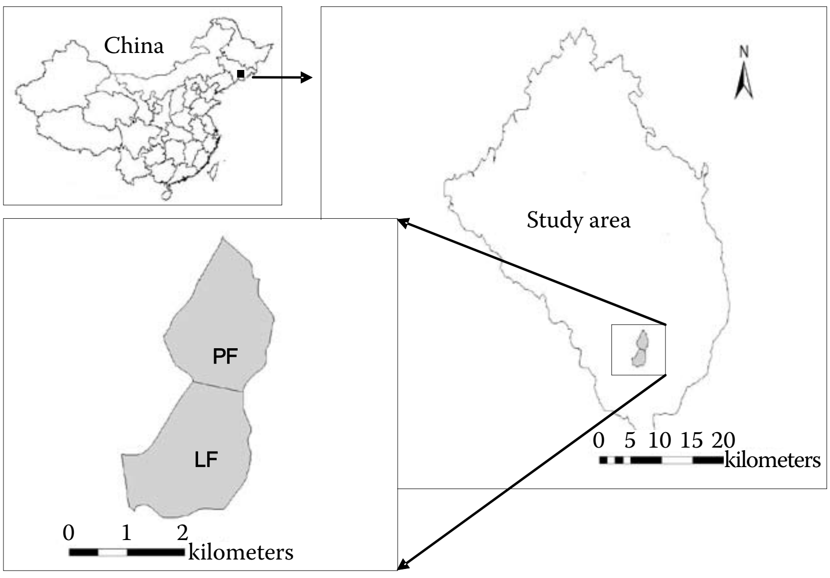

Fig. 1. Location of the primary forest (PF) and logged forest (LF) within study area, located on the northwest-facing slope of Changbai Mountain, Northeastern China

Differences between the two forest sites with respect to mean dbh, basal area, stem density and three diversity indices (Magurran 2004) – species richness (*S*), Shannon's diversity index (*H'*) and Simpson's diversity index (*D*) – were assessed using *t*-tests. Species richness (*S*) was calculated as the number of species recorded at the sampled area, Shannon's diversity index (*H'*) was calculated as

$$H' = -\sum (p_i \log_2 p_i)$$

and Simpson's diversity index (*D*) was calculated as

$$D = \sum p_i^2$$

where p_i is the relative abundance of species *i*. As *D* increases, diversity decreases and therefore Simpson's index is usually expressed as 1 – *D* or 1/*D* (Onaindia et al. 2004). In this study, the former expression (i.e. 1 – *D*) was used. Normality and homogeneity of variance were tested and data were log-transformed if the homogeneity of variance was not met. These analyses were conducted using the software R (R-Development Core Team 2004). Multi-response permutation procedures (MRPP) within the PC-ORD computer package (McCune, Mefford 2006) were used to test for differences in species composition between the two forest sites. We conducted MRPP analyses using the Sřrensen distance measure (McCune, Grace 2002).

RESULTS

Mean diameter, basal area and stand density differed significantly between the primary and logged forest sites (Table 1). The mean diameter for overall trees (≥ 2 cm dbh) was higher in PF (14.9 ± 0.3 cm) than in LF (8.1 ± 0.2 cm) (t_{14} = 18.24, *P* < 0.001), although the mean diameters of saplings, poles and large trees did not differ significantly between the two forests (*P* > 0.05). The mean basal area for overall trees was markedly lower in LF (27.08 ± 2.77 $m^2 \cdot ha^{-1}$) than in PF (38.06 ± 1.79 $m^2 \cdot ha^{-1}$) (t_{14} = 3.33, *P* < 0.01). Measures for the mean basal area of saplings and large trees were also significantly lower in LF than in PF (*P* < 0.01). Although the mean basal area of poles was higher in PF (6.18 ± 0.42 $m^2 \cdot ha^{-1}$) than in LF (5.12 ± 0.36 $m^2 \cdot ha^{-1}$), this difference was not significant (t_{14} = 1.93, *P* = 0.074). Overall tree density was significantly greater in LF (1,921 ± 79 $trees \cdot ha^{-1}$) than in PF (994 ±

Table 1. Structural characteristics (mean ± SE) of primary forest (PF) and logged forest (LF)

Parameter	PF	LF	
Mean dbh (cm)			
Saplings	4.9 ± 0.1	4.5 ± 0.3	t_{14} = 1.22, *P* = 0.241
Poles	16.0 ± 0.3	15.5 ± 0.5	t_{14} = 0.9, *P* = 0.383
Large trees	48.5 ± 0.9	47.1 ± 2.0	t_{14} = 0.6, *P* = 0.559
Overall trees	14.9 ± 0.3	8.1 ± 0.2	t_{14} = 18.24, *P* < 0.001
Basal area ($m^2 \cdot ha^{-1}$)			
Saplings	1.24 ± 0.09	2.95 ± 0.29	t_{14} = –5.65, *P* < 0.001
Poles	6.18 ± 0.42	5.12 ± 0.36	t_{14} = 1.93, *P* = 0.074
Large trees	30.64 ± 2.08	19.01 ± 3.26	t_{14} = 3.01, *P* < 0.01
Overall trees	38.06 ± 1.79	27.08 ± 2.77	t_{14} = 3.33, *P* < 0.01
Density ($trees \cdot ha^{-1}$)			
Seedlings	6,350 ± 270	9,650 ± 196	t_{30} = –9.58, *P* < 0.001
Saplings	559 ± 39	1,577 ± 85	t_{14} = –10.85, *P* < 0.001
Poles	279 ± 24	246 ± 18	t_{14} = 1.08, *P* = 0.301
Large trees	156 ± 6	98 ± 13	t_{14} = 3.96, *P* < 0.01
Overall trees	994 ± 34	1,921 ± 79	t_{14} = –10.76, *P* < 0.001

Seedlings: < 2 cm dbh, ≥ 50 cm tall; saplings: 2–9.9 cm dbh; poles: 10–29.9 cm dbh; large trees: ≥ 30 cm dbh; overall trees: ≥ 2 cm dbh

Table 2. Tree density (trees·ha^{-1}) by size classes for all species in primary forest (PF) and in logged forest (LF)

Family	Species	Shade tolerant[a]	Seedlings		Saplings		Poles		Large trees		Overall trees	
			PF	LF	PF	LF	PF	LF	PF	LF	PF	LF
Aceraceae	*Acer mandshuricum*	ST	150	0	15	0	27	0	2	0	44	0
Aceraceae	*Acer ginnala*	ST	0	0	2	0	0	0	0	0	2	0
Aceraceae	*Acer ukurunduense*	ST	2,150	1,450	31	49	2	1	0	0	33	50
Aceraceae	*Acer pseudo-sieboldianum*	ST	900	0	142	102	84	48	2	0	228	150
Aceraceae	*Acer triflorum*	ST	0	0	1	2	1	3	0	0	2	5
Aceraceae	*Acer tegmentosum*	ST	250	350	90	178	16	2	0	0	106	180
Aceraceae	*Acer mono*	ST	2,250	700	89	123	52	31	5	9	146	163
Aceraceae	*Acer tschonoskii*	ST	0	0	0	130	0	1	0	2	0	133
Betulaceae	*Betula platyphylla*	Pioneer	0	0	8	52	15	25	0	0	23	77
Betulaceae	*Betula costata*	MD	0	0	4	88	2	2	2	0	8	90
Betulaceae	*Carpinus cordata*	MD	0	0	66	0	1	0	0	0	67	0
Fagaceae	*Quercus mongolica*	Pioneer	0	0	2	20	2	3	13	8	17	31
Juglandaceae	*Juglans mandshurica*	MD	0	300	0	22	0	7	0	2	0	31
Leguminosae	*Maackia amurensis*	MD	50	1,200	3	9	3	5	0	0	6	14
Oleaceae	*Syringa amurensis*	MD	100	1,450	50	111	3	5	0	0	53	116
Oleaceae	*Fraxinus mandshurica*	ST	0	750	5	2	2	1	16	5	23	8
Pinaceae	*Pinus koraiensis*	ST	0	1,400	2	32	34	10	75	38	111	80
Pinaceae	*Abies nephrolepis*	ST	0	400	2	7	0	9	2	7	4	23
Pinaceae	*Picea jezoensis*	ST	0	0	0	0	0	1	0	0	0	1
Rhamnaceae	*Rhamnus davurica*	ST	0	0	0	2	0	0	0	0	0	2
Rosaceae	*Prunus padus*	ST	0	0	2	13	2	0	0	0	4	13
Rosaceae	*Malus baccata*	ST	0	0	5	19	1	2	0	0	6	21
Rosaceae	*Sorbus alnifolia*	ST	0	0	5	2	0	1	0	1	5	4
Rutaceae	*Phellodendron amurense*	MD	0	450	2	127	2	2	0	2	4	131

Table 2. to be continued

Family	Species	Shade tolerant[a]	Seedlings		Saplings		Poles		Large trees		Overall trees	
			PF	LF	PF	LF	PF	LF	PF	LF	PF	LF
Salicaceae	*Salix matsudana*	Pioneer	0	0	0	213	0	44	1	2	1	259
Salicaceae	*Populus davidiana*	Pioneer	0	0	0	98	1	20	1	5	2	123
Tiliaceae	*Tilia amurensis*	ST	0	950	20	116	22	10	32	13	74	139
Ulmaceae	*Ulmus japonica*	MD	500	250	13	60	7	13	5	4	25	77
Total			6,350	9,650	559	1,577	279	246	156	98	994	1,921

[a] Pioneer – pioneer species; MD – mid-tolerant species; ST – shade tolerant species

Seedlings: < 2 cm dbh, ≥ 50 cm tall; saplings: 2–9.9 cm dbh; poles: 10–29.9 cm dbh; large trees: ≥ 30 cm dbh; overall trees: ≥ 2 cm dbh

34 trees·ha^{-1}) (t_{14} = −10.76, P < 0.001). Seedlings and saplings were significantly more abundant in LF than in PF (P < 0.001), whereas large trees were more abundant in PF (156 ± 6 trees·ha^{-1}) than in LF (98 ± 13 trees·ha^{-1}) (t_{14} = 3.96, P < 0.01). Although pole density in PF (279 ± 24 trees·ha^{-1}) exceeded that in LF (246 ± 18 trees·ha^{-1}), this difference was not significant (t_{14} = 1.075, P = 0.301).

A total of 28 tree species belonging to 20 genera and 13 families were recorded on the two forest sites (Table 2). In PF, 24 tree species were found, representing 17 genera and 11 families; in LF, 25 species from 19 genera and 13 families were identified. Of the overall number of tree species, 21 were present on both the primary and logged forest sites: 6 species of seedlings, 19 species of saplings, 15 species of poles and 9 species of large trees (Table 2). With respect to tree density, for saplings, poles and overall trees, the numbers per hectare of pioneer species (such as *S. matsudana*, *P. davidiana* and *B. platyphylla*) and mid-tolerant species (such as *P. amurense* and *U. japonica*) were generally much higher in LF than in PF. In contrast, the numbers per hectare of shade tolerant species (such as *P. koraiensis* and *T. amurensis*) were higher for poles and larger trees in PF than in LF (Table 2).

For all trees in PF, the top seven species ranked in terms of basal area were *P. koraiensis*, *T. amurensis*, *F. mandshurica*, *Q. mongolica*, *A. pseudo-sieboldianum*, *A. mono* and *U. japonica*. These seven species accounted for around 91% of the total basal area in PF, whereas these same species accounted for about 74% of total basal area in LF (Table 3). It is noteworthy that the pioneer species *S. matsudana* and *P. davidiana* were among the top seven species ranked by the basal area in LF but not in PF. Multi-response permutation procedures (MRPP) demonstrated that there were significant differences in species composition for seedlings (A = 0.418, P < 0.001), saplings (A = 0.409, P < 0.001), poles (A = 0.165, P < 0.001), large trees (A = 0.142, P = P < 0.01) and overall trees (A = 0.349, P < 0.001) between the primary and logged forest sites.

The values of species richness (S), Simpson's diversity index (D) and Shannon's diversity index (H') all differed significantly between the primary and logged forest (Table 4). The values of the three indices for seedlings, saplings and overall trees (≥ 2 cm dbh) were greater in LF than in PF (P < 0.05), whereas there were no significant differences among the three indices for poles and large trees between the two forests (P > 0.05).

Table 3. Tree species accounting for 90% of the total basal area in primary forest (PF) and in logged forest (LF), trees ≥ 2 cm dbh

Site	Tree species	Family	Basal area	
			($m^2 \cdot ha^{-1}$)	(%)
PF	*Pinus koraiensis*	Pinaceae	15.26	40.11
	Tilia amurensis	Tiliaceae	6.62	17.40
	Fraxinus mandshurica	Oleaceae	4.49	11.80
	Quercus mongolica	Fagaceae	3.21	8.44
	Acer pseudo-sieboldianum	Aceraceae	2.02	5.31
	Acer mono	Aceraceae	1.90	4.99
	Ulmus japonica	Ulmaceae	1.18	3.10
	17 other species		3.39	8.85
LF	*Pinus koraiensis*	Pinaceae	9.31	34.38
	Tilia amurensis	Tiliaceae	3.38	12.48
	Quercus mongolica	Fagaceae	2.10	7.75
	Acer mono	Aceraceae	1.98	7.31
	Salix matsudana	Salicaceae	1.36	5.01
	Populus davidiana	Salicaceae	1.31	4.84
	Abies nephrolepis	Pinaceae	1.17	4.32
	Ulmus japonica	Ulmaceae	1.12	4.14
	Acer pseudo-sieboldianum	Aceraceae	1.04	3.84
	Fraxinus mandshurica	Oleaceae	1.00	3.69
	Betula platyphylla	Betulaceae	0.66	2.44
	14 other species		2.65	9.80

DISCUSSION AND CONCLUSION

Although the logged forest may outwardly resemble the primary forest in some features like canopy height and closed canopy stories, there are clearly important structural differences between the two. For the logged forest, the values of both stem density and basal area of large trees were significantly lower than those for the primary forest, while the numbers of seedlings and saplings were significantly higher (Table 1). This suggests that the selective harvest did have a lasting impact on structural characteristics of the forest two decades after harvesting. By initially decreasing overstorey density and basal area, canopy openings created by logging triggered a rapid increase in recruitment into the seedling and sapling layers. The fact that the density of seedlings and saplings of the logged forest increased, confirmed that tree regeneration after selective logging was significantly stimulated. These results agree with those of many previous studies (e.g. Liu et al. 1998; Gu, Dai2008).

Shifts in species composition may be related to logging intensity (Bergstedt, Milberg 2001; Zenner et al. 2006). For instance, Nagaike et al. (2005) reported that restoring the species composition of clear-cut forests to that of primary forests in central Japan was difficult; while other studies have described anywhere from a limited response to rapid recovery of species composition in a range of forest types following various cutting methods and intensities (e.g. Schelleer, Mladenoff 2002; Kern et al. 2006). In our study, the primary forest was dominated by seven tree species (*P. koraiensis, T. amurensis, F. mandshurica, Q. mongolica, A. pseudo-sieboldianum, A. mono and U. japonica*), which accounted for 63% of all trees and 91% of the total basal area (Tables 2 and 3). These percentages reflect the typical composition of the climax stage of a broadleaved-Korean pine mixed forest (Zhang et al. 2007). However, these seven tree species accounted for only 34% of all trees and 74% of the total basal area in the logged forest (Tables 2 and 3). These

Table 4. Species diversity indices (mean ± SE) in primary forest (PF) and in logged forest (LF)

Parameter	PF	LF	
Species richness (*S*)			
Seedlings	4 ± 1	8 ± 1	$t_{30} = -5.4$, $P < 0.001$
Saplings	11 ± 1	17 ± 1	$t_{14} = -5.68$, $P < 0.001$
Poles	9 ± 1	11 ± 1	$t_{14} = -1.67$, $P = 0.118$
Large trees	7 ± 1	6 ± 1	$t_{14} = 1.23$, $P = 0.239$
Overall trees	15 ± 1	18 ± 1	$t_{14} = -3.96$, $P < 0.01$
Shannon (*H'*)			
Seedlings	1.78 ± 0.17	2.61 ± 0.16	$t_{30} = -3.51$, $P < 0.01$
Saplings	2.71 ± 0.07	3.29 ± 0.13	$t_{14} = -3.85$, $P < 0.01$
Poles	2.60 ± 0.07	2.78 ± 0.12	$t_{14} = -1.11$, $P = 0.286$
Large trees	2.04 ± 0.10	2.20 ± 0.14	$t_{14} = -0.99$, $P = 0.34$
Overall trees	3.18 ± 0.07	3.46 ± 0.11	$t_{14} = -2.19$, $P < 0.05$
Simpson (*D*)			
Seedlings	0.66 ± 0.02	0.79 ± 0.02	$t_{30} = -4.16$, $P < 0.001$
Saplings	0.80 ± 0.01	0.86 ± 0.02	$t_{14} = -2.81$, $P < 0.05$
Poles	0.78 ± 0.02	0.79 ± 0.03	$t_{14} = -0.26$, $P = 0.801$
Large trees	0.67 ± 0.03	0.74 ± 0.03	$t_{14} = -1.77$, $P = 0.099$
Overall trees	0.86 ± 0.01	0.89 ± 0.01	$t_{14} = -2.4$, $P < 0.05$

Seedlings: < 2 cm dbh, ≥ 50 cm tall; saplings: 2–9.9 cm dbh; poles: 10–29.9 cm dbh; large trees: ≥ 30 cm dbh; overall trees: ≥2 cm dbh

results indicate that the selective logging altered the species composition by decreasing the number of larger trees, leading to a significant increase in stem density and basal area of pioneer species (e.g. *S. matsudana* and *P. davidiana*) and mid-tolerant species (such as *P. amurense*) (Table 2). As a result, shade tolerant species would not become dominant in the forest. The results of the multi-response permutation procedures (MRPP) further confirmed the dissimilarity of species composition in the primary and logged forests.

Many studies have found that species diversity increases after logging and that this change results primarily from the invasion of pioneer species (Halpern, Spies 1995; Cannon et al. 1998). Some studies have reported an increase in diversity as a short-term response of the system to logging (e.g. Peltzer et al. 2000), while other studies have suggested that logging either has a low effect on species diversity (e.g. Verburg, van Eijk-Bos 2003) or actually leads to a decrease in diversity (e.g. Okuda et al. 2003). On an overall basis, changes in species diversity vary considerably for different original habitat types (Nagaike et al. 1999) and disturbance regimes (Elliott, Swank 1994). In our study, the values of species richness, Simpson's diversity index (*S*) and Shannon's diversity index (*H'*) for seedlings, saplings and overall trees were greater in the logged forest than in the primary forest, but the values of the three indices for poles and large trees did not demonstrate any significant differences between the two forests (Table 4), indicating that the impacts of selective logging on species diversity differed for different diameter classes; selective logging contributed to increased species diversity for seedling and sapling layers. This echoed the findings of Halpern and Spies (1995) and Cannon et al. (1998).

In conclusion, although the logged forest may share some superficial features with the primary forest, the former still possesses only about 70% of the basal area of the primary forest two decades after harvesting. There are still major differences in species composition between the primary and logged forest, with the latter having more pioneer species and mid-tolerant species than the primary forest. There are also differences in species diversity, with the logged forest displaying greater diversity than the primary forest due to the invasion of pioneer species. Twenty years is clearly an insufficient time for the logged forest to return to the structure of the 'primary' forest. The present logging cycle needs to be reconsidered from the perspective of both sustaining timber yields and ecologically sustainable forest management; in the process the structure and composition of the primary forest may be used as a reference for developing management plans for forest regeneration.

Acknowledgements

We would like to thank the Lu Shuihe Forestry Bureau for providing assistance in field data collection. We would also like to thank Dr. Bernard J. Lewis at University of Missouri for editing assistance.

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Received for publication August 9, 2009
Accepted after corrections November 5, 2009

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