Forest cover types derived from Landsat Thematic Mapper imagery for Changbai Mountain area of China

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Abstract: The distributions of various forest cover types on Changbai Mountain of northeastern China were examined by interpreting Landsat Thematic Mapper satellite data. The area studied consists of the Changbai Nature Reserve plus an 8 km wide buffer zone. The dominant forest cover types were mixed Korean pine (*Pinus koraiensis* Sieb. & Zucc.) hardwood forest below 1100 m above sea level (asl) and evergreen coniferous forest between 1100 and 1650 m asl. These two forest cover types accounted for about 70% of the area inside the reserve, and 50% of the area outside the reserve. Other forest cover types included aspen (*Populus davidiana* Dode) – white birch (*Betula platyphylla* Sukachev) forest, hardwood forest, larch (*Larix olgensis* A. Henry) forest, sparse forest land, and mountain birch (*Betula ermanii* Cham.) forest. Above the forest line (1950 m asl), a zone of tundra was distributed on the top of Changbai Mountain. The mountain birch forest was located between tundra and the evergreen forest. Human-altered areas, including forest clearcuts and urban areas, accounted for only 10% of the whole study area. More than 90% (in area) of the human-altered areas was found in the zone surrounding the reserve. To better protect the old-growth forest ecosystems inside and outside Changbai Nature Reserve, conservation planning for the reserve and forest management for the surrounding area need to be modified.

Résumé : La distribution des divers types forestiers sur la montagne Changbai, dans le nord-est de la Chine, a été examinée au moyen de l'interprétation des images du satellite de cartographie thématique Landsat. La zone étudiée comprenait la réserve naturelle de Changbai, ainsi qu'une zone tampon de 8 km de largeur. Les types forestiers dominants étaient, en-dessous de 1100 m d'altitude, une forêt mixte de pin de Corée (*Pinus koraiensis* Sieb. & Zucc.) et de feuillus et, entre 1100 et 1650 m d'altitude, une forêt sempervirente de conifères. Ces deux types forestiers constituaient environ 70% de la superficie de la réserve et 50% de la zone extérieure. Les autres types forestiers comprenaient une forêt de peuplier (*Populus davidiana* Dode) et de bouleau (*Betula platyphylla* Sukachev), une forêt feuillue, une forêt de mélèze (*Larix olgensis* A. Henry), un terrain forestier clairsemé et une forêt montagnarde de bouleau (*Betula ermanii* Cham.). Au sommet de la montagne Changbai, au-dessus de la limite de la forêt (1950 m), se trouvait une zone de toundra. La forêt montagnarde de bouleau se situait entre la toundra et la forêt sempervirente. Les aires altérées par l'homme, incluant les coupes à blanc et les zones urbanisées, comptaient pour 10% seulement de l'étendue étudiée. Une superficie de plus de 90% des aires altérées a été découverte dans la zone entourant la réserve. Dans le but de mieux protéger les écosystèmes forestiers vierges, tant à l'intérieur qu'à l'extérieur de la réserve naturelle de Changbai, une modification de la planification de la conservation de la réserve et de l'aménagement forestier des zones environnantes s'avère nécessaire.

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Introduction

After 4 decades of extensive forest cutting, old-growth forest ecosystems have been almost completely destroyed in northeastern China. Remaining old-growth forests can be found only in nature reserves, such as Changbai Nature Reserve, and other remote areas. Changbai Nature Reserve is one of the few large areas in the temperate zone with forests relatively undisturbed by man's activities (Jeffers 1987) and is a major source of biotic diversity. In Changbai Nature Reserve, there are 251 species of mushrooms, 148 species of lichens, 339 species of bryophytes, 87 species of pteridophytes, and 1250 species of seed plants (Xu 1992). In 1979, Changbai Nature Reserve was designated by the United Nations as a Biosphere Reserve.

Forest ecosystem research at Changbai Nature Reserve was initiated in 1979 when the Changbai Forest Ecosystem Research Station was founded by the Chinese Academy of Sciences. During the subsequent 15 years, ecosystem research at the research station has focused on understanding the structure, function, and productivity of the typical forest ecosystems in the reserve. The major results from this research were published in several volumes of *Research of Forest Ecosystems* (in Chinese). Xu (1992) summarized the first-phase results of the forest ecosystem research program at Changbai Research Station. Most of these research activities were carried out at several permanent plots along a road (from the bottom to the top) on the northern slope of Changbai Mountain.

In 1987, an international symposium on temperate forest ecosystems was held at Changbai Nature Reserve. In the last decade, several joint research endeavors between Chinese scientists and scientists from other countries have been developed (e.g., Burger and Zhao 1988; Harmon and Chen 1991; Barnes et al. 1993; Geng et al. 1993; Shao et al. 1994). These studies cover a wide range of research topics, including forest structure, dynamics, and nutrient cycling, but are focused on only one mixed forest stand on the northern slope.

Numerical classification of vegetation suggests that there are at least nine major forest types within the reserve (Xu 1992). However, spatial distribution patterns of different forest types in the reserve have not yet been studied. As a major task of the Changbaishan Project of the Cooperative Ecological Research Program (CERP-N2) between China and Germany, a forest-cover map was created based on a Landsat Thematic Mapper (TM) satellite image. This map was one of the major outputs for CERP-N2 activities. In the present paper, the structure of the forest cover on Changbai Nature Reserve will be discussed. The spatial distribution patterns of the forest cover types will be analyzed for the Changbai Nature Reserve and its surrounding area. The objective of this paper is to provide ecologists, foresters, and reserve managers with spatially explicit data and information about forest distribution on Changbai Mountain. In particular, we will examine the boundaries for different cover types and will compare cover type differences between the reserve and its surrounding area. The implications of these results for forest management and forest conservation will also be discussed. We hope that the information and data published in this paper will be useful in the organization of future joint international research activities and that it will focus more international attention on the protection and management of the old-growth forest ecosystems in Changbai Mountain area.

Study area

Changbai Mountain (Changbaishan in Chinese), the highest mountain in northeastern China, is located along the border of China and North Korea (Fig. 1*a*). The study area is located on the higher part of Changbai Mountain and consists of Changbai Nature Reserve and an 8 km wide buffer zone around the reserve (Fig. 1*b*). Changbai Nature Reserve covers the Chinese side of Changbai Mountain and is nearly 200 000 ha. This reserve is located from 127°42′E to 128°16′32″E, and from 41°42′54″N to 42°26′26″N. On the top of the mountain, at the center of the reserve, there is a volcanic eruption lake (locally called Sky Lake) with depths up to 373 m. The elevation of the highest point of the mountain is 2691 m, while that of the lowest part of the reserve is around 740 m (Fig. 2). The topographical conditions on the four slopes of the mountain are very different. The northern slope is relatively flat, while the southern slope has large topographical variations. Because the reserve boundary is not parallel to contour lines, the relative difference in elevation along the boundary line can be as much as 1300 m (from 740 to 2000 m) (Fig. 2).

There are two major meteorological stations within the reserve (Fig. 1*b*). One of them is located at Sky Lake and is operated by the Meteorological Bureau of China. The other is located at the northern boundary of the reserve (at Changbai Research Station) and is operated by the Chinese Academy of Sciences. A summary of local climatic conditions is presented in Table 1.

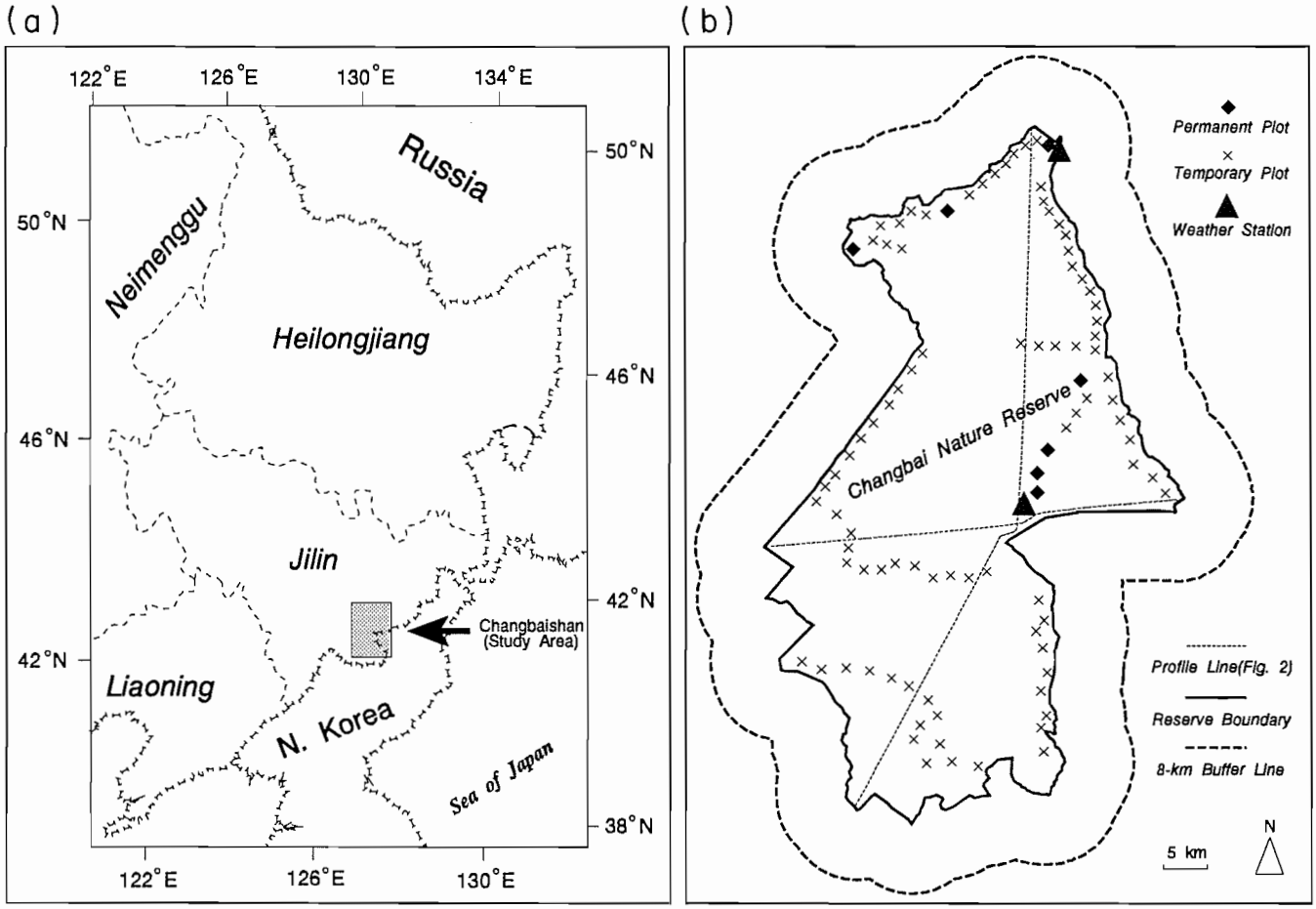
Changbai volcano has erupted four times since the 15th century (in 1413, 1597, 1668, and 1702). Earlier, between 1000 and 1100 (Machida et al. 1987; Zhao 1987), a large-scale, highly destructive eruption occurred. Until the early part of this century, the Changbai Mountain area had not been disturbed by humans (Tao 1987; Shaw 1914). The reserve was established in 1958. At that time, extensive forest cutting had not spread to Changbai Mountain. Thus, the major vegetation within the reserve has experienced approximately 1000 years of natural succession following the last major volcano eruption. Volcanic soils above deep volcanic ash and pumice deposits can be observed throughout the reserve. The forests on Changbai Mountain have been grouped into nine major forest types, according to dominant species composition, using numerical classifications (Table 2).

Methods

Ground surveys were conducted in the summers of 1989 and 1990 at eighty-six 0.1-ha (20 × 50 m) temporary plots and seven 1-ha permanent plots (Fig. 1*b*). These survey locations were chosen to sample as many different stand types as possible along major roads. The locations of all the survey plots were marked on 1 : 50 000, 10-m-interval, topographical maps. Diameter at breast height (DBH) was measured and species recorded for each tree at each plot. Height was also recorded for a subset of the trees at each plot. These data were used as a basis for vegetation classification with the intent of grouping remote sensing classifications. The 1 : 100 000, 50-m-interval, topographical maps covering the whole reserve were digitized using the ARC/INFO GIS (geographical information systems) package. This GIS database initially was created for analyzing elevation relationships among different cover types.

Data for the Changbai Nature Reserve and its surrounding area were extracted from September 21, 1987, TM satellite imagery and converted to a Universal Transverse Mercator coordinate system with a 30 × 30 m spatial resolution. The computer-assisted classification was done using ERDAS© software. The classification procedure was broken into two steps. The first step was to compare three unsupervised training methods (sequential clustering,

Fig. 1. The location of Changbai Nature Reserve (*a*) and detailed descriptions of the study area (*b*).



statistical clustering, and ISODATA clustering) and two band combinations (1, 2, 3, 4, 5, 7, or 2, 4, 5). Classifications were done on a subset of the study area on the northern slope, where detailed ground information was available. The different approaches were assessed according to their performance in separating major forest types, such as hardwood and larch forests. The comparisons suggested that the band combination of 2, 4, and 5 was the most sensitive to the forests examined, and the ISODATA method resulted in more accurate classifications. The second step was to classify the cover types with the entire TM quarter-scene using bands 2, 4, and 5 with the ISODATA method. Class groupings were assigned based on plot data, field observations, and the existing forest classifications. The output classes were grouped into 1 of 14 distinguishable cover types. The final map was smoothed to remove isolated pixels using a three by three window and majority rule (Lillesand and Kiefer 1994). The output map was clipped with an 8-km buffer line around the reserve. The size of the surrounding buffer was about the same as the reserve area. Classification results were checked via ground survey data. For some unknown classes, a ground check was done on the China side of Changbai Mountain by participants from the Changbai Nature Reserve.

To define elevation boundary lines for major cover types, the output map was compared with potential vegetation maps produced using existing vegetation–elevation models. Assuming that p_{ij} is the joint proportions (area) between category i in map A and category j in map B, the agreement between two maps is determined with the κ-statistic (Scheffé 1959) as follows:

$$[1] \quad \kappa = \frac{p_0 - p_e}{1 - p_e}$$

where

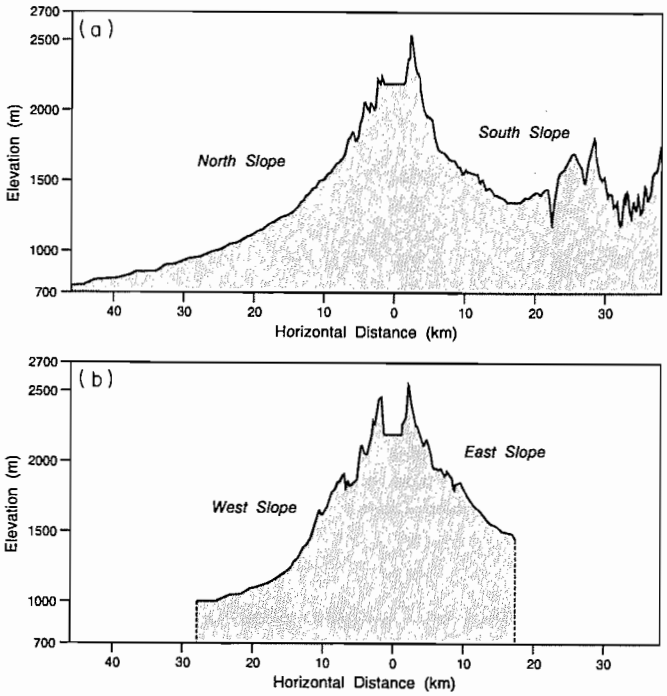
$$p_0 = \sum_{i=1}^{c} p_{ii}$$

$$p_e = \sum_{i=1}^{c} p_{i\cdot} p_{\cdot i}$$

where c is the number of categories and p_{ii}, p_0, and p_e are calculated from Table 3.

The κ-statistic has several desirable properties. It has a value of 1 when there is perfect agreement ($p_0 = 1$). It has a value close to zero when the observed agreement is approximately the same as would be expected by chance ($p_0 \approx p_e$). In addition, the κ-statistic does not assume that the marginal probabilities are equal for the two maps (Monserud and Leemans 1992). The degree of agreement can be considered good or acceptable if the κ-statistic value is over 0.55 (Monserud and Leemans 1992).

Fig. 2. Profiles of Changbai Mountain. (*a*) North–south profile. (*b*) West–east profile.



Results

The TM image classifications were grouped into 14 distinguishable cover types on Changbai Mountain (Fig. 3). These cover types include bare rock, mountain birch (*Betula ermanii* Cham.) forest, sky lake, evergreen coniferous forest, Korean pine (*Pinus koraiensis* Sieb. & Zucc.) – hardwood forest, larch (*Larix olgensis* A. Henry) forest, hardwood forest, aspen (*Populus davidiana* Dode) – white birch (*Betula platyphylla* Sukachev) forest, human land use (human-altered type), meadow, tundra, sparse forest, abandoned land, and windthrow area. The dominant cover types were the evergreen coniferous forest and Korean pine – hardwood forest, which accounted for about 70% of the area inside the reserve and 50% of the area outside the reserve (Table 4). The first dominant cover type in the reserve was the evergreen coniferous forest, which is a mixture of five forest types listed in Table 2: mongolian oak (*Quercus mongolica* Fisch ex Turcz.) – Korean pine forest, hardwood – Korean pine forest, spruce – fir – Korean pine forest, mountain birch – spruce – fir forest, and Changbai Scots pine (*Pinus sylvestriformis* T. Wang) forest (more detailed classifications of this cover type will be discussed in another paper). The Korean pine – hardwood forest was the second dominant cover type in the reserve (accounts for 21% of whole reserve), but was the first dominant cover type in the surrounding area (accounts for 29% of surrounding area). By definition, this cover type was the same as that listed in Table 2. The definitions for the hardwood forest, mountain birch forest, and larch forest cover types were also the same as those listed in Table 2. The mountain birch forests were mainly distributed in the reserve (almost 80%), while nearly 80% of the hardwood and larch forests were located in the surrounding area. The sparse forest, created likely by windthrows decades ago (no specific records are available), is not listed in Table 2. This cover was dominated by larch, but the trees were much smaller than the trees in the larch forest cover type. The smallest forest cover type was the aspen – white birch forest, which takes only 2% of the study area. This cover type was a secondary growth forest regenerated after clear-cuttings at lower elevation. More than 80% of the aspen – white birch forests were found outside reserve. These seven forest cover types covered 88% of the land inside the reserve and 78% of the surrounding area.

Table 1. Meteorological characteristics of Changbai Mountain.

Location of weather station	Research station	Sky Lake
Elevation (m asl)	740	2623
Annual mean temperature (°C)	3.3	−7.3
10°C-based growing degree-days (°C)	2350	707
Annual precipitation (mm)	733	1332
Mean temperature in January (°C)	−19.5	−23.2
Mean temperature in July (°C)	19.2	8.6
Length of record	1982–1990	1959–1980

The remaining seven cover types were all nonforest cover types. The human land use cover type included towns, roads, cutting fields, farmlands, and ginseng areas. The aerial extent of this cover type was very small in the reserve, but accounted for almost 20% of the land in the surrounding area. The subdivisions of the human land use cover type normally can be recognized by spatial patterns. Cutting fields basically consisted of disconnected small patches, because the forest cutting had to follow small-area (15–20 ha) regulations of the Chinese government. The larger patches were either towns or farmlands. The abandoned land cover type was farmland before being placed in the reserve 35 years ago, but at the time of this study it was basically shrub land dominated by *Lonicera edulis* Turcz. ex Freyn, *Rubus matsumuranus* Levl. et Vaniot, and *Rosa davurica* Pall. Younger trees of larch, aspen, and white birch were also observed over this cover type. The windthrow cover type was created by a 1986 winter tornado. This cover type contains very few large living trees. The dead trees were removed by local government for economic values. The Sky Lake cover type, as mentioned earlier, was on the top of the mountain. The highest vegetation cover type on Changbai Mountain was the tundra, which includes 59 plant associations classified by Qian (1992). The dominant species included mainly *Rhododendron confertissimum* Nakai, *Rhododendron chrysanthum* Pall, *Vaccinium vitis-idaea* L., and *Dryas octopetala* L. var. *asiatica*. The meadow was a cover type distributed in swales at higher elevations, where snow cover can last as long as 10–11 months per year (Qian 1992). The dominant species for meadow on Changbai Mountain were *Sanguisorba sitchensis* C.A. Mey., *Aconitum monanthum* Nakai, *Aconitum tschangbaishanensis* Liet

Table 2. Tree species composition for typical forest types (after Xu 1992).

Forest type	Relative composition by basal area (%)	Mean DBH (cm)	Mean height (m)
Hardwood	Ash, 30; basswood, 30; maple, 20; oak, 10; other, 10	42	21
Oak – Korean pine	Pine, 90; basswood + oak, 10	45	27
Hardwood – Korean pine	Pine, 70; basswood, 20; birch, 10	52	26
Korean pine – hardwood	Hardwood, 70; pine, 30	36	23
Spruce – fir – Korean pine	Spruce, 40; pine, 30; fir, 10; larch, 10; birch, 10	36	29
Mountain birch – spruce – fir	Spruce, 90; fir + birch, 10	44	28
Mountain birch	Birch, 80; larch, 20	12	9
Larch	Larch, 100	38	29
Changbai Scots pine	Pine, 100	48	26

Note: Ash is *Fraxinus mandshurica* Rupr.; basswood is *Tilia amurensis* Rupr.; maple is *Acer mono* Maxim.; oak is *Quercus mongolica* Fisch. ex Turcz.; Korean pine is *Pinus koraiensis* Sieb. & Zucc.; spruce includes two species: *Picea koraiensis* Nakai and *Picea jezoensis* (Sieb. & Zucc.) Carr. var. *komarovii*; birch (in hardwood group) is *Betula costata* Trautv. (yellow birch); fir is *Abies nephrolepis*; mountain birch is *Betula ermanii* Cham.; larch is *Larix olgensis* A. Henry; and Changbai Scots pine is *Pinus sylvestriformis* T. Wang.

Table 3. Calculation of Scheffé's (1959) κ-statistic.

	Map B categories					
Map A categories	1	2	. . .		c	Total
1	p_{11}	p_{12}	. . .		p_{1c}	$p_{1\cdot}$
2	p_{21}	p_{22}	. . .		p_{2c}	$p_{2\cdot}$
.	.	.	.		.	.
.	.	.		.	.	.
.	.	.			.	.
c	p_{c1}	p_{c2}	. . .		p_{cc}	$p_{c\cdot}$
Total	$p_{\cdot 1}$	$p_{\cdot 2}$	. . .		$p_{\cdot c}$	1

Huang, *Calamagrostis angustifolia* Roth, and *Phleum alpinum* L. The bare rock, with less than 10% of vegetation cover, was a cover type found mainly around Sky Lake.

These cover types showed some regularity in their distribution patterns on Changbai Mountain (Fig. 3). Around the Sky Lake and bare rock cover types, there was a well-developed tundra zone. On the northern, western, and southern slopes, the tundra was bordered by mountain birch forests. On the eastern slope, there were almost no mountain birch forests below the tundra; instead, most of the slope was covered with larch forests. The southern slope was largely covered with evergreen coniferous forests. Associated with this broad cover type, there exist scattered patches of mountain birch forests and meadows. On the better protected northern slope and on the western slope, there was a relatively large area of Korean pine – hardwood forests below the coniferous forests. In the northwest corner of the reserve, there were several large patches of hardwood forests. A belt-shaped pattern of windthrow cover type (blowdown) was found on the western slope of the mountain.

According to the existing altitude vegetation distribution theory (Wang et al. 1980), there were four potential vegetation zones on Changbai Mountain: tundra (from 2000 m above sea level (asl) to the top of the mountain), birch (1700–2000 m asl), coniferous (1100–1700 m asl), and broad-leaved – coniferous mixed forest (700–1100 m asl). The model used in the past was developed based on vegetation changes along a single road on the northern slope.

These four vegetation zones can be readily extracted from the forest cover type map. By comparing the forest cover type map with the potential vegetation zone map based on the northern part of the reserve, a more reliable elevation vegetation distribution model was developed. Based on the agreements (κ-values) between the forest cover type map and potential vegetation zone maps, the boundary line between the mixed forest and coniferous forest was set at 1100 m asl (because the κ-values became lower when the boundary line was set at 1050 or 1150 m asl) (Table 5), which was same as Wang et al.'s (1980) model. By the same gradient-search technique, the other two lines between coniferous and mountain birch, and between mountain birch and tundra, were located at 1650 and 1950 m asl, respectively. These two lines were both 50 m lower than what was found using the existing model developed by Wang et al. (1980). The boundary line between mountain birch and tundra defined here matched a systematic observation by Qian (1992).

Discussion

Changbai Nature Reserve is about 80 km long and 40 km wide. Its relative elevation can be as high as 2000 m. Such a steep elevation gradient leads to explicit patterns for the natural forest cover types. Some irregular patterns on Changbai Mountain have resulted from either human disturbances or natural disturbances. The human disturbances were mainly the extensive forest cuttings around the reserve. It was found that such human activities were getting close to the reserve boundary (Fig. 3). In fact, most of the forestry bureaus around Changbai Nature Reserve have been faced

Table 4. Total area for each cover type.

Cover type	Area (ha)		
	Inside reserve	Outside reserve	Total
Bare rock	914.3	454.5	1 368.8
Mountain birch forest	10 767.4	3 219.2	13 986.6
Sky Lake	648.9	500.4	1 149.3
Evergreen coniferous forest	94 823.3	37 257.2	132 080.5
Korean pine – hardwood forest	42 334.3	60 357.6	102 691.9
Larch forest	10 392.2	33 605.9	43 998.1
Hardwood forest	5 281.1	18 103.5	23 384.6
Aspen – white birch Forest	757.1	8 462.7	9 219.8
Human land use	3 106.8	39 106.4	42 213.2
Meadow	4 414.4	72.8	4 487.2
Tundra	10 356.9	6 896.7	17 253.6
Sparse forest	11 298.9	2 709.1	14 008.0
Abandoned land	909.3	0.0	909.3
Windthrow	2 530.2	0.0	2 530.2
Total	198 535.0	210 745.9	409 280.9

Table 5. Comparisons of forest cover type map using different potential vegetation models.

Potential vegetation model			
Elevation of mixed forest – coniferous forest boundary line (m)	Elevation of coniferous forest – mountain birch forest boundary line (m)	Elevation of mountain birch forest – tundra boundary line (m)	κ-statistic
1050	1650	2000	0.646
1100	1650	2000	0.657
1150	1650	2000	0.594
1100	1700	2000	0.645
1100	1600	2000	0.642
1100	1650	2050	0.640
1100	1650	1950	0.667
1100	1650	1900	0.653

with serious forest resource crises (Z. Wang, personal communication). If the cutting of forest in the surrounding areas cannot be controlled, the old-growth forests around Changbai Nature Reserve will soon vanish. Forest cutting in northeastern China was started by the Japanese in the early part of this century. During that time only large and timber-quality trees were removed from the forests. Many hardwood forests observed on Changbai Mountain (and other areas) were the successional results of the removal of Korean pine trees during the turn of the century. The hardwood forest listed in Table 2, dominated by Manchurian ash (*Fraxinus mandshurica* Rupr.) and basswood (*Tilia amurensis* Rupr.), is the typical preclimax forest type in low-elevation areas of Changbai Mountain (Shao et al. 1994). The aspen – white birch forests, distributed along some roads and in the north of Changbai Mountain, are typical secondary forests resulting from clear-cutting. The climax forest type for both the hardwood forests and aspen – white birch forests in the lower northern and western slopes of Changbai Mountain is the mixed hardwood – Korean pine forest (Shao et al. 1994). The hardwood forest was situated on the hills of the northeastern corner of the reserve, with elevation ranging from 1050 to 1350 m asl. This high-elevation hardwood forest was composed mainly of maple (30%) (*Acer mono* Maxim. and *Acer mandshuricum* Maxim.), elm (30%) (*Ulmus japonica* (Rehd.) Sarg. and *Ulmus laciniata* Mayr), yellow birch (20%) (*Betula costata* Trautv.), Manchurian ash (10%), and Mongolian oak (10%) and was very different from the lower elevation hardwood forest type listed in Table 2. Micro climate effects may be the major controlling factors for the special forest composition.

The natural disturbances were mainly volcanic eruptions and windthrows. Though the last major eruption occurred about 1000 years ago, three minor eruptions occurred 300–400 years ago. The eastern corner of the reserve was covered with larch forests, but the potential forest cover types should be mountain birch forest at higher locations and evergreen coniferous forest at lower locations.

Fig. 3. Distribution of forest cover types on Changbai Mountain.

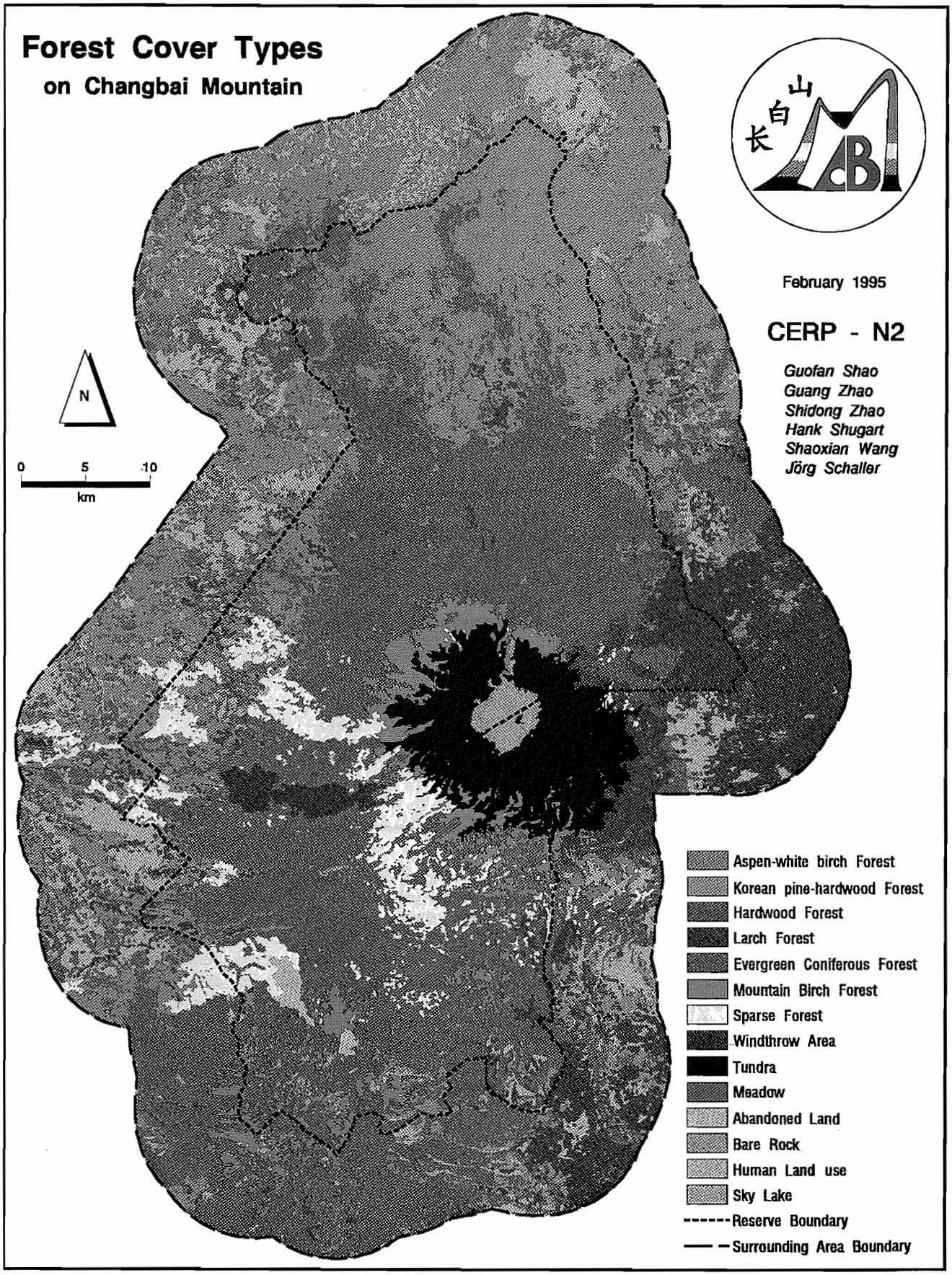


Table 6. Extreme climate conditions for the potential vegetation zonations on Changbai Mountain.

Potential vegetation type	Yearly mean temperature (°C)	10°C-based growing degree-days	Annual precipitation (mm)
Hardwood – Korean pine forest	>1.6	>2080	<832
Coniferous forest	1.6 to −1.8	1556–2080	832–1023
Mountain birch forest	−3.5 to −1.8	1294–1556	1023–1118
Tundra	<−3.5	<1294	>1118

In fact, the whole eastern slope, including the Korean part, of Changbai Mountain was covered with larch forests (field observations by authors). The larch forests on the eastern slopes might be the result of secondary regeneration after fires caused by the minor eruptions. Regeneration for some larch species, like Dahurian larch (*Larix gmelinii* (Rupr.) Rupr. ex Kuzen.) in northeastern China, is best on bare, burned sites (Bonan 1992). The mountain birch forest cover type did not completely circle the top of the mountain, probably because the birch forest is more sensitive to fire disturbances. ^{14}C analyses of carbonized wood samples suggested that tree-line forests on Changbai Mountain, including mountain birch and dwarf Siberian pine (*Pinus pumila* (Pall.) Regel.) forests, were damaged by the 1597 eruption (Liu et al. 1992).

The windthrow that occurred in 1986 was the latest major disturbance for the reserve. Nearly every large coniferous tree in a whole valley on the western slope, including Korean pine at lower elevation and spruce at higher elevation, was blown down by a strong tornado in December 1986. The natural restoration cannot be observed in this disturbance area (except for several protected, permanent plots) because of extensive timber harvesting and artificial regeneration. The species planted are mainly Korean pine and larch.

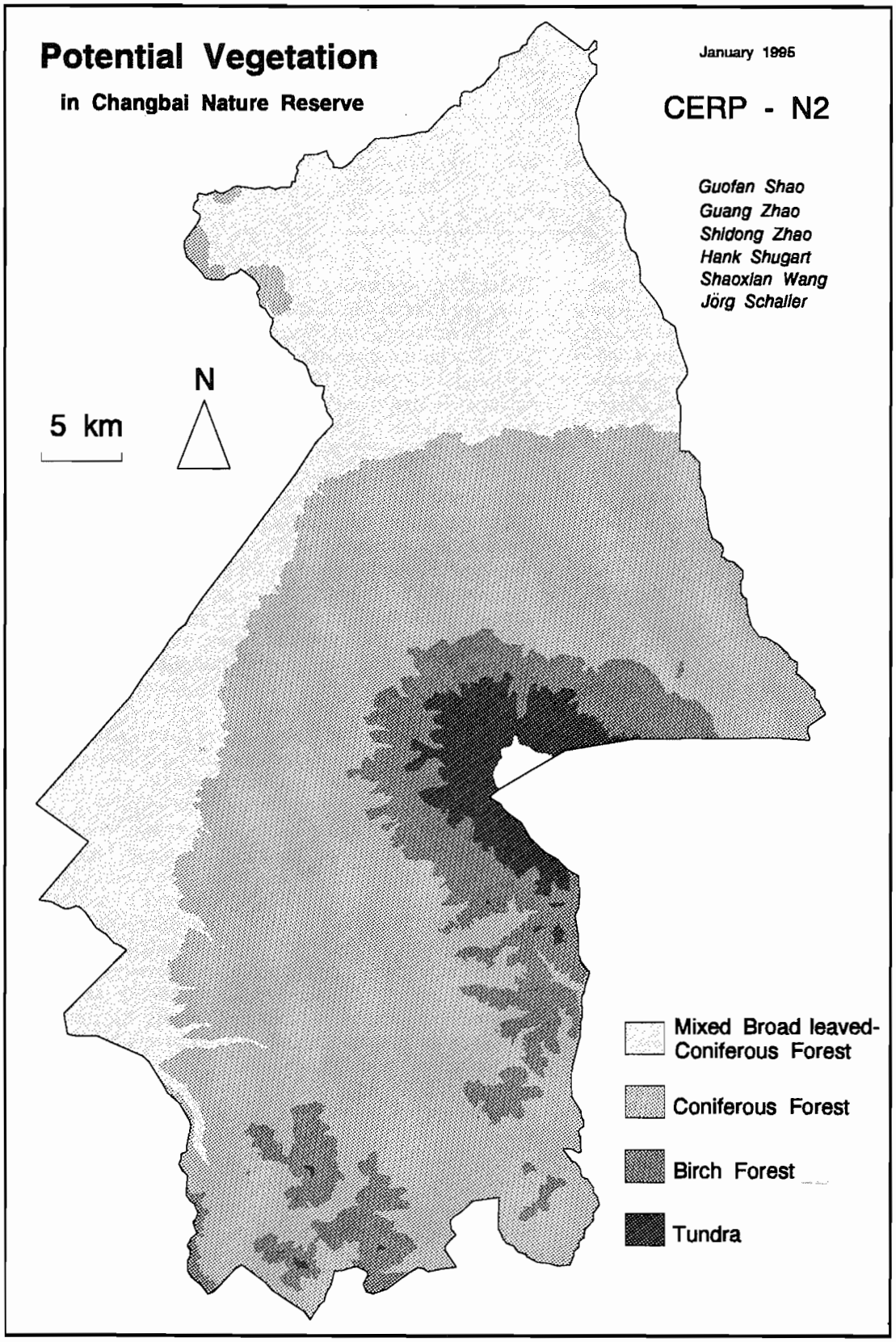
Though there were irregular distribution patterns, the elevational distribution patterns still played the dominant role in vegetation distribution for the reserve. The actual cover type distribution patterns were similar to the potential vegetation distribution zones (Fig. 4). A good level of agreement was reached between the potential vegetation map (Fig. 4) and the actual vegetation cover map for the reserve (from Fig. 3) according to the κ-statistic. The north boundary the coniferous forests extended into the Korean pine – hardwood forests because the oak – Korean pine forest type was included in the evergreen coniferous forest cover type (Fig. 3). The extreme climatic conditions for the four potential vegetation types, derived with linear interpolations (Table 6), were located between the climatic extremes of the corresponding biome types at a continental scale (CVEC 1980).

Forest management and conservation prospects

People have long believed that old-growth Korean pine – hardwood mixed forest was the dominant forest type (by area) at the Changbai Nature Reserve (Yang 1984). Because of the complex geographic conditions in the reserve, there have not been enough researchers and field technicians to conduct a reserve-wide vegetation survey since the reserve was founded in 1958. Our results showed that Korean pine – hardwood mixed forest, the best habitat for Manchurian tiger (*Panthera tigris subsp. longipilis*), accounted for only 21% of whole reserve in area. This cover type had more extensive distributions in the surrounding areas of the northern and western slopes of Changbai Mountain (Fig. 3). Thus, major problems may exist in the original design and planning for this reserve. It is also clear that the human land use cover type is very important in the surrounding area and was already very close to the reserve edge (Fig. 3). At the present rate of forest cutting, within 20 years the Changbai Nature Reserve may become an isolated island in a matrix of anthropogentically altered landscapes. The general statement that the land outside the protected areas is extremely important as well as the biggest challenge for biological conservation (Western and Pearl 1989) is particularly true for the Changbai Nature Reserve.

The contrasting forest distribution patterns between the reserve and surrounding areas on Changbai Mountain represent a typical landscape feature that can be found in many places where nature reserves are located in China. This phenomenon has resulted from very different strategies of forest resources management inside and outside the reserves. In the surrounding areas, forest cutting was one of most important and inevitable human activities; inside the reserve, the cutting of any single living tree was considered illegal (Richardson 1990; Ross and Silk 1987). The forestry bureaus and the reserve bureau may be doing very well in terms of their own duties, but the overall consequences need to be considered. Changbai Mountain preserves water sources for several large rivers in northeastern China, including the Songhua, Yalu, Tumen, Mudan, and Suifen, and provides habitats for numerous endangered species, such as Manchurian tiger and ginseng (*Panax ginseng* C.A. Mey.) (Tao 1987). It appears that there are less than 20 tigers left on Changbai Mountain and these have been observed only in Korean pine – hardwood mixed forests and low-elevation larch forests (Yang 1992). The tigers observed in the larch forests (thought to be marginal habitat) may indicate that the current distributions of Korean pine – hardwood mixed forests are not sufficient for the population. While it could help the situation if the Changbai Nature Reserve extended its western and eastern boundaries, this may not be practical in the near future. If more selective forest cuttings practices are applied in the surrounding areas, the conservation values of these

Fig. 4. Zonations of potential vegetation types in Changbai Nature Reserve.



lands and of Changbai Mountain as a whole could be enhanced.

There was a sharp increase in the population of the Changbai area in the past decades (Tao 1987). In many regions of developing countries, population growth has initiated a process of forest destruction (Filius 1986). In the Changbai area, like other forestry areas of China, forest land cannot be converted into agricultural land because of the forest laws formulated by the Chinese government (Richardson 1990; Ross and Silk 1987). However, the quality of forest land has been undergoing large changes in the Changbai area: principally a conversion from old-growth forests to young plantations of larch or Korean pine. This kind of forest conversion has led to many ecological problems, such as loss of biological diversity, soil erosion, and insect outbreaks (Xu et al. 1987). Economically, local people will potentially face more serious crises resulting from the failure of sustainable management of forest resources. Because the forest cuttings around Changbai Nature Reserve at higher elevations have come later than those in the low-elevation areas, the opportunity still exists to improve the forest management in the surrounding area of Changbai Nature Reserve.

Chinese forest laws forbid the conversion of forest into agriculture land, but at this time, they do not stipulate different forest management practices for areas around natural reserves. In terms of protection of biological diversity, there are no relevant regulations like the federal law of the United States, which includes a clear regulation: "management prescriptions shall preserve and enhance the diversity of plant and animal communities ... so that it is at least as great as that which would be expected in a natural forest" (Buongiorno et al. 1994). The controversy on forest cutting methods of Korean pine – hardwood mixed forests started in the 1950s (Liu 1963). Studies have shown that selective cutting of the old-growth Korean pine – hardwood forests can have advantages over clear-cutting in many aspects (e.g., Liu 1963; Xu et al. 1987; Shao et al. 1994). However, clear-cutting has been broadly accepted in the Changbai area because of its ease in application. Since the 1980's, a compromise policy has been implemented resulting in less large-area clear-cutting and more small-area clear-cutting (suggested less than 10 ha). For this reason, scattered small-patch forest cutting patterns (around 15 ha) can be observed around the Changbai Nature Reserve. In northeastern China, the basic forest management unit is a forest compartment consisting of several subcompartments, such as each cutting patch seen in the current vegetation map for Changbai Mountain. Because the costs of road construction and maintenance are normally very high, a whole compartment normally should be cut within several years after the first round of cutting is started. Otherwise, the road system has to be totally reconstructed for the subsequent harvest. Therefore, this so-called small-area cutting will, in a relatively short period, result in a consolidation of the small clearcuts and a net result of forest clearing similar to that of the large-area cutting. The current problem is knowing when the remaining forests among those now harvested will also be cut.

Changbai Nature Reserve, like other natural reserves in China, is struggling against various human impacts. One of the human impacts is the illegal harvesting of Korean pine seeds in the old-growth Korean pine – hardwood forests. Modeling experiments showed that the harvesting of Korean pine seeds would not change the forest structure until 200 years later (Shao et al. 1994). Therefore, more attention should be focused on the potential impacts of human activities on the forest ecosystems. Because both the Changbai reserve and surrounding forest industries are administrated under the Forestry Ministry of China, protocols for the best management of the reserve and the neighboring forests should be developed without administrative difficulties. These rules should force the forest industries to use selective cutting or other cutting methods in some special areas, and redivide management districts for Changbai Nature Reserve based on the newer forest cover map. Because about a quarter of Changbai Mountain belongs to North Korea, more international efforts should be made to promote various joint conservation activities.

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