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长白山森林景观破碎的遥感探测

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摘要:天然林数量的减少以及质量的降低对中国的生态环境和经济发展产生不利影响。虽然林地的破碎对各种自然灾害起到关键性作用,林地是如何被破碎的尚不十分清楚。应用卫星遥感技术,以及地理信息系统和空间分析手段研究中国东北一原始的针阔混交林的破碎过程。结果表明,本来完整的原始森林,已经被一种"复叶"状小面积皆伐作业分割为零碎的斑块。采伐地的面积平均为 15hm^2,但随着采伐的继续,采伐地段连为一体,增大了采伐迹地的面积,从而保留的林地面积越来越小。采伐地点的选择没有考虑物种和环境的保护。林地破碎的特征是保留林地面积的缩小,中、小林地数量的增加,林地斑块形状的改变,以及林缘长度的增加。最后就保护东北森林植被完整性的角度提出林业政策与森林经营的改进意见。

关键词:森林景观;森林经营;破碎;红松林;原始林

Remote sensing of forest landscape fragmentation on Changbai Mountain

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Abstract: The degradation of natural forests and environments has led to ecological and economic difficulties in China. Forest fragmentation plays an important role in natural disasters but how forests are fragmented is poorly understood. This study utilized satellite Thematic Mapper (TM) data, a geographic information system (GIS), and spatial analysis tools (Fragstats) to examine the fragmentation of an old-growth mixed forest in Northeastern China, one of the most important timber bases in China. The study showed that the old-growth forest has been fragmented into small patches by leaflet-like "small-area clearcutting". The size of clearcutting was around 15 hm^2 on average at the beginning stage of forest harvesting but was expanded rapidly as clearcutting continued. No specific cutting preferences or restrictions have been given to certain aspects or slopes where important winter or lowland habitats may be located. Fragmentation conditions were characterized by the reduced forest patch sizes, the increased frequency of small- or medium-sized forest patches, changes in patch shape, and the increase in forest edges. Several recommendations have been proposed to improve forest policy and management planning in order to protect the integrity of native forests in the region.

Key words: forested landscape; forest management; fragmentation; Korean pine forest; old-growth forest
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1 Introduction

Forest fragmentation and its effects on species habitat have attracted world-wide concerns[1~10] Although fragmentation occurs in natural landscapes through, for example, fire and windthrow[11,12], forest cutting has created additional large-scale disturbances[13]. Large forest tracts have been progressively divided into smaller, isolated, and geographically more complex fragments. Developing alternatives for cutting size, shape, frequency, and spatial distribution have become major issues in planning for sustainable use of forest resources and conservation of biodiversity at landscape scales[1,14~18].

Although the issues of forest fragmentation may vary across the world, studies of forest cutting practices and fragmentation in different geographic regions of the world will help better understand forest resource management practices in a common sense. In recent years, a number of studies have been conducted to evaluate timber harvesting strategies at landscape levels in the U.S. using remote sensing and GIS approaches[19] and computer simulation[20~33]. However, there has been little research on the details of cutting practices and fragmentation conditions in China, where extensive and unique forest practices have been applied for more than four decades[24,25]. and forest quality has sharply declined[26].

The Korean pine (*Pinus koraiensis* Sieb. & Zucc.) - broadleaf mixed forest is one of the most valuable old-growth forest types for its high-quantity and quality timber production in northeastern China[27,28,14]. The complex ecosystem structure and rich soil fertility retain higher biological diversity than other forest types in eastern Eurasia continent[29,30]. This climax vegetation, which is similar to the old-growth mixed conifer-northern hardwood forests (with the absence of characteristic dominants of *Tsuga* and *Fagus species*) of North America[31]. once covered most of the mountain areas in the east portion of northeastern China[14,27,28,32~34]. The mixed forest provides habitats for many rare and endangered wildlife species such as the Siberian tiger (*Pantha tigris longipilis* L.), Sika deer (*Cervus nippon* Temminck), Chinese Qiusha duck (*Mergus squdmatus*), and endangered plant species such as wild ginseng (*Panax ginseng* C. A. May). Studies of forest distribution, conservation, and dynamics have been conducted at the regional scale in Changbai Mountain area[24,25,32,35]. It was found that forest cutting was approaching to the border of Changbai Nature Reserve but details about forest cutting were not studied. This study focuses on how silvicultural treatments have caused forest fragmentation at landscape levels outside Changbai Nature Reserve. The analysis was carried out by: (1) using integrated satellite image processing and a GIS to characterize old-growth forest landscapes and forest fragmentation and (2) applying spatial analysis tools to quantify fragmentation conditions in both managed and unmanaged forest landscapes. Recommendations are proposed based on the study for improving management of the old-growth forest landscapes in northeastern China.

2 Study sites and methods

The study area is located at the lower elevations of Changbai Mountain, which lies along the border of China and North Korea (Fig. 1a). With elevations ranging from 550 to 2690 meters, Changbai Mountain is covered by five vegetation zones: hardwood forest, Korean pine-broadleaf mixed forest, coniferous forest, mountain birch forest, and sub-alpine tundra[24]. The Korean pine-broadleaf mixed forest covers most areas where elevations range between 700 to 1100 m. This forest is the major timber source for the local forest industries and one of the core ecosystems inside Changbai Nature Reserve. With a total area of 190 000 hm^2 of largely old-growth forests, Changbai Nature Reserve was established in 1960 as one of the three stations within the UNESCO's Man and Biosphere (MAB) network in 1979. The reserve is located along the Chinese side of Changbai Mountain (Fig. 1b) and has been well protected since its establishment. Forests surrounding the reserve are managed by forest industries, locally called forestry bureaus.

Three study sites were selected in this area (Fig. 1b). One site lies inside the reserve and is referred to as a "Control" site in this study. This 17 583 hm^2 landscape represents a large area of contiguous Korean pine-broadleaf forest inside the reserve. The other two sites, 19 798 hm^2 and 14 477 hm^2, are located inside the territory of Baihe forestry bureau, and are referred to as "Site A" and "Site B" in this study. Site A is about 15 km away from the Control site and is at an early stage of logging whereas Site B is adjacent to Control site and has been logged for over 10 years. Sites A and B represent different cutting stages but with the same cutting method. Topographic conditions are similar among the three study sites, so are vegetation structures. Three types of forest exist at each study site. The major forest type is Korean pine broadleaf mixed forest dominated by *Pinus koraiensis* Sieb. & Zucc., *Acer mono* Maxim., *Fraxinus mandshurica* Rupr, *Quercus mongolica* Fisch. ex Turcz, and *Tilia amurensis* Rupr. There are also sparsely distributed aspen-birch forest (secondary forest after fire or clearcutting) and spruce-pine forest (located at higher elevations, dominated by *Picea koraiensis* Nakai, *Abies nephrolepis* (Trautv) Maxim., and *Larix olgensis* A. Henry). Landsat Thematic Mapper (TM) images acquired on September 21, 1989 and May 28, 1993 were used to derive forest type maps for the study areas. The TM images were rectified using 1 : 50 000 topographic maps and ERDAS (Earth Resources Data Analysis System) Imagine software. The RMS error was below 0.4 pixel. Training statistics were defined using various types of information such as field plot data (20 by 50 square meters in size), black/white aerial photographs, and color infrared aerial photographs combined with unsupervised cluster analysis. Supervised classifications were then applied and a forest cover map was generated for the three study sites. A stratified random sampling scheme and sampling polygon approach were selected for accuracy assessment. At each sampling site, a unit of 9×9 pixels (6.6 hm^2) was inspected using a stereoscope on black/white and color infrared aerial photos. The overall classification accuracies of the 1989 and 1993 data, were 88% and 89%, respectively. The "cutting field" class was mapped with 90% and 92% accuracies whereas the mixed Korean pine-broadleaf forest was mapped with 85% and 88% for 1989 and 1993 images, respectively.

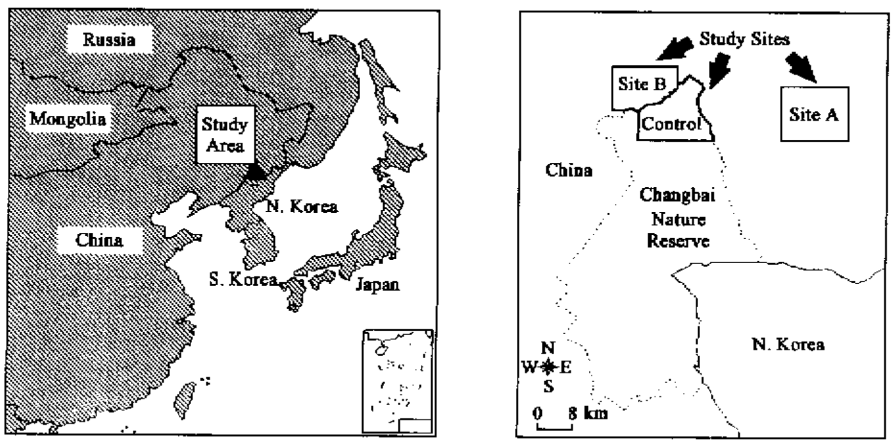

Fig. 1　Three study sites are located inside and near Changbai Nature Reserve of China

Topographic maps scaled at 1 : 50 000 with 10m intervals were digitized for generating slopes, aspects, and river networks for Site B. However, the same data were not available for Site A. Visual interpretation and simple correlation analysis were made to examine if the locations of forest cutting were related with physiographical conditions. Fragmentation conditions were quantified and compared among the three study sites. Selected landscape indices, including Percent of Landscape, Patch Density, Mean Patch Size, Edge Density, and Area-Weighted Mean Shape Index were computed for forest and cutting classes, and Modified Simpson's Evenness Index was computed for entire landscapes using FRAGSTATS[36]. Forest patches were grouped into three size classes: small patches (<10 hm^2), large patches (>1000 hm^2), and intermediate patches (10~1 000 hm^2).

3 Results

The Control site represents a natural forest landscape where human disturbance is minimal (Fig. 2), and only sparse cutting practices were observed. The cutting areas accounted for only 1% of the entire area of Control site (Fig. 3a). The percentage of forest cover at this site was much higher and remained more stable over time than at Sites A and B (Fig. 3a), where cutting operations occurred, the percentage of forest cover declined dramatically while percentages of cutting areas increased over time (Fig. 3a). For example, percentages of the mixed forest were reduced from 76% to 67% at Site B and from 67% to 54% at Site A between 1988 and 1993.

The cutting operations had generated an interesting leaflet pattern along roadside (Fig. 2) although the harvest intensity and patch size varied between Sites A and B. Patch density of forest areas was nearly doubled from 1988 to 1993 for both Sites A and B, while patch density of cleared areas increased by 70% for Site A but decreased by 40% for Site B.

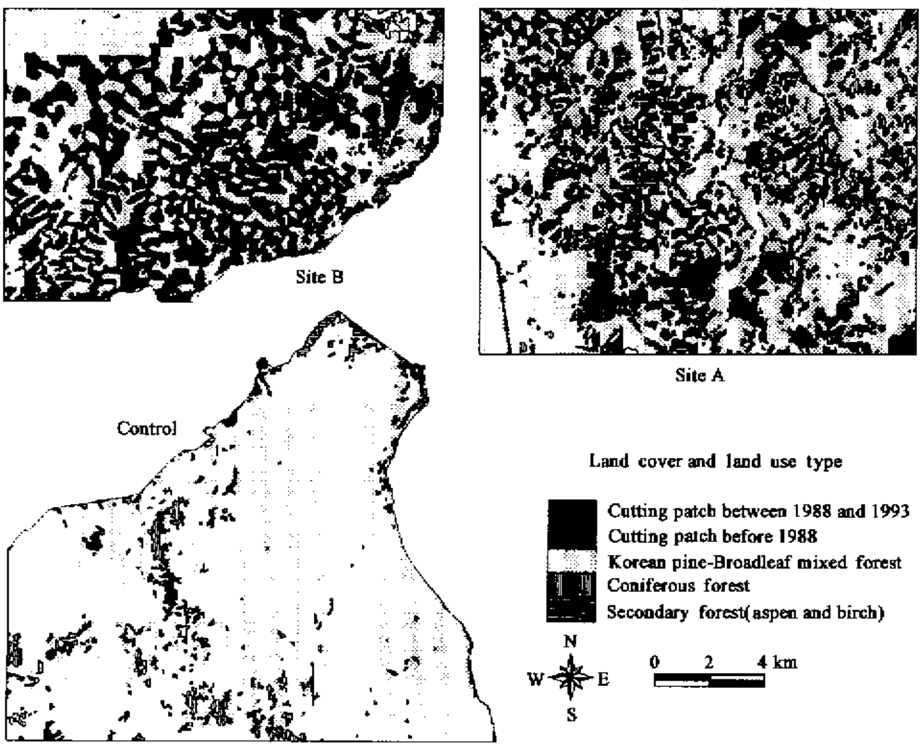

Fig. 2 Land use and land cover types, including cutting fields, in three study sites

All the three study sites have elevations within the range from 650 to 1 100 m. The old-growth forests at these sites should have had similar composition and structure before logging occurred in 1970s. The forest cutting activities created the difference in landscape structure between the managed and Control sites. For example, forest cutting activities not only have reduced forest cover to 54%, and but also fragmented the remaining forest into smaller patches (Fig. 2, Fig. 3c). The mean forest patch size for Control site was relatively stable over time, but decreased by 50% for both Sites A and B from 1988 to 1993. The mean patch size of clearcutting slightly increased from 14 to 16 hm^2 for Site A but doubled (from 54 to 107 hm^2) for Site B between 1988 and 1993 (Fig. 3c). The mean cutting patch size was more sensitive than land percentage in terms of quantifying landscape fragmentation. For example, in 1993, forest coverage at Site B (54%) was more than a half of that at Control site (93%), while forest mean patch size at Site B (69 hm^2) was as low as 20% of forest mean patch size (1 362 hm^2) at Control site.

Among the three study sites, Control site had the lowest values of Area-Weighted Mean Shaped Index (AWMSI) (Fig. 3d). Though AWMSI values of cutting patches became higher when cutting intensity was increased, AWMSI values of forest patches declined at Site B where the forest cutting was more intensive. It seems that the AWMSI of forest patches had similar sensitivity to the cutting patch density to forest cutting intensity (Fig. 3b&d). Cutting Patch Edge Density (Fig. 3e) and Modified Simpson's Evenness Index for the entire landscapes (Fig. 3f) shared a similar trend, increasing over time and with cutting intensity.

It appears that the managed forest landscapes contained all the three size classes, while Control site consisted of only small and large forest patches but did not contain intermediate patches (Fig. 4). Comparing the two managed sites, Site B, where forest cutting was more intensive, had more intermediate forest patches. The number of intermediate patches is a reliable index for explaining forest cutting intensity.

Overall, each landscape index used in this study remained stable at Control site but showed great changes at Sites A and B from 1988 and 1993. It appears that the fragmented old-growth forests at Sites A and B were undergoing continuous fragmentation in the past decade. Some newer logging roads in forests could be seen on the 1988 satellite image and most of the forests along the roads disappeared on the 1993 image (Fig. 2). Because logging road networks were built along rivers in Changbai Mountain area, forest cutting along the roads indicated that many riparian forests were removed along the rivers.. Visual interpretation also indicated that the cutting operations did not change with topographic conditions (slopes and aspects). The harvested area on different aspects or slope was closely related with total land area of the aspects or slopes at Site B ($R^2 \geqslant 0.92$), meaning that forest cutting was applied equally to all the aspects and slope positions.

4 Discussion

The harvest patches appeared as a "leaflet" pattern in the landscape, primarily because logging practices have been concentrated along the road network. The leaflet pattern may be more expensive than the conventional continuous-strip clearcutting but the logging costs could be reduced if the residual forests were minimized. This economic consideration explains why the existing clearcutting pattern is characterized by narrow forest belts between cutting patches. In many cases, several cutting patches were connected , forming larger clearcutting patch clusters as the fragmentation proceeds, and caused a sharp increase in mean patch size[13]. If the remaining forest blocks were removed by either natural or human disturbances, more clearcutting patches would be connected as a single large patch (Fig. 2). This will result in a large-scale damage to a forested landscape.

South-facing slopes should be maintained as a contiguous unit of old-growth habitat type, because

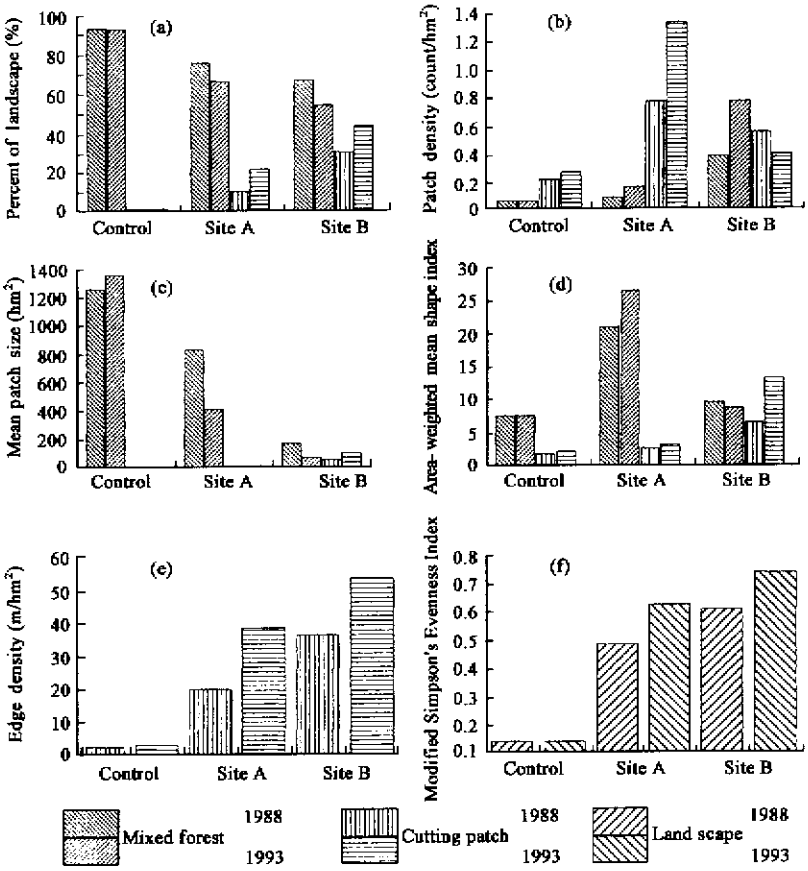

Fig. 3 Selected landscape indices for > 1 hm^2 mixed forest and clearcutting patches (a～e) or the entire landscapes (f)

they provide critical late winter habitat needed by wildlife, particularly deer. The upper portion of a watershed is also suggested to be harvested first, as this will retain important lowland habitats during most of the first rotation. It appears that no specific cutting priority or limitation has been given to certain aspects or slopes during practical logging operations. The overall design of forest cutting did not concern issues of preserving wildlife habitats at certain topographic positions in Changbai Mountain area.

Riparian zones are specifically critical for maintaining water quality and serving as habitats and corridors for wildlife[47]. Wildlife species diversity associated with the riparian system is usually rich and unique. A study by Li *et al*[29] has showed that 10 of a total of 120 forest breeding bird species in Changbai Mountain area were observed within riparian zones. More importantly, all the species occurring in riparian zones were exclusively associated with riparian forests. They represented 18% of the total 56 unique bird species on Changbai Mountain although riparian zones accounted for <5% of total land in the region. For example, both black stork (*Ciconia nigra*) and Chinese Qiusha duck (*Mergus squdmatus*) are the forest breeding bird species found only in Changbai Mountain area. They have been listed as the most rare and endangered species at national level in China, which are solely depend on riparian forests with an elevation range between 650 and 1150 m. Clearly, continuous forest cutting within the riparian zones will produce the most significant threaten to these species.

Forest edges of a landscape are often critical in a study of fragmentation[36]. An increasing edge density may indicate a growing loss of large and contiguous forest patches and our analysis has showed that both the managed landscapes had much higher forest edge density than the protected landscape. Because forest cutting continued between 1988 and 1993, edge density values have become even higher with time. Studies have showed that maximizing forest edges by management activities may greatly affect interior species[38,5,29]. found that forest edges or shrubs were important habitats for many characteristic forest breeding bird species in Changbai Mountain area. At what level forest edges should be maintained depends on the major conservation objectives in a managed forest. A fragmented landscape with a high edge density and contrast may degrade quality of certain wildlife habitats, but it may also create new types of habitats near the edges. Obviously, understanding amount of edge needed in a landscape for sustainability of different species and ecological functions remain as a great challenge for the future research. The differences in forest patch density and patch size distributions between the managed and unmanaged forest landscapes are indicators of interactive relationships between natural succession and human disturbances. The gap-phase dynamics are common in old-growth forests[39], but normally create only smaller-scale gaps. This natural forest dynamic process leads to a number of small "cutting" patches. Human disturbance at Control site included limited forest cutting for power lines, roads or ginseng farming along the reserve borders. These activities also led to smaller cutting patches. Because of most of the old growth forest ecosystems around Changbai Mountain have been developed under relatively homogenous geographic conditions, it is not surprising to find large and contiguous forest patches at Control site. At Sites A and B, the leaflet clearcutting firstly split a part of large forest patches into many small-size patches between cutting patches. As forest harvesting continues, clusters of cutting patches are connected across the landscape and large forest patches are divided into medium-size patches. It is expected that the medium-size patches may disappear when forest harvesting spreads to an entire landscape[13]. In this case, extreme forest fragmentation occurs. Forested landscapes in Changbai Mountain area will undergo such an extreme fragmentation within a couple of decades if the current forest management system continues.

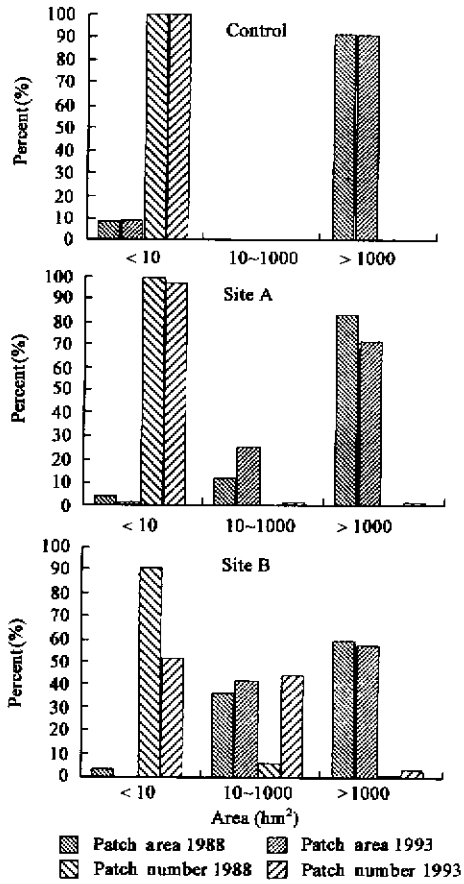

Fig. 4 The frequency and total area of three sized patches levels for forest in three study sites

5 Conclusions and suggestions

Forest cutting practices at Sites A and B demonstrated common management procedures of the old-growth forests in Changbai Mountain area. The leaflet clearcutting practice formed large-area cutting patches and cut large forest patches into smaller pieces. The forest fragmentation was rapid and extensive. The mean patch size of clearcutting was about 15 hm^2 at the beginning stage of forest harvesting but was doubled and redoubled when intensity of clearcutting reached a higher level. There was no cutting priority or limitation given to certain geographic locations where wildlife may find proper habitats. Forest zones along rivers have also been damaged by clearcutting activities within riparian zones. This had negative impacts on habits of wildlife species associated exclusively with riparian forests. Forest cutting along the border of Changbai Nature Reserve was at the same intensity as in areas with a distance from the reserve border. If such a forest harvesting method continues for another decade, the functional transition zone of the biosphere reserve will probably disappear, and Changbai Nature Reserve will become an old-growth island in the region. The old-growth forest fragmentation was characterized by reduced forest patch size, increased number of medium-sized forest patches, altered distribution patterns of forest patch classes, and increased shape complexity of forest patches and forest edge density. All these landscape analyses support a conclusion that the leaflet clearcutting method led to severe fragmentation, and further, led to changes in ecological processes and functions of the old-growth forests on Changbai Mountain.

Several measures must been taken to slow down or minimize forest fragmentation in Changbai Mountain area. Firstly, clearcutting should be with the transition zone of Changbai Biosphere Reserve. Uneven aged forest management methods should be applied. Secondly, the design of forest cutting patterns must consider protection of wildlife habitats. Cutting intensity, topographic conditions, forest edges, and riparian zones should be carefully considered and determined based upon both timber production and habitat protection/restoration requirements. Research on home range size for target wildlife, the relationship between wildlife population and old-growth distribution patterns, and ecological impact of different clearcutting patterns (dispersed or concentrated) should be established and continuously operated to guide further forest management. Thirdly, the local authorities and forest managers should pay attention to the rapid decrease of old-growth coverage on Changbai Mountain. The conventional principles of evaluating a forest landscape should be changed from only looking at its timber value to referring to its ecological, social and economic values, as well as from short-term benefits to long-term sustainability of forest resources. Uneven aged forest management methods should be encouraged in Changbai Mountain area. Fourthly, for a large area of managed landscapes where old-growth stands have already been fragmented, habitat restoration program should be considered as early as possible. Gradually, natural or semi-natural forests should be regenerated on the cutting sites. Mono-species larch or pine plantations should not be regenerated around the reserve. Design for corridors between isolated old-growth habitats, fences, forest roads, inter open space, and roadside should facilitate migration, foraging, sheltering, and resting of wildlife. Finally, communications between the reserve and its surrounding forest industries must be improved. Forest management and harvesting plans of adjacent forestry bureaus should be designed to support conservation goals of the reserve. Conservation programs operated inside the reserve could not be successful without sufficient cooperation from its surrounding forest industries which provide a large area of buffered forest landscapes. Since Changbai Nature Reserve covers only higher-elevation portions of Changbai Mountain, it may not be large enough to provide safe habitats for large mammals such as Siberian tiger. All the previously insufficient conservation programs should be re-defined, corrected, and extended from the reserve to the adjacent managed forest landscapes. An integrated conservation plan to be developed by the Reserve and forestry bureaus together will help protect the integrity of forested landscapes from further fragmentation.

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