Exploring Conservation Options in the Broad-Leafed Korean Pine Mixed Forest of the Changbai Mountain Region

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The broad-leaved Korean pine (Pinus koraiensis) mixed forest (BKPF) is one of the most biodiverse zonal communities in the northern temperate zone. Changbai Mountain in northeastern China contains one of the largest BKPFs in the region. The government of China has established a network of 23 nature reserves to protect the BKPF and the species that depend on it for habitat, including the endangered Siberian tiger (Panthera tigris altaica). This study used the conservation planning software C-Plan to calculate the irreplaceability value of each unit to assess how efficiently and comprehensively the existing conservation network supports biodiversity and to identify gap areas that, if integrated into the network, would expand its protection capability. Results show a number of high-conservation-value planning units concentrated along certain ridges. The existing conservation network is structured such that the habitats of only 24 species (out of a total of 75) achieve established conservation targets. Of the other 51 species, 20 achieve less than 50% of their conservation targets. However, expanding the network to include high-conservation-value gap areas could achieve conservation targets for 64 species and could provide different degrees of protection to the other 11 species. Using C-Plan software can guide decision-making to expand the conservation network in this most precious of mountainous ecological zones.

Keywords: Biodiversity conservation; conservation network; Pinus koraiensis; Changbai Mountain; China.

Peer-reviewed: January 2015 Accepted: March 2015

Introduction

Rapid population growth puts great pressure on biodiversity conservation in mountain regions. Habitat loss combined with climate change leads to species extinction (Pimm et al 2014). Only 12.9% of earth's land surface is considered protected (Jenkins and Joppa 2009), and many key ecological zones remain unprotected. One important ecological zone that is only partially protected is the Changbai Mountain region in China, where the government has established 23 nature reserves.

This region has contiguous primary forest landscapes, referred to as broad-leaved Korean pine (Pinus koraiensis) mixed forest (BKPF), and the highest biodiversity in the cool temperate zone (Tang et al 2010). It is covered by well-developed altitudinal vegetation zones, including mixed forest (700–1100 m), coniferous forest (1100–1700 m), Erman birch forest (1700–2000 m), and tundra (>2000 m) (Shao et al 1996).

However, the region also has a dense road and railway network, and human disturbances—including tourism, harvesting of medicinal plants, poaching, and deforestation—have had a serious impact on biodiversity conservation (Yang and Xu 2003; Tang et al 2011), contributed to habitat degradation, and lowered the efficiency of existing conservation networks.

In the wild, some species listed as occurring in the Changbai Mountain region as recently as the 1990s, such as the monk vulture (Aegypius monachus) and the northern groundcone (Boschniakia rossica), could not be found 10 years later (Chen et al 2010), and the Siberian tiger (Panthera tigris altaica) is now extremely endangered (Luan et al 2011). In 2002 Changbai Mountain was declared by the government of China to be a key biodiversity area with global conservation significance (Ministry of Environmental Protection 2011). This brought new opportunities and challenges to conservationists in the region. At present, most research focuses on individual national-level nature reserves, especially in the Sino-Russian and Sino-Korean border regions east of Changbai...
Mountain (Luan et al. 2011; Tang et al. 2011; Yu et al. 2014). None focuses on biodiversity conservation in the broad-leaved Korean pine (*Pinus koraiensis*) mixed forest (BKPF) of the Changbai Mountain ecological zone.

Based on the biodiversity features of BKPF in the Changbai Mountain region, this study used the widely applied Systematic Conservation Planning (SCP) theory framework (Ferrier et al. 2000; Margules and Pressey 2000; Pressey and Taffs 2001; Pressey et al. 2002; Cowling, Pressey, Rouget, and Lombard 2003; Cowling, Pressey, Sims-Castley, et al. 2003; Pressey et al. 2003; Lourival et al. 2009) to identify gap areas with high conservation value and consider human disturbance factors to provide 3 scenarios—prioritizing in turn ecological value, species habitat rescue, and economic development—by which to choose and prioritize which gap areas to add to the network according to different protection requirements. The main objectives were to identify ecologically critical areas outside the existing conservation network and provide a scientific basis for a Natural Forest Conservation Program (Zhang et al. 2000), which will improve the efficiency of the conservation network in the Changbai Mountain region and help guide the sustainable development of ecological zones in other mountainous areas.

**Study area**

The Changbai Mountain region is located at 40°41’N–44°30’N, 125°20’E–130°20’E and has a total area of 105,151.89 km². It is in the continental monsoon climate zone, with annual rainfall of 550 to 910 mm. The frost-free period generally lasts for 120 to 160 days. The region contains 3 mountains and 9 ridges (Figure 1); the peak elevation of the highest mountain is 2691 m. BKPF occurs mainly from 700 m to 1100 m. The vegetation changes to dark coniferous forest from 1100 m to 1700 m, alpine vegetation from 1700 m to 2000 m, and alpine tundra above 2000 m (Shao et al. 1996).

**Methods**

**Protected species selection**

Species are designated for protection if they meet at least 1 of the following criteria: found mainly in China and endangered; included on the International Union for Conservation of Nature Red List of Threatened Species (IUCN 2004); disseminates the seeds of the Korean pine; is a major accompanying species of Korean pine and dominant species at various vegetation zones in the Changbai Mountain region; and has multiple economic

![Figure 1](https://example.com/figure1.png)

**FIGURE 1** Location of the study area. The Changbai Mountain region comprises 3 mountains and 9 ridges. This region has a dense road and railway network. (Map by Lin Ma)
values. A total of 75 species meet these criteria: 21 animal species, 16 bird species, and 38 plant species.

Species distribution was mapped using species-location data sets and existing field studies (CAS 2001, 2011a, 2011b; Gao 2006; Wang and Xie 2009; Zhou 2009). Administrative division, land use, roads, and residential distribution data come from the 1:250,000 National Terrain Database (National Geomatics Center of China 2001) and 26 frames of a 30-m-resolution digital elevation model derived from Geospatial Data Cloud (2013). From these databases, we determined the major types of vegetation, elevation, and other habitat data. We also employed the intersect analysis function of geographic information system (GIS) tools based on the species’ suitable habitat characteristics (elevation, vegetation types) to accurately delineate species distribution (Zhang et al. 2014).

Conservation targets

The SCP theory framework advocates protection requirements to quantitatively determine the target (Margules and Pressey 2000; Pressey et al. 2003). In this paper, conservation targets were determined based on expert interpretation of the biodiversity features of Changbai Mountain and defined as appropriately proportioned areas in which protected species are distributed. Experts assessed indicators such as endangerment, economic value, and national protection level and were asked to give scores for each species as a conservation target index ($T_{\text{species}}$). They then worked out the product for each species’ distribution area according to specific indicators:

\[
\text{Conservation Target (km}^2\text{)} = T_{\text{species}} \times \text{Distribution area}
\]

The species conservation target index ($T_{\text{species}}$) for animals is represented by the equation

\[
T_{\text{species}} = \left( I_{\text{En}} + I_{\text{Pro}} + I_{\text{KP}} + I_{\text{Spa}} + I_{\text{Ac}} \right)/5.
\]

$T_{\text{species}}$ is thus the average value of the indicators $I_{\text{En}}$ (degree of endangerment), $I_{\text{Pro}}$ (national protection level and endemism), $I_{\text{KP}}$ (recovery function of BKPF), $I_{\text{Spa}}$ (space demands of animals), and $I_{\text{Ac}}$ (area of a species' habitat). $T_{\text{species}}$, therefore reflects the rarity of a protected species. Species with a small habitat are a higher priority for protection. Space demand ($I_{\text{Spa}}$) was not considered for birds; instead, the average values of the other 4 items in the equation were calculated.

For plants, $I_{\text{Spa}}$ was replaced by $I_{\text{Eco}}$, an indicator representing the plant's economic value, including its use in medicines and pigments and as a source of potheaters, oils, fiber, nectar, and spices. Plants with multiple economic uses received higher scores.

Site-selection software

We divided the study area into planning units on the basis of watershed boundaries, using a 30-m-resolution digital elevation model with a cell accumulation threshold of 2000. This resulted in 15,871 planning units, with an average area of 6.025 km$^2$. We identified priority conservation gaps using C-Plan (New South Wales Department of Environment and Conservation 2005), a software package that provides decision support for designing reserve systems within a GIS interface.

The degree of irreplaceability (IR) of each planning unit was used to calibrate the selection algorithm. It indicates the importance of a planning unit and assesses the achievement of regional conservation targets within it (Ferrier et al. 2000). IR values range from 0 to 1. Areas with high IR were considered as potential additions to the network. Before the operation of the C-plan software, land areas that did not serve as species habitat were noted as “excluded” from the existing nature reserves and ignored when the IR value was calculated (Figure 2). All other planning units were considered in the selection of sites for priority conservation networks. We connected our calculated results using GIS (Arcview 3.3) to produce an IR distribution map.

Development of conservation scenarios with different priorities

The level of human disturbance in each selected priority area was calculated as an indicator for prioritization (Zhang et al. 2014). Road and population density were selected to reflect human threat conditions. The threat of human disturbance to the ecosystem radiates out from the source of the disturbance, and its peripheral buffer area forms the domain of influence. Different amounts of disturbance have different levels of influence on biodiversity. The human disturbance index (HTI) of each planning unit was calculated using the equation

\[
HTI_i = \left( \sum W_j S_j + \sum W_j R_j \right)/2.
\]

HTI$_i$ is the HTI of the $i$th planning unit, $W_j$ is the weight of the $j$th HTI in the $i$th planning unit (Table 1), and $S_j$ stands for the area percentage occupied by the $j$th human settlement buffer in the $i$th planning unit. $R_j$ stands for the area percentage occupied by the $j$th road buffer in the $i$th planning unit (Table 1).

A comparison was made between planning units with relatively high IR values and the distribution of existing reserves so as to identify gaps in the existing networks. Based on the IR and HTI values of planning units overall, we also classified the units into different parts using GIS tools and designed 3 conservation scenarios with different strategies:
FIGURE 2  Irreplaceability value (IR) of planning units. Sites with values between 0.8 and 1 are considered to have high conservation value and would be included in the ecological-value-prioritized scenario for network expansion. (Map by Lin Ma)

TABLE 1  Disturbance factors and weight.

| Disturbance factor                          | Range of buffers | Assigned weight |
|---------------------------------------------|------------------|-----------------|
| Expressway, railway, or national road       | 1.50             | 0.40            |
| Provincial road                             | 0.50             | 0.30            |
| Municipal and county-level road             | 0.25             | 0.20            |
| Other lower-level road, eg low-cost road    | 0.10             | 0.10            |
| Provincial or municipal housing estate      | 8.00             | 0.40            |
| County-level housing estate                 | 5.00             | 0.30            |
| Township-level housing estate               | 3.00             | 0.20            |
| Residential area below township level       | 1.00             | 0.10            |
1. Prioritizing ecological value (0.8 < IR ≤ 1; HTI not considered)
2. Prioritizing habitat rescue (0.8 < IR ≤ 1; HTI > 0.2)
3. Prioritizing economic development (0.8 < IR ≤ 1; 0 < HTI ≤ 0.2)

Assessment of conservation contribution
For our study, the conservation contribution value (\(T_i\)) represents the degree to which the conservation targets of each protected species are achieved in protected areas, using the equation

\[T_i = \frac{A_{\text{Protected}}}{A_{\text{Target}}},\]

where \(A_{\text{Protected}}\) means the distribution area of a protected species in the planning unit and \(A_{\text{Target}}\) refers to the conservation target of the protected species. \(T_i \geq 100\) represents achieved conservation targets, as defined by the expert assessment. We compared the \(T_i\) of the existing conservation networks and new network involved in the scenario where ecological value is prioritized.

Results

Distribution of high-conservation-value planning units and conservation gaps
The IR value of planning units eligible for priority conservation site selection can be divided into 5 levels (Table 2). Planning units with high conservation value make up 16% of the total study area. These units tend to be concentrated along mountain ridges and are especially concentrated in the following areas: Zengfeng Ridge, Changbai Mountain, Weihu Ridge, Zhangguangcai Ridge, and Harba Ridge (Figure 2). Such areas are not covered by existing conservation networks; these conservation gaps should be given priority for conservation.

Three conservation scenarios
We considered 3 conservation scenarios for the Changbai Mountain region based on different combinations of human disturbance and conservation values. The first scenario prioritizes ecological value (gaps shown in Figure 2). Using ecological protection as the priority strategy, this scenario excludes consideration of the influence of human disturbance on conservation effects. In this scenario, all current high-conservation-value gaps in the existing conservation networks become fully protected.

The second scenario prioritizes species rescue (Figure 3A). In this scenario, high-conservation-value gaps with high human disturbance are given priority for incorporation into conservation networks to avoid further damage to the habitats of threatened species by highways and railways.

The third scenario prioritizes economic development (Figure 3B). In this scenario, areas with a high density of human economic activities are rejected for inclusion in the conservation networks; only areas with low human disturbance and high conservation value are considered. Environmental protection and economic development are supported at the same time.

Assessment of conservation contribution
The existing conservation network is 17,125 km², accounting for 16% of the total study area. The habitats of Korean larch (Larix olgensis), dhole or Asiatic wild dog (Cuon alpinus), and 22 other species (75 in total) are covered by existing conservation networks and reach their conservation targets (Supplemental material, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00069.1), accounting for 32% of the total types. The habitats of Siberian tiger, sika deer (Cervus nippon), Korean pine, Amur leopard (Panthera pardus orientalis), and another 16 species (accounting for 26.7% of the total) have not been effectively protected and reach less than 50% of their conservation targets. This indicates that the existing conservation networks need to be expanded to make more species achieve their conservation targets.

If we include the high-conservation-value planning units that currently are not part of the conservation networks (the scenario that prioritizes ecological value), the new network is 27,897 km², accounting for 26% of the total study area. It potentially enables 64 protected

| Irreplaceability | Conservation value | Area (km²) | % of study area |
|------------------|--------------------|------------|-----------------|
| 0.8 < IR ≤ 1     | High               | 10,725.06  | 15.94           |
| 0.6 < IR ≤ 0.8   | Relatively high    | 5772.58    | 8.58            |
| 0.4 < IR ≤ 0.6   | Moderate           | 6691.47    | 9.94            |
| 0.2 < IR ≤ 0.4   | Relatively low     | 10,917.07  | 16.22           |
| 0 < IR ≤ 0.2     | Low                | 33,193.44  | 49.32           |
FIGURE 3 Two conservation scenarios with the same irreplaceability value (0.8 < IR ≤ 1) and different human disturbance values. (A) Rescue-prioritized conservation network (HTI > 0.2); (B) economic-development-prioritized conservation network (0 < HTI ≤ 0.2). (Maps by Lin Ma)
species (Supplemental material, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00069.S1) or 75 in total to achieve conservation targets, accounting for 85% of the total protected species. For the remaining 11 species whose conservation targets are not completely achieved, their conservation contribution value ($T_i$) is also improved to different degrees (Figure 4), and so they are better protected in this network.

After addition of the ecological-value-prioritized areas, the area proportion of the new conservation network is increased by 10% (Figure 5) when compared with the area proportion of the existing conservation network in the total area of the study region. The proportion of species achieving conservation target of total species is increased by 53% (Figure 5). This shows that scientific site selection to expand protection area can increase the beneficial contribution of the conservation network.

**Discussion**

Although it has played a very important role ecologically and economically in northeast China, the Korean peninsula, and far-eastern Russia, the BKPF has suffered excessive exploitation for decades (Shao et al 1996). Research suggests that primitive forests in the Changbai Mountain region are cut at an average rate of over 10,000,000 m$^3$ per year. A total of 86,000 ha of BKPF at the periphery of the Changbai Mountain Natural Reserve disappeared between 1972 and 1988; these forests are decreasing at a rate of 1.12% per year (Xia 2007). Herb gathering, poaching, and excessive tourism also affect the region (Yang and Xu 2003; Tang et al 2011). The rapid increase in tourism endangers water quality, soil, air, plants, and other species. Since the late 1980s, there have been over 100,000 visitors to the Changbai Mountain Natural Reserve annually (Yang and Xu 2003), with 881,100 tourists in 2008 (Chen et al 2010).

The Chinese government has launched new forest programs such as the Natural Forest Conservation Program (Zhang et al 2000) and the Jilin Province Biological Diversity Protection Strategy and Action Plan (2013) to restore natural forests in ecologically sensitive areas and determine the key areas of biodiversity conservation. Unfortunately the low income of local residents caused many of them to turn to poaching medicinal plants and certain endangered animals for income, regardless of the long-term interests of habitat and species conservation (Yang and Xu 2003). One possible solution would be for the government to compensate local residents for refraining from plundering the mountain’s natural resources; these payments for ecosystem services would help ease the tension between ecological protection and economic needs (Jin et al 2007; Ouyang et al 2013). In order to provide strategies for the government to protect Changbai Mountain’s precious natural resources, and to solve the problem that the sites that have been chosen for protection are usually too small to meet conservation targets (Tang et al 2011), we designed options for expanding the conservation network.

Representing a great improvement over previous methods that used multiple separate indices to reflect the biodiversity of a region, the irreplaceability analysis in Systematic Conservation Planning is an integrated index used to reflect the significance of a planning unit in achieving an overall conservation target (Ferrier et al 2000). The IR value is driven both by the biodiversity features of the research region and by the habits and needs of the protected species. Based on the features of

**FIGURE 4** Percentage of conservation target achieved by 11 protected species in the existing conservation network and after ecological value-prioritized additions.

**FIGURE 5** Comparison of area proportion of the conservation network in the total area and the proportion of species achieve conservation target in the total species types before and after ecological-value-prioritized additions.
the BKPF in the Changbai Mountain region, this study selected typical and representative species, including key ecological species capable of spreading the seeds of the Korean pine, including the squirrel (Sciurus vulgaris) and nutcracker (Nucifraga caryocatactes). It also included large mammals at the top of the food chain that can maintain the stability and balance of the BKPF ecological system (e.g., the Siberian tiger and the Amur leopard); accompanying species of Korean pine; endemic species; and dominant species at various vertical zones on Changbai Mountain. Wetland vegetation and waterfowl were less emphasized in the selection of protection objectives; therefore, results showed that mountainous regions have relatively high IR values, while rivers, wetlands, prairies, and other ecological systems do not. As we demonstrated in this paper, we need to integrate only those planning units with high IR values into the existing conservation networks in Changbai Mountain region to markedly increase the beneficial contribution of the conservation network.

Our approach is to increase the conservation contribution of the conservation network by increasing the area of the conservation network in the most judicious way. The resulting increment under our methods of conservation contribution is much higher than the percentage increase of the protected area (Figure 5); with a 10% enlargement to the area of the existing conservation network, 53% of protected species are predicted to achieve conservation target. This shows that scientific site selection of conservation areas is quite important, leading to ideal conservation effects as well expansion of only a small area, thus using limited land resources to maximize protected biodiversity features in regional areas (Wilson et al 2006).

We have proposed 3 conservation network scenarios with different strategies and priorities designed to include the impact of human disturbance. Implementation plans should be specified and subject to adjustment by stages according to actual conditions. Our rescue-prioritized conservation network focuses on protecting gaps with high conservation value and strong human disturbance. We suggest a policy that establishes new reserves at sites where important habitat could be rescued (as shown in Figure 3A). We also suggest taking ecological engineering measures to avoid the loss of biodiversity caused by deforestation, poaching, herb gathering, excessive tourism, infrastructure construction, and urban expansion.

The scenario in which the conservation network prioritizes ecological value does not factor in the effects of human disturbance. It is an ideal conservation strategy. Conservation measures used in this scenario mainly include construction and reconstruction of reserves. Settlements in such areas have been identified as eligible for migration against payment, and we propose that a mechanism to adequately compensate local residents for the loss of access to natural resources be established. The time limit for constructing reserves in this scenario could be based on availability of funds and other resources. Some reserves should be selected to be established first, and relevant measures must be taken to control further deterioration caused by human disturbance.

Finally, the scenario in which conservation networks prioritize economic development does not involve conservation gaps with substantial disturbance by economic activity. Instead, it is devoted to protecting regions with high conservation value and light human disturbance and preventing them from further damage. Conservation networks are distributed in sparsely populated areas at relatively high elevations in the Changbai Mountain region. The environment is maintained in a relatively primitive state. Such conservation gaps should be subject to long-term monitoring. Furthermore, their original biodiversity levels should be maintained as much as possible.

The conservation of the forest ecosystem is closely related not only to the degree of biodiversity but also to the value of ecosystem services, climatic variation trends, and the cost of establishing reserves (Popescu et al 2013; Wang et al 2014). Human disturbance includes social (population density on cultivated land), economic (per capita GDP and per capita income), and other factors (Tian and Chang 2012; Buschke and Vanschoenwinkel 2014). Additionally, research will yield different results if it also considers natural disturbance factors, such as fire, earthquakes, floods, and other ecological threats (Wilson et al 2005; Shokri and Gladstone 2013). We hope to analyze these factors as well in future research on conservation planning and consider the need to protect the ecological and evolutionary processes that create and maintain biodiversity (López-Pujol et al 2011) to help develop an expanded conservation network combined with biodiversity conservation and, more specifically, conservation strategies.

Conclusion

We explored conservation options for the conservation network in the BKPF in the Changbai Mountain region using C-Plan software and established that increasing the existing conservation network by 10% would help 64 species—accounting for 85% of total species—to achieve their conservation targets. Three conservation scenarios, driven by different protection demands, are proposed to help guide decision-makers as they improve the conservation of biodiversity in the Changbai Mountain region.
ACKNOWLEDGMENTS

This research was financially supported by the 12th 5-year National Science and Technology Plan of China (2012BAC01B03). We thank Dr Shen Guozhen, Dr Lu Xianfeng, Dr Xu Weihua, and Professor Zhu Ning for their suggestions.

We also thank the anonymous reviewers for their useful comments and Dr Anne Zimmermann for providing suggestions on improving the figures in this paper.

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Supplementary data

TABLE S1 Protected species in the Changbai Mountain region and the extent to which their conservation targets would be achieved by adding ecological-value-prioritized areas to the existing conservation network.

Found at DOI: 10.1659/MRD-JOURNAL-D-14-00069.S1 (161 KB PDF)