ARTICLE IN PRESS
BIOC-06749; No of Pages 6
Biological Conservation xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Biological Conservation
journal homepage: www.elsevier.com/locate/bioc

Habitat conservation redlines for the giant pandas in China

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ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 5 March 2016
Accepted 24 March 2016
Available online xxxx

Keywords:
Giant panda
Habitat
Conservation
Redline
Population
Connectivity

ABSTRACT

Considering the impossibility to cover the entire population of an endangered species in protected areas, a new approach (species conservation redlines) was recently been proposed in China. It constitutes the baseline space for species conservation but mapping and managing a species redline is not clear. In this study, a procedure on how to map habitat conservation redlines for the endangered giant panda was proposed. Panda habitat was first modeled based on field survey and remotely sensed data. Redline area was proposed after comparing three different scenarios, covering different proportions of panda habitat and populations. Results showed that the proposed redline area covered 9358 km^2. This area can protect more than 80% of the populations in all mountain regions in the study area, while keeping the connectivity of the habitat. The current nature reserves cover 60% of the redline area. Suggestions on how to manage redline areas inside and outside reserves are proposed, to limit human development activities in panda habitat. Our study provided a new approach for managing panda habitat, and would have implications for conservation of other endangered species in China and the world.

1. Introduction

Finding the balance between conservation and development is still a challenge globally, and even more serious in a country with a huge population such as China. A redline paradigm has evolved at the central government level in China in 2011 to set the ecological redline in the key ecological functioning regions, eco-sensitive regions and eco-fragile regions (Lü et al., 2013; Zheng and Ouyang, 2014). Through reasonable layout and minimum area constraint, the redline is delineated in the regions needing special protection to coordinate the ecological environment and economic development, and the regions must be strictly protected (Rao et al., 2012). Among different redline areas for ecological conservation, the redline for species conservation started to be named by the State Forestry Administration in 2013, and defined by the Environmental Protection Administration (Gao, 2015). The redline for species conservation is based on the establishment of key areas displaying a minimum habitat area to maintain viable populations. This redline constitutes the baseline space for species conservation, and long-termed survival of the populations will be threatened if the redline is occupied by human development. The redline does not only comprise the spatial boundary for controlling human activities but also contains quantitative conservation management requirements (Yang et al., 2014). Although the definition was proposed for two years, there are no readily available procedures to map species conservation redlines. Here we take the endangered giant panda (*Ailuropoda melanoleuca*) as an example to describe, for the first time, how to delineate a species conservation redline.

The giant panda is the symbol of species conservation in China. This species once ranged throughout most of China, northern Vietnam, and northern Myanmar (Pan et al., 2001). However, the geographic distribution of the species in China has sharply declined mainly due to human activities (Hu, 2001). Currently, the wild giant panda is distributed in the six mountain regions (Qinling, Minshan, Qionglai, Daxiangling, Xiaoxiangling and Liangshan) (State Forestry Administration, 2015). During the last 60 years, China has established 67 nature reserves specifically to protect panda habitat. The program of National Wildlife Protection and Nature Reserve Construction, which started in 2001, has promoted the conservation of the giant panda, while the National Forest Conservation Program (NFCP) and the Grain-to-Green Program (GTGP) have shown the potential for restoring and expanding the panda habitat (Xu et al., 2006). In addition, the State Forestry Administration in China has carried out four national surveys of giant pandas. Much research has been carried out on habitat mapping, habitat change (Linderman et al., 2005a; Viña et al., 2010; Vina et al., 2007; Zhang et al., 2014), impacts of climate change and/or natural disasters on the giant panda (Li et al., 2015a, 2015b; Xu et al., 2009; Zheng et al., 2012), design of nature reserves or corridors (Loucks et al., 2003; Xiao et al., 2011; Xu et al., 2006), and impacts of human factors (Bearer et al., 2008; Linderman et al., 2005b; Liu et al., 2001; Yiming et al., 2003). However, it is still difficult to establish nature reserves in some regions where the panda habitat is not under conservation because it will affect local economic development, while also it is difficult to manage the habitat outside reserves. In addition, different human activities (e.g., road construction,

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http://dx.doi.org/10.1016/j.biocon.2016.03.028

tourism, large hydropower stations, agricultural expansion, residential development) cause reductions and fragmentation of the panda habitat, further threatening the current panda conservation system. Therefore, the development of effective management measures to restrict human activities within the panda distribution area is important for panda habitat conservation.

In this paper, the approach for delineating the panda habitat conservation redline described, generates effective panda habitat conservation measures. Specific aims included a habitat assessment across the entire giant panda geographic range, comparison of different strategies for identifying the redline area, analysis of the spatial relationship between the redline and the current conservation system, and discussion of management approaches.

2. Methods

2.1. Study area

The study area (172,150 km^2) was defined by the six mountain regions currently inhabited by the giant panda in Sichuan, Shanxi and Gansu provinces in China, which comprise 56 counties. The region includes the Southwest China hotspot, one of the world's top 25 Biodiversity Hotpots (Myers et al., 2000). Most areas are characterized by high mountains and deep valleys, with elevations between ca. 260 and 7140 m. This significant change in elevation with its associated high variation in climate and soils causes high biodiversity in the region. The major vegetation types in the region are evergreen and deciduous broadleaf forests at lower elevations and evergreen coniferous forests at higher elevations (Fig. 1). The understory of the forests is dominated by ca. 60 bamboo species, with approximately 35 of them being the preferred food of giant pandas (Hu and Wei, 2004; Li, 1997). There are more than 300 hydropower stations, about 470 mines and more than 20 scenic spots in the study area, while the length of the road network in the study area is about 1300 km (State Forestry Administration, 2015).

2.2. Habitat assessment

We used a conceptual model to assess potential panda habitat (Liu et al., 1999; Ouyang et al., 1995). This model is based on previous studies on giant panda (Ouyang et al., 2001; Xu et al., 2006; Xu et al., 2009), and national panda surveys, and considers biotic and abiotic factors (e.g., vegetation types, elevation, slope and bamboo distribution). Assessment criteria are listed in Table 1. Potential suitable habitat for the giant panda is considered to be a function of the four main criteria. The Vegetation data was obtained from the China Ecosystems assessment dataset in 2010 at a spatial resolution of 30 m (Wu et al., 2014), which used the Chinese HJ-1A/B satellites as the major data source and method of object oriented automatic classification, combined with ground investigation and radar data. The classes of the vegetation include three levels of classifications (e.g., forest, broadleaf forest, evergreen broadleaf forest), and the vegetation types suitable for the giant panda were listed in Table 1. Elevation and slope were obtained from Digital Elevation Model (DEM; 1:50,000) in 2011, produced by the National Geomatics Center of China, and the bamboo distribution map was obtained from the Fourth National Giant Panda Census (State Forestry Administration, 2015).

2.3. Identification of the panda habitat conservation redline

The distribution of the panda occurrence locations can spatially reflect the degree of utilization of the habitat by panda individuals. On the basis of the potential habitat described previously, we delineated the panda habitat conservation redline using the density of panda occurrence locations. Data on panda population distribution was then overlaid to judge the proportion of the population conserved in the redline. The panda occurrence data and the population data were obtained from the Fourth National Giant Panda Census (State Forestry Administration, 2015).

The procedure for delineating the redline is as follows: first, the potential habitat is divided into 3 km ∗ 3 km grids, and the number of panda occurrence locations within each grid was calculated, as well as the number of occurrences within a buffer zone of 10 km around each grid. Second, the grids were sorted in descending order by the number of occurrence locations. Grids exhibiting the same number of occurrence locations were further sorted by the number of locations in the buffer zone. Finally, the grids are sorted into different levels based on the proportion of the occurrence locations (i.e. 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%). The grids with the top 10%

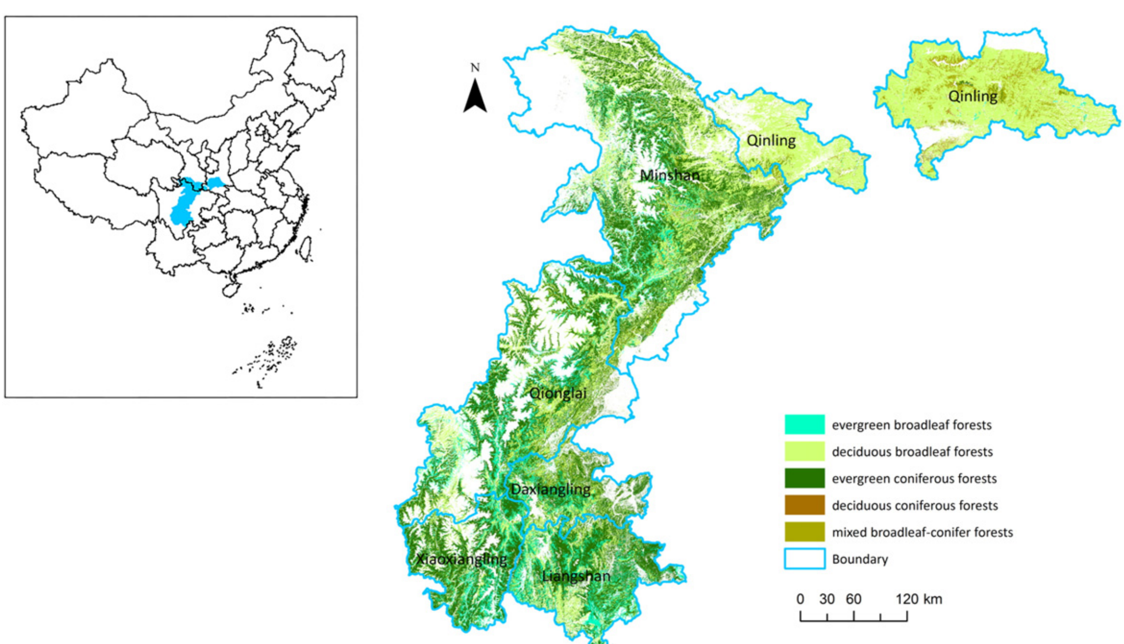

Fig. 1. Distribution of the different forest types in the study area (Wu et al., 2014).

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Table 1
Potential habitat assessment criterion for the giant panda.

Mountains	Elevation (m)	Slope (degree)	Vegetation	Bamboo
Qinling	[1100,3000]	[0,55]	Evergreen coniferous forests;	Bamboo
Minshan	[1200,3800]	[0,60]	Mixed broadleaf–conifer	
Qionglai	[1200,3800]	[0,60]	forests;	
Daxiangling	[1200,3800]	[0,60]	Evergreen–deciduous	
Xiaoxiangling	[1200,3800]	[0,60]	broadleaf forests;	
Liangshan	[1200,3800]	[0,60]		

Table 2
Redline area in the six mountains in scenario I (km^2).

Proportion of occurrences	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Daxiangling	0	0	0	9	9	9	9	33	50	307
Xiaoxiangling	0	0	18	21	30	30	38	66	87	146
Liangshan	0	0	16	33	51	95	215	312	545	1053
Minshan	18	75	335	707	1155	1733	2191	2741	3441	4649
Qinling	235	521	685	851	1010	1116	1250	1385	1632	2152
Qionglai	0	9	64	117	279	517	957	1576	2361	3643

occurrence locations constitute the top level of the redline, while those 100% constitute the bottom level.

Considering the uneven distribution of the panda occurrence locations among different mountain regions, together with population isolation, we established three scenarios to define the conservation redline. In scenario I, we sorted the grids according to panda occurrence location density across the entire panda geographic range. In scenario II, we sorted the grids in each of the six mountain ranges separately and then combined the results. In scenario III, the connectivity of isolated small populations was considered on the basis of scenario II. The isolated grids were connected to their nearest grids if the distances separating them were less than 10 km, which considers the distance of panda movement (Hu, 2001). For scenario III, the proportions of panda occurrence locations, together with the population within the redline areas, were analyzed. Considering the proportion of the population inside nature reserves was 67%, we chose the appropriate redline area with the proportion of population under conservation above 80% in every mountain region, as the panda habitat conservation redline. To measure the distribution of the redline areas in and out of the current conservation system, the panda habitat conservation redline was overlapped with the boundaries of nature reserves.

3. Results

3.1. Spatial distribution of potential panda habitat

The total area of potential panda habitat in the entire study area was 58,728 km^2, most of which was distributed in Minshan (35%), followed by Qinling (18%), Liangshan (17%), Qionglai (16%), Daxiangling (8%), and Xiaoxiangling (6%) (Fig. 2).

3.2. Panda habitat conservation redline

For scenario I and scenario II, there were some differences in the redline distribution among mountain regions. For covering the same proportion of occurrence locations or panda population (with exception of 100%), redline in scenario I covered more area in the mountains with higher density of occurrences such as Qinling and Minshan Mountains, covered less area in the mountains with lower density of occurrences such as Daxiangling and Xiaoxiangling (Table 2). Redline in scenario II covered the same proportion of occurrence locations for all the six mountains ranges (Table 3), and redline in scenario III covered areas without occurrence locations but considered the connectivity between isolated populations. In scenario III, most isolated redline patches generated in scenario II were connected. The isolated patches' number in scenario III was only 29% of that for scenario II on average (Table 4). Consequently, the scenario III had the largest redline area, the total population conservation proportions in the whole area were 4% higher than that in scenario II on average. This proportion in scenario II was 5% higher than that in scenario I on average (Fig. 3(a–d)). For instance, the redline area was 2534 km^2, 3049 km^2 and 3970 km^2 for the first, second and third scenarios separately, when comprising the top 50% of occurrence locations.

By the strategy in scenario III, which was selected as the most effective method because of the consideration of habitat connectivity, the appropriate area of the panda habitat redline was generated for conservation in current conservation practice, and it showed a population conservation proportion of 85% in the whole area, which could be a threshold to differentiate the redline area and non-redline area. With this proportion, the redline area is 9358 km^2 (Fig. 4(a)), while the proportion of the population under conservation is above 80% in all mountain regions (Fig. 4(b)).

3.3. Overlap between panda conservation redline and nature reserves

The proposed panda habitat conservation redline was overlapped with the current areal distribution of nature reserves. By the end of 2015, 67 nature reserves were established in the study area. Among them, 49 overlapped with the redline areas (Fig. 5). Within the redline area, there were 5585 km^2 (60% of the redline area) of panda habitat inside the nature reserves, which accounted for 17% of the entire area of the nature reserves. However, there was a large proportion (40%) of redline area outside the nature reserves.

Some nature reserves have a large redline area. Eighteen reserves (e.g. Wolong, Xuebaoding, Baishuijiang, Foping, Baiyang), have the redline area above 100 km^2. Wolong nature reserve has the largest redline area among all reserves, reaching more than 10% of the entire redline area. In addition, the ratio of the redline area in the nature reserve area is large for some reserves. For instance, the redline in nine reserves (Foping, Huangboyuan, Anzihe, Changqing, Xiaohegou, Xiaozhaizigou, Laoxiancheng, Fengtongzhai and Heizhugou) comprised more than 60% of the nature reserve areas.

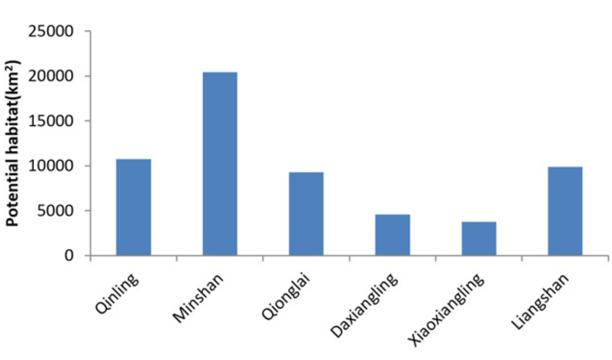

Fig. 2. Area of potential habitat in each of the six mountains comprising the panda geographic range.

Table 3
Redline area in the six mountains in scenario II (km^2).

Proportion of occurrences	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Daxiangling	9	17	33	50	77	111	138	199	251	307
Xiaoxiangling	9	9	18	21	30	45	62	75	93	146
Liangshan	25	78	137	206	269	365	477	609	778	1053
Minshan	159	376	604	891	1221	1592	2016	2540	3252	4649
Qinling	56	133	221	313	417	547	702	936	1250	2152
Qionglai	117	295	509	759	1035	1357	1712	2161	2676	3643

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Table 4
Number of redline patches in scenario II and scenario III.

Occurrence proportion	Scenario II	Scenario III
10%	35	19
20%	73	25
30%	86	19
40%	92	18
50%	92	16
60%	91	18
70%	82	22
80%	72	26
90%	81	30
100%	110	26

4. Discussion

In this study, we proposed an approach to map the species conservation redline areas using the endangered giant panda as a case. We established three scenarios for delineating the redline and chose a strategy that included habitat connectivity as the best strategy. Our approach comprehensively considered the degree of habitat utilization in the six mountains, the connectivity of the isolated populations and reached good population conservation proportion. When the redline area was overlapped with the boundaries of current nature reserves we not only showed the correspondence between redline and the current nature reserve system but also its conservation gaps.

This study attempted to design the method of delineating the species conservation redlines. There are several issues that could be further studied. Firstly, while the procedure described here is useful, it did not consider the impact of human activities on panda habitat utilization. During the procedure in detailed planning and implementation in local level (e.g. county level), it is necessary to identify the major human activities and consider the impact within the redline area. Secondly, we set ten different levels of the redline to analyze the redline with various conservation proportions, to show the overall layout of the redline, perhaps finer divisions of the levels could be made for detailed conservation planning. Thirdly, among the redlines with different conservation rates, how to choose the optimal redline layout to maintain the populations' long-termed survival should be further studied. Finally, it should be noted that redline areas are dynamic. Therefore, they should be adjusted through time in response to changes in the geographic ranges of species, particularly under different global change scenarios.

Redline area management constitutes an important component of biodiversity conservation. First of all, it is important to establish specific management regulations within redline areas approved by the legislature

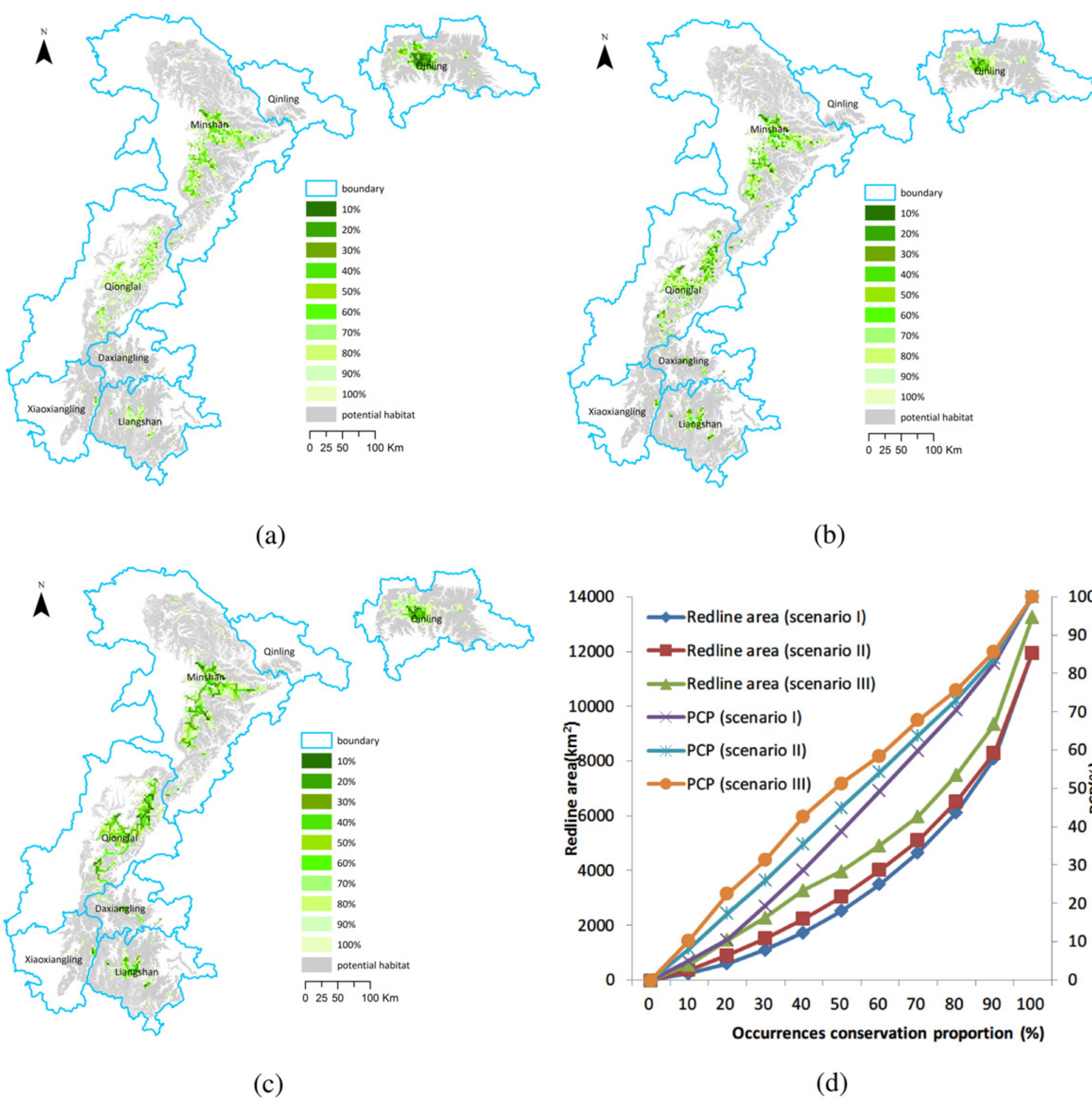

Fig. 3. (a) Redline in scenario I; (b) redline in scenario II; (c) redline in scenario III; (d) comparison of the three scenarios (PCP: proportion of the population under conservation).

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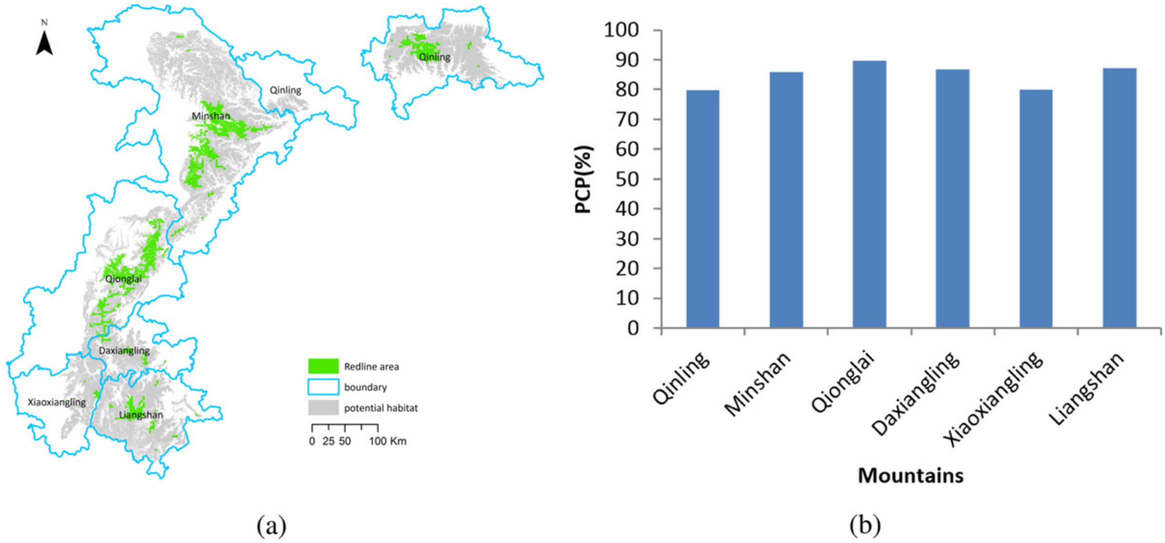

Fig. 4. (a) Panda habitat conservation redline; (b) PCP (population conservation proportion) in the six mountains by the redline.

since the redline only constitutes a management unit. Second, management activities in both nature reserves and redline areas outside them should be coordinated. For those redline areas inside nature reserves, areas covering high density of panda occurrences should be included into core zones. Reserves should also be established or expanded to cover more redline areas outside the current nature reserves. Strict management measures (such as the bans on urbanization and industrialization) should be taken to lessen the human impacts. And third, management measures need to be differential, according to the different types and extents of human disturbances.

Although the redline areas covering high density panda population should be strictly protected, this does not mean that the habitat located in areas with smaller panda populations or less panda occurrences is less important. Areas with smaller populations that are isolated from other populations should also receive attention, to reduce local extinctions. Thus, measures involving habitat restoration and reduction of

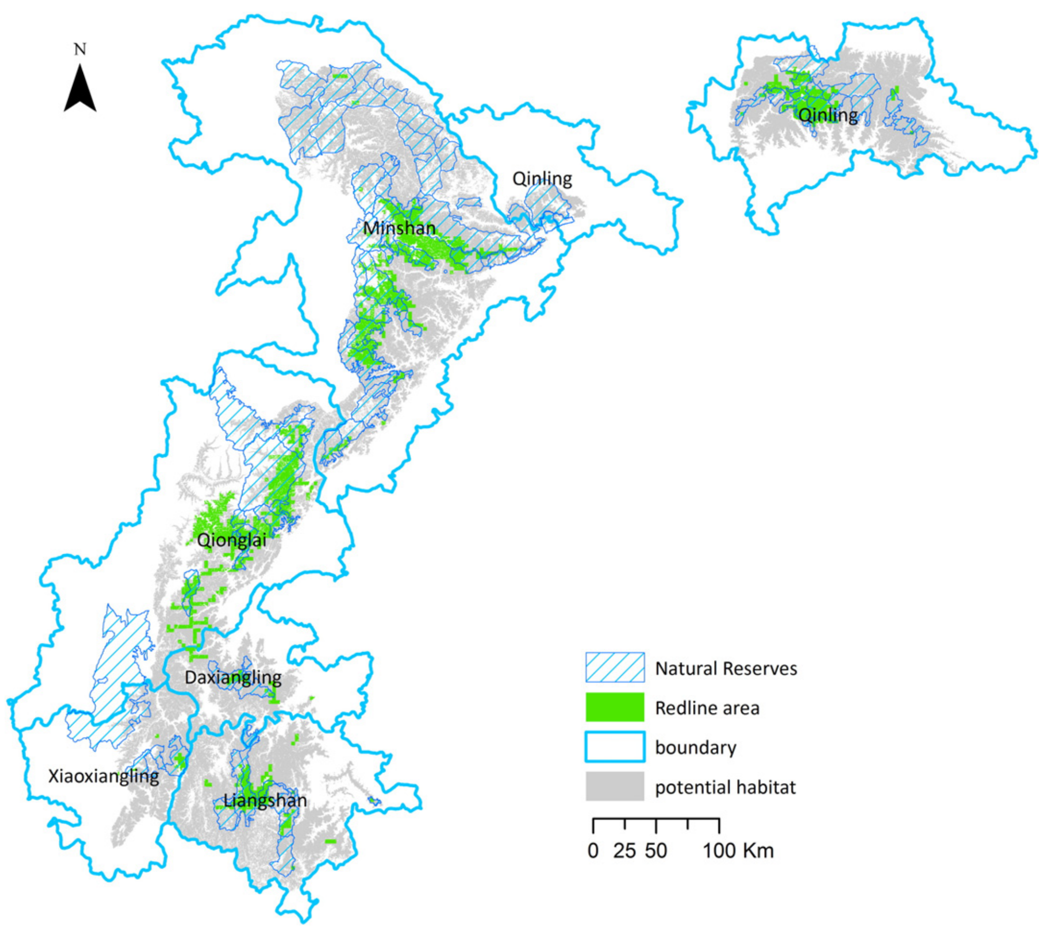

Fig. 5. Redline distribution within nature reserves.

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human impacts should also be taken into consideration, in order to increase the connectivity of these areas to other locations with higher panda populations.

There are many other kinds of endangered species living within the panda distribution area (State Forestry Administration, 2006; Xu et al., 2014). Thus, the study of habitat conservation redline for the giant panda is helpful not only for protecting this endangered species but also many other endangered species. Due to its general applicability the approach provided here can also be implemented for the identification of redline areas for other species not only in China but also around the world.

Acknowledgment

This research was supported by the Giant Panda Conservation Center of the State Forestry Administration of China (CM1417) and the National Natural Science Foundation of China (40901289). We thank State Forestry Bureau Survey Scheme Designing Institute for provision of panda survey data. We also acknowledge Andrés Viña for constructive suggestions to the manuscript.

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