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Giant panda habitat networks and conservation: is this species adequately protected?

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Abstract

Context. Giant pandas (*Ailuropoda melanoleuca*) are restricted to six mountain ranges at the edge of the Tibetan Plateau. One of these ranges, the Qinling Mountains, contains the highest density of giant pandas and is home to ~20% of those remaining in the wild. Commercial logging and other developments have resulted in habitat fragmentation, and an efficient and powerful conservation network is now needed for the species in this area.

Aims. This study sought to assess giant panda habitat and estimate the carrying capacity of this reserve network. Our goal was to improve the function and carrying capacity of the reserve network and facilitate population growth and gene flow among subpopulations of giant pandas.

Methods. We use habitat suitability models to assess the efficacy of conservation networks. With estimation of carrying capacity by home range, we can reveal issues facing reserves and populations of endangered species they contain. Here, we define key habitat, linkages, corridors and overall connectivity and then use habitat network modelling and spatial analyses to design a conservation landscape for giant pandas across their Qinling Mountains stronghold.

Key results. We found that 91% of giant panda sightings were in suitable or marginally suitable habitat. The total area of giant panda habitat present in the Qinling Mountains is ~1600 km^2 fragmented across four key habitat blocks by national roads or other human activity. The current nature reserve network encompasses 71% of available suitable habitat and 62% of available marginal habitat, meaning a significant proportion of panda habitat remains outside the current conservation network. We found that giant panda reserves across this region are not equal in their carrying capacity; some reserves contain an overabundance of giant pandas and the wellbeing of these populations are in doubt.

Conclusions. Our results highlight the potential risk of high densities and bamboo flowering events to the safety of giant pandas. With poor population size and heavy isolation, small populations will not persist without translocation.

Implication. Redrawing the reserve network to correct localised problems may improve the function of the giant panda protection system, build capacity in the reserve network, and decrease human–wildlife conflict. We propose a new reserve and adjustment of the borders and region for three reserves.

Additional keywords: carrying capacity, giant panda, habitat suitability, reserve network.

Introduction

Giant pandas (*Ailuropoda melanoleuca*) were once found throughout the lowland forests of eastern and southern China, northern Vietnam, and northern Myanmar (Pan and Lü 2001). Commercial logging and developments in agriculture, infrastructure and hydropower across this region have resulted in gradual fragmentation and degradation of core giant panda habitat (Loucks *et al*. 2003). This species is now restricted to six mountain ranges (Qinling, Minshan, Qionglaishan, greater Xiangling, smaller Xiangling, Liangshan) at the edge of the Tibetan Plateau (State Forestry Administration 2006). The population consists of 24 subpopulations separated by mountain ranges, rivers, roads, forest clearings and human settlements (Loucks *et al*. 2001). Some populations comprise fewer than 20 animals, making them demographically and genetically vulnerable (Pan and Lü 2001; State Forestry Administration 2006; Yang *et al*. 2007). Current legislation prohibits activities such as logging, mining and road construction, but livestock grazing, the collection of materials for Chinese medicine and tourism continue to take place within reserves (State Forestry Administration 2006). As a consequence, habitat fragmentation has been identified as a significant threat to the survival of this species (Loucks *et al*. 2003; Ran *et al*. 2009).

The primary mechanism driving *ex situ* giant panda conservation is increasing the amount of land under government protection. There are now 59 reserves established

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for giant pandas encompassing 71% of remaining habitat and 54% of animals remaining in the wild. As China continues to reform social and economic systems, this system of reserves is facing challenges from modernisation, changes to conservation mechanisms and development (He *et al*. 2007). Loucks *et al.* (2003) conducted a habitat analysis directed at establishing linkage areas to facilitate dispersal and form a giant panda conservation unit through the extension of existing reserves and creation of new reserves in unprotected areas at the landscape scale. These have largely been adopted by the Chinese government in recent years (State Forestry Administration 2006). Given the risk that current protected areas may become too small to maintain viable populations, a new approach to giant panda conservation planning based on large-scale temporal and spatial habitat requirements is required (Shen *et al*. 2008). Habitat network analysis can be an effective tool in vertebrate conservation (Rowland and Wisdom 2009). These networks consist of spatially explicit portrayals of environmental conditions across a large area and can be used to understand wildlife status and trends. A habitat network methodology is underpinned by an understanding of how the needs of species can be met through management of habitat abundance and distribution (Rowland and Wisdom 2009). This approach is well suited to giant panda management because of the large area, widespread human population, number of administrative boundaries and continuing reforms to collective forest tenure in China (Su *et al*. 2007; Xu *et al*. 2010). Xu *et al.* (2006) used the approach to identify five key areas and four linkage areas and designed a conservation unit for giant pandas in the Qionglai Mountains. These approaches facilitate the exchange of animals among previously isolated habitat blocks and improve giant panda survival. Here, we apply habitat suitability and habitat network modelling to assess giant panda habitat and to assess the current conservation network of giant pandas across their stronghold in the Qinling Mountains (Rolof and Kernohan 1999; Wikramanayake *et al*. 2004). This mountain range consists of several reserves and is home to 20% of wild giant pandas (State Forestry Administration 2006). By using overall habitat suitability and the carrying capacity for 13 giant panda reserves along this mountain range, we hoped to identify crucial areas for giant panda conservation and suggest readjustments to the current reserve network in the Qinling Mountains. Our goals are to improve the function and carrying capacity of the reserve network and facilitate population growth and gene flow among subpopulations. By illustrating this approach here, we hope our approach can later be applied across the entire distribution of giant pandas.

Materials and methods

Study area

We conducted this study in the Qingling Mountains (33°18′–34°00′N, 107°11′–108°47′E) (Fig. 1). The mountains cover an area of 5700 km^2, are located at a transitional zone between northern subtropical and warm temperate zones, form a watershed between the Yangtze and Yellow Rivers, and are a source of several lesser tributaries. This region is characterised by steep high-altitude slopes (Taibai Mountain peaks at 3767 m above sea level) and narrow catchments in the north, and gentle low-altitude slopes and broad open catchments in the south. Average annual precipitation is 900 mm. Vegetation is characterised by deciduous broadleaf forest, mixed coniferous broadleaf forest, coniferous forest, coniferous shrubs and meadows (Ren 2007). Three major roads dissect the range (National Roads 108 and 210 and Xihan highway). The Qinling Mountains contain 13 giant panda nature reserves that cover an area of 3652 km^2.

Spatial data

The entire mountain range was chosen as the reference area and modelled as a raster map based on WGS 84 UTM (30 × 30 m). We used seven ecogeographical variables derived from government databases. Digital elevation models can yield a variety of landscape morphological characteristics important to wildlife, such as elevation, slope and aspect (Jenness 2007). Using 1 : 50 000 topographic maps (National Fundamental Geographic Information Centre, Beijing, China) we created a digital elevation model for panda-inhabited areas across the Qinling Mountains and derived key data on elevation, slope and aspect. We ascertained five predominant land cover types (forest, shrubs, meadow, farmland and other) using a 1 : 100 000 National Land Cover Map produced (Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences, Beijing, China). Spatial data relating to giant pandas such as the extent of areas known to contain giant pandas, subpopulation boundaries, the distribution of bamboo, and sites where pandas have been found were obtained from the third national survey of giant pandas. This survey was conducted by China's State Forestry Administration and the World Wildlife Fund for Nature (WWF), completed in late 2001, and later published (State Forestry Administration 2006; Sun 2007). Data on roads and human settlements were provided by the Shanxi Province Wildlife Management Station.

Variables and mapping

From what we know about habitat selection by giant pandas in the Qinling Mountains, forest type is one of the main biotic factors when assessing habitat suitability (Ran *et al*. 2004; Liu *et al*. 2005). More than 90% of giant pandas in the Qingling Mountains are found in forests and less than 10% in shrubbery; no pandas have been found in other land cover types (State Forestry Administration 2006). Therefore, suitable habitat for giant pandas should consist of forests, marginally suitable habitat would be shrubs, and farmlands and meadows would be unsuitable habitat (Xu *et al*. 2006) (Table 1). Here we included primary forests and secondary forests across the distribution range of the giant panda (Ouyang *et al*. 2001; Pan and Lü 2001; Ran *et al*. 2004; Liu *et al*. 2005). The distribution of bamboo is another important biotic factor impacting upon the suitability of habitat (Schaller *et al*. 1985; Linderman *et al*. 2005) and areas devoid of bamboo were also marked as unsuitable. Slope and elevation are major habitat abiotic factors (Table 1). To conserve energy, giant pandas prefer flat areas or areas with gentle slopes (Hu 2001) and do not tolerate the low temperatures, inadequate resources and poor vegetation of extremely high elevations (Liu *et al*. 1999). On the basis of the above information, we classified habitat as suitable, marginal or unsuitable using vegetation, bamboo and elevation data (Table 1).

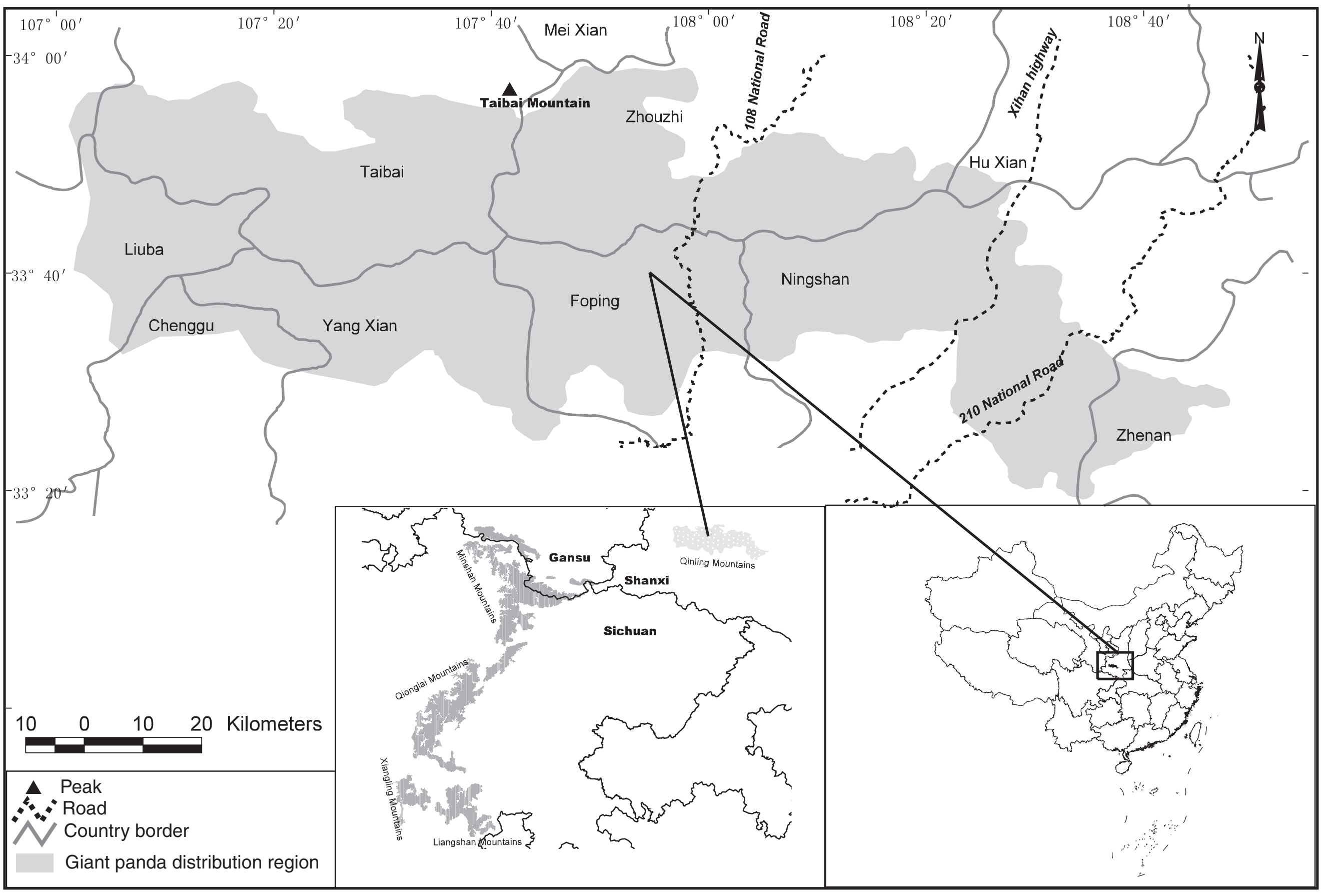

Fig. 1. Current distribution of giant pandas and the Qingling Mountains.

Table 1. Assessment of biotic and abiotic factors used to determine habitat suitability

Factor	Degree of habitat suitability		
	Suitable	Marginally suitable	Unsuitable
Vegetation	Forests	Shrubs	Other cover (excluding forests and shrubs)
Bamboo	Bamboo	–	Absence of bamboo
Elevation (m)	>1500–3100	1350–1500	<1350, >3100
Slope (°)	<30	30–45	>45

Table 2. Effect of human factors on giant panda habitat

Factor	Degree of effect			
	Strong	Moderate	Weak	None
Distance to major road (m)	60	60–210	210–720	>720
Distance to minor road (m)	n.a.	n.a.	30	>30
Distance to human settlements (m)	900	900–1410	1410–1920	>1920

Human-related factors are the primary drivers of change in forests (Liu *et al*. 1999). Roads and human settlements directly disturb giant pandas and also facilitate further disturbance through greater access to their habitat. Roads and human settlements are ubiquitous features of most landscapes throughout the distribution of giant pandas and the influence of these factors on giant pandas is well known (Pan and Lü 2001). According to Ouyang *et al*. (2001) and Xu *et al*. (2006), the influence of these landscape features on giant pandas weakens with proximity, so we classified the effect of these parameters accordingly (Table 2).

A combination of habitat and human landscape features was used to determine overall giant panda habitat according to three categories (suitable, marginal, and unsuitable) following the conceptual framework of Liu *et al*. (1999) and Store and Kangas (2001). Our assessment also followed the protocols suggested by Xu *et al*. (2006). Combining panda distribution sites from the most recent survey of giant panda (State Forestry Administration 2006) and from monitoring programs on fixed-transect samples (State Forestry Administration of China; WWF) we compiled a distribution map containing every giant panda location and a buffer for average daily movement (411 m: Pan and Lü 2001). Our giant panda distribution map was used to evaluate accuracy of the habitat suitability map.

Selection of key habitat and linkage areas

Once suitable and marginal habitat has been identified, key habitat areas and linkage areas can then be analysed. Here, key habitat areas are those areas containing a large area of suitable habitat with no or little human disturbance and that could be included in future conservation decisions (Xu *et al*. 2006). Linkage areas were defined as areas composed of suitable habitat or marginally suitable habitat, where location can facilitate population exchange and genetic flow between key areas (Hargrove *et al*. 2004). Following this criterion, linkage areas in Qinling Mountains should have an elevation of 1500–3100 m above sea level, a slope of <30°, cover a distance less than 3.6 km between two pockets of key habitat area (the diameter of giant panda home range: Pan and Lü 2001), and have low levels of human disturbance.

Assessment of current conservation and reserve network

Assessing the security and adequacy of protection measures is important to the long-term survival of giant pandas. One method is to evaluate carrying capacity at regional and reserve scales (Sun 2001). Though patches of suitable habitat are different in size and shape, we assumed that habitat quality was uniform. Further, for convenience when assessing the reserve network we omitted differences in quality between suitable and marginal habitat. Although giant pandas are territorial animals and have an average home range in the Qinling Mountains of 10.62 km^2, their ranges overlap ~36%, based on data from two animals (Jiaojiao overlapped with fourteen individuals and Huzi overlapped with nine individuals) (Pan and Lü 2001). Thus, we adjusted the average home range to 8.69 km^2 and using this value we were able to calculate the theoretical carrying capacity of each reserve as:

$$K = A_R / A_H$$

where K represents the carrying capacity of suitable habitat of a given reserve, A_R is the size of suitable habitat within the reserve, and A_H is the average home range of giant pandas (8.69 km^2). We also calculated the theoretical carrying capacity of marginally suitable habitat for each reserve, as well as the carrying capacity of each reserve based on its total size using the above equation.

Results

The Qinling Mountains contain 1600.57 km^2 of giant panda habitat, comprising 473.73 km^2 of suitable habitat and 1126.84 km^2 of marginally suitable habitat (Fig. 2, Table 3). This habitat is not continuous and is divided across four blocks by national roads (G108, G210 and Xihan expressway) and human activity taking place in the Xushui River valley. We named these four key habitat areas Niuweihe (NW), Xinglongling-Taibaishan (XT), Tianhuashan-Jinjiliang (TJ) and Pingheliang (PH) and herein will refer to them by acronym to improve readability. XT was the largest area and contained the most suitable habitat (Table 4; Fig. 2).

Most (91.25%) giant panda sightings occurred in suitable or marginally suitable habitat (Fig. 2) and this validates the precision of our selection of habitat factors and habitat calculation. Subpopulations contained within each of the four blocks were 29 giant pandas in NW, 219 in XT, 18 in TJ, and 5 in PH. We identified two areas as possible linkages (Fig. 2): the first is located around the upper reaches of the Xushui River between NW and XT at 2000 m above sea level; the second linkage is located at the centre of Qinling between XT and TJ and includes

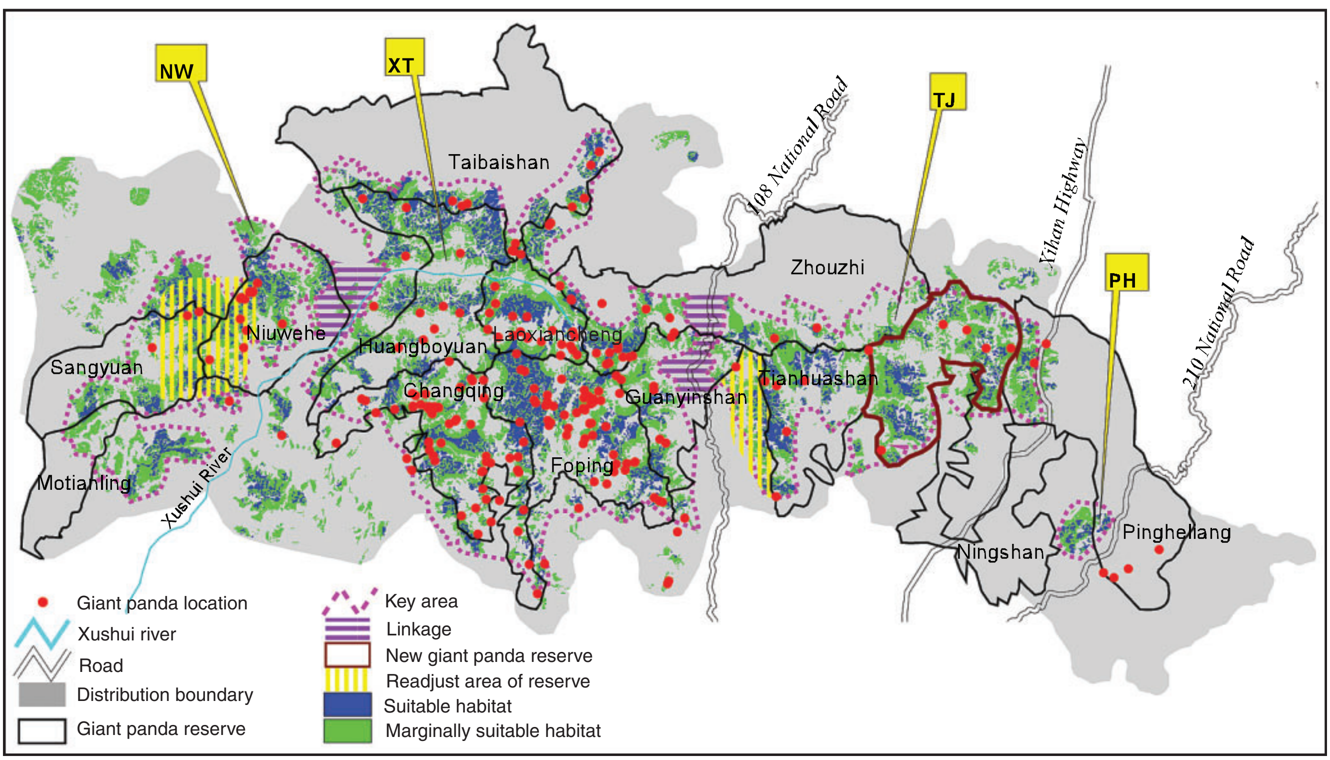

Fig. 2. Key habitat areas, linkage and proposed adjustments to the reserve network.

Table 3. Distribution of giant panda habitat across the Qinling Mountains

Habitat type	Inside nature reserve		Outside nature reserve	
	Area (km^2)	Ratio to total habitat area (%)	Area (km^2)	Ratio to total habitat area (%)
Suitable	337.11	71.16	136.62	28.84
Marginally suitable	696.25	61.79	430.59	38.21
Unsuitable	2567.54	48.14	2766.11	51.86

a section of the closed national road G108 (Fig. 2). Elevation in the area is 2000–3000 m above sea level and vegetation is dominated by conifer and broadleaf forests.

The current nature reserve network encompasses 71% of the total suitable habitat and 62% of the total marginally suitable habitat available across the Qinling Mountains. Although the reserve network appears comprehensive, ~35% of suitable or marginal habitat remains outside the conservation network. We also found that ~12% of giant pandas found across the Qinling Mountains (32 of 271 animals) inhabit areas outside the current system (Fig. 2).

Our assessment of the quality of the reserves revealed that they are unequal in their potential to sustain giant pandas and contained varying levels of suitable and marginally suitable habitat. Some reserves contain sufficient suitable habitat and others comprise poor habitat and only few giant pandas (Table 5). For example, the theoretical carrying capacity of Foping Reserve is 34 animals and only 18 animals when actual habitat is included; however, 76 giant pandas are known to inhabit this reserve. On the basis of our analyses, the number of pandas in the XT block is higher than its theoretical carrying capacity. This pattern was strongest for the XT reserves Foping, Changqing and Laoxiancheng (Table 5). We also found that giant pandas in the habitat-poor south-eastern section of Pingheliang Nature Reserve are an isolated population of five animals located at least 30 km from other habitat patches (Fig. 2).

Discussion

Our findings reveal that giant pandas inhabiting the Qinling Mountains actually comprise four subpopulations occupying distinct patches of habitat created by roads and other human activity. Early reserves in the Qinling Mountains were predominantly established in the XT block and reserves such as Taibaishan, Foping, Zhouzhi, Laoxiancheng and Changqing have been in place since 1978. The creation of other reserves has followed since initiation of the Natural Forest Conservation Program in 2000. It appears that National Roads 108, 210 and the Xihan expressway are major barriers to giant pandas, and associated forest clearing has further fragmented sections of habitat to the east (e.g. XT and TJ) (Sun 2007). Human settlements and agriculture have also contributed to this divide, and deepened the separation between XT and NW along the Xushui River Valley.

Table 4. Habitat group properties

Habitat patches	Suitable habitat		Marginal habitat		Unsuitable habitat		Carrying capacity of key habitat area	Present number of pandas
	Area (km^2)	Ratio to habitat (%)	Area (km^2)	Ratio to habitat (%)	Area (km^2)	Ratio to habitat (%)		
NW	81.35	2.78	211.88	7.24	209.02	7.14	58	29
XT	269.61	9.21	495.04	16.91	815.13	27.85	182	219
TJ	91.74	3.13	245.45	8.39	334.7	11.43	77	18
PH	6.54	0.22	11.2	0.38	155.576	5.31	20	5

Table 5. Habitat properties of reserves and their theoretical carrying capacities across the Qinling Mountains
SH, suitable habitat; MSH, marginally suitable habitat

Reserve name	Suitable habitat (km^2)	Suitable habitat (%)	Marginally habitat (km^2)	Marginally habitat (%)	Unsuitable habitat (km^2)	Unsuitable habitat (%)	Carrying capacity of reserve's SH	Carrying capacity of reserve's MSH	Carrying capacity of reserve	Current number of pandas
Motianling	0.16	0.14	12.21	11.04	98.24	88.82	0	1	13	2
Ninshan	0.74	0.31	7.91	3.33	229.18	96.36	0	1	27	1
Pingheliang	7.23	1.87	29.96	7.75	349.52	90.38	1	3	45	5
Zhouzhi	24.02	4.58	78.16	14.91	421.9	80.5	3	9	60	21
Taibaishan	28.48	5.1	34.11	6.11	495.37	88.78	3	4	64	11
Guanyinshan	10.57	6.37	47.74	28.76	107.67	64.87	1	5	19	8
Sangyuan	19.54	8.8	60.45	27.22	142.06	63.98	2	7	26	3
Niuwehe	28.36	12.61	65.07	28.93	131.47	58.46	3	7	26	18
Changqing	41.08	13.66	90.91	30.23	168.75	56.11	5	10	35	52
Tianhuashan	30.37	15.33	44.78	22.61	122.9	62.06	3	5	23	5
Huangboyuan	55.85	18.27	90.37	29.57	159.4	52.16	6	10	35	9
Laoxiancheng	24.82	19.78	49.32	39.31	51.34	40.92	3	6	14	28
Foping	65.89	22.54	85.26	29.17	141.12	48.28	8	10	34	76

Our results are similar to those of Loucks *et al*. (2003) as both studies found that the area along Qinling ridge is the most suitable habitat for giant pandas. However, different methods and habitat variables were used. We combined measures of vegetation, bamboo, elevation and disturbance and calculated habitat suitability, while Loucks *et al*. (2003) identified potential habitat as natural forests and bamboo at high elevation. Consequently, there are some differences in the results. For example, a significant gap in habitat along the upper reaches of the Xushui River was found by Loucks *et al*. (2003), but we located connecting habitat of value in this area (Fig. 2). Loucks *et al*. (2003) also separated habitat as core habitat and secondary habitat according to bamboo species and the number of giant pandas, whereas we classified habitat on the basis of overall habitat variables, which included not only forest, bamboo and elevation, but also human disturbance. As a result, the linkage areas identified and recommended by Loucks *et al*. (2003) and the present study are different. The location of linkage between NW and XT in our study is further to the north-east than was recommended by Loucks *et al*. (2003).

The carrying capacity of landscapes preferred by giant pandas is an important factor restricting giant panda population growth and sustainability (Zhou and Pan 1997). Though we did not take differences in habitat quality between suitable habitat and marginally suitable habitat into account, our assessment of the carrying capacity for 13 reserves found that the number of giant pandas exceeded the theoretical carrying capacity for several reserves and for specific habitat within reserves. For example, our assessment of the theoretical carrying capacity of Foping, Laoxiancheng and Changqing nature reserves within the XT habitat block is below the number of giant pandas currently supported (Table 5). The current population size of Foping Reserve is more than double its theoretical carrying capacity, and the population density of pandas inhabiting the reserve has been relatively stable since records began in 1974 (Yong and Zhang 1993; Pan and Lü 2001; State Forestry Administration 2006). Despite what appears to be a stable number of animals, incidents such as death, injury and illness of giant pandas are frequent, and brown giant pandas have began appearing in the reserve (Liang and Wang 1991; Yong and Zhang 1993; Henry 2010). These factors have likely restrained growth in the number of animals in this reserve and resulted in a stable population density. High population densities can lead to increased competition, stress and disease epidemics (Van Dyke 2008). A high density of giant pandas may also explain the prevalence of giant pandas entering local villages and the increasing poor health or death of giant pandas in Changqing and Laoxiancheng reserves (Sohu 2006*b*, 2008, 2009; WWF China 2007; China Net 2009; Henry 2010).

In the Qinling Mountains giant pandas mainly feed on two bamboo species, *Bashania fargesii* and *Fargesia qinlinggensis*, the former distributed across winter habitat, the latter in summer habitat. A high population density also poses a risk to food resource continuity as some of these reserves contain only one species of bamboo and provide no alternative food source, such as during flowering events (Ren 2007). The habitat pattern of giant pandas revealed by our study indicates a strong relationship with the distribution of bamboo. Bamboo is largely absent between key habitat in TJ and PH (Fig. 2; State Forestry Administration 2006). Bamboo reforestation should take place in this area to improve the size of the suitable or marginally suitable habitat, and to increase carrying capacity. As a consequence, monitoring programs in XT should be streamlined and contingency plans established in order to cope with bamboo flowering events and potential disease epidemics.

Habitat connectivity is essential as it permits ecological flow and recolonisation while ensuring the persistence of wildlife (Matisziw and Murray 2009). Our results indicate that the current population size within XT exceeds its theoretical carrying capacity (Table 4). A simple remedy would be to create corridors to ensure habitat connectivity and allow dispersal from XT to NW and TJ (Fig. 2). XT and NW are only 3 km apart in some areas (Fig. 2) and reforestation and controls around agriculture would easily transform a linkage zone into usable habitat for giant pandas. Once a corridor is established giant pandas will use previously hostile areas. For example, XT and TJ were previously separated by National Road 108 but after a section was closed in 2002 giant panda tracks and scats appeared (Sohu 2006*a*).

When the connection of habitat blocks is not feasible, the translocation of animals is often necessary (Pullin 2002). Translocations can increase the number of animals in a population or increase the size, genetic diversity, demographic balance, and chance of survival of small populations (Pullin 2002). According to previous results using population viability analysis (Wang *et al*. 2002; Yang *et al*. 2007), the giant panda population in the south-eastern section of Pingheliang reserve will not persist because the population size is five animals and 30 km from the nearest population in TJ. The area of PH that is suitable and marginally suitable is just 17.74 ha (Table 4) and, theoretically, cannot support more than three giant pandas. Reintroduction of giant pandas would not increase the chances of this population persisting. Translocation of giant pandas from PH to reserves supporting populations below carrying capacity such as Huangboyuan and Tianhuashan reserve may be the only method available in this part of the Qinling Mountains.

Our habitat network analysis across an endangered species' stronghold has revealed deficiencies in the reserve system. Our results suggest that the current reserve system could benefit substantially from the inclusion of additional areas of suitable habitat and restoration of currently isolated habitat. Some reserves possess little suitable habitat and just one or two giant pandas whereas others contain many more pandas than predicted by the distribution of habitat alone (Table 5). This situation has arisen because reserves have historically been established following administrative boundaries and not according to giant panda habitat requirements. Redrawing the reserve network to correct localised problems may improve the function of the giant panda protection system, build capacity in the reserve network, and decrease human–wildlife conflict. In conclusion, we propose that (1) a new reserve (named Jinjiliang Reserve here) be established in the north-east of the Qingling Mountains, (2) Niuweihe reserve and Sangyuan should be connected to increase suitable habitat and genetic exchange, and (3) Tianhuashan reserve should be expanded to cover suitable habitat to the west (Fig. 2). Our findings more broadly show that landscape-wide studies of metapopulations of endangered species can reveal novel information regarding population processes, and determine weaknesses in current networks. For the future safety of giant pandas, we suggest conducting landscape-wide studies across their entire range.

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