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The next widespread bamboo flowering poses a massive risk to the giant panda

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ABSTRACT

The IUCN Red List has downgraded several species from “endangered” to “vulnerable” that still have largely unknown extinction risks. We consider one of those downgraded species, the giant panda, a bamboo specialist. Massive bamboo flowering could be a natural disaster for giant pandas. Using scenario analysis, we explored possible impacts of the next bamboo flowering in the Qinling and Minshan Mountains that are home to most giant pandas. Our results showed that the Qinling Mountains could experience large-scale bamboo flowering leading to a high risk of widespread food shortages for the giant pandas by 2020. The Minshan Mountains could similarly experience a large-scale bamboo flowering with a high risk for giant pandas between 2020 and 2030 without suitable alternative habitat in the surrounding areas. These scenarios highlight thus-far unforeseen dangers of conserving giant pandas in a fragmented habitat. We recommend advance measures to protect giant panda from severe population crashes when flowering happens. This study also suggests the need to anticipate and manage long-term risks to other downgraded species.

1. Introduction

Giant pandas (*Ailuropoda melanoleuca*), the globe's most beloved conservation icon as well as the symbol of the World Wide Fund for Nature (WWF), are only found in China's Sichuan, Shaanxi and Gansu provinces. According to the Fourth National Giant Panda Survey (the fourth survey) conducted by the Chinese government in 2011–2014, there were 1864 giant pandas in the wild (China's State Forestry Administration, 2015). The number of wild giant pandas has increased by 17% since the Third National Giant Panda Survey (the third survey) conducted in 1999–2003 (China's State Forestry Administration, 2006). This increase led to the downgrading of the giant panda from “endangered” to “vulnerable” on the International Union for Conservation of Nature (IUCN) Red List in 2016. Indeed, some threats such as logging stopped in late 1999 (Xu et al., 2017) and much more of the species range is now protected. However, what risks giant pandas will

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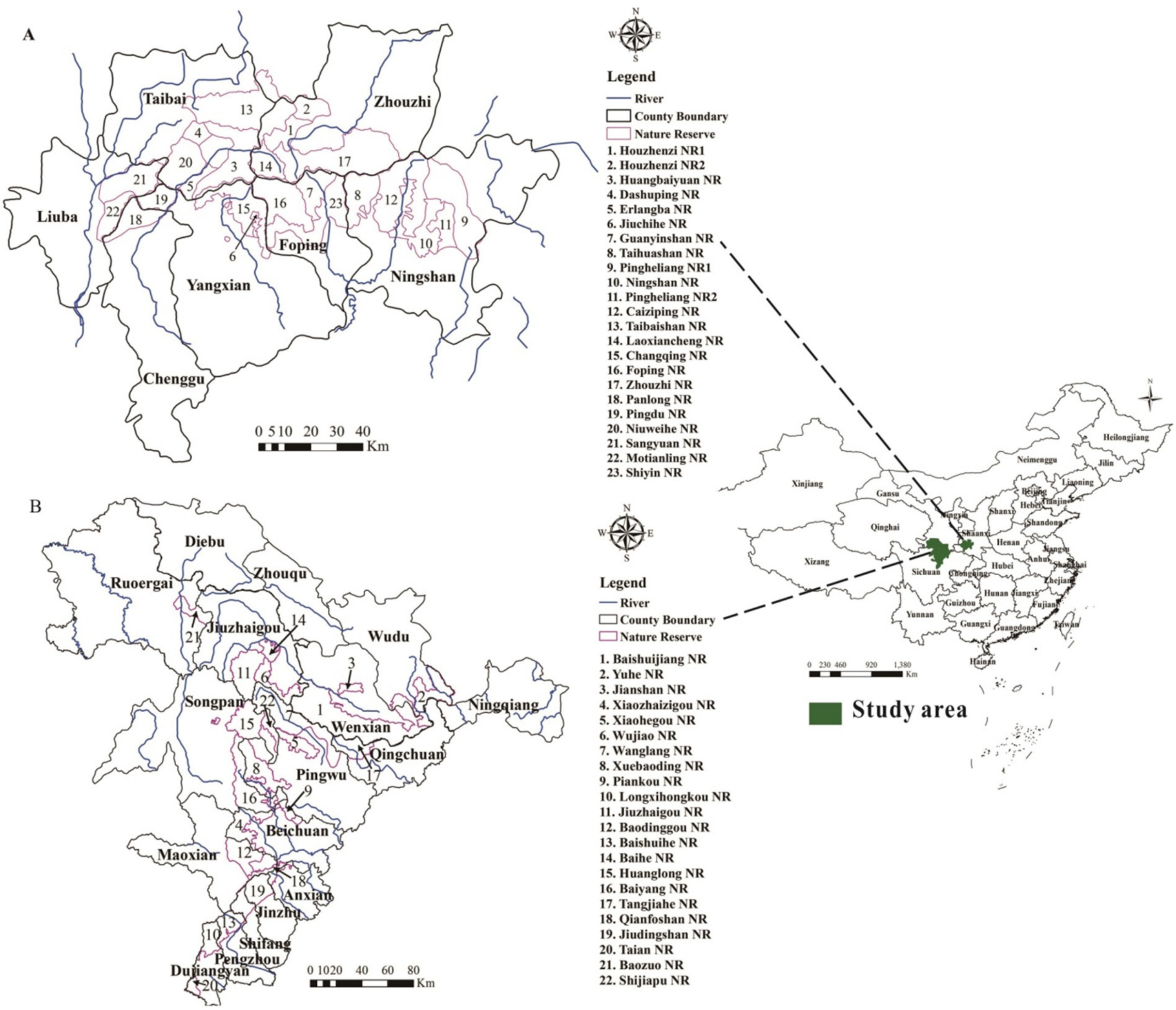

Fig. 1. Study area in China. The Qinling Mountains with 23 nature reserves (A) and the Minshan Mountains with 22 nature reserves (B).

encounter after the delisting remain unclear.

Human activities like farming, deforestation, or other development, have driven the giant panda out of the lowland areas where it once lived (Pan et al., 2014; Wei et al., 2015; Yang et al., 2017). It now lives only in six mountains, i.e. the Minshan, Qionglai, Liangshan, Daxiangling, Xiaoxiangling Mountains, and the southern slope of the Qinling Mountains. The giant panda habitat is becoming more fragmented and their populations becoming more isolated (Li et al., 2015; Xu et al., 2017), with the smaller ones having high risk of local extinction (Shen et al., 2015). Despite comprehensive conservation efforts over the last few decades, threats to the giant panda remain. For example, human activities degraded the Wolong Nature Reserve (Liu et al., 2001). The Daxiangling Mountains have been fragmented by exploitation of forest, mining, traffic, and agriculture (Xu, 2006). Grazing has degraded Wanglang Nature Reserve (Li et al., 2017) and giant pandas were trapped in snares poachers set for musk deer (Schaller, 1987). Besides land-use change and fragmentation, climate change will also likely affect giant pandas through habitat degradation and a predicted substantial reduction of three dominant bamboo species in the Qinling Mountains during the 21st century (Tuanmu et al., 2013). As with other ecosystems, direct human activities and climate change are the two factors that can limit the recovery of the giant panda population and constrain its future (Malhi et al., 2014). We ask: do features of the panda's ecology predispose it to be vulnerable to natural changes given its current circumstances? A study on bamboo is essential.

Giant pandas rely on bamboo for 99% of their diet. Bamboos are semelparous — they flower and then die, doing so infrequently but synchronously over large areas. Researchers have long explored the features of bamboo flowering and have established a series of theories including cyclicity of flowering periods, dynamic of bamboo nutrition, and responsiveness to drought (Ding, 2006; Peng et al., 2013). The giant panda has evolved behavioral, physiological, morphological, and genetic adaptations that enable them to survive on a bamboo diet (Nie et al., 2015). Bamboo recovery after episodic bamboo flowering events is a natural process but takes several years before it provides sufficient nutrition for giant pandas (Jeffrey, 1984). During field surveys, 13 dead giant pandas were found during the large-scale bamboo flowering event in Wanglang Nature Reserve in 1975 (Kang and Li, 2016). Between the 1970s and 1980s, there were two large-scale *Fargesia* bamboo flowering events in the Minshan and Qionglai Mountains in Sichuan province. Remains of 138 giant pandas were found in the following years (Hu, 1986). In Wolong Nature Reserve, 40–50% of the giant pandas may have died, and other individuals may have emigrated as the consequence of flowering during 1983–1985 (O'Brien and Knight, 1987). Suitable giant panda habitat must contain at least two bamboo species that allows giant pandas to migrate to another suitable patch if one bamboo species flowers (Schaller et al., 2012). Although dispersal has been the strategy evolved in response to widespread, simultaneous die-offs of bamboo, highly fragmented panda habitat and substantial barriers, including new roads, likely make their dispersal much more difficult.

The IUCN Red List has downgraded the risk for giant pandas after wild numbers improved over the last few decades. However, long-term risks for this species remain largely unquantified. In this study, we show the importance of quantifying risks after downgrading. Our objective is to propose spatially-explicit risk scenarios that will help managers identify the forces driving the system changes and the possible vulnerabilities, and develop better management strategies in anticipation.

2. Materials and methods

2.1. Study area

In this study, we focus on the Qinling and Minshan Mountains. The Qinling Mountains which run west to east across Shaanxi in central China with the highest peak in Taibai Mountain (3767 m above sea level) (Fig. 1A). The area comprises both mid-elevation and sub-alpine areas that experience temperatures and rainfall which are suitable for the growth of the bamboo species (Fan et al., 2014). There are 23 nature reserves in these mountains.

The Minshan Mountains span Sichuan and Gansu Provinces, in southwest China (Fig. 1B). This area has high mountains and deep valleys, with elevations between 496 and 5561 m (Wang et al., 2009). Our research considered 22 nature reserves in these mountains.

2.2. Giant panda population density

The Qinling Mountains are a stronghold for giant pandas and contain 18.5% of all wild giant pandas. They have the largest density — ca. 0.1/km^2, calculated from the report of the fourth survey. In addition, giant pandas in the Qinling Mountains live geographically and genetically isolated from other populations (Pan et al., 2001). The Minshan Mountains, have the largest population of giant pandas — accounting for 36% of 1864 in total based on the fourth survey report on giant pandas. The habitat of the central part of the Minshan is less fragmented, but is extensively fragmented in the north.

Based on signs of giant pandas from the fourth survey, we produced the giant panda density map in the Qinling and Minshan Mountains. Signs include sightings, droppings, hair, claw, and bamboo feeding signs. We calculated the sign density to indicate the panda density (Eq. 1). We divided the densities into six categories (Table S1).

$$D_p = \frac{N_p}{A_m} \tag{1}$$

where D_p is the sign density (represent the giant panda density in our research), N_p is the number of signs of the giant panda, A_m is the size of each area (km^2).

2.3. Dominant bamboo species

2.3.1. Distribution of dominant staple-food bamboo species for giant pandas

We obtained data on dominant staple-food bamboo distribution from the report of the third survey. (There is no difference of bamboo distribution between the third and fourth surveys). Fig. S1 gives the distribution of the dominant bamboo species in both mountains. There are four kinds of staple-food bamboo species in the Qinling Mountains: *Bashania fargesii*, *Fargesia qinlingensis*, *Fargesia dracocephala* and *Fargesia nitida* (Fig. S1A). Among them, *Bashania fargesii* has the largest areas covering 1814 km^2, accounting for 44% of the total areas, followed by the *Fargesia qinlingensis*, covering 1524 km^2 (37%). These two species are the main food sources for giant pandas in the Qinling Mountains, accounting for 81% of the total area. The distribution of *Fargesia dracocephala* and *Fargesia nitida* only accounted for 19% of the total area.

In the Minshan Mountains, there are 12 staple-food bamboo species for giant pandas (Fig. S1B): *Fargesia denudata*, *Fargesia nitida*, *Fargesia rufa*, *Fargesia obliqua*, *Yushania brevipaniculata*, *Fargesia scabrida*, *Fargesia dracocephala*, *Bashania fangiana*, *Fargesia robusta*, *Fargesia qinlingensis*, *Chimonobambusa szechuanensis* and *Bashania fargesii*. Among them, the first three largest distributions are *Fargesia denudata* (2510 km^2, accounting for 35% of the total areas), *Fargesia nitida* (1697 km^2, accounting for 24% of the total areas) and *Fargesia rufa* (1055 km^2, accounting for 14% of the total areas). The nine other bamboo species occupy the remaining 27% of the area.

2.3.2. Spatial flowering pattern

Using questionnaires, we surveyed 45 giant panda nature reserves in the Qinling and Minshan Mountains in 2014, since the data of the fourth survey were not available. The questionnaires were given to the experienced staffs in the nature reserves, who worked in the mountains for many years, and they mainly participated in the National Giant Panda Surveys. The survey information included the spatial distribution of bamboo flowering between the third and fourth survey, as well as the flowering year of each bamboo patches. After the report of the fourth survey came out, the questionnaires were also used as supporting materials together with the report to confirm and refine for the data.

To obtain the latest flowering time of each major bamboo patches, we used the spatial distribution vector layers of the staple-food bamboo distribution by the three National Giant Panda Surveys. We then calculated the difference based on the bamboo flowering information. Table S2 showed the flowering statistics at different times with the corresponding flowering areas. By scanning the historical data maps from the report of the second and third surveys, combined with the data from the questionnaires, we used ArcGIS 10.0 for geospatial rectification (Geo-reference tool), and finally tracked and digitized each flowering patch and assigned attributes, including flowering time and bamboo species. Fig. S2 shows the spatial distribution of bamboo flowering areas during different periods in the Qinling and Minshan Mountains.

2.3.3. Flowering period

We acquired the flowering periods of staple-food bamboo species for giant pandas from the literature (Table S3) (Chai et al., 2006; Liu and Fu, 2007; Qin et al., 1993). We restricted our inquiry to the second half of the 20th century.

2.4. Risk database construction

2.4.1. Risk system

To assess the risk levels of bamboo flowering in both mountain ranges, our study developed a unified risk assessment system. The mathematical calculation of estimating flowering risks, we use Eqs. (2) and (3):

$$R_f = Y_n - Y_p \tag{2}$$

$$Y_n = Y_l + P_f \tag{3}$$

where R_f is the flowering risk, Y_n is the year of next bamboo flowering, Y_p is the year of project implementation (i.e. 2015 in this paper), year Y_l is the year of last bamboo flowering, P_f is the flowering period for each bamboo species (refer to Table S3). We then divided the risk levels into low risk, moderate risk, high risk and extremely high risk according to the R_f value, see Table 1.

2.4.2. Establishment of scenario

Scenario development is necessary when faced with high levels of

Table 1
Levels for risk of bamboo flowering.

Flowering risk R_f (years)	Flowering risk level
More than 10 years	Low risk
6–10 years	Moderate risk
3–5 years	High risk
0–2 years	Extremely high risk

uncertainty (Peterson et al., 2003). We present scenarios using existing databases, overlaying giant panda density distribution, bamboo species distribution and bamboo flowering information. A critical variable in our scenario development is the date of the initial large-scale flowering of the staple-food bamboo species. Different bamboo species have different flowering period varying from 20 to 60 years. It makes sense to do a scenario analysis for the bamboo with the longer flowering period rather than short flowering period, so we chose the longest period of 60 years in our case as the standard to build the scenarios. In addition, the largest number of bamboo species have 60 years flowering period including *Fargesia qinlingensis* and *Fargesia nitida*, which are the second dominant bamboo species in the Qinling and Minshan Mountains, respectively. If these species flowered in 1955, they would have been widespread flowering in 2015. But it did not happen. The sporadic areas of bamboo flowering in the Qinling and Minshan Mountains in 2014–2015 suggested that there probably was a large-scale flowering period after 1955. This date represents the earliest date for our various scenarios.

We collected data from the three National Giant Panda Surveys. There was no mention of the bamboo flowering during the first survey (years 1974–1977). There was large-scale flowering of bamboo in both the second (years 1985–1988) and the third surveys (years 1999–2003). We formulate the hypothesis that the previous large-scale flowering of staple-food bamboo species occurred in the Qinling and Minshan Mountains between 1955 and 1974 (the period of the first survey) This date represents the latest date for our various scenarios.

We established three scenarios for the initial flowering time running backwards from 1974 (the beginning year of the first survey): in years 1970 (scenario 1), 1965 (scenario 2) and 1960 (scenario 3), see Fig. 2.

3. Results

3.1. Possible impacts of the next bamboo flowering in the Qinling Mountains

In scenario 1, our analysis shows that in 2020 the Qinling Mountains have an extremely high risk of experiencing bamboo flowering across nearly half of the areas in the mountains. (Henceforth, we will simply use "areas" instead of "mountainous areas"). The bamboo *Bashania fargesii* dominates these areas at low elevation. In 2020, 2063 km^2 (49%) of the giant panda staple-food bamboo species will be at extremely high risk of flowering (Fig. 3A, Table S4). These areas are mainly in the western, southwestern regions, and part of the southern region of the Qinling Mountains including the Changqing, Niuweihe, Huangbaiyuan, and Sangyuan Nature Reserves. Flowering areas with moderate risk account for 42% of the total areas and are mostly in the central, northern, and eastern regions. Flowering areas with low risk only account for 9%, distributed in patches. By 2030, we anticipate 49% of the areas to have an extremely high risk of flowering, with a different pattern (Fig. 3B, Table S4) dominated this time by another species *Fargesia qinlingensis*, distributed at higher elevations. The flowering areas cover the central, northern, eastern, and some parts of the western regions of the Qinling Mountains. By 2040, we expect the bamboo to enter the recovery phase, after which the Qinling Mountains' extent of possible flowering goes down (Fig. 3C, Table S4). A high risk of significant habitat loss for panda is only in the Foping Nature Reserve. Other patches with the extremely high risk of flowering are small. Table S4 provides detailed percentages of the flowering risk areas in the Qinling Mountains under scenario 1. The grey color marked items indicates that the areas of extremely high or high risk are more than 20% of the total areas.

We divided the giant panda population density into six classes based on the number of giant pandas per km^2 (Table S1). The giant pandas of the Qinling Mountains are mainly in Foping, Changqing, Niuweihe, and Taibaishan Nature Reserves (Fig. 3, bottom right). The total population of giant pandas in Changqing and Foping Nature Reserves was recently estimated at 128 individuals — about 50% of the total number (345) of giant pandas in the Qinling Mountains (China's State Forestry Administration, 2015). The risk pattern of bamboo flowering can facilitate the migration and evacuation of giant pandas from high-risk areas to neighboring areas of low risk, suggesting that the threat to the giant pandas in this scenario is low. The period of the highest risk for bamboo flowering in the Qinling Mountains is from 2020 to 2030.

In scenario 2, in 2020, the areas in the Qinling Mountains with an extremely high risk and low risk of bamboo flowering are nearly equal in area, being approximately 49% and 51% respectively (Fig. 3D, Table S4). The northern, eastern, and central areas have an extremely high risk, while the western and southwestern parts are at low risk. Fortunately for the pandas, the areas with extremely high risk and low risk are adjacent to each other so that low-risk areas may mitigate the threat of forage scarcity to the giant pandas. In years 2030 and 2040, the Qinling Mountains have low levels of risk in 98–99% of the area (Fig. 3E, F, Table S4), representing the bamboos' recovery after the widespread flowering anticipated for 2020. Scenario 2 suggests the Qinling Mountains are the priority for preparing adaptation strategies by 2020.

In scenario 3, the Qinling Mountains in 2020 will also have high (49%) and low (51%) risk areas of bamboo flowering (Fig. 3G, Table S4). In 2030 and 2040, 98–99% of areas fall back to levels of low risk of bamboo flowering (Fig. 3H, I, Table S4).

3.2. Possible impacts of the next bamboo flowering in the Minshan Mountains

Scenario 1 in the Minshan Mountains for 2020 suggests areas with a moderate risk of bamboo flowering account for 45% of the total area, distributed in the southern and northern parts. Areas of low risk represent 47% of the total, distributed in the central and northern parts (Fig. 4A, Table S4). In 2030, there would be more areas under extremely high to high risk of bamboo flowering (53% of the total; 4633 km^2, Fig. 4B, Table S4). These areas are mainly in the southern and northern parts and are not adjacent to moderate- and low-risk areas. The distribution of giant pandas in the Minshan Mountains has some areas of high giant panda population density including Tangjiahe, Wanglang, Baiyang, and Xiaozhaizigou Nature Reserves (Fig. 4 bottom right). The habitats with high densities of the giant panda in the southern Minshan Mountains coincide with the areas of high risk of

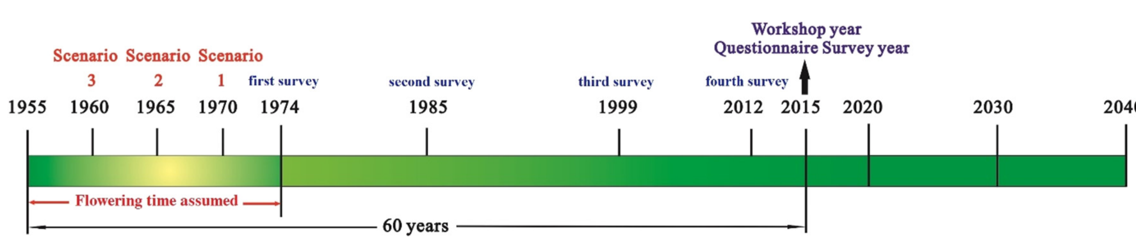

Fig. 2. Three scenarios of the latest large-scale bamboo flowering time before 1974. The recurring period for the flowering of the bamboo species dominating the study area is 60 years. Based on the absence of large-scale flowering in 2015 and working backwards, it is possible to estimate upper and lower limits for the initial large-scale flowering time of staple-food bamboo.

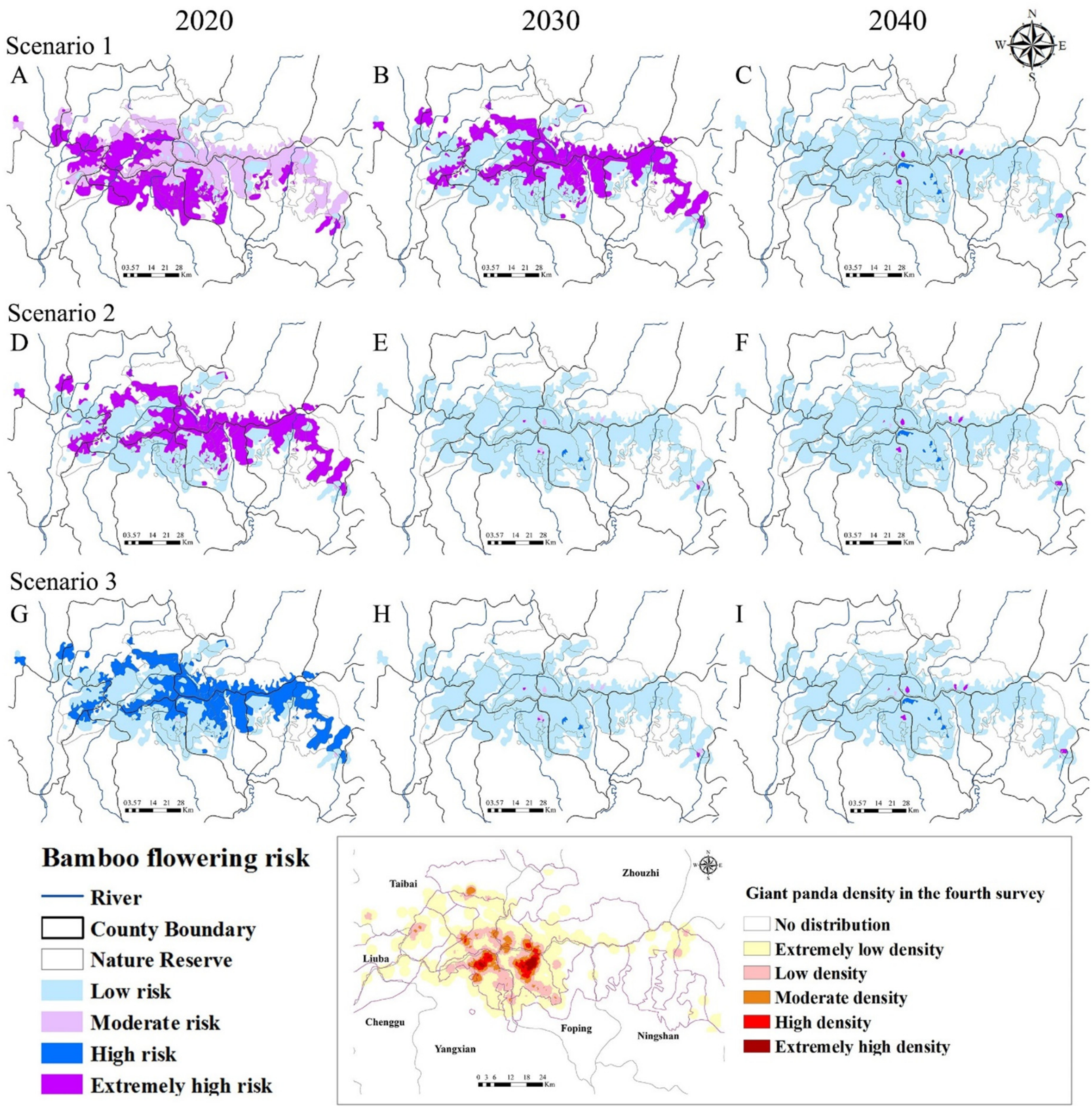

Fig. 3. Spatial distributions of risk levels of bamboo flowering in the Qinling Mountains in years 2020, 2030, and 2040 for three scenarios (see Fig. 2). Bottom right: the giant panda density in the Qinling Mountains in the fourth survey.

bamboo flowering and lack nearby low-risk areas. The high exposure and the high risks combine to create a high vulnerability for giant panda. This is where the giant pandas will face a high threat of food shortage in 2030. By the 2040 (Fig. 4C), 70% of the Minshan Mountains will have reverted to low risk and 25% to moderate risk (Table S4). The late stage areas of extremely high risk are in Jiuzhaigou Nature Reserve, with adjacent low-risk areas that can serve as a refuge for evacuation and release of individuals if food resources get too low. We expect that by 2040, bamboo flowering will no longer pose a threat to the survival of the giant pandas.

In scenario 2, by 2020, the Minshan Mountains have 43% at high risk and 51% at low risk of flowering (Table S4). High-risk areas are in the central and south parts in Xuebaoding, Baiyang, Xiaozhaizigou, and Baodinggou Nature Reserves (Fig. 4D). The most northern parts of the Minshan Mountains are newly-gazetted nature reserves which also have a high bamboo flowering risk. The vulnerability of giant pandas during 2020 will be high because the habitat with high giant panda density and the areas of high flowering risk overlap in the southern Minshan Mountains. There is little opportunity for giant pandas to migrate to nearby low-risk areas. By 2030 and 2040, pandas will be relatively safe, covering approximately 70% of the areas at low risk (Fig. 4E, F, Table S4). The remaining 30% of the areas have moderate or high risk with high giant panda density in Wanglang, Tangjiahe, Wujiao, and Jiuzhaigou Nature Reserves. These need to anticipate bamboo flowering events for years 2030 and 2040. Overall, the most dangerous situation for giant pandas in the Minshan Mountains under scenario 2 would be 2020.

In scenario 3, the Minshan Mountains in 2020 have 46% of the areas at extremely high risk of bamboo flowering, primarily distributed across the most northern part and some southern reserves, such as Xuebaoding and Baiyang Nature Reserves (Fig. 4G, Table S4). By 2030, 89% of the areas will have low to moderate flowering risk (Fig. 4H, Table S4). By 2040, the Minshan Mountains will have 26% of the areas at extremely high risk, including Wanglang, Jiuzhaigou, and Xiaohegou Nature Reserves (Fig. 4I, Table S4).

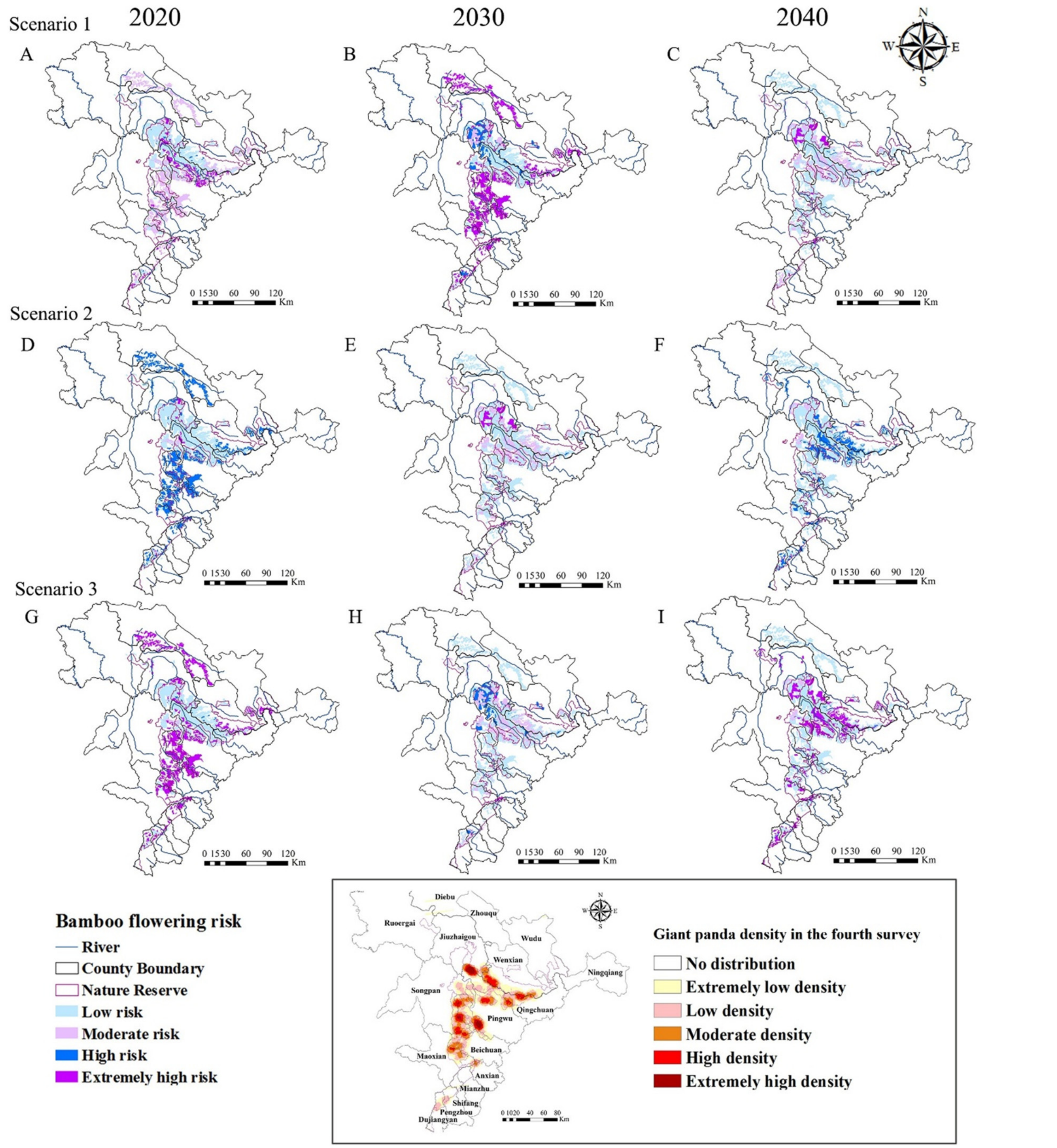

Fig. 4. Spatial distributions of bamboo flowering risk levels in the Minshan Mountains in 2020, 2030, and 2040 for three scenarios (see Fig. 2). Bottom right: the giant panda density in the Minshan Mountains in the fourth survey.

4. Discussion

Possible scenarios show that the staple-food bamboo species in the Qinling Mountains could face the highest bamboo flowering risk in the year 2020, impacting nearly all areas. Meanwhile, the southern nature reserves and the most northern newly-gazetted nature reserves in the Minshan Mountains could have a high or extremely high risk of flowering in the years from 2020 to 2030.

What we have presented here are not accurate prediction of the things that will be. However, we have developed scenarios that consider a variety of possible futures, and that included the key drivers of change of the system, and a measure of the irreducible uncertainties inherent to them. A fundamental assumption in our narrative is the widely-accepted view that periodicity in bamboo flowering is the product of an endogenous mechanism caused by genetics or biological clocks that is relatively immune to environmental influences (Campbell, 1985; Nelson, 1994; Widmer, 1998). In contrast, research highlights that environmental perturbations (severe flooding, fire, cyclone damage, temperature, soil nutrient) also influence flowering time (Chai et al., 2006; Franklin, 2004; Rensing et al., 2001). It is possible that both endogenous and exogenous factors dictate the actual circumstances. In a range of environmental and evolutionary contexts, selection should favor varying interactions between exogenous and endogenous cues. In any case, the combination of patchy resource distribution, gregarious behavior, heterogeneous giant panda distribution, and increased fragmentation remain the key parameters that will influence the vulnerability of the population to mass flowering and the loss of forage. It is unlikely we will be able to significantly reduce the uncertainties without massive investments of time and resources. It might not be effective, even if we did so.

How do the potential impacts of flowering risk on the giant pandas in the Qinling and Minshan Mountains compare? The influence in the Qinling Mountains may be higher than that in the Minshan Mountains since it is an isolated habitat with only two dominant bamboo species (*Bashania fargesii* in lower altitude and *Fargesia qinlingensis* in higher altitude, accounting for 81% of the total area, Fig. S1A). Moreover, these two bamboo species have adjacent distributions so producing a potential disaster for giant pandas in the Qinling Mountains if these two species flower at the same time or in continuous years. In comparison, the potential risk impact is lower in the Minshan Mountains as it contains 12 staple-food bamboo species (Fig. S1B). However, the risk cannot be underestimated because there are only three dominant bamboo species among them (*Fargesia denudata*, *Fargesia nitida* and *Fargesia rufa*, accounting for 73% of the total area). Therefore, the worst situation of dominant bamboo species flower at the same time worth to mention and notice by the relative managers, especially in the Qinling Mountains.

Does the flowering risk present an opportunity for the giant pandas? If bamboo flowering occurs in the areas with high degree of habitat connectivity, it might force the giant panda populations to disperse and genetically rescue currently isolated populations. After all, giant panda populations have survived from bamboo flowering many times in their evolution. Bamboo die-off may put a giant panda population above the local carrying capacity of that bamboo, so giant pandas must spend time moving through dead bamboo to reach live patches. During this process, the rate of ingestion will be increased by eating more from culms and stems (Reid et al., 1989). Dispersal and reproduction may also compensate for increased mortality resulting from the relative shortage of food.

However, more giant pandas now live in small habitats without dispersal corridors than in the past. Bamboo flowering could be a disaster for them. In fact, with a long history of human disturbance around and within the Qinling and Minshan Mountains, maintaining or restoring the ecological connectivity among those nature reserves will not be easy. The combination of fragmented landscape and climate change will hinder the range shifts of both bamboos and giant pandas once large-scale bamboo flowering occurs. The naturally evolved strategies may no longer allow the survival of the species in its currently fragmented habitat. We must develop the capacity to anticipate future changes and take responsibility to act upon that foresight (Butz and Hoffmann, 2002; Castelfranchi, 2005). And this is an effective way to change the risk into an opportunity. With advanced warning, we can strengthen the corridor construction to protect the isolated habitats, as well as introducing and restoring multiple bamboo species in the restoration of current habitats, rather than single bamboo species. Furthermore, Qin et al. (1991) found that the dieback of bamboo after flowering was the best time for the restoration of panda's habitat. So, in the giant panda's range, it is highly advisable to plant forests of mixed trees and different bamboo species on clear-cut slashes, raise the survival rate of bamboo seedlings, and create a favorable environment for the growth of the giant panda. Such important measures can also change the flowering risk into an opportunity to the giant pandas.

5. Conclusion and recommendation

Our study shows enormous risks to giant panda after the Red List downgraded it. The bamboo flowering anticipated by year 2020 in both Qinling and Minshan mountain regions expose a critical vulnerability in the conservation strategy of the giant panda. As a slowly reproducing species, giant pandas cannot maintain themselves when massive staple-food bamboo flowering occurs in fragmented habitats. We should carefully consider whether giant pandas will be ready for the upcoming food shortage. Detailed planning and adaptation strategies might mitigate the risk of bamboo flowering, but are beyond the scope of this paper. There are limited possible interventions here. (1) Expand the habitat of giant pandas and establish habitat corridors between protected areas. If we cannot restore natural corridors, it may be necessary to translocate pandas between fragmented nature reserves or to newly-gazetted ones. (2) Prepare emergency plans to rescue the starving giant pandas when the large-scale bamboo flowering occurs, either with supplemental feeding or bringing them into temporary captivity until the bamboo recovers. Except for the giant panda, our research also lays a foundation for studies on risks to other downgraded species around the world. Specific risks may differ among species, but the general lesson may be similar — manage risks after downgrading to prevent them from becoming endangered again.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2019.03.030.

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