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Effect of China's rapid development on its iconic giant panda

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Anthropogenic factors affect biodiversity and have led to the contraction or extinction of animal populations worldwide. Here, we use historical demographic data, spanning the past 300 years, to show that a rapid distributional contraction of giant pandas took place during the 18th and 19th centuries alongside the increase in human population. Land-use also underwent a significant change across the areas where giant pandas were found because of government agricultural policy and the introduction of new crops. The impact of social development on giant pandas includes habitat loss and fragmentation, and range reductions. Our findings would facilitate the design of effective conservation strategies that seek to conserve and increase current habitats of this iconic species, especially in areas that our analysis has identified as places where pandas have suffered from high human pressure.

giant panda (*Ailuropoda melanoleuca*), distributional contraction, human populatoin explosion, land-use increases and habitat loss, conservation implication

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Human activities, such as agriculture, industry and deforestation, have led to environmental change and habitat loss around the globe [1] and are driving the decline, and extinction, of countless species [2]. Numerous regional, continental and global analyses have shown that human impact on biodiversity is greatest when human settlements coincide with areas of high biological value [3–7]. For instance, population extinction is a linear function of habitat loss, and it has been reported that approximately 1800 populations per hour, or about 16 million annually, are being extirpated in tropical forests alone [8]. Many mammals are considered endangered. Because of taxonomic diversity and ecological niches, the health of mammalian populations can serve as an indicator of what is occurring in the rest of the Earth's biota [9]. For this reason it is imperative to understand the causes of population contraction, or extinction, due to human development, so that we can trace such changes and adopt effective conservation strategies.

The giant panda (*Ailuropoda melanoleuca*) is a slow-breeding species endemic to China [10,11]. It is highly specialized and spends the majority of its life moving within bamboo forests and eating bamboo [10]. Radio-tracking studies have shown that this species prefers well-wooded forests with a continuous forest canopy [10,11]. During the 18th and 19th centuries, the giant panda occupied a wide range spanning Sichuan (including Chongqing), Shaanxi, Hunan, Hubei, Guizhou and Yunnan provinces [10,12,13] (Figure 1). Nowadays, it is found only on the edge of the Tibetan Plateau, and confined to Sichuan, Shaanxi and Gansu [10,14]. Despite awareness of local population extinctions, relatively little is known about why the population contracted so rapidly and extensively [15]. In this study, we use demographic and historical data concerning changes in human population size and land-use areas to examine some of the potential processes that led to this distributional contractions and local population extinctions. Specifically, we aim to (1) quantify increases in the human population and land use changes upon the historical distribution of giant pandas; (2) compare this data with present data collected from the current range of the giant panda; (3) uncover the main causes that led to the severe contraction of the giant panda population; and (4) present effective conservation

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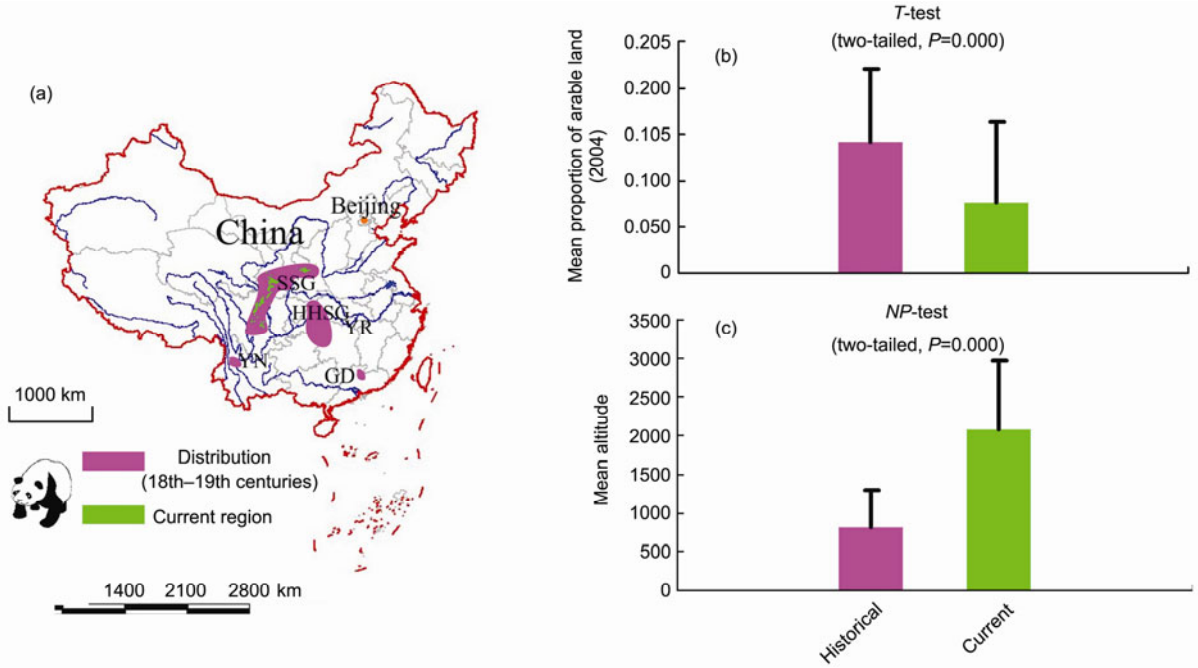

Figure 1 Giant panda populations have undergone local extinctions due to environmental changes, including human population size increase and use of land, over the past 300 years. (a) Changes in giant panda distributions from the 18th century (purple) to the present (green). Abbreviations: YR, Yangtze River; SSG, distribution in Sichuan, Shaanxi and Gansu provinces; HHSG, distribution in Hunan, Hubei, Sichuan (Chongqing) and Guizhou provinces; YN and GD, distribution in Yunnan and Guangdong provinces, respectively. (b) Mean proportion of the arable land across current and historical panda distribution counties. (c) Mean altitude of historical and current giant panda distributions.

strategies for the current populations, based on our findings.

1 Materials and methods

1.1 Defining historical distribution region

Throughout Chinese history, the giant panda has been known by a variety of common names [10] and because of this we chose to focus on detailed records from the past 300 years only. The past 300 years also correspond with a period of rapid human population growth in China and rapid giant panda decline [12]. We use the term 'historical distribution' to refer to counties where giant pandas were known to have occupied at some stage during the past 300 years but do not occupy now. This historical data was collected through a literature search [10,12,13]. The current distribution region comprises counties where giant pandas were found during the 3rd National Giant Panda Survey in 2006 [14].

1.2 Human population size, arable land and panda population density

An estimation of the human population in each county over the past 300 years was gathered from county annals published during the Qing Dynasty (1644–1911). Data before and after 1949 were obtained from county annals deposited in the National Science Library, Chinese Academy of Sciences, Beijing. After 1953, literature [16,17] and provincial yearbooks were also used to approximate the human population size for each province. Arable land is defined as land used to cultivate crops, as measured from local government economic records for each province ([16,18]; Provincial Yearbooks after 1949). We estimated arable land as the mean proportion of total land area in the current and historical distribution according to county. The current population density of giant pandas (by county) was calculated based on information from the 3rd National Giant Panda Survey [14].

Altitude data were downloaded from the CGIAR-CSI SRTM 90-m digital elevation database (http://srtm.csi.cgiar.org/). We calculated the average altitude of each county of interest using ArcGIS 8.3 (ESRI, Redlands, USA). The classification of human pressure in current distribution regions is based on historical human densities in regions where giant pandas rapidly disappeared, and these classifications were mapped using Arcview3.2 (ESRI, Redlands, USA).

1.3 Statistical analysis

In order to evaluate the difference between the mean proportion of arable land in the historical and current distribution counties, we used an independent *t*-test. Because of unequal variances among our altitude data, we used a non-parametric independent sample test to compare mean altitudes in the historical and current distribution counties. In addition, we used a regression analysis to test the relationship between both human density and arable land area, and

human density and giant panda density. All statistical analyses were performed using SPSS version 15 (SPSS Inc., USA).

2 Results

Based on available records, we determined that the historical distribution of the giant panda included 53 counties in Sichuan, Hunan, Hubei, Guizhou, Yunnan and Guangdong provinces (Figure 1(a), purple region). The current distribution includes 45 counties located in Sichuan, Gansu and Shaanxi provinces (Figure 1(a), green region).

2.1 Changes in human population, land use and altitude of panda distribution

Human population has increased sharply over the last 300 years in areas historically occupied by giant pandas. Mean human density increased 7-fold from the 18th to late 19th centuries. From 1661 to 1912, the human population of Sichuan, Hunan, Yunnan and Guizhou provinces increased 12-, 7-, 4- and 4-fold, respectively. More exactly, over a 150-year period, the human population density of Xiushan in Sichuan Province increased nearly 40-fold, Qianjiang in Sichuan increased 13-fold, and Zheng'an in Guizhou Province increased nearly 10-fold. Even from the middle of the 18th century to early in the 19th century (less than 100 years), the human density of Enshi in Hubei Province increased 8-fold. Similar rapid increases were also found at the provincial level in historical distribution areas of giant pandas (Figure 2(a)).

During the past 300 years, land use by people in Sichuan increased 81-fold. Large increases were also found for Guizhou, Yunnan, and Hunan provinces (21-, 5- and 3-fold, respectively). From 1661 to 1887, land use across all of the distribution provinces of the giant panda increased approximately 10-fold (Figure 2(b)).

The mean proportions of arable land in current and historical distribution counties were 0.075 (±0.088) and 0.142 (±0.079), respectively with a significant difference (two-tailed, P=0.000; Figure 1(b)). Mean altitude of panda distribution was 802 m (±480 m) historically and 2072 m (±887 m) currently, with a significant difference calculated by the Mann-Whitney test (two tailed, P=0.000; Figure 1(c)). A comparison of the above parameters suggests that giant pandas have been forced, due to human pressures, to higher and less arable regions. Our results reveal a significant positive relationship between human density and the proportion of arable land (P<0.01 for both historical and current distribution counties), indicating that the more people are inhabiting the area, the more land will be used to grow crops, in order to support the expanding human population.

2.2 Human pressure on giant panda populations

We examined human density as a proxy for human pressure. The mean human density for historical distribution regions in the early 19th century was 61 individuals km^{-2}. However, in the early 20th century (after a rapid contraction of the panda population), human density swelled to 95 individuals km^{-2}. In 2004, the mean human density of current distribution counties was 125 individuals km^{-2}. Therefore, we took 60 individuals km^{-2} as the historical referent and 125 individuals km^{-2} as the current value, in order to classify levels of low, moderate and high human pressure on current distribution regions (Figure 3).

Eighteen counties showed an area with low human pressure (<60 individuals km^{-2}), meaning only 40% of all current distribution counties (Figure 3, green region). This region had a total habitat of 13584 km^2, occupying nearly 59% of the current panda habitat. Twelve counties were accessed as being an area with moderate human pressure (60–125 individuals km^{-2}), with the total habitat area of 6016 km^2, occupying 26% of the current panda habitat (Figure 3, yellow region). Fifteen counties were classified as an area with high human pressure (over 125 individuals km^{-2}), occupying a total of approximately 3528 km^2 or 15% of the current panda habitat (Figure 3, red region).

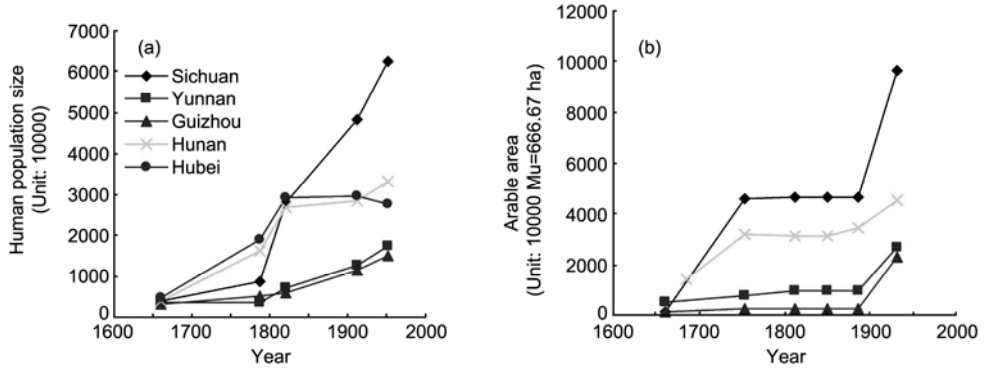

Figure 2 Human population size and land use changes from 18th to 19th centuries in Sichuan, Hunan, Yunnan, Guizhou, and Hubei provinces. (a) Human population. (b) Land use.

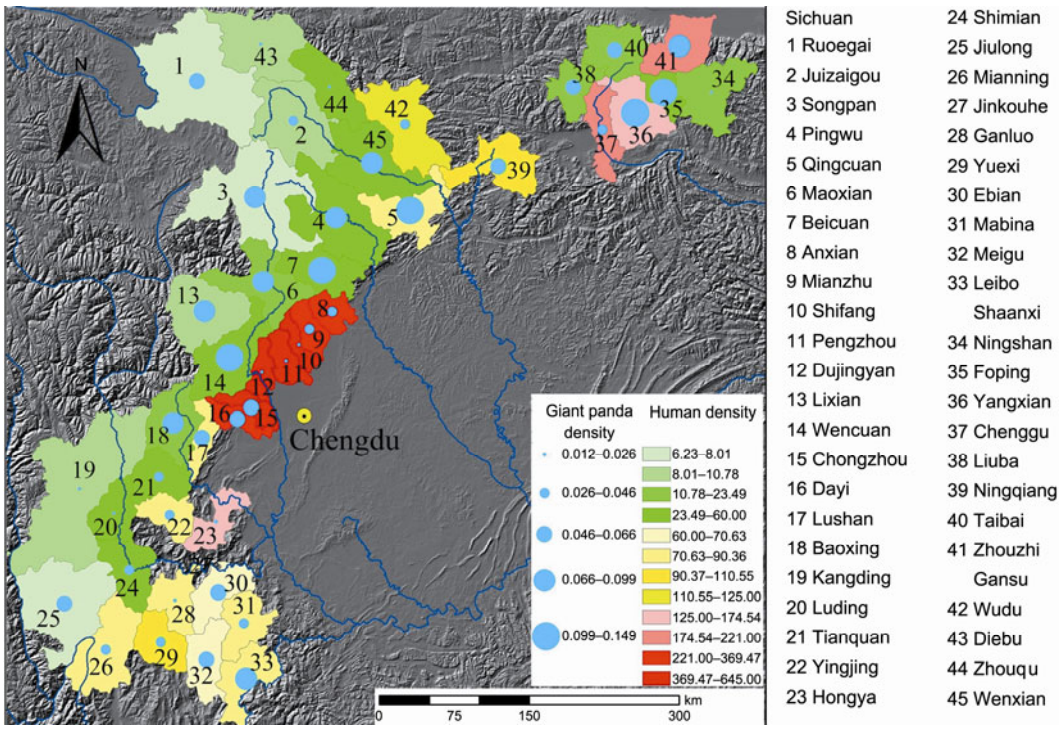

Figure 3 The human density in current distributional regions of the giant panda. Green shades represent human density of 6–60 individuals km^{-2} with low human pressure. Yellow shades represent human density of 60–125 individuals km^{-2} with moderate human pressure. Red shades represent human density of 125–645 individuals km^{-2} with high human pressure. Blue shades represent different giant panda densities.

3 Discussion

Our analysis revealed that during the 18th and 19th centuries giant pandas experienced rapid population contraction, and local extinctions, across Sichuan, Hubei, Hunan, Guizhou, Yunnan and Guangdong provinces. During the same period, human population and land use increased rapidly in these regions. Our results suggest that the anthropogenic impacts of human encroachment on the panda's habitat (e.g. due to an increase in deforestation and arable land used to cultivate crops) led to habitat loss and fragmentation, and eventually the local extinction of giant pandas in these regions. Two main factors stimulated the human population expansion and land use in history. First, the warmer climate from 18th to early 19th centuries [19,20] had benefited the growth of crops and increased the farm yielding [20], which in turn could support more people on the land, therefore also leading to further deforestation and further increase of arable land (at the same time, decreasing habitat available to the giant panda). Second, the human population in provinces, such as Sichuan, Hubei, Hunan, Guizhou, Yunnan and Guangdong increased rapidly due to government policies aimed at decreasing human taxes, reclaiming land and encouraging migration to China's western provinces [21].

Why did humans have such a large impact on giant pandas? First, more people need more land. Land use in mountain regions increased nearly 10-fold from 1661 to 1887, and the introduction of maize, potato and sweet potato in the late 17th century made it possible for farmers to cultivate crops at middle to high elevations. In fact, the cultivation of these crops still encroaches on panda habitat today. Therefore, major deforestation has greatly affected the low to middle altitude regions, and even high altitude regions have been altered by the practice of slash-and-burn agriculture [16]. As a result, for the panda, the most serious concern is that large amounts of habitat has been lost or severely fragmented. As has been shown, the mean altitude of the panda's historical distribution region was significantly lower than that of the current distribution regions, suggesting that humans have encroached upon panda habitat extensively at lower altitudes and this has forced giant pandas higher into the mountains. Consistent with this hypothesis, the mean proportion of arable land within the historical regions is significantly higher than that within current distribution regions. Second, the main fuel for local people in these areas was wood: locals almost exclusively used wood for heating, cooking and house construction. These had further lead to habitat loss of the giant panda. Third, our data further revealed the negative correlation between human population growth and panda population size. Clearly, the higher the local human density is, the lower the giant panda density is. In addition, we found that the higher the local human density in a given area recorded as part of the historical range of the giant panda, the further back in the literature (i.e. the further back in time) was the last recorded sighting of a giant panda in that area. Previous studies have

reported local population contractions, or extinctions, in many other species with distributions sympatric to that of the giant panda [22]. Extreme examples are those of the rhinoceros (*Rhinoceros unicornis* Linnaeus, 1758 and *Rhinoceros sondaicus* Desmarest, 1822). The rhinoceros was relatively common in the extreme southern tip of China; however, due to rapid habitat loss and fragmentation (and also poaching), this species is now extinct in China [22].

Therefore, habitat loss and fragmentation caused by human population expansion has already led to population contraction, and local extinction, of the giant panda. Recently, genetic studies have indicated that the evolutionary outlook of the giant panda is improving, according to increases seen in the size of local populations and medium levels of genetic variation [23,24]. However, a work on the smallest, and currently most fragmented population has demonstrated strong indications of population collapse, which commenced around 250 years ago, due to serious habitat loss caused by human population increase and land use expansion [25]. Population viability analysis [26] revealed that small, fragmented panda populations, as mentioned above, are at high risk for future extinction, even in the absence of inbreeding or other natural catastrophes such as bamboo flowering and die-off. The vulnerability of giant pandas to the impact of habitat loss and fragmentation may be due primarily to its own biological characteristics. Radio collar data and habitat suitability analyses have shown that the giant panda is an ecological specialist in terms of its preferred bamboo food and old forest habitat [27–29]. Unfortunately, such areas often overlap with human activities, such as habitation and farming. Moreover, the giant panda is a large mammal that requires a large home range, has a low reproduction rate, as well as a low population growth rate in the wild [30]. Both habitat specialization and small population size are believed to enhance the giant panda's risk of extinction [31–33]. Drastic habitat loss because of environmental changes caused by deforestation and fragmentation due to human population expansion has negatively impacted the giant panda populations, which have been struggling to survive over the past several hundred years.

Although most of wild giant pandas are protected in over 60 nature reserves [14], habitat loss and fragmentation continue to threaten this species. The application of more effective conservation strategies, with the goal of protecting populations in their current distribution regions, is needed. In particular, greater attention should be given to regions that have been identified as being under high human pressure. We propose that policymakers seek to conserve current giant panda habitats and decrease the level of human disturbance in these regions. This would benefit not only giant pandas, but also countless other sympatric species, such as red pandas (*Ailurus fulgens*), golden monkeys (*Rhinopithecus roxellanae*) and takins (*Budorcas taxicolor*).

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