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Establish an environmentally sustainable Giant Panda National Park in the Qinling Mountains

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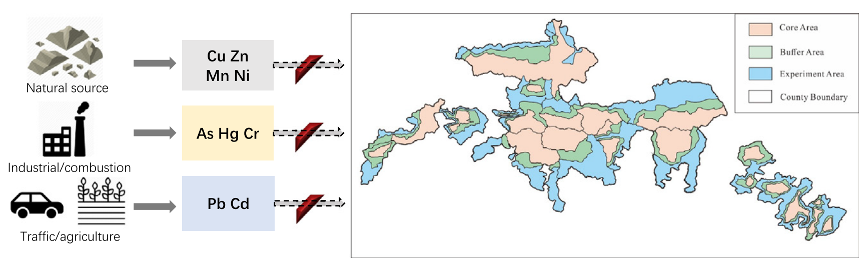
HIGHLIGHTS

- Heavy metals contents increased from core, buffer to environmental areas in Qinling.
- Heavy metal distribution was correlated with altitude and latitude in Qinling.
- Minimizing heavy metals emission is a long-term task for panda conservation.
- Expanding core area and adherence to the basic principle of functional areas
- Establishing pollutants monitoring and staple bamboo protection

GRAPHICAL ABSTRACT



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ABSTRACT

The giant panda (*Ailuropoda melanoleuca*) is one of the most endangered animals in the world and is recognized worldwide as a symbol for conservation. The Qinling subspecies of giant panda (*Ailuropoda melanoleuca qinlingensis*) is highly endangered; fewer than 350 individuals still inhabit the Qinling Mountains. Last year, China announced the establishment of the first Giant Panda National Park (GPNP) with a goal of restoring and connecting fragmented habitats; the proposal ignored the environmental pollution caused by economic development in panda habitats. The spatial distribution of heavy metals (Cd, Pb, Hg, Cu, Zn, Mn, Cr, Ni and As) was analyzed in giant panda feces, soil, bamboo, and water in four of GPNP's functional areas at different altitudes and latitudes. Heavy metal pollution decreased with anthropogenic influences, from outside the park through the buffer and into the core area. Cu, Mn, Ni and Zn accumulated from natural sources; As, Hg and Cr were associated with fuel combustion; and Pb and Cd were associated with traffic and agriculture sources. The presence of heavy metals at high altitudes and latitudes in the proposed GPNP is due to emissions from Xi'an and other upwind industrial cities. We conclude that reducing emissions and heavy metal input should be included in the design of the GPNP. Policy interventions should consider functional zones planning, wind direction, reducing mining, and the abandonment of existing roads and farmland within the GPNP to reduce other direct human impacts on the Qinling panda.

1. Introduction

The giant panda (*Ailuropoda melanoleuca*) is a global icon of biodiversity conservation. Sixty-seven nature reserve zones totaling 3.36 million hectares had been established for panda conservation in

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southwestern China through 2015 (State Forestry Administration, 2017). According to the results of China's Fourth Investigation Report on giant pandas, the number of pandas living in the wild was 1864 in 2015, and its conservation status was downgraded from endangered to vulnerable by the International Union for Conservation of Nature (IUCN) in 2016. However, this action was too optimistic, and it is too early to say that the giant panda is no longer endangered (Chen and Ellison, 2017). Pandas are still distributed in 33 isolated habitats in the Qinling, Bashan, and Qionglai Mountains, and 18 local populations are at a high degree of extinction risk (State Forestry Administration, 2015). The Qinling subspecies of giant panda (*Ailuropoda melanoleuca qinlingensis*) is highly endangered, with <350 individuals still inhabiting the Qinling Mountains. The Qinling panda has been geographically isolated from the Sichuan subspecies for at least 10,000 years, resulting in significant morphological and genetic differences (Wan et al., 2005). From the perspective of biodiversity protection, the conservation of the Qinling panda is most pressing.

China's Wildlife Protection Law of 1988 banned poaching, and subsequent protection of the panda has focused on habitat fragmentation, bamboo protection, epidemics, and potential impacts of human activity, including mining and road construction. With rapid economic development and urbanization, hazardous pollutants also have increased (Wang et al., 2014). Recent reports have shown that pandas are exposed to persistent organic pollutants (POPs) and heavy metals, and the pollutant exposure level of the Qinling subspecies of panda is higher than that of the Sichuan subspecies (Chen et al., 2016). Atmospheric deposition is the primary source of these pollutants (Chen et al., 2017b); road traffic and farming activities in nature reserves or surrounding villages also introduce pollutants into giant panda habitat (Zheng et al., 2016).

Last year, the Chinese government approved a decision to construct a Giant Panda National Park (GPNP) in Sichuan, Shaanxi, and Gansu Provinces that will link six types of existing protected areas: nature reserves, forest parks, scenic spots, geological parks, natural cultural heritage, and state-owned forests (State Council Information Office of China, 2017). These efforts focus on integrating scattered and fragmented habitats to strengthen biodiversity conservation. However, other environmental issues have not been addressed in the GPNP project. For example, excessive public curiosity could increase disturbance from tourism, habitat degradation (Grossberg et al., 2003), or pollution.

In this study, we studied environmental pollution in three typical nature reserves (core-buffer-experimental area) occupied by the Qinling panda on the southern slopes of the Qinling Mountains: the Foping National Nature Reserve (FNNR), Laoxiancheng National Nature Reserve (LNNR), and Guanyin Mountain National Nature Reserve (GNNR). Soil, bamboo, water and feces samples were collected from different altitudes and latitudes of the four different functional areas (core area, buffer area, experimental area and anthropogenically-dominated area) to determine the spatial distribution of heavy metals in the habitat of the Qinling panda. Our analysis of possible sources of contamination and associated human activities suggest ways to minimize pollution in the GPNP.

2. Methods

2.1. Study area and sample collection

Our fieldwork was carried out in the LNNR (33°43′–33°50′ N, 107°40′–107°49′ E), GNNR (33°35′–33°45′ N, 107°51′–108°01′ E) and FNNR (33°33′–33°46′ N, 107°40′–107°55′ E) (Fig. 1). The relative elevation difference among the three nature reserves >1300 m and included 55,385 ha of Qinling panda habitat.

Fifty soil, fifty bamboo, and forty-one water samples were collected from the three functional areas of nature reserves in November 2016. The description of these three areas in a nature reserve was given in Table A.3. An additional three soil, three bamboo, and three water samples were collected on the way to Foping County to represent anthropogenically-dominated area samples. The bamboo samples were collected along a 50-m altitudinal gradient, the topsoil (0–5 cm) around bamboo roots was collected without humus layers, and the four soil samples collected at each site were pooled. Each water sample was collected around the bamboo site from the closest stream. Because the core area and the experimental area were relatively flat, three samples were taken in each of the two functional areas and combined into a new core area or a new experimental area sample. A total of 21 fecal samples were collected in April 2017, and sampling locations were spaced 6 km apart. All solid samples were put into clean plastic bags and water samples were collected in clean plastic vials to avoid contamination.

The soil samples were air dried at room temperature and then oven-dried at 50 °C to constant weight; the dried samples were ground, sieved, and stored at ambient temperature. The bamboo and fecal samples were oven-dried separately at 50 °C to constant weight, and then the samples were ground and stored at −20 °C for subsequent analysis. The water samples were also stored at 4 °C.

2.2. Heavy metal analysis

Soil sample digestion of heavy metals was done using standard methods (Zheng et al., 2016). In brief, approximately 500 mg of each

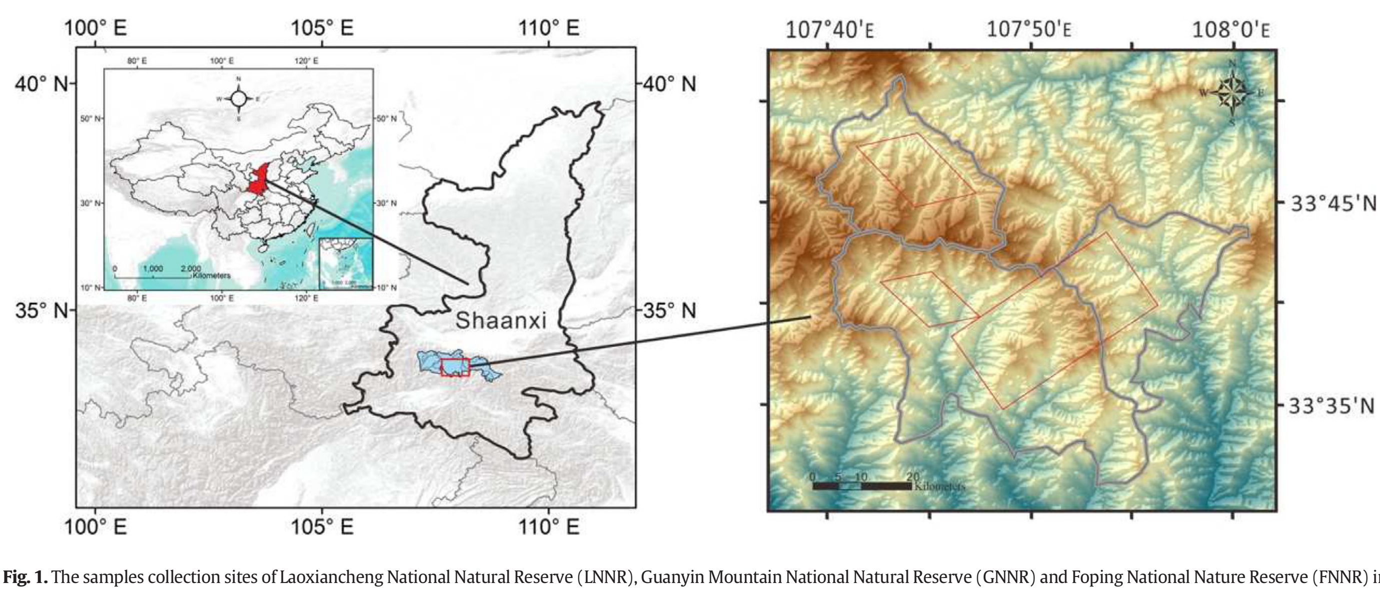

Fig. 1. The samples collection sites of Laoxiancheng National Natural Reserve (LNNR), Guanyin Mountain National Natural Reserve (GNNR) and Foping National Nature Reserve (FNNR) in Shaanxi province, China.

soil sample was placed in a Teflon digestion vessel with a guaranteed Reagent (GR)-grade acid digestion mixture (1 mL HNO_3, 3 mL HCl, 5 mL HF, and 2 mL $HClO_4$). Then, the samples were digested on an electric hot plate. Approximately 200 mg of each bamboo or fecal sample was digested in a Teflon digestion vessel with 8 mL of GR-grade nitric acid using a microwave system (CEM Mars 5, USA) (Liu et al., 2015). After digestion, soil, bamboo, and fecal samples were transferred to a polypropylene tube and diluted to 50 mL with ultrapure water (18.2 MΩ/cm^2 Milli-Q water, Millipore, France). The water samples (100 mL) were digested using 5 mL of GR-grade HNO_3, and after heating, set up to 20–25 mL and diluted to 25 mL with ultrapure water until the concentration factor (CF) of 4 was achieved (μg/L).

We assayed Cd, Ni, Pb, Cu, Zn, Mn, Cr, As, and Hg in the samples using atomic absorption spectroscopy (AAS; ZEEnit 700P, Analytik, Jena, Germany). In soil, bamboo, and fecal samples, concentrations of Cd, Ni, and Pb were measured using a graphite furnace AAS coupled to a MPE 60 (ZEEnit 700P, Analytik, Jena, Germany) graphite autosampler with two-field mode Zeeman effect background correction. Concentrations of Cu, Zn, Mn, and Cr were measured using the air acetylene flame method with an electrically modulated deuterium–HCl background correction. The hydride-forming elements As and Hg were analyzed using the HS55 Hydride System (AAS; ZEEnit 700P, Analytik, Jena, Germany) of the AAS. The unit of measurement was mg/kg dry mass. Water samples, except for As and Hg, were measured in the same way given above, and the remaining seven elements were all measured using a graphite furnace AAS with the units of μg/L.

2.3. Statistical analysis

Statistical analyses were done in SPSS 20.0 (IBM SPSS Statistics, IBM Corp., USA) and Origin 8.0 (OriginLab Corporation, USA). Normality and homoscedasticity of data were confirmed with Kolmogorov–Smirnov and Levene tests, then data were analyzed using a one-way ANOVA followed by Tukey's post-hoc tests, or using K-independent sample tests followed by the Nemenyi method. The significance level was set at $P < \alpha = 0.05$.

Correlation analysis (CA) was used to explore associations between samples of feces, soil, bamboo, and water with nine different metals. Principal components analysis (PCA) and hierarchical cluster analysis (HCA) were used to identify the possible sources of contamination. Before multivariate statistical analysis, all data were checked and standardized, and all data met the requirements of the analyses.

3. Results

3.1. Heavy metal concentrations

The concentrations of Cd, Pb, Hg, Cu, Zn, Mn, Cr, Ni, and As in soil, bamboo and water decreased from anthropogenically-dominated areas outside of the reserve (AA), through the experimental area (EA), buffer area (BA), and core area (CA) (Figs. 2, 3 and 4). The concentrations of Cd, Pb, Hg, Cu, Zn, Mn, Cr, Ni, and As in nature reserves were list in Table A.4.

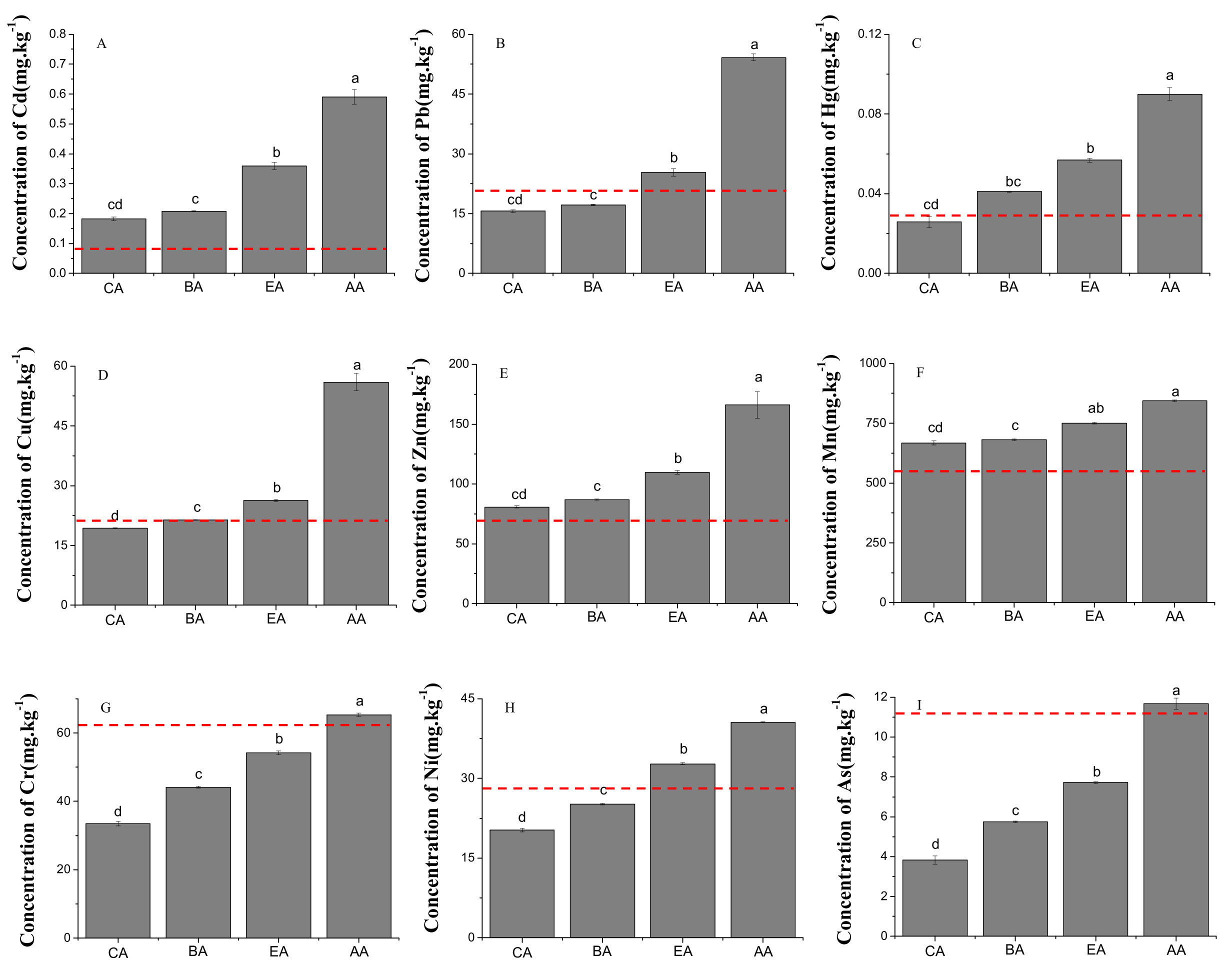

Fig. 2. Concentrations of heavy metals (mean ± standard error, mg/kg dry weight) in soil samples collected from FNNR, GNNR and LNNR. A dashed red line in each panel indicates the soil background criteria value for polluted soils (CNEMC 1990). The four bars represent the four different functional areas of core area (CA), buffer area (BA), experimental area (EA) and anthropogenically-dominated area (AA), respectively. Different letters (a, b, c, d) indicate significant differences identified using a Tukey post-hoc HSD test. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

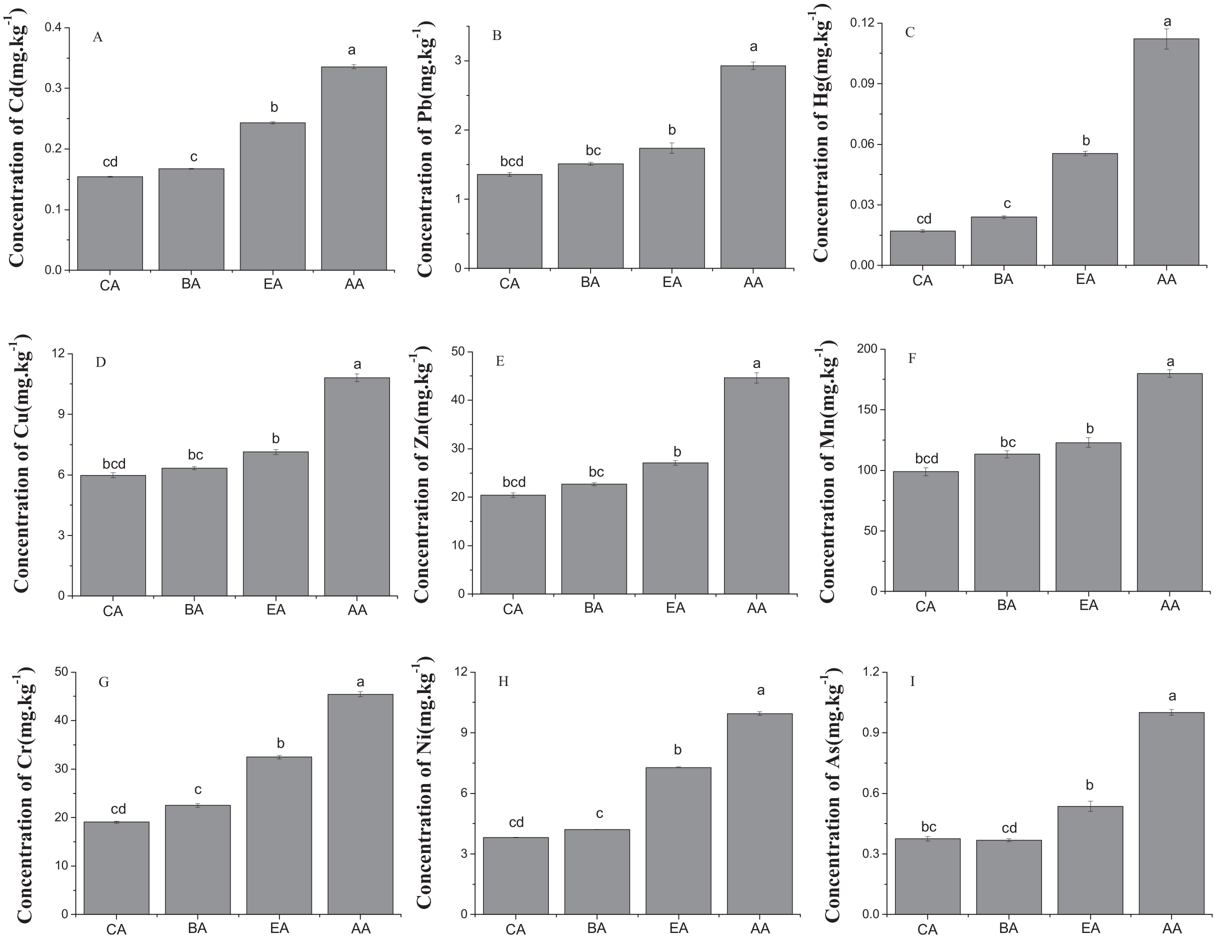

Fig. 3. Concentrations of heavy metal (mean ± standard error, mg/kg dry weight) in bamboo samples collected from FNNR, GNNR and LNNR. CA, BA, EA, and AA stand for the different function areas of core area, buffer area, experimental area and anthropogenically-dominated area as Fig. 2, respectively. Different letters (a, b, c, d) indicate significant differences identified using a Tukey post-hoc HSD test.

In soils, the concentrations of heavy metals (except for Mn) of the AA were significantly higher than in the nature reserves (Fig. 2F). The concentrations of heavy metals of the EA were significantly higher than those of the BA and CA (Fig. 2C). There were no statistically significant differences between the BA and CA for concentrations of Cd, Pb, Hg, Cu, Zn or Mn (Fig. 2A–F). Concentrations of all nine elements exceeded the background soil standard in the AA, and the concentrations of seven heavy metals (all but Cr and As) in the soil of the nature reserve exceeded standard (CNEMC 1990) (Fig. 2G and I). Concentrations of Cd, Zn and Mn exceeded the soil background criteria in the CA (Fig. 2A, E and F).

In bamboo samples, the concentrations of heavy metals in the AA were significantly higher than in the nature reserve. Between the EA and BA, we only observed differences in concentrations of Cd, Hg, Cr, Ni and As (Fig. 3A, C, G, H and I). Concentrations of heavy metals in bamboo did not differ between the BA and CA ($P > 0.1$).

The concentrations of heavy metals in water samples of the AA were significantly higher than in the nature reserve. Only concentrations of Zn, Mn and As differed in water samples taken in the EA and BA, and there were no significant differences in heavy metals in water between the BA and CA.

Similar patterns were observed in fecal samples. Except for Cu and Mn, concentrations of heavy metals in EA were significantly higher than those in the CA (Fig. 5D and F); concentrations of Hg, Zn, Cr, Ni and As between the EA and BA also differed significantly. Between BA and CA, the concentrations of Cd, Pb, Hg, Cr and As differed significantly (Fig. 5).

3.2. Correlations and multivariate analysis

Concentrations of heavy metals other than Mn and Cu increased with altitude (1200–2550 m; $0.1864 < R^2 < 0.6237$, $R^2_{Cu} = 0.0499$ (soil) and 0.0431 (bamboo), $R^2_{Mn} = 0.0426$ (soil) and 0.0365 (bamboo)) (Figs. A.1, A.2), whereas the concentrations of heavy metals in fecal samples (1250 m–2050 m) were not significantly correlated with elevation ($R^2 < 0.0599$) (Fig. A.4). Similarly, concentrations of heavy metals other than Mn and Cu in soil and bamboo increased with latitude (33°35′0″N–33°50′0″N) in the same longitude interval (107°40′45.00″E–107°60′0″E) ($0.2410 < R^2 < 0.4817$, $R^2_{Cu} = 0.0124$ (soil) and 0.0066 (bamboo), $R^2_{Mn} = 0.0694$ (soil) and 0.0199 (bamboo)) (Figs. A.5, A.6). The concentrations of metals other than Hg, Cr, and As in feces also increased with latitude (107°45′0″E and 107°55′0″E; ($0.0050 < R^2 < 0.0553$)) (Fig. A.8). There was no obvious relationship between either the different altitude or latitudes and the concentrations of heavy metals in water ($0.0014 < R^2 < 0.2183$) (Figs. A.3 and A.7).

Heavy metals other than Ni in feces and bamboo were strongly correlated ($0.688 < r < 0.909$). Cd, Hg, Cu, Zn and Mn in fecal and soil samples also were positively correlated ($0.697 < r < 0.836$). Correlation coefficients of the same element concentrations between bamboo and feces were greater than those between soil and feces; except for As, there were also significant correlations between metals in bamboo and soil ($0.565 < r < 0.833$, $P < 0.01$). The concentrations of heavy metals in water samples were not significantly correlated with any of the other samples except for Cu and As in soil (Table A.1).

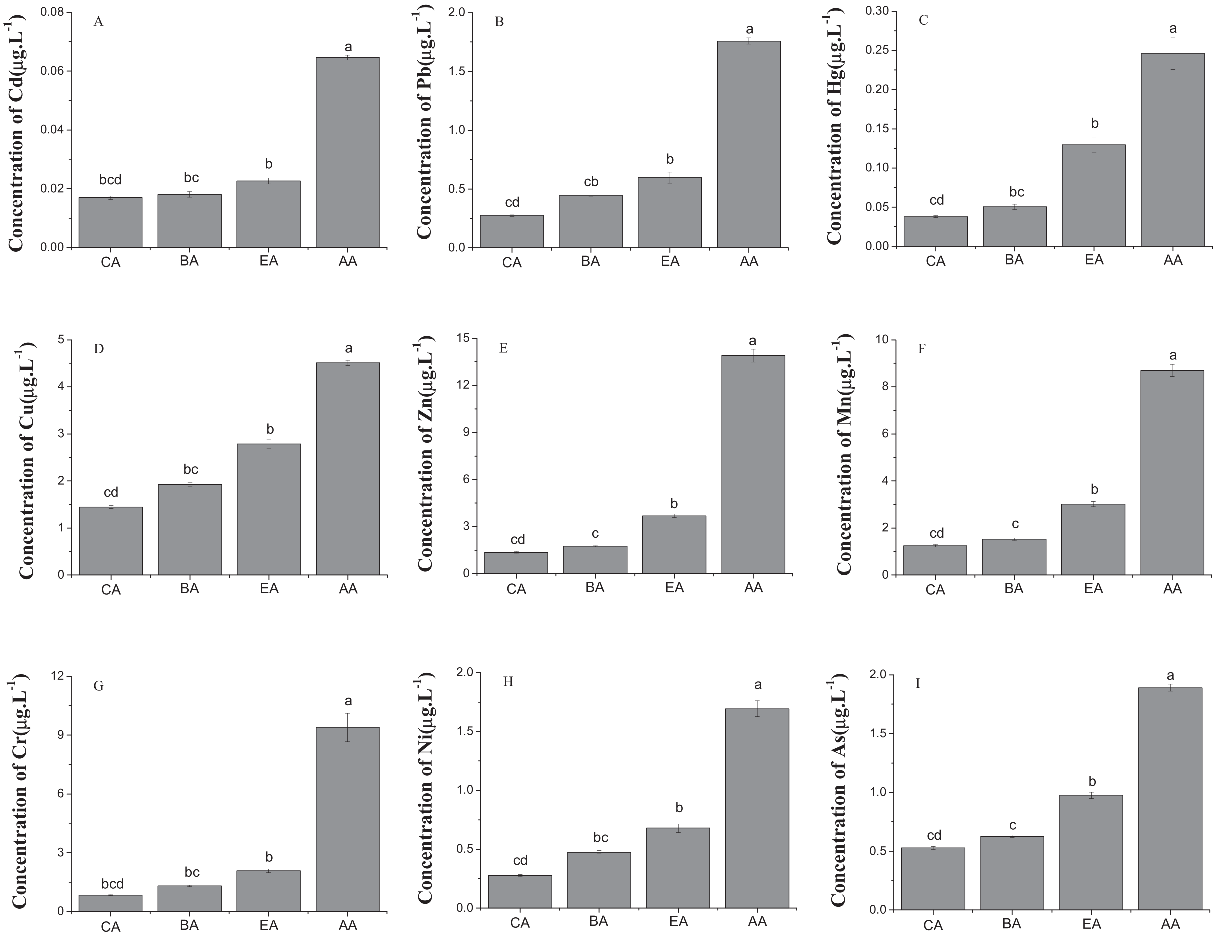

Fig. 4. Concentrations of heavy metal (mean ± standard error, $\mu g \cdot L^{-1}$) in water samples collected from FNNR, GNNR and LNNR. CA, BA, EA, and AA stand for the different function areas of core area, buffer area, experimental area and anthropogenically-dominated area as Fig. 2, respectively. Different letters (a, b, c, d) indicate significant differences identified using a Tukey post-hoc HSD test.

The PCA and HCA (Fig. 6) grouped the fecal metal concentrations into three main clusters. The first three principal components were able to explain 81.36% of the total variance. The first principal component, which explained 41.28% of the total variance, was positively associated with concentrations of Cu (0.96), Zn (0.88), Mn (0.87), and Ni (0.59). The second component, dominated by Hg (0.94), As (0.70), and Cr (0.90), accounted for 20.82% of the total variance, and the third component, associated primarily with Cd (0.87) and Pb (0.90), accounted for 19.26% of the total variance.

4. Discussion

4.1. Spatial distribution of heavy metals

The 67 nature reserves established over the past 50 years have protected two-thirds of the remaining wild pandas and just over half of their habitat. However, this flagship species still faces many risks (Chen and Ellison, 2017; Kang and Li, 2016), including environmental pollution (Chen et al., 2016; Chen et al., 2017a; Chen et al., 2017b). In this study, the concentrations of heavy metals in fecal samples, which can be regarded as indicators of exposure to pollutants (Pokorny et al., 2004), decreased from outside the proposed GPNP through the protected experimental, buffer, and core areas. This result suggests that pollutants are strongly associated with human activities, >90% of which occurred in EA and BA within the nature reserves. (Song et al., 2017). However, the concentrations of heavy metals that cause physiological damage to pandas and its habitats should be further studied.

We observed similar trends in heavy metal concentrations in bamboo, soil, and water. Concentrations of Cd, Zn, and Mn exceeded the soil background criteria in all areas. Cadmium has the highest hazard quotient (HQ) for the Qinling panda (Zheng et al., 2016). Zinc also may cause detrimental effects (Blagojević et al., 2009). Cd and Zn can continuously bioaccumulate in soil (Khan et al., 2012), leading to its accumulation in bamboo. The average Zn concentration in bamboo in our research is even higher than that in leaves of unfertilized and unmanaged moso bamboo in mountain base located in Seto (17.8 mg/kg) and Noguchi (22.7 mg/kg) (Umemura and Takenaka, 2014). Finally, the high concentration of Mn is mainly attributed to the parent materials of the Qinling Mountains (Liu and Zhang, 2003; Zhu et al., 1992).

Heavy metals in soil and bamboo were also positively correlated with elevation and latitude, implying that long-term transport of atmospheric pollutants from large northern cities are passing over the Qinling Mountains and being deposited on the summit, perhaps because there is higher precipitation at high elevation sites (Šoltés, 1998). Our results were similar to those of Ding et al. (2013) who reported that the concentration of heavy metals on the southern slope of Lushan Mountain increased with elevation due to air pollution from tourism, traffic exhaust, and fuel combustion. Distance from the source, direction and speed of winds, frequency and quantity of precipitation, and prevailing winds in the investigated area may influence downwind distribution of pollutants (Dragović et al., 2014). In parallel with our results, increasing concentrations of fluorochemicals were found in giant pandas as the distance from urbanization and industrialization decreased (Dai et al., 2006). Therefore, strict monitoring and prevention of excessive air pollution emissions in large cities near nature reserves

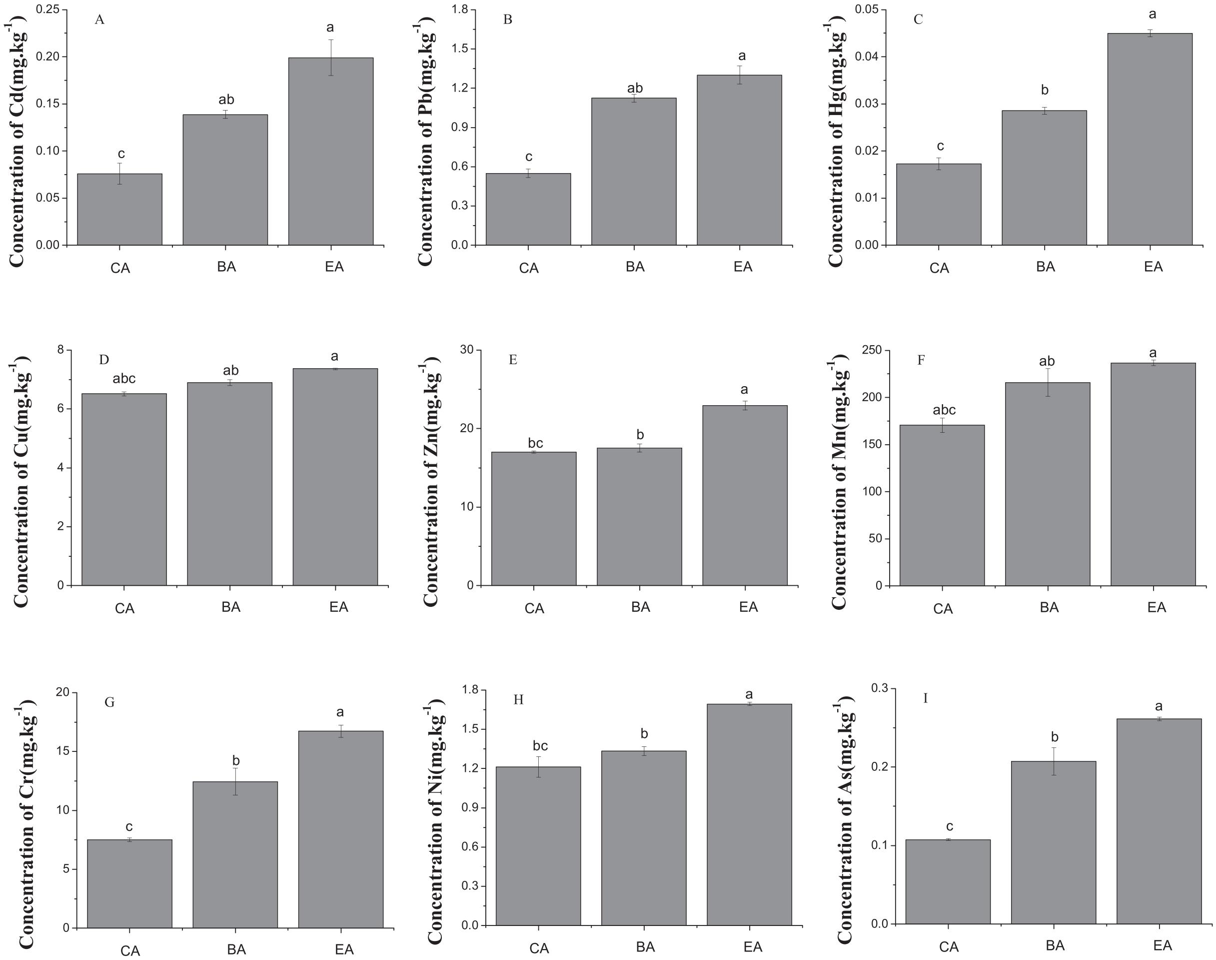

Fig. 5. Concentrations of heavy metal (mean ± standard error, mg/kg dry weight) in feces samples collected from FNNR, GNNR and LNNR. CA, BA, and EA stand for the different function areas of core area, buffer area, and experimental are, respectively. Different letters (a, b, c, d) indicate significant differences identified using a Tukey post-hoc HSD test.

could have a positive effect on the environmental protection of Qinling panda habitats.

4.2. Source analysis of pollution

The PCA and HCA suggest three main sources of the heavy metals. In one group, Cu and Mn are rich mineral resources in the Qinling Mountains (Zhu et al., 1992); their concentrations on the southern slopes naturally exceed soil reference levels (Liu and Zhang, 2003). Ni and Zn were classified as a natural source and related to the soil parent material (Liu et al., 2015; Luboš et al., 2005; Hernandez et al., 2003). We therefore hypothesize that metals in this group were synthetically influenced by soil parent materials. Metals in the second group have a different origin. As and Hg are usually considered indicators of industrial

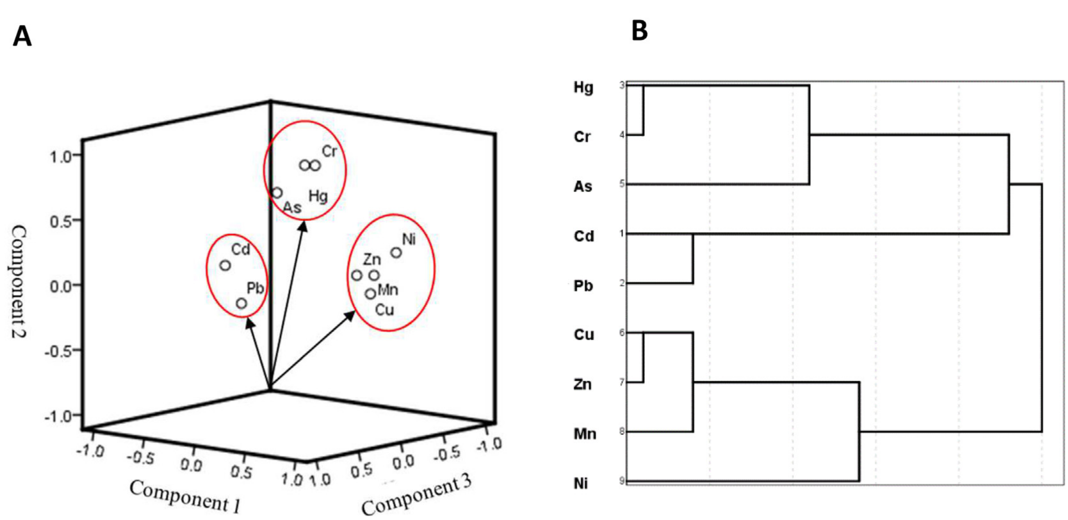

Fig. 6. Principal component triplot (A) and hierarchical clustering analysis (B) of nine heavy metals in feces of Giant Pandas taken at FNNR, GNNR and LNNR.

emissions and combustion of coal and waste, all of which are major anthropogenic sources of total Hg emissions in China (Yang et al., 2011). Fuel combustion also is considered to be an anthropogenic source of Cr (Ha et al., 2014). Liu et al. found that As, Hg and Cr were higher in feces of golden monkeys in Qinling during the heating season, suggesting that these three elements were associated with pollution caused by fuel combustion in winter (Liu et al., 2015). Finally, Cd and Pb also are classified as traffic and agriculture source elements, supported by Zheng's investigation of heavy metals in soil along 108 national roadsides (Zheng et al., 2016) and Zhang's investigation of heavy metals in soil along the Qinghai-Tibet railway (Zhang et al., 2012). Vehicle emissions are an important source of Pb pollution (Wang et al., 2018). Although sales of leaded gasoline in China ended in 2000, historical lead pollution cannot be ignored. Cd mainly comes from losses from gasoline and lubricating oil (Johansson et al., 2009), and agricultural activities (Bolan et al., 2014).

Atmospheric pollutants are deposited not only on the surface of bamboo consumed daily by pandas but also in soil from where it has bioaccumulated in bamboo (Chen et al., 2017b). An average of 20 kg of fresh bamboo can be consumed by a wild giant panda every day (Tuanmu et al., 2012), and bamboo accounts for >99% of their diet (Hu, 2000). Concentrations of heavy metals in fecal samples are positively correlated with those in bamboo samples, suggesting that polluted bamboo is the main direct route of exposure of pandas to these pollutants.

4.3. Pollution control strategy and policy advice

4.3.1. Core area expansion is a positive political decision

Currently, 33 panda populations are distributed in six mountains in Sichuan, Shaanxi and Gansu Province. Twenty-two of these have fewer than 30 individuals and 18 have fewer than 10 individuals. However, the status of habitat fragmentation has not changed fundamentally, especially in the Qinling Mountains, where the panda population density ≈0.096 individual/m^2 (State Forestry Administration, 2015). There, approximately 345 individual Qinling pandas are distributed in six isolated areas; the central and western regions are mostly intact, whereas the eastern region is highly fragmented (Fig. 8A) due to severe anthropogenic disturbance, particularly tourism (WWF, 2016). Thus, the expansion of core area to 4386 km^2 is a positive political decision in the national GPNP plan, which is doubling the existing core area to provide efficient protection of Qinling panda habitat (Fig. 8B). At the same time that giant pandas accumulate pollutants by eating bamboo, this staple food is also declining. Bamboo flowering and subsequent mortality increased by 68% according to the Fourth Report (Table 1). This decline, coupled with climate change that is reducing the amount and distribution of many bamboo species, is further exacerbating the loss and fragmentation of panda habitat (Tuanmu et al., 2012). To ensure the health and adequacy of bamboo in a broader core area, we strongly suggest establishing a protection and monitoring network for it to provide early warning of bamboo flowering, disease and pests.

Table 1
Comparison of general disturbances in the Qinling habitat of the Fourth and Third Investigation Report.

Interference types	Interference points in the Third Report	Interference points in the Fourth Report	Change (%)
Mining	**2**	**21**	**950.00**
Bamboo flowing	**125**	**210**	**68.00**
Cultivating	229	137	−40.17
Roads	1279	452	−64.66
Tourism	66	31	−53.03
Herb collecting	1090	297	−72.75
Cutting Bamboo	556	56	−89.93
Grazing	498	185	−62.85
Cutting trees	3165	152	−95.20
Poaching	382	65	−82.98

4.3.2. Strict control and reduction of mining within GPNP

The Qinling Mountains are rich in mineral resources (Zhu et al., 1992) and field encounter rates of mining increased by 950% in the Fourth Report (Table 1). Mining increases Mn, Cu, Zn and Ni inputs, associated noise, construction vehicles, and water contamination, all of which disturb and fragment panda habitat. However, ecological restoration in such mining regions is extremely slow, which inevitably limits the activity range of giant panda. Hence, reducing the interference of mining mainly relies on relevant agencies to strengthen project approval, supervision, and inspection of forest land occupation, and timely remediation of areas damaged by mines.

4.3.3. Control pollution emissions from upwind sources

Wind is one of the dominant drivers of pollutant transmission (Dragović et al., 2014). Xi'an City is upwind of the Qinling panda habitat (Fig. 7A and B) and severe atmospheric pollution in the Qinling Mountains originates primarily in Xi'an (Wang et al., 2013; Chen et al., 2017b) (Table A.2). For example, in January 2013, the highest observed $PM_{2.5}$ concentration in Xi'an was 700 $\mu g \cdot m^{-3}$/h, and the monthly average concentration was 250 $\mu g \cdot m^{-3}$ during a serious air pollution incident (D. Wang et al., 2014; S. Wang et al., 2014). Therefore, successful management of the Qinling panda in the GPNP will require effective control and management of air quality of large cities upwind of Qinling habitats. Pollution of As, Hg, and Cr from coal and industrial emissions can also be reduced by energy conservation and emissions reductions outside nature reserves when planning the GPNP.

4.3.4. Road abandonment and ecotourism restrictions in Qingling GPNP

Road construction is a major cause of habitat loss and fragmentation, and also is an important source of Pb and Cd pollution. The total length of roads in Qinling panda habitat in Shaanxi alone is nearly 1200 km. Although the road interference points were reduced by 65% between the Third and Fourth Investigation Reports (Table 1), traffic flow has grown rapidly in the past decade. The annual average daily traffic volume of national ways and highways has increased by 35% and 62%, respectively (Ministry of Transport of the People's Republic of China, 2008, 2017). The Fourth Investigation Report also pointed out that the reduction of road interference mainly refers to the abandonment of logging roads, not to vehicle lanes. Highways and railways actually increased, resulting in an increase of road disturbance intensity. Furthermore, tourism has expanded road-building across the panda's range, even in protected core zones of nature reserves (Liu et al., 2016). Although the Fourth Report showed a 53% decrease in tourism, this result can be attributed to surveys being done during non-tourist seasons; in fact, tourism has increased significantly (Zhou, 2017). Therefore, we strongly recommend an electric, noise-free, and non-polluting high-speed rail system in the Qinling panda national park; reduction of motorways; and abandonment of existing roads to reduce the pollution of Cd and Pb. Meanwhile, we advocate strict control of tourism in the east Qinling habitat to avoid further fragmentation. Ecological restoration also is urgently needed in smaller patches.

4.3.5. Grain for green and population migration within Qinling GPNP

One of the possible sources of Cd pollution input is the long-term use of chemical fertilizers and livestock manure (Nookabkaew et al., 2016). For the nature reserve in Qinling habitat, Cd sources are mostly livestock organic manure due to the prohibition of chemical fertilizer. In addition, large villages and farmland also increase the area of non-forest patches, fragmenting panda habitat (Zhou, 2017). Although the farming interference points were reduced by 40% between the Third and Fourth Investigation Reports of giant pandas (Table 1), we recommend still further reduction of agricultural activities, returning farmland to forests in protected areas, restoring bamboo growth, increasing forest cover, and

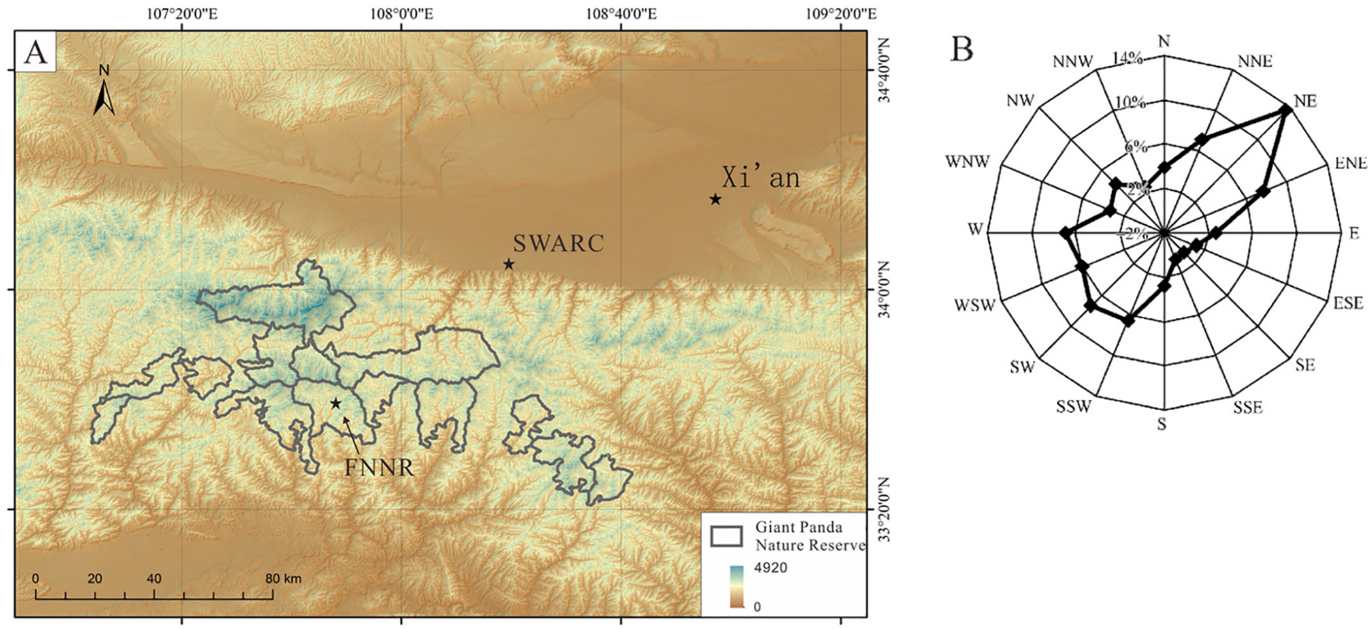

Fig. 7. Giant panda distribution point and nature reserve in Qinling, Shannxi (A); the wind direction frequency in Xi'an City from 1960 to 2012 (D. Wang et al., 2014; S. Wang et al., 2014) (B).

implementing resettlement for villagers outside the Qinling GPNP. Interference from grazing and herb collection also need to decrease.

5. Conclusion

Our study demonstrated that the CA was less polluted by heavy metals, followed by the BA, and the EA was heavily contaminated in the Qinling panda nature reserves (NR). At the same time, heavy metal pollution increased with altitude and decreased with distance to cities. Given these environmental characteristics, there is an urgent need to rethink the design of the Qinling portion of the GPNP aimed at conserving the Qinling panda to make it more environmentally sustainable. Appropriate policy interventions to reduce heavy metal inputs should include: (1) Scaling up the distribution of existing habitats and adherence to the basic principle of the CA, BA, and EA to gradually weaken heavy metal pollution from anthropogenic activities; (2) Expanding the CA and designating areas in which human activities are totally banned; (3) Considering degree of environmental pollution in the GPNP and locating it upwind of large industrial cities and future urbanization, while implementing strict emissions reductions standards in large cities and industrial intensive areas around and upwind of the GPNP; (4) Abandoning original roads, reducing agricultural activities and forbidding the exploitation and utilization of forest resources and mines; (5) Establishing a protection and monitoring network for bamboo to realize a suitable broader core area for giant pandas.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.03.070.

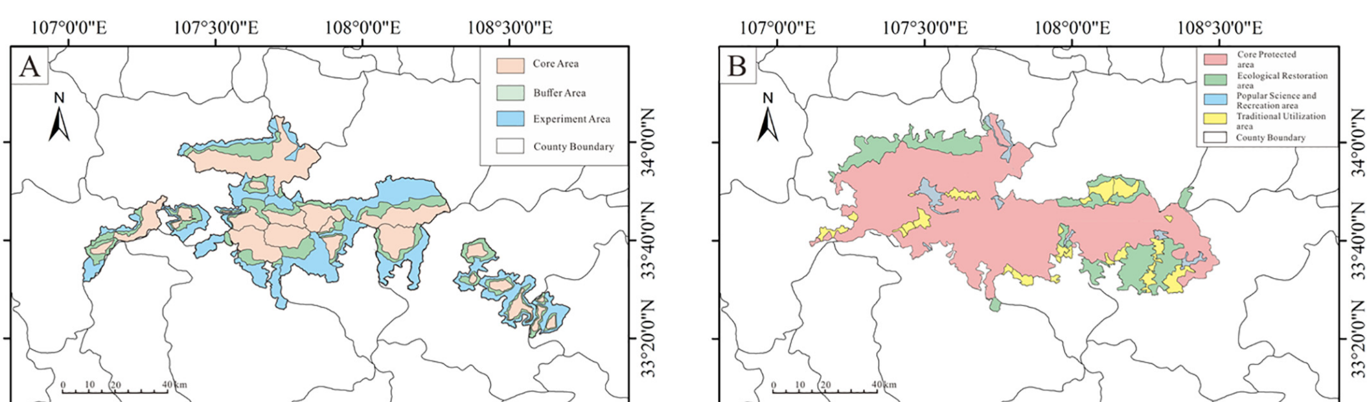

Fig. 8. Functional areas of Qinling nature reserves in three different color (A); functional areas of Qinling Giant Panda national park in four different color (An et al., 2017) (B). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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