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Research Article

Factors Predicting Den Use by Maternal Giant Pandas

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ABSTRACT We studied the denning ecology of giant pandas (*Ailuropoda melanoleuca*) in the Foping Nature Reserve, China. We identified 17 used and 21 unused cavities of appropriate size to accommodate denning and measured several variables potentially affecting the suitability of these cavities for panda denning. Principal component analysis, combined with traditional univariate tests, indicated that maternal females preferred deeper cavities with a high interior-to-entrance ratio for height and width, suggesting a preference for narrow entrances and roomy chambers. Microhabitat features, including slope and distance to water, were also useful in predicting den use by maternal females. We believe that the availability of suitable dens may limit population size, especially in areas where tree dens have been eliminated by logging of old growth forests. Conservation managers in giant panda reserves can use our data to determine the number of suitable panda dens that are in an area, estimate whether there are enough for the adult female population to use as birthing dens, and—if needed—construct suitable artificial dens to increase the rate of reproduction. (JOURNAL OF WILDLIFE MANAGEMENT 71(8):2694–2698; 2007)

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KEY WORDS *Ailuropoda melanoleuca*, denning ecology, endangered species, giant panda, limiting resources, maternal care, ursids.

Hibernation in bears probably evolved as a mechanism to circumvent the problems of inclement weather and food shortages during winter (Lindzey and Meslow 1976, Johnson and Pelton 1981). However, dens are also used for birthing, even among ursid species that do not hibernate, such as the giant panda (*Ailuropoda melanoleuca*; Garshelis 2004). Ursid young, being extremely altricial, are dependent on access to suitable dens for survival. Dens may protect cubs from predators and buffer them from cold and wet weather. Several structural characteristics of dens, such as dimensions of the entrance and interior, may influence how well these functional needs are met (Johnson and Pelton 1981, Petram et al. 2004). Microclimatic variables outside dens may also affect their suitability (e.g., distance to water, accessibility, slope, aspect, vegetation structure, and food resources; Ovsyanikov 1998, Seryodkin et al. 2003).

To the extent that these factors affect offspring survival, the availability of suitable dens may be a limiting resource affecting population size. For example, forest management practices that affect the availability of suitable dens can significantly decrease cub survival in American black bears (*Ursus americanus*; White et al. 2001). It is important to research which attributes of dens are associated with optimal offspring survival. Such studies of fitness are difficult to carry out, especially for K-selected species such as bears, but it is reasonable to assume that females have evolved through natural selection to identify and choose dens with characteristics that correlate with offspring survival. To date, few studies have addressed choice of den sites by comparing the characteristics of used versus unused potential den sites (but see Petram et al. 2004).

The giant panda is critically endangered, with a wild population estimated by the 2000 national census to be approximately 1,600 individuals confined to 6 isolated mountain ranges in China. Giant panda cubs are the most altricial of all eutherian mammals (Gittleman 1994) and, therefore, are likely to be especially sensitive to suboptimal conditions in and around maternal dens. The first 3–4 months of life are spent in the den, with the mother leaving only occasionally for food and water (Hu et al. 1985, Schaller et al. 1985, Zhu et al. 2001). Panda mothers face substantial challenges to the successful rearing of offspring in captivity (Zhang et al. 2000) and probably also in the wild. Some limited data are available on den use in the wild (Schaller et al. 1985, Zhu et al. 2001), but these studies do not allow den preferences to be ascertained. If pandas are forced to use dens with less-preferred attributes, they may forgo reproduction, abandon cubs, or suffer higher cub mortality. Thus, an important first step toward understanding conservation needs for this species is to identify the characteristics of preferred den sites.

We measured several characteristics of used and unused cavities in the Foping Nature Reserve, China. Our goal was

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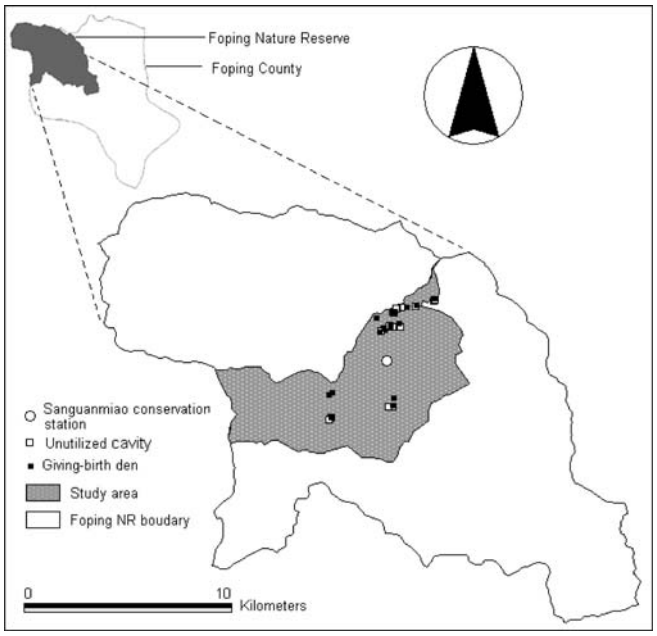

Figure 1. Distribution of potential giant panda dens in Sanguanmiao district, Foping Nature Reserve, China, 2001–2005.

to provide data on den preferences that can be used to manage for increased den availability and quality to optimize panda population growth, aiding in the rapid recovery of the species.

STUDY AREA

Spanning about 293 km^2, Foping Nature Reserve (33°32′–33°45′N, 107°40′–107°55′E; hereafter Foping), Shaanxi Province, China was established in 1978 primarily for the preservation of giant pandas. Foping has been an active site for intensive conservation monitoring for more than a decade and contains 5 conservation stations and 6 monitoring bases. Our survey area covered approximately 62 km^2 of habitat known to be occupied by giant pandas (Fig. 1).

The elevation in Foping ranged from 980 m to 2,904 m. The average annual temperature was about 13° C and the total annual rainfall was 920 mm. July was the month with the highest rainfall (200 mm) and highest temperature (28° C), and January was the coldest month (−3° C). Vegetation in the reserve showed characteristic vertical zonation, with deciduous broadleaf forests below 2,000 m, birch (*Betula* spp.) forests between 2,000–2,500 m, and conifer forests, shrub, and meadows above 2,500 m (Ren et al. 1998). Two bamboo species, *Bashania fargesii* (below 1,900 m) and *Fargesia qinlingensis* (above 1,900 m), were dominant in the reserve and comprised the majority of the giant panda diets.

METHODS

We visited den sites from September 2005 to March 2006 but relied on records dating back 5 years. For each potential den site, we recorded 17 variables (Table 1). Foping Reserve staff has conducted frequent surveys for pandas and panda sign for the past 5 years, documenting the location of potential den sites, defined as cavities large enough for an adult panda to enter and stand quadrupedally inside. We set these criteria to ensure that we excluded from analysis potential dens that fell outside the normal size range for use by pandas. We used these criteria to obviate the need to make subjective evaluations of what might constitute a suitable den site from a panda's perspective. Instead, we used these criteria to provide human managers of panda populations with objective and quantifiable measures for determining suitability of potential den sites. During the 5 years in which we systematically monitored the study site, cavities were visited at least once monthly during the denning season from July to November. If a cavity was occupied by a mother and cub at any time during this period, we labeled it used; otherwise, we labeled it unused. This method was superior to inferring panda use from hair or feces, which might be left by giant pandas that did not use the den for rearing cubs. This research was approved by the Zoological Society of San Diego's Institutional Animal Care and Use Committee (Proposal 221).

We conducted independent-samples *t*-tests to compare used and unused cavities when data were normally distributed and Mann–Whitney *U* tests when distributional assumptions were not met. One variable, vegetation, was on a nominal scale and we used a chi-square test. Because multicollinearity will either inflate or reduce the contribution of predictor variables, we used principal component analysis (PCA) to transform original continuous variables into several uncorrelated principal components to eliminate multicollinearity. Then we used the subsets of principal components with the largest proportion of the total variance and the categorical variables not included in the PCA as new variables in subsequent logistic regression to identify the minimal subsets of variables that best explained den use (Jabi et al. 2003, Sebastein et al. 2003). The logistic regression analysis from generalized linear framework allows the inclusion of categorical variables. We set the significance level at $P \leq 0.05$.

RESULTS

In the Sanguanmiao district of Foping Nature Reserve, we surveyed 38 rock dens (Fig. 1) and found 17 dens occupied by mothers with cubs at least once during the 5-year study period. Only 4 variables (i.e., depth, interior:entrance width ratio, interior:entrance ht ratio, and distance to water) were significantly different between used and unused cavities. Compared with the unused cavities, female giant pandas preferred cavities that were >50% deeper, nearly twice the ratio of height and width of interior to entrance, and less than half as far to water (Table 2), testifying to the biological significance of these variables.

Principal component analysis extracted 4 principal components with eigenvalues >1.00, and their cumulative contribution explained 73% of the variation in the data (Table 3). In interpreting the results from the PCA, we focused on variables with loading coefficients >0.50, indicating that they made larger contributions to the outcome of the analysis. For principal component (PC) 1,

Table 1. Definition and method of measurement for giant panda den characteristics and microhabitat, Foping Nature Reserve, China, September 2005 to March 2006.

Variables	Definition and measurement
Altitude (m)	Altitude at den sites; measured with Global Positioning System
Slope (°)	Slope at den sites; measured with a 65-type box and needle
Slope aspect (°)	Slope aspect at den sites; measured with a 65-type box and needle
Den aspect (°)	Aspect at each den entrance; measured with a 65-type box and needle
Entrance ht (cm)	Ht at each den entrance
Entrance width (cm)	Width at each den entrance
Depth (cm)	Distance from the entrance to the back of each den
Interior ht (cm)	Max. ht in each den
Interior width (cm)	Max. width in each den
Interior:entrance ht ratio	(Ht of interior)/(ht of entrance)
Interior:entrance width ratio	(Width of interior)/(width of entrance)
Humidity	Degree of humidity on the ground in den: dry, medium, or wet
Vegetation	Vegetation at den sites: deciduous forest, mixed deciduous and coniferous forest, coniferous forest, or other
Distance to water (m)	Direct distance from the den to the nearest water source
Heterospecific feces	Presence or absence of feces left by other mammals in the den

the most important variables were—ordered by the size of the loading coefficient—entrance height, entrance width, interior:entrance width ratio, and distance to water, suggesting that female pandas focus on these characteristics when selecting a birthing den. Together, these variables explained 27% of the variation. An additional 19% of the variation in our data was explained by PC2. The depth of cavity was the most important variable in PC2, followed by the width of the interior, and the steepness of the slope where the cavity was located. PC3, explaining 15% of the variation in our data, identified cavity aspect and slope aspect as additional variables contributing to selection of dens by maternal females. PC4 explained another 11% of the variation in our data, suggesting that the height of the interior, interior:entrance height ratio, and the elevation of the cavity may be secondary cavity characteristics important for den site selection.

We only included the 2 factors explaining the most variation in our data, PC1 and PC2, in the forward stepwise logistic-regression equation. The combination of variables in these components together correctly predicted cavity use 80.6% of the time ($G^2 = 26.63$, df = 2, $P < 0.001$; Table 4), suggesting that conservation managers could use criteria derived from our data to predict which dens will or will not be used by maternal pandas. Combined with the results from PCA, we concluded that variables with relatively greater contribution to PC1 and PC2 (i.e., entrance ht, ratio of width, entrance width, distance to water, depth, interior width, and slope) were important factors predicting den use by maternal female giant pandas.

DISCUSSION

Our data indicated that giant panda females selected maternal dens with specific characteristics: a narrow

Table 2. Pairwise comparisons for all variables for used and unused cavities for giant pandas in Foping Nature Reserve, China, 2001–2006.

	Use of cavity by maternal pandas					
	Used		Unused			
Variables	$\bar{x}$	SE	$\bar{x}$	SE	t or U[a]	P
Elevation	1,849	91	1,826	122	$t = -0.6$	0.54
Slope	41.2	9.9	37.0	8.1	$t = -1.4$	0.16
Slope aspect	191.7	45.4	183.5	79.3	$t = -0.4$	0.71
Den aspect	202.1	66.8	197.6	78.3	$t = -0.2$	0.85
Entrance ht	136.1	71.7	173.5	90.5	$t = 1.4$	0.17
Entrance width	206.9	182.3	290.6	239.0	$t = 1.2$	0.24
Depth	369.2	209.8	236.4	129.3	$t = -2.3$	0.03
Interior ht	135.3	76.8	117.1	52.2	$t = -1.5$	0.16
Interior width	240.9	182.9	172.0	122.3	$t = -1.4$	0.18
Interior:entrance ht ratio	1.14	0.54	0.72	0.31	$t = -2.8$	0.009
Interior:entrance width ratio	1.76	1.32	0.86	0.72	$U = 95.5$	0.02
Humidity	1.00	0.00	1.30	0.73	$U = 144.5$	0.10
Vegetation[b]	D = 9	M = 8	D = 14	M = 6	$\chi^2 = 1.1$	0.29
Distance to water	79.1	76.9	177.8	148.3	$U = 91.5$	0.03
Heterospecific feces	0.18	0. 39	0.20	0.41	$U = 166.0$	0.86

[a] t = independent-samples t-tests; U = Mann–Whitney U tests.
[b] D = deciduous forest; M = mixed coniferous–deciduous forest.

Table 3. Principal component analysis comparing giant panda den characteristics and microhabitat for used and unused cavities, Foping Nature Reserve, China, 2001–2006.

Variables	Principal components (PC)			
	PC1	PC2	PC3	PC4
Entrance ht	0.84	0.28	−0.29	0.10
Interior:entrance width ratio	−0.82	0.17	0.11	0.22
Entrance width	0.76	0.46	0.16	−0.14
Distance to water	0.53	−0.24	0.40	0.005
Depth	0.21	0.86	−0.25	−0.016
Interior width	0.011	0.79	0.37	0.13
Slope	−0.058	0.63	−0.11	−0.046
Den aspect	−0.12	0.015	0.89	−0.044
Slope aspect	0.024	−0.039	0.71	0.16
Interior ht	0.18	0.36	0.15	0.85
Interior:entrance ht ratio	−0.37	−0.14	0.41	0.69
Elevation	0.28	0.36	0.30	−0.67
Eigenvalue	3.28	2.33	1.82	1.37
% of variance	27.35	19.37	15.15	11.43

entrance and roomy, deep interior chambers, located close to water. These findings suggest that—among the variables we studied—the characteristics of the den itself are more important than microhabitat features surrounding the den. A small entrance with a deep roomy interior should minimize heat loss while still providing room for the mother and cub to make small movements. These thermal properties may not only affect the cubs directly but may also allow the mother to leave the den earlier for brief periods to obtain food and water. The small entrance and deep cavity may serve as a deterrent to predators, making it easier for the mother to detect and prevent entry by predators, which include the Asian wild dog (*Cuon alpinus*), yellow-throated marten (*Martes flavigula*), and Asiatic golden cat (*Catopuma temmincki*; Hu et al. 1985, Schaller et al. 1985, Hu 2001). It is interesting that pandas selected against smaller interiors, even when the cavity was of sufficient volume to contain the mother and cub. Comfort and ease of movement may explain this preference, but captive pandas appear more prone to accidentally step on and crush a cub when confined to too small a space (R. R. Swaisgood, Zoological Society of San Diego, personal observations). Together, these 3 factors (i.e., thermal properties, predator deterrence, and risk of cub injury) may explain the preferred characteristics of dens. Thus, it seems plausible that if dens with these characteristics were not available cubs would suffer lower viability and survival. Panda mothers do not leave the den for several days following parturition and, for several weeks, make short forays outside to eat, drink, and eliminate waste (Zhu et al. 2001). Proximity to water is likely important so that the female can return to the den quickly to provide the cub thermal support and protection from predators.

In the Wolong Nature Reserve, where logging has not removed most of the old growth forests, maternal pandas often den in tree cavities (Schaller et al. 1985). Although the possibility of preferential selection was not studied for the Wolong population, it is possible that tree dens are preferred by giant pandas. Interestingly, the structural characteristics

Table 4. Results from logistic regression model using 2 extracted principal components explaining the most variance for predicting use of potential den cavities by maternal giant pandas in the Foping Nature Reserve, China, 2001–2006.

Factors	β[a]	SE	Wald statistic	Significance
PC1[b]	−2.11	0.88	5.79	0.016
PC2	1.40	0.65	4.62	0.032
Constant	−0.45	0.50	0.80	0.37

[a] β = parameter estimate of the logistic regression model.
[b] PC = principal component.

of used cave dens in our study were more like those of tree cavities—a narrower entrance and larger chamber inside. However, the characteristics of tree and cave dens still differ substantially. For example, den entrances for used cave dens in Foping are still 6 times larger than those found in Wolong tree dens.

These data would not have been possible if the Foping staff had not maintained an active monitoring program over the past decade or so. New knowledge of panda ecology—other than habitat (e.g., Zhang et al. 2006)—is rare because of the 1994 governmental moratorium on radiocollaring (Durnin et al. 2004). In the absence of detailed data afforded by radiotracking, this study highlights the value of intensive on-the-ground monitoring in protected areas.

MANAGEMENT IMPLICATIONS

If availability of suitable dens limits population growth (as found for black bears; White et al. 2001), then management practices can be altered to increase the availability of optimal denning sites. Conservation managers in panda reserves can use our data on the size and shape of preferred cavities, and distance to water, to estimate the number of suitable cavities available for birthing dens. They should also survey the population to determine the number of female pandas likely to give birth in the area in a given year. If the number of suitable dens is not sufficient to meet this need, then the reserve should be managed to increase den availability. A long-term goal is to increase den availability by allowing the return of old growth forests with trees of sufficient size and age to support dens of suitable size for pandas. In the short term, managers can construct artificial dens of similar dimensions to the preferred den sites in our study and place them sufficiently close to water. In reserves where suitable dens are deficient, these conservation measures could aid in rapid population growth and recovery.

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