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POPULATION VIABILITY ANALYSIS COMPUTER MODEL OF GIANT PANDA POPULATION IN WUYIPENG, WOLONG NATURAL RESERVE, CHINA

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Abstract: The giant panda (*Ailuropoda melanoleuca*) population in Wuyipeng is a well-protected, well-studied population, and many parameters for population viability analysis (PVA) computer modeling are available. We used Vortex software (Version 5.1) to model the conservation status of the Wuyipeng giant panda population. The initial population size modeled was 25 in 1981 at Wuyipeng, with a carrying capacity of 62. Because of a bamboo (*Bashania fangiana*) die-off in 1983, carrying capacity declined from 62 to 50, with a 4.21% annual decrease for 5 years. Results showed a potential annual growth rate of 1.066. Though this small population has a potential for population growth, the extinction rate of all simulations were >10%, and expected heterozygosity retained <80%, even without inbreeding depression or catastrophes. All extinction rates modeled failed to meet the minimum tolerance of 2% for probability of extinction in 100 years set by the conservation objectives under realistic assumptions. Therefore, these results support immediate conservation measures for wild giant pandas in China.

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Key words: *Ailuropoda melanoleuca*, China, demography, extinction, giant panda, survival, viability.

Life table analyses yield average long-term projections of population growth or decline but do not reveal the fluctuation in population size that results from variability in demographic processes. When a population is small and isolated from conspecifics, these random fluctuations can lead to extinction even if populations have, on average, positive population growth (Lacy 1991, 1993). Population viability analysis (PVA) is a tool for evaluating the probability of extinction and loss of variation in populations. It provides a quantitative summary of the conservation status of populations and permits evaluation of the effects of different management recommendations on long-term survival of the population (Ballou and Padua 1990, Shaffer 1990). PVA computer models have been used in recent years to evaluate animals such as Puerto Rican parrot *(Amazona vittata;* Lacy et al. 1989), eastern barred bandicoot (*Perameles nasuta*; Lacy and Clark 1990), Leadbeater possum *(Gymnobelideus leadbeateri;* Lindenmayer et al. 1991, 1993, Lindenmayer and Lacy 1995, Lindenmayer and Possingham 1996), Florida panther *(Felis concolor;* Seal and Lacy 1989), Florida key deer *(Odocoileus virginanus clavium;* Seal and Lacy 1990), lion tamarins (*Leontopithecus* spp.; Ballou and Padua 1990, Seals et al. 1990), Javan rhinoceros (*Rhinoceros sondaicus;* Seals and Foose 1989), African elephant *(Loxodonta africana;* Armbruster and Lande 1993), red-cockaded woodpeckers *(Picoides borealis;* Haig et al. 1993), and crested ibis *(Nipponia nippon;* Li 1996).

The giant panda population in Wuyipeng Study Area, Wolong Natural Reserve, China, has been well protected and long studied through the cooperation of the China Wildlife Conservation Society and other organizations (Schaller et al. 1985, Hu et al. 1990). Many parameters required by PVA computer model are known for this population. This project evaluated the current conservation status of the giant panda population in Wuyipeng, Wolong Reserve and evaluated the sensitivity of its status to potential changes in biology, ecology, environment, and management.

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METHODS

A number of genetic computer models such as Vortex (Lacy, 1993), ALEX (Possingham and Davies 1995), and RAMAS/Space (Akcakaya et al. 1990) are available for PVA, and the selection of the most appropriate one depends on many factors including the characteristics of taxon under investigation, the particular management problem in question, and how these match the strength and limitations of a given package (Lindenmayer et al 1995, Lindenmayer and Possingham 1996). We selected Vortex (Version 5.1) to model the giant panda population for 100 years. Each simulation was repeated 1,000 times. Both probability of extinction and expected heterozygosity were tracked over time. When the population size dropped to zero, it was considered extinct. The probability of extinction was based on the average extinction rate over all simulations. Expected heterozygosity was calculated by monitoring allele frequencies over time in the population (Ballou and Padua 1990). To evaluate sensitivity of population trends, each population was simulated several times using different starting parameters.

Our computer model concentrated on the giant panda population in Wuyipeng Study Area, Wolong Natural Reserve, China. Wuyipeng Study Area was established in 1978 with a total area of about 30 km^2 and many studies of the biology and ecology of this population have been completed (Schaller et al. 1985, Hu et al. 1990). These results allow us to estimate critical parameters such as reproduction, age-specific mortality, and carrying capacity that are required for Vortex.

Reproduction is a very important parameter in the Vortex model. Normally, the breeding age of pandas in the wild is 7 years for females and 8 years for males. Sex ratios are 1:1 and maximum reproductive age is 20 years. Females produce at best 1 litter/year with a maximum of 2 offspring (Wei et al. 1988, 1989, 1990; Hu 1990, Wei and Hu 1994). The reproductive rate of giant pandas is low (Table 1; Wei and Hu 1994). Each year 37.5% of females produce no offspring, 58.3% of females produce 1 offspring, and 4.2% of females produce 2 offspring (Table 2).

Age-specific mortality of giant pandas is difficult to estimate in the field. We developed a life table to evaluate mortality (Table 2; Wei et al. 1989, 1990) from our fieldwork using droppings and radiocollar methods (Hu 1987). The population size was estimated at 25 in 1981.

Carrying capacity of the giant panda is complex, and influenced by factors such as spatial distribution, home range, optimal feeding strategy, and food biomass. Because of the difficulty in estimating these parameters, we used food biomass to estimate the carrying capacity in Wuyipeng Study Area. Reid et al. (1989) estimated the total biomass of the study area and yearly consumption/ panda of bamboo before and after the bamboo die-off in 1983. During 1981–82, the total bamboo biomass in the Wuyipeng Study Area was 2.9×10^7 culms. Eighteen giant panda consumed a total of 8.39×10^6 culms, or 4.7×10^5 culms/panda (Reid et al. 1989). Therefore, we estimated the 1981–82 carrying capacity as 62 pandas ($2.9 \times 10^7/4.7 \times 10^5$). In 1983, *Bashania fargessi* flowered and died off, reducing bamboo biomass to 1.7×107 culms by 1986. Fifteen giant pandas consumed a total of 5.15×10^6 culms, or 3.4×10^5 culms each (Reid et al. 1989). Thus, the carrying capacity in 1986 was estimated as 50 pandas ($1.7 \times 10^7/3.4 \times 10^5$). The carrying capacity in Wuyipeng Study Area decreased by 12 pandas, with an annual decrease of 4.21% years from 1981 to 1986.

Reduced survival and reproduction due to inbreeding is a common phenomenon in mammal species, especially with small populations. The PVA model considered the effects of inbreeding depression on survival by stochastically modeling the effects of lethal genes in the population (Ballou and Padua 1990). Ralls et al. (1988) studied inbreeding depression of 40 species of captive mammals and found the average lethal equivalents was 3.14 for 40 captive mammals. They predicted that the lethal equivalents for wild isolated populations were higher than those of captive populations. Because data on the inbreeding depression of giant pandas were not available, no inbreeding depression and a very low inbreeding depression (1 lethal equivalent) were used to model the panda population.

Variation in the probability of reproduction and mortality that occurs because of changes in the environment over time is environmental variation (EV). Sources of EV are extrinsic to the population itself and include weather, predation, prey populations, and parasite loads (Lacy 1991, 1993). Because no data were available for EV for the giant panda, EV = 0 was used for the model.

Catastrophes are extremes of environmental variation, events that occur with some specified probability and reduce survival and reproduction for one year. Catastrophes include habitat destruction, floods, fire, and disease (Lacy 1991, 1993). For wild giant pandas, bamboo die-off greatly

Table 1. Reproductive rate of wild giant panda in Wolong Natural Reserve, China.

		Number of litters		Reproductive rate	
Name	Years	Single	Twins	Single	Twins
Wangwang	1979–82	3		0.75	
Zhenzhen	1978–82	4		0.80	
Jingjing	1983–86	2		0.50	
Xinyue	1982–88	4		0.57	
Xinxing	1988–89	1		0.50	
No name	1990–91		1		0.50
Weighted mean				0.5833	0.0417
Total	24	14	1	0.625	

Table 2. Age-specific mortality (%) of wild giant pandas.

Age	Male	Female
0–1	40.00	40.00
1–2	9.67	9.67
2–3	3.14	3.14
3–4	1.52	1.52
4–5	1.55	1.55
5–6	1.57	1.57
6–7	1.60	1.60
7–8 (Females ≥7)	3.45	13.33
≥8	14.16	

effects their survival. During the bamboo die-off of *Fargesia dunudata* and *scabrida* in the Minshan Mountains in the 1970s, about 100 dead pandas were found in the field (Qin 1990). Because the bamboo flowering cycle is about 60 years (Qin 1990), we estimated that catastrophes influenced panda's survival and reproduction 1.67% (1/60). Initial values for Vortex population viability analysis are summarized in Table 3.

RESULTS AND CONCLUSION

Potential Population Growth Rate

The Vortex model calculated deterministic population growth rates and estimated the generation length for males and females based on females assuming no limitation of mates and no inbreeding depression (Table 3).

Table 3. Summary of initial values for VOTEX population viability analysis for giant pandas in Wuyipeng, Wolong Natural Reserve, China.

Simulation times	1,000	
Inbreeding depression type	H	
Type of mating system	Polygamous	
Age at first reproduction	Male, 6.5; Female, 7.5	
Sex ratio at birth (Proportion of males)	0.5	
Maximum litter size	2	
Percentage females producing 0 young	37.5	
Percentage females producing 1 young	58.3	
Percentage females producing 2 young	4.2	
Mortality Rates	Male	Female
0–1 years	40	40
1–2 years	9.67	9.67
2–3 years	3.14	3.14
3–4 years	1.52	1.52
4–5 years	1.55	1.55
5–6 years	1.57	1.57
6–7 years	1.60	1.60
7–8 years (Females, ≥7)	3.45	13.33
≥8 years	14.16	
Initial population size	25	
Carrying capacity	62, with 4.21% of annual decrease in 5 years	

The panda population on the Wuyipeng Study Area has a positive population growth (Table 2). When environmental effects are added, the growth rates decrease. Therefore, environmental catastrophes are a very important factor in the continued existence of the giant panda population.

Probability of Extinction and Heterozygosity

To model probability of extinction and heterozygosity, different starting parameters were used for the Vortex model (Table 4). Simulation 1 (Table 5) shows the effects on the Wuyipeng panda population with no inbreeding depression and no catastrophes over 100 years. Even with these optimistic conditions, the probability of extinction >10% and heterozygosity <80% do not meet the conservation criteria of <2% probability of extinction and 90% heterozygosity retained. When genetic load and catastrophes increase (Simulation 4 [Table 5]), the probability of extinction dramatically increases and heterozygosity decreases (Figs. 1, 2). Thus, inbreeding and catastrophes significantly affect results, even if inbreeding depression and catastrophes are minor.

Our results failed to meet the conservation objectives using assumptions considered realistic for the population. For isolated populations, even small inbreeding depression could increase the extinction probability and decrease heterozygosity because of no gene exchange from other populations. Moreover, environmental variation, especially catastrophes such as bamboo die-off, has a negative effect on the giant panda's survival.

Although the giant panda population in Wolong Natural Reserve is not currently isolated, our simulations indicate this population will go to extinction in 100 years if it can not be protected properly. The entire giant panda population has been isolated into over 20 small populations, and its habitat will continue to be destroyed and fragmented because of economic demand. These results clearly support immediate governmental protection for the habitat of the giant panda in China. In 1993 the "Habitat Protection Project" was started by the Chinese government. It will spend 200 million Yuan RMB ($25 million U.S.), and bring a ray of brightness to the wild giant pandas.

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Table 4. Deterministic population growth rate of giant panda population for various model simulations in Wuyipeng, Wolong Natural Reserve, China.

				Generation length (years)	
Parameters	R_0[a]	r[b]	λ[c]	Male	Female
No catastrophes	1.066	0.006	1.006	11.28	11.95
Catastrophes (1.67%)	1.033	0.001	1.001	12.25	11.94

[a] Net reproductive rate.
[b] Instantaneous rate of increase.
[c] Finite rate of increase.

Table 5. Probability of extinction (%) and heterozygosity (%) for the giant panda population in Wuyipeng, Wolong Natural Reserve, China.

Simulation	Model description	Probability of extinction	Heterozygosity
1	No inbreeding, no catastrophes	19.9	73.6
2	Genetic load=1, no catastrophes	30.3	72.8
3	No inbreeding, catastrophes=1.67%	33.4	70.2
4	Genetic load=1, catastrophes=1.67%	45.7	69.8

Simulation 1 shows the effects on the Wuyipeng, Wolong Natural Reserve panda population with no inbreeding depression.

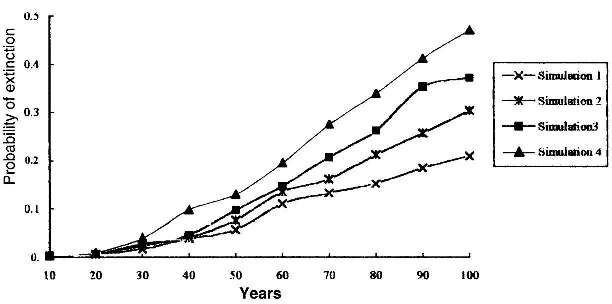

Fig. 1. Probability of extinction of giant panda population in Wuyipeng, Wolong Natural Reserve, China, using population viability analysis.

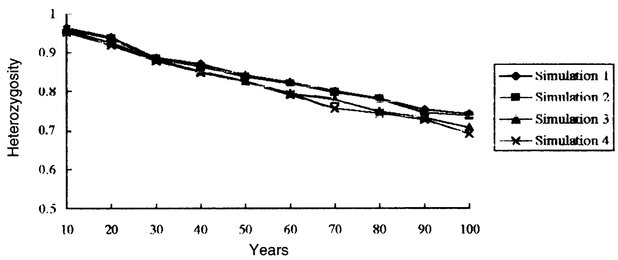

Fig. 2. Heterozygosity of giant panda population in Wuyipeng, Wolong Natural Reserve, China, using population viability analysis.

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