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ESSAY

Can science save the giant panda (*Ailuropoda melanoleuca*)? Unifying science and policy in an adaptive management paradigm

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Abstract

The giant panda (*Ailuropoda melanoleuca* David, 1869) is an iconic species for global conservation, yet field research has only recently advanced to the point where adaptive management is possible. Here, we review recent developments in giant panda conservation science and propose a strategic plan for moving panda conservation forward. Because of scientific, funding, political, and logistical hurdles, few endangered species management programs have embraced adaptive management, wherein management decisions are shaped iteratively by targeted scientific research. Specific threats, such as habitat destruction, anthropogenic disturbance and fragmented nonviable populations, need to be addressed simultaneously by researchers, managers and policy-makers working in concert to understand and overcome these obstacles to species recovery. With the backing of the Chinese Government and the conservation community, the giant panda can become a high-profile test species for this much touted, but rarely implemented, approach to conservation management.

Key words: adaptive management, conservation policy, endangered species, giant panda, strategic conservation plan.

INTRODUCTION

Today we know so much about giant panda (*Ailuropoda melanoleuca* David, 1869) biology but the question remains: do we have enough information to save this iconic species from extinction? Here we discuss implications of recent scientific findings for policy and planning in panda conservation, and briefly chart a course where scientists and policymakers form a new partnership. We believe that science for pandas has matured to the point that an adaptive management paradigm can ensure effective conservation. With an estimated 1600 giant pandas in the wild today, informed and active management is the only hope for this species, and many others facing similarly daunting conservation challenges.

The past decade has witnessed remarkable progress in the accumulation of giant panda data. Substantial new knowledge has been acquired on panda behavior, repro-

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ductive physiology, endocrinology, nutrition, genetics and veterinary care (Wildt *et al*. 2006; Zhang & Wei 2006), much of it finding application to conservation breeding (Swaisgood *et al*. 2004, 2006). These advancements have been made using an approach akin to the adaptive management advocated for monitoring and management of habitat for conservation-dependent species (Walters 1986; Schreiber *et al*. 2004; Nichols & Williams 2006; Wei *et al*. 2009). This integration of science with animal care has incrementally reduced uncertainty about factors important for successful breeding, allowing new management strategies to be formulated. As a result, since 1998, the number of pandas *ex situ* has more than doubled (to more than 300 animals).

That science has played a critical role in the conservation breeding of pandas is irrefutable. Will we also one day be able to look back and say the same for conservation science *in situ*? Prospects look promising. Field biology for giant pandas has experienced a similar, if somewhat belated, scientific rebirth (Lindburg & Baragona 2004), most recently highlighted in a symposium on panda field conservation at the 2009 Society for Conservation Biology Conference (Swaisgood *et al*. 2010). However, much of this knowledge has yet to find its way into management and policy. Genetic tools are advancing rapidly, yielding important insights into ecological processes (Schwartz *et al*. 2007), such as dispersal, mating, and anthropogenic obstacles to gene flow, and might enable more accurate census of these elusive animals (Zhan *et al*. 2006). Such data are especially insightful when combined with new information on spatial movements and resource use made available by Global Positioning System satellite telemetry now that the Chinese Government has lifted the moratorium on radio collaring of giant pandas (see review in Durnin *et al*. 2004). We are on the cusp of a deeper understanding of giant panda habitat needs, ranging from denning requirements to feeding resources (Wei *et al*. 2000; Linderman *et al*. 2005; Zhang *et al*. 2007). For example, new data suggest that old-growth forests might be more important than previously believed (Bearer *et al*. 2008; Swaisgood *et al*. 2010; Zhang *et al*. 2011), requiring adjustments to analyses delineating suitable habitat (Shen *et al*. 2008; Feng *et al*. 2009; Qi *et al*. 2009). Habitat fragmentation, forest patch size and isolation, anthropogenic barriers and the movement patterns of individuals also influence the distribution of pandas on the landscape (Qi *et al*. 2009; Hu *et al*. 2010a,b; Wang *et al*. 2010; Zhu *et al*. 2010, 2011). Such information is likely to be critical for the Chinese Government's pending decision on whether to renew the range-wide logging ban (Zhang *et al*. 2011) and other conservation planning activities. Sophisticated approaches to socioeconomic variables impacting the giant panda habitat are making new inroads into the human dimension of panda conservation (Bearer *et al*. 2008; Chen *et al*. 2009).

Meanwhile, Chinese Government policy makers have not been idle and deserve credit for significant achievements, the most laudable being the Grain-to-Green programs, the logging ban (Natural Forest Conservation Program), and a remarkable increase in the number of panda nature reserves, from 4 in 1962, to 62 today. These reserves provide protection for many other endangered animals and plants living in one of the world's biodiversity hotspots. These advancements, although significant, have not been informed by specific scientifically acquired data. With these basic protections in place, there is an environment where adaptive management can flourish.

INTEGRATING CONSERVATION SCIENCE AND POLICY: THE ROAD TO ADAPTIVE MANAGEMENT

It is now time to wed panda conservation science with policy to capitalize on this momentum in both scientific and government circles. Adaptive management, the systematic reduction of uncertainty by carrying out (controlled) management actions (Walters 1986; Schreiber *et al*. 2004; Nichols & Williams 2006), is the way forward. Adaptive management begins with a strategic plan, crafted jointly by researchers and managers that sets goals and articulates specific hypotheses. This process involves a review of the best available information, construction of predictive models, implementation of management experiments, and application of newfound knowledge to improved management action. Confidence in the course of management increases as plans are revised to incorporate "lessons learned" from monitoring and results evaluation.

Although widely advocated in conservation biology, in reality, adaptive management is rarely implemented (Sutherland 2006). All too often there is a disconnect between science and management, wherein researchers proceed in one direction, collecting data that might or might not be useful for management, and managers proceed in another, managing without the benefit of scientifically-acquired knowledge. Adaptive management does *not* mean waiting until "all the science is in" and, in its application, there is no intention to cause delays to active on-the-ground management. There are several likely reasons why adaptive management has been used infrequently, including failure to adequately understand what constitutes adaptive management versus reactive management. Clearly, it can be costly, and might also threaten the decisions made by authorities. In addition, rather large manipulations might be required to yield a population-level response, and the larger the manipulation, the greater the risk of negative consequences. Despite these obstacles, adaptive management has been successfully applied. Some of the best-known examples are large-scale programs for managing sustainably-harvested species, such as mallard ducks *Anas platyrhynchos* Linnaeus, 1758 (review in Nichols & Williams 2006). A major advantage of adaptive management is that even failures yield progress. For example, because early reintroductions of the New Zealand hihi (*Notiomystis cincta* Du Bus and Gisignies, 1839) were implemented using adaptive management principles, researchers were able to learn from failures and apply this knowledge successfully in recovering the species elsewhere (Armstrong *et al*. 2007).

We advocate taking an adaptive management approach for giant pandas without further delay because a more scientific approach is needed to guide the current management of giant pandas. Failure to adopt an adaptive management approach could be costly in terms of financial and staff resources if ineffective management actions are perpetuated without adequate evaluation. Of course, misuse of adaptive management itself also entails risks if the management action has potential detrimental effects. In these cases, adaptive management should begin on a smaller scale to test for any negative consequences and efficacy before scaling up to management on larger landscapes. Another approach is for investigators to identify management actions that are already planned or in effect and to devise studies to test their efficacy. In these circumstances, additional risks are not added in the name of science.

The overarching goal for a giant panda strategic conservation plan is to ensure healthy, viable populations. A first step is identifying the ecological factors limiting panda population size. Correlative studies will be informative, but ultimately manipulative research is needed. Research targeting putative limiting factors provides objective feedback on the effectiveness of varying management strategies, allowing optimal strategies to be selected. Some limiting factors might be stochastic and operate over long time scales, making measurement challenging, but perhaps representing the gravest threats to long term species persistence (e.g. disease outbreaks, climate change, and mass mortality of bamboo). That some of these events will occur is likely: for example, the synchronous flowering and die-off of entire bamboo species, an event that caused starvation and severe population declines in the 1980s (Reid *et al*. 1989). Pandas are especially vulnerable to bamboo die-offs in today's landscape, where, due to widespread habitat loss at lower elevations, pandas often cannot migrate to feed on alternative bamboo species (Carter *et al*. 1999).

A significant challenge to adaptive management for this species will be the ability to monitor population response to management actions, a goal that presupposes the capacity to count panda, which are notoriously difficult to detect. New DNA technologies might eventually provide the most accurate measure (Zhang & Ryder 2004; Zhan *et al*. 2006), but they will not be the most appropriate tool in all circumstances. It might be impractical to determine total panda numbers and, therefore, it might be more sensible to consider measures of relative abundance, which will probably be sufficient, and more cost-effective, for making management decisions. Given that panda feces are conspicuous, frequently voided and degrade slowly, fecal surveys might be all that is needed to monitor and compare panda populations, trends and responses to adaptive management across reserves (and unprotected areas), without undertaking the greater effort to obtain an accurate estimate of the number of pandas. For example, if survey effort is well designed and held constant, a significant increase in the number of feces following a management action is indicative of an increase in panda numbers (with the key and plausible assumption that defecation rates are relatively constant). Reserves with a higher density of panda feces, moreover, will have a higher density of pandas, providing an indication that the habitat and resources therein support pandas better than in the reserves with lower densities of panda feces. Therefore, these low-technology methods, readily available to most reserve managers, might provide important insights for adaptive management. DNA-based population estimates also have important uses (Zhan *et al*. 2006), but are not always necessary to support good adaptive management.

STRATEGIC CONSERVATION PLAN FOR GIANT PANDAS

The need for adaptive management for pandas seems clear, but the important question remains: what management actions should we pursue? A comprehensive plan is beyond the scope of this article, but such a plan should address: (i) forest loss, fragmentation, and degradation; (ii) direct and indirect impacts of human activities on pandas and habitat; (iii) range expansion through re-colonization of unoccupied areas and/or supplementation of nonviable populations; (iv) a comprehensive *ex situ* management plan with a targeted population size, and genetic diversity goals; and (v), if needed, approaches for preparing captive-bred pandas for release to the wild. It is clear that habitat loss and degradation constitute the most serious threat to pandas, and we illustrate an adaptive management approach to these challenges in Figure 1.

Human activities might impact pandas directly or indirectly through effects on habitat. Poaching of pandas or capturing pandas in snares set for other species can reduce population size directly (Li *et al*. 2003). Firewood collection and illegal logging reduces forest cover (Bearer *et al*. 2008), while harvesting bamboo might reduce foraging resources, particularly the bamboo shoots on which pandas are seasonally dependent (Schaller *et al*. 1985; Wei *et al.* 1999). These activities also bring people into contact with pandas, which might be a source of stress or may cause pandas to stop using habitat heavily trafficked by humans. People and their domesticated animals might also introduce pathogens to panda populations. Potential management responses to these threats include increased patrolling, providing alternative resources to reduce human dependence on forest resources, and educating of local people.

Efforts to extend the panda range and to increase the viability of small populations offer significant opportunities for scientists to engage policy makers and reserve managers. Giant panda populations are highly fragmented (Hu & Wei 2004). Barriers to dispersal between populations include bodies of water, altered habitat, roads and other human-made structures (Zhu *et al.* 2011). Without mitigation, pandas living in small, isolated populations will lose genetic diversity, with inbreeding depression and reduced fitness a likely consequence (Zhang & Ryder 2004; Zhu *et al.* 2010). In some areas, there is good evidence for suitable, but unoccupied habitat. Although we need to know why pandas do not live in these areas, remedial management could include establishing habitat corridors to encourage natural immigration, translocating wild pandas into unoccupied or under-occupied habitat (Zhu *et al.* 2010, 2011) and/or reintroducing captive-reared animals. China's State Forestry Administration, among others, is now considering these options and developing a comprehensive plan for reintroduction.

Each of these options for panda range expansion presents an opportunity for policy makers and managers to work together with scientists to determine the relative efficacy of these proposed measures. The authorities must determine when, where, and whether to encourage re-colonization of unoccupied areas by release of captive-bred individuals, and through translocation and habitat corridors. The only way to determine the efficacy of these techniques is to enlist the scientific community to design studies to monitor dispersal, survival and reproduction of colonizing pandas and determine if viable populations are established. Carefully designed and implemented studies will inform managers whether these methods are working and provide a knowledge-based framework for improving upon these methods or rejecting their use in future efforts.

Here, we have provided a non-exhaustive overview of the types of management questions that need to be addressed using an adaptive management paradigm. From these general management actions, specific hypotheses need to be articulated. To give one example, it has been proposed that old growth forest might be a factor limiting giant panda population size (Zhang *et al*. 2011), perhaps because large trees with cavities are critical resources for female pandas rearing cubs (Qi *et al.* 2011). The quality and quantity of alternatives (rock cave dens) might be insufficient to support a larger panda population. One proposed management action is to construct artificial dens (see Fig. 1; Zhang *et al.* 2007). The primary prediction stemming from this hypothesis is that the addition of artificial dens in areas where few suitable denning trees exist will lead to an increase in population size. To test this hypothesis, research could be devised to monitor whether artificial dens are used (an assumption of the hypothesis), whether offspring survival is equivalent to or better than that observed in natural cave dens and whether measures of population size indicate an increase in population size. Demographic data could provide relatively rapid feedback on possible population responses, with an increased proportion of young pandas indicating greater reproduction and offspring survival after the management action is implemented. Fecal surveys could be used to determine this demographic shift if it could be shown that fecal size is reliably smaller for young than for adult pandas. If this hypothesis were tested in one reserve and results were promising, the management action could be replicated in other reserves, with further monitoring to determine efficacy. By contrast, it could be detrimental to adopt artificial den construction as a range-wide policy without adequate data previously attained on a smaller scale, because this action might be predicated on false assumptions (pandas are limited by den quality and quantity); pandas might not use artificial dens or the disturbance involved in den construction might have negative consequences. Such an experiment would require approval by, and close coordination with, both local reserve managers and governmental policy makers; we are not aware of any such collaborative effort other than the periodic national survey to estimate the entire population size across the panda's range, yet the benefits of such a partnership seem unambiguous.

Management actions/Treatments

1. Continuation of the logging ban.
    a. Assumptions:
        i. Forest cover loss degrades panda habitat and/or makes it less accessible, thereby contributing to giant panda population decline.
    b. Where:
        i. All current and potential giant panda habitat.
    c. Additional monitoring activities:
        i. Remote sensing of forested habitat.
        ii. Document evidence of timber removal along patrolling routes.

2. Reforestation in key areas. Only mixed species native to the local area should be used in reforestation programs, with the goal of re-establishing functional forest ecosystems.
    a. Assumptions:
        i. Habitat can be restored to allow giant panda use.
        ii. Forest cover is a key component of panda habitat.
    b. Where:
        i. Within current protected areas.
        ii. Buffer zones adjacent to current protected areas.
        iii. Corridors connecting occupied giant panda habitat.
        iv. Lower elevations should be prioritized to extend diversity of current forest, in particular bamboo species.
    c. Additional monitoring activities:
        i. Remote sensing of forested habitat.
        ii. Ground-truthing to evaluate functional integrity of reforested habitat.
        iii. Tracking of acres restored.

3. Minimize human expansion and forest-use activities that contribute to habitat degradation, such as firewood extraction and bamboo harvesting.
    a. Assumptions:
        i. Human extraction of forest resources reduces the carrying capacity of giant panda habitat.
    b. Where:
        i. All current protected areas.
        ii. In current and potential giant panda habitat.
    c. Additional monitoring activities:
        i. Document signs of human activity along patrolling routes, including evidence of forest and bamboo harvesting.
        ii. Interview local villagers as to forest product use.

4. Provide ecologically-sustainable alternative fuel sources for villagers living in or near to giant panda range.
    a. Assumptions:
        i. Fuel-wood collection seriously degrades giant panda habitat, and provision of alternative fuel sources decreases human dependence on forest resources.
    b. Where:
        i. All current and potential giant panda habitat.
    c. Additional monitoring activities:
        i. Interview villagers concerning fuel-wood use.
        ii. Document evidence for fuel-wood removal along patrolling paths.

5. Ensure giant panda habitat includes sufficient suitable den sites for successful reproduction; protect existing old-growth forests and explore construction of artificial dens, if needed.
    a. Assumptions:
        i. Availability of suitable den sites is a factor limiting in at least some giant panda populations.
        ii. Pandas will use artificial dens.
    b. Where:
        i. Otherwise suitable giant panda habitat (young forests without sufficient numbers of mature trees or caves that are suitable for denning).
    c. Additional monitoring activities:
        i. Surveys to document distribution and abundance of suitable giant panda den sites.
        ii. Research to evaluate whether management actions to increase quantity and quality of dens affects cub survival and ecological carrying capacity.

Figure 1 Example of an adaptive management plan for forest loss, degradation and fragmentation.

There are barriers to the implementation of adaptive management for giant pandas, some unique to the species and situation, and some common throughout the developing world. Reserve staff is a critical source of expertise and must be given leeway in making management decisions as adaptive management requires flexibility to deal with locally varying conditions. Centralized governmental involvement might best be directed at establishing overarching goals, but not at resolving local issues. Scientists also need avenues for conveying knowledge to policy-makers and managers, and vice-versa, so that actions can be jointly crafted. Finally, the training and capacity of reserve staff must continue to improve. As staff has the opportunity to make decisions, it is essential that they be equipped to understand the potential (and the limitations) of scientific data. Whereas field techniques are currently a common skill within the reserves, data management and analysis are now concentrated largely at the provincial or national level.

CONCLUSION

Are pandas ready for adaptive management? We believe the answer is a qualified "yes." This species could be an exceptional model for, and beneficiary of this strategy if: (i) reliable ways are found to measure population response to management actions, and (ii) scientists and policy makers agree to work closely together to chart a new course for panda conservation. Science can help save the giant panda if there is reciprocal cooperation between scientists and Chinese Government officials, who have the power to permit on-the-ground action.

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REFERENCES

Armstrong DP, Castro I, Griffiths R (2007). Using adaptive management to determine requirements of re-introduced populations: the case of the New Zealand hihi. *Journal of Applied Ecology* **44**, 953–62.

Bearer S, Linderman M, Huang JY, An L, He GM, Liu JG (2008). Effects of fuelwood collection and timber harvesting on giant panda habitat use. *Biological Conservation* **141**, 385–93.

Carter J, Ackleh AS, Leonard BP, Wang H (1999). Giant panda (*Ailuropoda melanoleuca*) population dynamics and bamboo (subfamily Bambusoideae) life history: a structured population approach to examining carrying capacity when the prey are semelparous. *Ecological Modelling* **123**, 207–23.

Chen X, Lupi F, He G, Ouyang Z, Liu J (2009). Linking social norms to efficient conservation investment in payments for ecosystem services. *Biological Conservation* **142**, 1740.

Durnin ME, Swaisgood RR, Czekala NM, Zhang H (2004). Effects of radiocollars on giant panda stress-related behavior and hormones. *Journal of Wildlife Management* **68**, 987–92.

Feng TT, Van Manen FT, Zhao NX, Li M, Wei FW (2009). Habitat assessment for giant pandas in the Qinling mountain region of China. *Journal of Wildlife Management*, **73**, 852–8.

Hu J, Wei F (2004). Comparative ecology of giant pandas in the five mountain ranges of their distribution in China. In: Lindburg D, Baragona K, eds. *Giant Pandas: Biology and Conservation*. University of California Press, Berkeley, California, pp. 137–48.

Hu YB, Zhan XJ, Qi DW, Wei FW (2010a). Spatial genetic structure and dispersal of giant pandas on a mountain-range scale. *Conservation Genetics* **11**, 2145–55.

Hu YB, Qi DW, Wang HJ, Wei FW (2010b). Genetic evidence of recent population contraction in the southernmost population of giant pandas. *Genetica* **138**, 1297–1306.

Li YM, Guo ZW, Yang QS, Wang YS, Niemela J (2003). The implications of poaching for giant panda conservation. *Biological Conservation* **111**, 125–36.

Lindburg DG, Baragona K (2004). *Giant Pandas: Biology and Conservation.* University of California Press, Berkeley, California.

Linderman M, Bearer S, An L, Tan YC, Ouyang ZY, Liu JG (2005). The effects of understory bamboo on broad-scale estimates of giant panda habitat. *Biological Conservation* **121**, 383–90.

Nichols JD, Williams BK (2006). Monitoring for conservation. *Trends in Ecology and Evolution* **21**, 668–73.

Qi DW, Hu YB, Gu XD, Li M, Wei FW (2009). Ecological niche modeling of the sympatric giant and red pandas on a mountain-range scale. *Biodiversity Conservation* **18**, 2127–41.

Qi DW, Zhang SN, Zhang ZJ *et al.* (2011). Different habitat preferences of male and female giant pandas. *Journal of Zoology*, doi: 10.1111/j.1469-7998.2011.00831.x

Reid DG, Hu J, Dong S, Wang W, Huang Y (1989). Giant panda *Ailuropoda melanoleuca* behaviour and carrying capacity following a bamboo die-off. *Biological Conservation* **49**, 85–104.

Schaller GB, Hu J, Pan W, Zhu J (1985). *The Giant Pandas of Wolong*. University of Chicago Press, Chicago.

Schreiber SG, Bearlin AR, Nicol SJ, Todd CR (2004). Adaptive management: a synthesis of current understanding and effective application. *Ecological Management and Restoration* **5**, 177–82.

Schwartz MK, Luikart G, Waples RS (2007). Genetic monitoring of individuals, populations, and species in the wild. *Trends in Ecology and Evolution* **22**, 25–33.

Shen GZ, Feng CY, Xie ZQ, Ouyang ZY, Li JQ, Pascal M (2008). Proposed conservation landscape for giant pandas in the Minshan mountains, China. *Conservation Biology* **22**, 1144–53.

Sutherland WJ (2006). Predicting the ecological consequences of environmental change: a review of the methods. *Journal of Applied Ecology* **43**, 599–616.

Swaisgood RR, Lindburg D, White AM, Zhang H, Zhou X (2004). Chemical communication in giant pandas. In: Lindburg D, Baragona K, eds. *Giant Pandas: Biology and Conservation.* University of California Press, Berkeley, California, pp. 106–20.

Swaisgood RR, Zhang G, Zhou X, Zhang H (2006). The science of behavioral management: creating biologically relevant living environments in captivity. In: Wildt DE, Zhang AJ, Zhang H, Janssen D, Ellis S, eds. *Giant Pandas: Biology, Veterinary Medicine and Management*. Cambridge University Press, Cambridge, pp. 274–98.

Swaisgood RR, Wei FW, Wildt DE, Kouba AJ, Zhang ZJ (2010). Giant panda conservation science: how far we have come. *Biology Letters* **6**, 143–5.

Walters CJ (1986). *Adaptive Management of Renewable Resources*. Macmillan, New York.

Wang T, Ye X, Skidmore AK, Toxopeus AG (2010). Characterizing the spatial distribution of giant pandas (*Ailuropoda melanoleuca*) in fragmented forest landscapes. *Journal of Biogeography* **37**, 865–78

Wei F, Feng Z, Wang Z, Li M (1999). Feeding strategy and resource partitioning between giant and red pandas. *Mammalia* **63**, 417–30.

Wei F, Feng Z, Wang Z, Hu J (2000). Habitat use and separation between the giant panda and the red panda. *Journal of Mammalogy* **81**, 448–55.

Wei F, Bravery BD, Xie Y (2009). Wildlife research in the developing world. *Integrative Zoology* **4**, 159–60.

Wildt DE, Zhang AJ, Zhang H, Janssen D, Ellis S (2006). *Giant Pandas: Biology, Veterinary Medicine and Management*. Cambridge University Press, Cambridge.

Zhan X, Li M, Zhang ZJ *et al*. (2006). Molecular censusing doubles giant panda population estimate in a key nature reserve. *Current Biology* **16**, 451–2.

Zhang Y, Ryder OA (2004). Genetic studies of giant pandas in captivity and in the wild. In: Lindburg D, Baragona K, eds. *Giant Pandas: Biology and Conservation*. University of California Press, Berkeley, California, pp. 155–8.

Zhang Z, Wei F (2006). *Giant Panda ex-situ Conservation: Theory and Practice.* Science Press, Beijing.

Zhang Z, Swaisgood RR, Wu H *et al*. (2007). Factors predicting den use by maternal giant pandas. *Journal of Wildlife Management* **71**, 2694–8.

Zhang Z, Swaisgood RR, Zhang S *et al*. (2011). Old-growth forest is what giant pandas really need. *Biology Letters* **7**, 403–6.

Zhu L, Zhan X, Wu H *et al.* (2010). Drastic reduction of the smallest and most isolated giant panda population: implications for conservation. *Conservation Biology* **24**, 1299–306.

Zhu L, Zhang S, Gu X, Wei F (2011). Significant genetic boundaries and spatial dynamics of giant pandas occupying fragmented habitat across southwest China. *Molecular Ecology* **20**, 1122–32.