J. Bamboo and Rattan, Vol. 2, No. 2, pp. 167–178 (2003)

Also available online - www.vsppub.com

The possible nutritional consequences for giant panda of establishing reserve corridors with various bamboo species

I. R. HUNTER [1], E. S. DIERENFELD [2,*] and F. JINHE [1]

[1] *International Network for Bamboo and Rattan, Beijing, China*
[2] *Wildlife Conservation Society, 2300 Southern Blvd, Bronx, New York, NY, USA*

Abstract—Efforts to conserve pandas in China now concentrate on providing a large enough contiguous reserve to ensure food sufficiency. Fragmented reserves are to be joined up by corridors. Planting or encouraging the growth of the panda's natural food — bamboo — will form an important part of the corridor formation. Local people, in general, lose income as a result of reservation and corridor formation. Planting alternative bamboo species gives local people the possibility to generate an alternative income. This study was undertaken to see if there might be either opportunities or threats to panda nutrition based on the way in which the species used to form the corridors were chosen. The nutritional contents of 12 suitable bamboo species from a bamboo garden nearby the most northerly panda population in China were analysed. Six species were native to the region and six were exotics. Three samples were taken from the mountainside in the panda reserve at Qinling mountains for comparison. It was found that there were only small differences between species or sites for most characteristics tested and the small differences that exist are unlikely to be of much practical significance. While only in the nature of a preliminary study, the results do not indicate any great opportunities for significant improvement in panda nutrition by bamboo species enrichment. However, neither do they indicate any great risk to panda nutrition by the introduction of bamboo species utilisable by village industries in the margin of these corridors. The use of the six native species should pose no ecological risk but the use of non-native species needs caution. However, our study has also shown that a diet of bamboo leaves by itself would not necessarily satisfy the panda's nutritional requirements. Given that nutrient contents vary seasonally and between plant parts, this study should be followed up by a more comprehensive sampling study.

Key words: China; panda; bamboo; nutrition; conservation; reserves; corridors; livelihoods.

*To whom correspondence should be addressed. E-mail: edierenfeld@wcs.org

INTRODUCTION: ISSUES IN PANDA CONSERVATION

It is estimated that only approximately 1000 giant pandas (*Ailuropoda melanoleuca*) currently survive, with a much restricted range and long generation intervals in nature [1, 2]. Further, until recent years with focussed efforts, captive reproductive programs (both in China and externally) have been limited. *In situ* conservation efforts tend to focus on providing large enough, contiguous reserves in the wild [2]. Both giant and red pandas (*Ailurus fulgens*) rely on various species of bamboo for much of their diet [1, 3, 4], hence the health and survival of bamboo species in their habitat is very important. It is thought that with large, contiguous reserves, even if something affects one species of bamboo (for example, flowering and die-back) in one part of the reserve, pandas can migrate to other sites in the reserve where that bamboo has not flowered, or eat other bamboo species. Clearly, bamboo is a keystone resource for this species and must be a focal point of conservation efforts.

Unfortunately, panda habitat in China has become highly fragmented, thus limiting potential animal movement. The World Wildlife Fund (WWF), among other conservation organizations, is therefore working with local Chinese administrations to advise on the best means of restoring contiguous panda habitat. The Chinese Government is facilitating the retirement from cultivation of steep lands and closing access to native forests, thereby providing sites for re-establishing corridors to link fragmented areas. One such area of panda habitat exists in the Qinling Mountains, just SW of Xian in North Central China (Fig. 1). The Qinling Mountains, of granite origin, form the northernmost refuge for the giant panda. The total reserve area for the panda is 71 757 ha. The reserve area is, however, currently split into 3 almost separate areas due to heavy human interference. This site is discussed further in Ref. [2]. The area provides a home for many other rare species: golden takin (*Gazella subgutturosa*), golden monkey (*Pygathrix spp.*), red pandas and fabulously coloured pheasants (*Chrysolophuspictus spp.*). Efforts to improve the habitat for the panda will almost certainly benefit these other species.

This mountain region presents the conundrum which is familiar from many similar conservation attempts worldwide: although the local people have, to some extent, been compensated for lost income as a result of forest closure and land withdrawal, they are, overall, poorer. Unless they are further compensated in some way they will become unwilling partners in (panda) conservation. For example, Liu *et al.* [5] report that fragmentation in Wolong Panda Reserve actually increased following reservation, and success of the 'Green for Grain' conservation initiative elsewhere in China has been equivocal (Zhang, personal communication). While the precise nature of a local people's interaction with a reserve is complex (see, e.g. Ref. [6]), alternative sources of income will be helpful to channel activities in a non-destructive direction. It seemed that in re-establishing corridors to re-integrate reserve patches, a range of opportunities presented themselves.

It might be desirable to re-introduce larger-stemmed native bamboo species or specific exotic species in the inner part of the corridor to protect the pandas against the adverse effects of one species of bamboo flowering and dying-off. However,

Figure 1. Map of location of Qinling Mountains in Shaanxi Province, China.

it is not known what effect this would have on panda nutrition. It might be possible to plant bamboo species that improve the panda's nutrition. It would certainly be possible to plant income-generating bamboo species on the corridor margins but would such bamboos enhance or reduce the opportunities for panda forage? It seemed desirable to investigate the possible nutritional implications of such strategies.

DESCRIPTION OF THE STUDY SITE

The Qinling Mountains and its surrounds were a good place to study such interactions. In Zhouzhi county, Louguantai National Forest Park, there is a bamboo garden with 17 genera and 150 bamboo species, most of which have been introduced from South China since 1965. Additionally, there is a Panda Breeding and Study Centre adjacent to the garden where 9 pandas are housed and some empirical knowledge has built up on the feeding of these bamboo species to pandas. Therefore, it was decided to select the leaves of a range of bamboo species from the gardens, and some bamboo samples from the mountainside, for chemical analysis and comparison. Leaves were chosen for sampling in this pilot study because they comprise nearly half of the panda's diet; they typically contain the highest levels of nutrients in the plant, and they could be sampled consistently between species at one sampling date.

METHODS

Twelve samples of bamboo leaves were collected from Louguantai Bamboo Garden. Six species were native to the region and six were introduced exotic species. The Garden lies at 500 m above sea level (m.a.s.l.). It has an annual average temperature of 13.2°C, with a minimum temperature of minus 20.2°C, annual rainfall averaging 680 mm and maximum up to 1088 mm. Its soil is sandy wash brown soil, pH 5–7. The 12 species sampled are shown in Table 1. All but one (*Phyllostachys sulphurea* (Carr.) A. et. Riviere) were said, by the park staff (Li Yue, personal communication), to be accepted by the neighbouring pandas as food. Three species were sampled from altitudes of approximately 1200–1500 m.a.s.l. in the Qinling mountains with the Black River Reserve. Two of these (*P. aureosulcata* McClure and *P. bambusoides f. shouzhu* Yi) provided direct comparisons with species grown in the garden. The third (*Fargesia nitida*) did not grow in the garden.

For each species sampled, exactly 30 g of leaves were collected from current season's shoots in August 2002. The length and width of the leaves were recorded in the field. Samples were then oven-dried at 60°C. Before being flown back to the laboratories of the Wildlife Conservation Society (New York, NY, USA) for analysis. Samples were analysed for dry matter, ash, crude protein, water-soluble carbohydrates, fibre fractions (neutral detergent fibre (NDF); acid detergent fibre (ADF)); hemi-cellulose, cellulose and sulfuric acid lignin according to standard methodologies for dry feeds [7]. Dried samples were digested and analysed for Na, Mg, P, K, Ca, Mn, Fe, Co, As, Cu, Zn, Mo, Cd, Se and Pb using inductively coupled plasma argon electron spectroscopy and atomic absorption spectroscopy according to methods outlined in Stahr [8].

RESULTS

The largest difference among the species was in leaf size, with the largest leaf being nearly six times in length and 13 times in width the size of the smallest. Despite this great disparity in sizes — which will certainly impact available biomass for consumption — there were much smaller and generally minor differences between species in chemical characteristics assessed in bamboo leaves. Crude protein (12 to 19% of dry matter, DM) concentrations measured were within

Table 1.
Physical and chemical analysis of bamboo species collected in Shaanxi province, China, August 2002

Species	Site collected/ altitude (m.a.s.l.)	Native/ exotic	Leaf length (cm)	Leaf width (cm)	Field water content (%)	Dry matter (%)	Ash (%)
Phyllostachys mannii Gamble	Bamboo garden/500 m	Native	11.0 ± 2.5	1.6 ± 0.2	80.050	19.950	10.448
Phyllostachys flexuosa (Carr.) A. et C. Riviere	Bamboo garden/500 m	Native	9.8 ± 2.0	1.8 ± 0.3	82.140	17.860	8.333
Phyllostachys heterocycla v. pubescens (Mazel) Ohwi	Bamboo garden/500 m	Native	6.8 ± 0.5	0.9 ± 0.1	82.110	17.890	9.937
Phyllostachys vivax f. huanvenzhn J. L. Lu	Bamboo garden/500 m	Exotic	14.5 ± 3.0	2.0 ± 0.4	79.840	20.160	10.124
Indocalamus latifolius (Keng) McClure	Bamboo garden/500 m	Native	31.8 ± 2.1	7.9 ± 1.5	76.910	23.090	8.085
Phyllostachys sulphurea (Carr.) A. et. Riviere	Bamboo garden/500 m	Exotic	7.0 ± 1.1	1.6 ± 0.2	79.700	20.300	9.148
Phyllostachys aureosulcata McClure	Bamboo garden/500 m	Exotic	6.9 ± 0.7	1.2 ± 0.1	78.360	21.640	10.381
Pseudosasa japonica (Sieb. Et Zucc.) Makino	Bamboo garden/500 m	Exotic	20.4 ± 0.3	2.7 ± 0.2	78.320	21.680	7.676
Bashania fargesii (E. G. Camus) Keng f. et Yi	Bamboo garden/500 m	Native	15.1 ± 3.2	2.7 ± 0.5	79.320	20.680	8.108
Phyllostachys bambusoides f. shouzhu Yi	Farmhouse/1200 m	Exotic	10.3 ± 2.0	2.4 ± 0.4	79.390	20.610	7.543
Phyllostachys arcana-FG	Black River Reserve/1400–1500 m	Native	5.3 ± 0.6	1.0 ± 0.0	73.910	26.090	7.051
Fargesia nitida (mitford) Keng f. ex Yi	Black River Reserve/1400–1500 m	Native	7.0 ± 1.1	0.6 ± 0.2	89.330	10.670	9.677
Phyllostachys arcana-BG	Bamboo garden/500 m	Native	6.9 ± 0.6	1.1 ± 0.1	76.470	23.530	8.761
Phyllostachys glabrata S. Y. Chen et C. Y. Yao	Bamboo garden/500 m	Exotic	8.4 ± 1.1	1.2 ± 0.2	77.000	23.000	8.559
Phyllostachys bambusoides f. shouzhu-BG	Bamboo garden/500 m	Exotic	10.7 ± 1.8	2.0 ± 0.3	79.040	20.960	8.387

Species	Crude protein (%)	Water-soluble carbohydrates (%)	NDF (%)	Hemicellulose (%)	ADF (%)	Cellulose (%)	Lignin (%)
P. mannii	16.04	2.85	71.36	37.44	33.92	17.59	16.33
P. flexuosa	17.64	3.08	71.42	38.52	32.90	14.16	18.73
P. heterocycla v. pubescens	18.05	2.56	70.16	38.17	31.99	15.56	16.42
P. vivax f. huanvenzhu	13.86	4.43	70.24	36.02	34.21	14.28	19.93
I. latifolius	12.36	3.21	71.74	31.60	40.14	26.38	13.76
P. sulphurea	14.58	3.78	69.20	36.49	32.71	12.69	20.04
P. aureosulcata	15.15	2.99	70.04	36.26	33.78	20.20	13.58

Table 1.
(Continued)

Species	Crude protein (%)	Water-soluble carbohydrates (%)	NDF (%)	Hemicellulose (%)	ADF (%)	Cellulose (%)	Lignin (%)
P. japonica	14.18	4.62	71.18	33.17	38.01	26.59	11.42
B. fargesii	15.58	3.84	69.91	33.17	36.74	19.52	17.22
P. bambusoides f. shouzhu-FG	17.01	5.07	67.84	36.34	31.50	18.19	13.31
P. arcana-FG	16.84	5.04	66.49	35.17	31.32	11.16	20.17
F. nitida	19.37	3.56	67.81	37.31	30.50	19.47	11.03
P. arcana-BG	14.31	6.03	67.60	37.12	30.48	12.76	17.72
P. glabrata	16.82	6.26	66.93	37.04	29.89	16.43	13.46
P. bambusoides f. shouzhu-BG	13.61	6.31	70.19	38.58	31.62	11.82	19.80

Nutrient data, except water content, reported on a dry matter basis.

Table 2.
Mineral content of bamboo leaves collected in Shaanxi province, China, August 2002[a]

	Na	Mg	P	K	Ca	Mn	Fe	Co	As	Cu	Zn	Mo	Cd	Se	Pb
P. mannii	27.9	2520	1240	18 500	5680	114	326	1.52	<0.5	28.3	18.2	0.422	<0.08	0.260	4.84
P. flexuosa	35.8	2160	1710	22 600	3030	51.4	288	3.37	<0.5	30.2	25.6	0.843	<0.08	0.250	3.02
P. heterocycla v. pubescens	39.0	1640	1760	27 200	3110	111	407	1.15	<0.5	20.5	17.7	0.245	0.186	0.230	4.46
P. vivax f. huanvenzhu	19.4	1220	1160	20 500	3310	28.2	267	2.06	<0.5	25.1	14.5	0.37	<0.08	0.200	2.15
I. latifolius	17.1	1100	1340	13 100	4480	94.9	207	3.42	<0.5	20.1	19.3	0.425	<0.08	0.230	2.78
P. sulphurea	23.2	1280	1240	17 100	3990	33.2	237	4.56	<0.5	26.8	16.8	0.377	0.094	0.21	1.81
P. aureosulcata	23.0	2440	1240	19 900	3140	27.4	332	2.01	<0.5	27.3	14.0	0.679	0.082	0.270	3.65
P. japonica	11.6	3010	1290	11 300	3340	26.1	260	1.96	<0.5	24.8	14.5	0.644	<0.08	0.150	2.03
B. fargesii	19.9	1550	1700	14 000	3980	62.7	281	1.25	<0.5	19.0	23.0	0.357	<0.08	0.100	4.48
P. bambusoides f. shouzhu-FG	16.8	2130	1870	18 100	4070	43.1	820	97.9	<0.5	144	29.5	0.437	<0.08	0.190	<0.5
P. arcana-FG	20.8	1670	1250	16 300	4510	14.2	222	0.981	<0.5	17.5	17.9	0.655	<0.08	0.270	2.08
F. nitida	33.9	1830	1490	16 400	7220	35.4	216	2.64	<0.5	24.8	22.5	0.538	0.085	0.140	1.63
P. arcana-BG	12.3	1370	1080	16 500	3910	33	286	7.55	<0.5	25	18.1	0.293	<0.08	0.250	4.00
P. glabrata	11.5	2380	1130	10 500	7270	55.1	247	1.52	<0.5	19.8	18.3	0.255	0.098	0.23	2.63
P. bambusoides f. shouzhu-BG	19.0	1260	1590	19 000	2810	23.4	283	1.46	<0.5	22.1	20.2	0.738	<0.08	0.320	2.12

Data reported on a dry matter basis; all values mg/kg (ppm).
[a] For specific details of collection, see Table 1.

ranges reported for other bamboos in China [1] and considered normal/high for temperate forage grasses in general. Sweet sugars (measured as water-soluble carbohydrates) comprised a minor fraction of cell contents in all bamboo leaf samples. Fibre fractions, with the exception of lignin, were rather typical of concentrations expected in mature temperate grass forages (total cell wall or NDF, approximately 65–75% of DM; hemicellulose, 25–35% of DM). The excessive lignin value reported (about twice the level found in most grasses), is likely a laboratory artefact of high silica content, which is known to encrust bamboo cell walls and acts to decrease digestibility [9]. Water soluble carbohydrates and cellulose were the only chemical characteristics that varied by a factor of more than two.

Macromineral (Ca, K, Mg and P) nutrient concentrations (Table 2) varied 2–3-fold within the species examined, but in general were within ranges previously reported for bamboo leaves collected and evaluated from the United States (unpublished data), China [1] and Canada [10]. Potassium was an exception, perhaps due to fertilizer applications in the cultivated garden samples; leaves in this study contained 1.1–2.7% K compared with reported values of 0.8% of DM. Sodium concentrations have been low in all bamboo samples examined ($\leqslant$0.1% of DM). Trace element levels also varied 2–3-fold among samples collected in this study. Cu concentrations were within ranges previously reported (15–30 mg/kg), Mn was at the low end of ranges reported (30–100 mg/kg), Zn values were low (range 50–100 mg/kg), and Fe concentrations were higher than expected (100 mg/kg; comparative data from Refs [1, 9]). Measurable lead was found in all but one sample, and may be of health concern. Excessive Fe, Cu and Co from the sample of *P. bambusoides* collected from near a farmhouse on the mountainside is suspected to be due to soil or water contamination, and felt to be atypical.

There are likewise very small differences between nutrients quantified from the high- and low-altitude comparisons of *Phyllostachys bambusoides f. shouzhu* and *Phyllostachys arcana* McClure and none that are likely to have major significance for the nutrition of the panda.

DISCUSSION

Although both giant and red pandas rely heavily on bamboo as a significant portion of the diet, neither species has a digestive tract specialized for consumption of vegetation, most nearly resembling that of a dog [11]. Pandas generally meet their dietary requirements by ingesting high quantities of bamboo daily to compensate for its low digestibility (approximately 20–26% of energy in bamboo leaves and 40–44% in shoots) [1, 4, 12, 13]. Free-ranging panda feeding behaviours are characterized by wide seasonal [4] and geographic variability in both species and plant parts consumed [1, 13–15], with an absolute dependence on local availability (abundance) of preferred species. Hence density of palatable bamboo species remains a critical resource parameter in reserve consideration. Captive pandas have been known to eat a variety of bamboo species (see, for example) Ref. [13] in addition to this report); individuals are also known, however, to be quite selective feeders, rejecting or accepting bamboos offered for no easily perceptible reason (data not shown). Nutrient factors may well underlie choices, but have not been clearly delineated among the various detailed field studies.

The main dietary bamboo species for panda in the Qinling Mountains are reported to be *Bashania fargesii* (E. G. Camus) Keng f. et Yi (which occurs between 900–1900 m.a.s.l.) and *Fargesia nitida (mitford)* Keng f. ex Yi (1800–3000 m.a.s.l.). At the beginning of April, at lower elevations, *B. fargesii* begins to sprout, progressing after that to higher elevations. At the end of April, most *B. fargesii* shoots have grown to 25–50 cm high, but are edible to panda. In this period, therefore, most pandas eat those shoots. From the beginning to the end of May, and above 2000 m, the *F. nitida* shoots begin to sprout, grow to 50 cm high, and are edible to panda. Then pandas begin to migrate to the higher altitudes to eat the new *F. nitida* shoots as well as last year's shoots (the one-year-old shoot does not sprout leaf). In September, the *F. nitida* shoots have grown up to 2 m high and become lignified, which are less preferred, so at that time most of pandas go down again to the *B. fargesii* forest and eat bamboo leaves. These altitudinal patterns of choice are similar to those previously reported for giant panda in Wolong Reserve, Sichuan province [1].

Reid *et al.* [3] found that the vigour of *Bashania fangiana* in Wolong Reserve (as indicated by stem thickness and height) was greater in the middle of its altitudinal range than at either extreme, suggesting that the quality of feed might likewise vary. In a separate example, Fimbel *et al.* [16], working with colobus monkeys (*Colobus angolensis*), found differences that were of nutritional significance in the same forage species found at different altitudes. Thus, one consequence of a restriction and fragmentation in habitat might be that pandas, although eating traditional bamboo species, may have suffered an adverse shift in nutritional value due to altitudinal influences.

There is generally a dearth of information with which to compare this study. Schaller *et al.* [1] published some results for *Fargesia nitida* at high level (2450 m.a.s.l.) in Wolong Reserve and Dierenfeld collected data (not shown here) for *P. aureosulcata* from 150 m.a.s.l. in Washington, DC, USA There are differences between this sample of *F. nitida* and that of Schaller *et al.* [1]. The crude protein is higher (by a factor of 37%) and the cellulose less (by a factor of 31%) in our lower-altitude sample, although one should note that these differences are within the between species range demonstrated in this comparison. The differences between the two samples of *P. aureosulcata* (one from China, the other from the USA) are very small and of doubtful practical significance. Proximate nutrient concentration in these leaf samples compares favourably with those reported previously for palatable Chinese and other temperate bamboos. Mineral concentrations in bamboo leaves, however, appear imbalanced with respect to estimated dietary requirements of the panda, and add to the limited data for this endangered species (estimated requirements: Ca, 0.7%; K, 0.5%; Mg, 0.1%; P, 0.5%; Na, 0.1%; Cu, 5 mg/kg; Fe, 100 mg/kg; Se, 0.1 mg/kg; Zn, 50 mg/kg [17]). As with green forage examined for most free-ranging herbivores, phosphorus and sodium are limiting nutrients. Giant pandas have been documented to reproduce on diets containing 0.5% Ca and 0.4% P (DM basis [17]), levels that, according to these and other extant data, cannot be met by bamboo leaves alone regardless of species or source.

The differences between the species in leaf nutrient content found in this study are small in comparison to that found in a study conducted by Hunter and Stewart [18] with tropical species. They collected foliage samples from a wide range of Central American shrub species growing together in one designed trial in Comayagua, Honduras. Their data suggested very large variations in foliar nutrient content between the species (threefold for nitrogen, phosphorus and potassium; sevenfold for calcium and magnesium; and sixfold for boron), which were not related simply to the relative size differences of the plants. They suggested that there could be an opportunity to use particular species to increase specific soil nutrient levels by mulching, or to use as fodder to redress animal health problems caused by poor mineral nutrition. Four of the species they tested they thought might be poor sources of animal fodder, *Quassia simarouba* and *Crescentia alata* because of low N content and high fibre content, and *Caesalpinia coriaria* and *Caesalpinia eriostachys* because of high lignin content. It must be noted that in this study plants from widely differing families were being compared, some nitrogen fixing leguminosae, others non-nitrogen-fixing. However, these findings help to set those from this present study in context.

While this preliminary study focused on bamboo leaves at one sampling time, it is known that pandas annually consume more culm biomass compared with leaves (approximately 55% culm, 45% leaves [1, 10, 11]). Our study focused on leaves because, leaves are known generally to contain 2–10-fold higher mineral concentrations compared with culm fractions [12]. However, some culm fractions and shoots contain higher concentrations of some critical nutrients, such as P, compared with leaves, especially seasonally. Thus culms may provide a critical source of this essential nutrient for pandas, and palatability of culms should also be factored into selection of species for reserve corridors and should be assessed in further studies.

Additionally, culms would supply the primary secondary economic focus for bamboo plantings within panda reserve corridors. INBAR has had considerable success in stimulating rural incomes by developing craft industries based on large-stemmed bamboo. Studies have shown that small plantings of only 0.13 ha can increase rural income by 30–40%. The small-stemmed species currently used by the pandas have only limited human uses as objects like arrows or fishing rods, but have sometimes been used as the stiffening for polythene greenhouses and therefore have limited capacity to raise rural incomes. Expanding both the choices and utilization of bamboo species available within reserve corridors may thus serve multiple purposes.

It seems, although this work is very much of a preliminary study, that there are no great risks nor are there any great benefits (from the standpoint of panda nutrition) in increasing the number and range of bamboo species to be planted in and around reserve corridors. While one would continue to plant the accepted ‘panda bamboos’, *B. fargesii* and *F. nitida*, in the heart of the corridor, it seems as if there is no great risk or great nutritional advantage in planting bamboos that can be used for village industries in the margins of those corridors. Neither would there be an ecological risk from planting the thicker-stemmed species native to the region. The distribution of species on the mountainside reflects altitudinal zoning. The larger-stemmed species are not currently present in the high altitude *Bashania* and *Fargesia* zone because they cannot tolerate the conditions. Though for this reason they would, therefore, not prove invasive, the introduction of exotic species would require pre-screening for invasive characteristics or potential negative impacts.

However, our study has shown that a diet of bamboo leaves by itself would not necessarily satisfy the panda’s nutritional requirements. Given that nutrient contents vary seasonally and between plant parts, this study should be followed up by a more comprehensive sampling study, including culm fractions and controlled palatability trials utilizing both captive and free-ranging pandas.

Acknowledgements

We are grateful to Mr. Li Yue of Louguantai Bamboo Garden and Mr. Li Huanfang of Shanxi Forestry Bureau for their help in the field, Jasmine Thomas and Joan Deutsch for laboratory analytical assistance.

REFERENCES

1. G. B. Schaller, J. Hu, W. Pan and J. Zhu, *The Giant Pandas of Wolong*. University of Chicago Press, Chicago, IL (1985).
2. C. J. Loucks, Z. Lu, E. Dinerstein, H. O. Wang, D. M. Olson, C. Zhu and D. Wang, Giant pandas in a changing landscape, *Science* **294**, 1446–1465 (2001).
3. D. G. Reid, A. H. Taylor, J. C. Hu and Z. S. Qin, Environmental influences on bamboo Bashania fangiana growth and implications for giant panda conservation, *J. Ecol.* **28**, 855–868 (1991).
4. F. W. Wei, Z. W. Wang, Z. H. Feng, M. Li and A. Zhou, Seasonal energy utilization in bamboo by the red panda (Ailurus fulgens), *Zoo Biol. J.* **19**, 27–33 (2000).
5. J. G. Liu, M. Linderman, Z. Y. Ouyang, L. An, J. A. Yang and H. M. Zhang, Ecological degradation in protected areas: the case of Wolong Nature Reserve for giant pandas, *Science* **292**, 98–101 (2001).
6. L. An, J. G. Liu, Z. Y. Ouyang, M. Linderman, S. Q. Zhou and H. M. Zhang, Simulating demographic and socio-economic processes on household level and implications for giant panda habitats, *Ecol. Model.* **140**, 31–49 (2001).
7. AOAC, *Official Methods of Analysis of AOAC International*, 16th edn. Association of Official Analytical Chemists International, Graithersburg, MD (1996).
8. H. M. Stahr, *Analytical Methods in Toxicology*, 85 pp. Wiley, New York, NY (1991).
9. E. S. Dierenfeld, The nutritional composition of bamboo and its utilization by the giant panda, MS Thesis, Cornell University, Ithaca, NY (1981).

10. S. A. Mainka, M. Li and G. Zhaol, Dietary vitamin and mineral concentrations of two juvenile female giant pandas (*Ailuropoda melanoleuca*), *J. Wildlife Dis.* **27**, 372–380 (1991).
11. E. S. Dierenfeld, H. F. Hintz, J. B. Robertson, P. J. van Soest and O. T. Oftedal, Utilization of bamboo by the giant panda, *J. Nutr.* **112**, 636–641 (1982).
12. E. S. Dierenfeld, Chemical composition of bamboo in relation to giant panda nutrition, in: *The Bamboos, Proceedings of an International Symposium*, London (1996), G. P. Chapman (Ed.), pp. 205–21l. Academic Press for the Linnean Society of London, San Diego, CA (1997).
13. D. G. Reid and J. C. Hu, Giant panda selection between *Bashania fangiana* bamboo habitats in Wolong reserve, Sichuan, China, *J. Appl. Ecol.* **28**, 228–243 (1991).
14. J. Hu, J. C. Hu, Z. B. Qu and D. L. Yang, The study on the giant panda's selection and utilization to Fargesia nitida in Huanglong, *Zool. Res.* **21**, 48–52 (2000).
15. P. Sunita, G. K. Saha and J. A. Khan, Ecology of the red panda *Ailurus fulgens* in the Singhalila national park, Darjeeling, India, *Biol. Conserv.* **98**, 11–18 (2001).
16. C. Fimbel, A. Vedder, E. Dierenfeld and F. Mulindahabi, An ecological basis for large group size in *Colobus angolensis* in the Nyungwe Forest, Rwanda, *Afr. J. Ecol.* **39**, 83–92 (2001).
17. E. S. Dierenfeld, X. Qui, S. A. Mainka and W. Liu, Giant panda diets fed in five Chinese facilities: an assessment, *Zoo Biol.* **14**, 211–222 (1995).
18. I. R. Hunter and J. L. Stewart, Foliar nutrient and nutritive content of Central American multipurpose tree species growing at Comayagua, Honduras, *Commonwealth Forestry Rev.* **72**, 193–197 (1993).