Zoological Studies **47**(4): 393-401 (2008)

Zoological Studies

Geographic Variation of Chevrier's Field Mouse (*Apodemus chevrieri*) (Milne-Edwards, 1868) (Muridae: Murinae) from Southwestern China Based on Cranial Morphometric Variables

Song Li*, Ying-Xiang Wang, Xue-Long Jiang, and Jun-Xing Yang*

Kunming Institute of Zoology, Chinese Academy of Sciences, 32 Jiaochang East Road, Kunming, Yunnan 650223, China

(Accepted November 27, 2007)

Song Li, Ying-Xiang Wang, Xue-Long Jiang, and Jun-Xing Yang (2008) Geographic variation of Chevrier's field mouse (*Apodemus chevrieri*) (Milne-Edwards, 1868) (Muridae: Murinae) from southwestern China based on cranial morphometric variables. *Zoological Studies* **47**(4): 393-401. A sample of 134 specimens of *Apodemus chevrieri* was investigated in the present study. Individuals were divided into male and female groups, and these were respectively subjected to multivariate analysis. Results indicated that 3 geographic populations of *A. chevrieri* inhabit southwestern China: a Sichuan population in western Sichuan Province; a northwestern Yunnan population ranging from northwestern Yunnan Province eastward to southern Sichuan Province; and a central Yunnan population in central Yunnan Province. In addition, a coefficient of difference analysis was performed among these 3 geographic populations. The results suggested that these 3 geographical populations of *A. chevrieri* belonged to 2 subspecies. Furthermore, we discuss the relationships of the subspecific differentiation of *A. chevrieri* with changes in latitude in southwestern China.
http://zoolstud.sinica.edu.tw/Journals/47.4/393.pdf

Key words: Geographic variation, Numerical analysis, *Apodemus chevrieri*, Morphometry.

Chevrier's field mouse, *Apodemus chevrieri* (Milne-Edwards, 1868), is an endemic species in China (Corbet and Hill 1992, Zhang et al. 1997, Wang 2003, Musser and Carleton 2005). *Apodemus chevrieri* was first included in *A. agrarius* (Pallas, 1771) by Allen (1940). While Ellerman (1941) regarded it as a distinct species, Ellerman and Morrison-Scott (1950) and Corbet (1978) listed it as a subspecies of *A. agrarius*. Xia (1984) finally established it as a distinct species, and subsequently investigators, such as Corbet and Hill (1992), Musser and Carleton (1993), Wang (2003), and Musser and Carleton (2005), all accepted this result.

Clearly, there is no longer any disagreement on the validity of its specific status, but, until now, there has been no study on differentiation within the species. *Apodemus chevrieri* occurs in areas of southwestern China, a place with the most abundant and complex biodiversity in China, and one of the most biodiverse regions in the world. No morphometric study has been conducted on this species, and geographic variations remain unclear. In this study, therefore, morphometrics and related statistical analyses were performed on the skull of *A. chevrieri*, to clarify geographic variations. Additionally, we also discuss relationships of differentiation within *A. chevrieri* and latitude in southwestern China.

MATERIALS AND METHODS

Data collection

This study was conducted at the Kunming Institute of Zoology, Chinese Academy of Sciences (KIZ, CAS), Kunming, China, and was based on

*To whom correspondence and reprint requests should be addressed. Tel: 86-871-5136964. E-mail:lis@mail.kiz.ac.cn; yangjx@mail.kiz.ac.cn

mammal collections of the Museum of KIZ, CAS. Numbers and collection localities of specimens that were examined in the study are listed in the Appendix.

A series of 134 specimens was studied; they were divided into male (n = 64) and female groups (n = 70), and were separately subjected to multivariate analyses. Because the molar eruption was complete, all specimens used in the study were considered to be adults. Four external measurements, head and body length (HB), tail length (TL), hind foot length (HFL), and ear length (EL), were excerpted from the original labels directly attached to the skins. Since these measurements may show considerable inter-observer variation, they were not included in the multivariate and coefficient of difference (CD) analyses. All 14 of the following cranial measurements were taken with digital calipers to an accuracy of 0.01 mm: greatest length of skull (GLS), condylobasal length (CBL), occipitonasal length (ONL), upper tooth row (UTR), M^2 length (M), auditory bulla length (ABL), distance between the bullas (DBB), breadth of the occipital condyles (BOO), breadth of the foramen magnum (BFM), height of the supraoccipital (HS), zygomatic width (ZW), nasal length (NL), nasal breadth (NB), and lower tooth row (LTR) (Fig. 1).

Data analysis

Based on the 14 variables described above, principal component analyses (PCAs) were conducted to highlight differences in skull shape among the samples. This technique combines the variables to show maximum variations among individuals without assuming prior groupings based on putative subspecies identification, and no a priori grouping based on putative group identifications was done. The groups identified by the PCAs were analyzed by a 2nd multivariate approach, discriminant analysis (DA). Finally, the

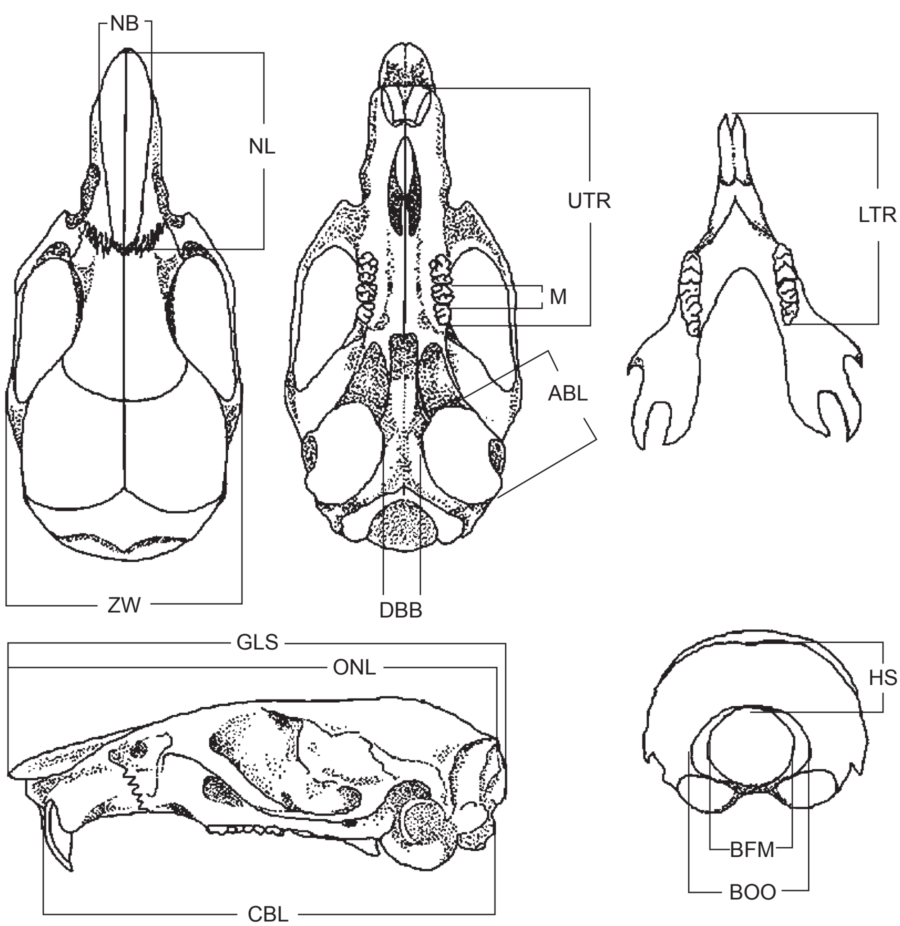

Fig. 1. Photographic representation of the 14 cranial measurements used in the study.

groups that were identified by the PCAs and DA were then assigned names, and the CD (Mayr 1969) between groups was calculated using the following equation: CD = (Mb - Ma)/(SDa + SDb), where Mb is the mean of population b, Ma is the mean of population a, SDa is the standard deviation of population a, and SDb is the standard deviation of population b.

PCAs and DA were performed using SPSS vers. 11.0 (Chicago, IL, USA).

RESULTS

Multivariate analysis

Male group: As noted above, 64 of the total samples were males that could be assessed by PCA and DA. Eigenvalues for the 1st 3 principal components were 7.54, 2.17, and 0.84 respectively, accounting for 75.32% of the total variance. Most characteristics had high positive loadings on the 1st principal component, suggesting that this component (53.82% of the total variance) represents size variation in the sample. The 2nd principal component (15.47% of the variance) was strongly correlated with DBB and BFM (with factor loadings of > 0.70), and the 3rd principal component (6.02% of the variance) was primarily correlated with HS (with a factor loading of > 0.70) (Table 1).

Because the eigenvalues of the 1st 2 principal components exceeded 2.00, and the third was much lower (0.84), we used PC1 and PC2 to make scatterplots for the PCA (Fig. 2A).

Results in figure 2A suggest that the samples tended to be separated into 3 different groups. Taking into consideration the collection localities, we suggest that the samples originating from western and southwestern Sichuan Province (including the Batang, Litang, and Daocheng areas), samples from northwestern Yunnan Province (including the Gongshan, Xiaozhongdian, Zhongdian, Deqin, Weishan, Ninglang, Binchuan, Jianchuan, Lijiang, and Weixi areas) and southern Sichuan province (including the Yanyuan and Huidong areas), and samples from central Yunnan Province (including the Jingdong, Kunming, and Eshan areas) formed 3 separate groups (Fig. 2A). According to the results of figure 2A, we then classified the samples into 3 different geographical populations. To confirm our observations, the 2nd multivariate approach (DA) was employed. Our results indicated that these samples were even more easily differentiated into 3 distinct populations (Fig. 3A).

Female group: Seventy of the samples were females, and they were also assessed by PCA and

Table 1. Factor loadings and percentages of variance explained by the principal component analysis. Variable codes are explained in figure 1

Variable	PC1		PC2		PC3	
	Male	Female	Male	Female	Male	Female
GLS	**0.907**	**0.957**	0.162	0.022	0.323	0.088
CBL	**0.914**	**0.983**	-0.003	-0.035	0.312	0.047
ONL	**0.959**	**0.942**	0.108	-0.008	0.171	0.080
UTR	**0.796**	**0.948**	0.119	0.132	0.431	0.061
M	0.208	0.040	0.556	0.530	0.236	0.375
ABL	**0.797**	0.672	-0.351	-0.597	0.152	0.039
DBB	-0.036	0.140	**0.752**	**0.866**	-0.376	0.071
BOO	0.260	0.428	0.693	0.048	0.405	**0.819**
BFM	-0.021	-0.187	**0.815**	0.295	0.120	**0.833**
HS	0.337	**0.763**	0.129	0.041	**0.801**	0.015
ZW	**0.795**	**0.881**	0.283	-0.056	0.298	-0.011
NL	**0.789**	**0.831**	0.217	0.006	0.018	0.054
NB	0.582	0.627	0.199	0.458	0.445	0.078
LTR	0.636	**0.788**	0.097	0.237	0.585	0.165
Eigenvalues	7.54	7.52	2.17	2.10	0.84	1.13
Variance explained (%)	53.82	53.69	15.47	15.01	6.02	8.10

DA. Eigenvalues for the1st 3 principal components were 7.52, 2.10, and 1.13 respectively, accounting for 76.80% of the total variance. Most characteristics had high positive loadings on the 1st principal component, suggesting that this component (53.69% of the total variance) generally represented size variation in the sample. The 2nd principal component (15.01% of the variance) was

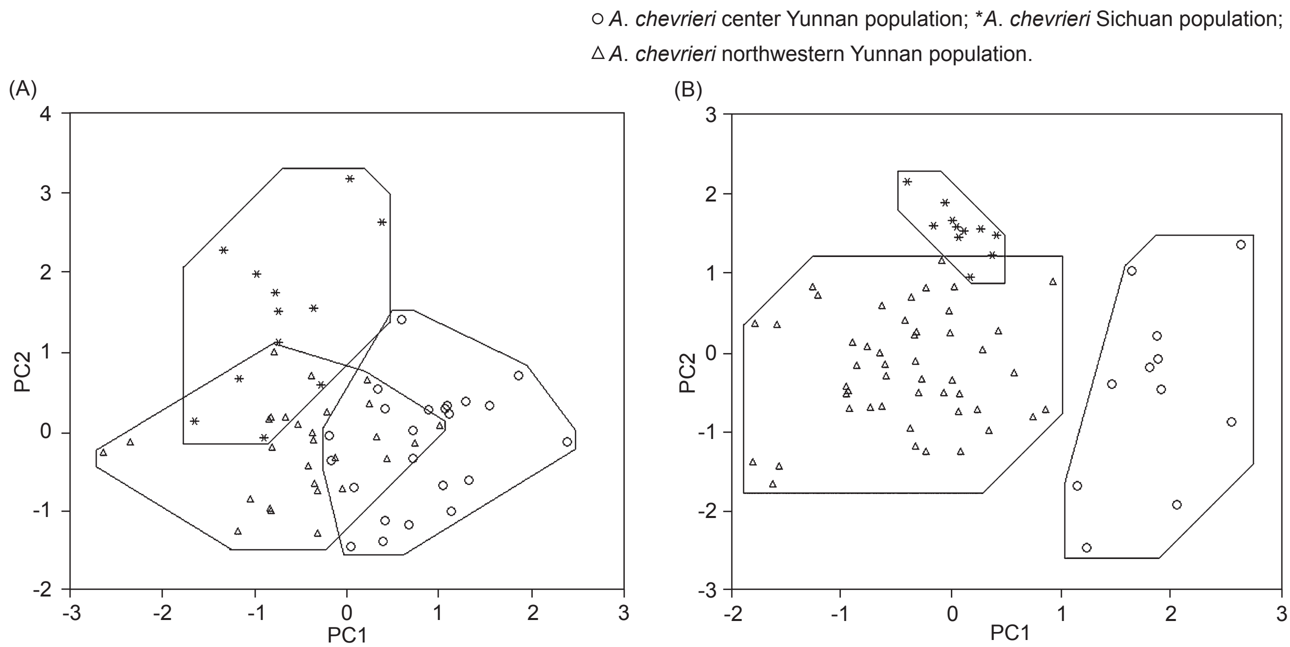

Fig. 2. Plots of *Apodemus chevrieri* populations on the principal components factors. (A) male; (B) female.

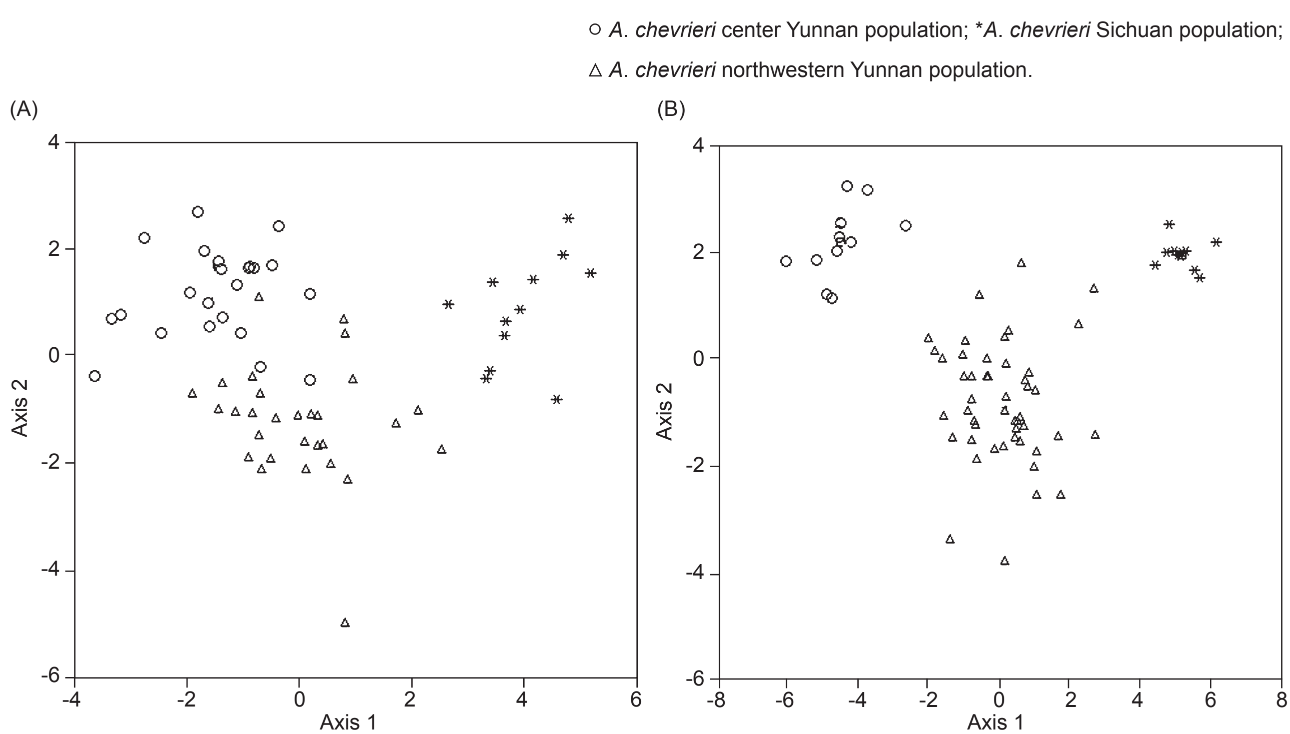

Fig. 3. Plots of *Apodemus chevrieri* populations on discriminant canonical axes 1 and 2. (A) male; (B) female.

strongly correlated with DBB (with a factor loading of > 0.70), and the 3rd principal component (8.10% of variance) was primarily correlated with BOO and BFM (with factor loadings of > 0.70) (Table 1).

Scatterplots of the PCA and DA were created, and the results are given in figures 2B and 3B, respectively.

Figure 4 shows the geographic distribution of samples in this study.

Coefficient of difference (CD)

The CD for subspecific differentiation should be ≥ 1.28 (Mayr 1969). The results compared the CDs for the 14 cranial measured variables among the 3 *A*. *chevrieri* geographic populations, which were identified by both the PCA and DA (Table 2). CDs of CBL and ONL were > 1.28 between the central and northwestern Yunnan populations;

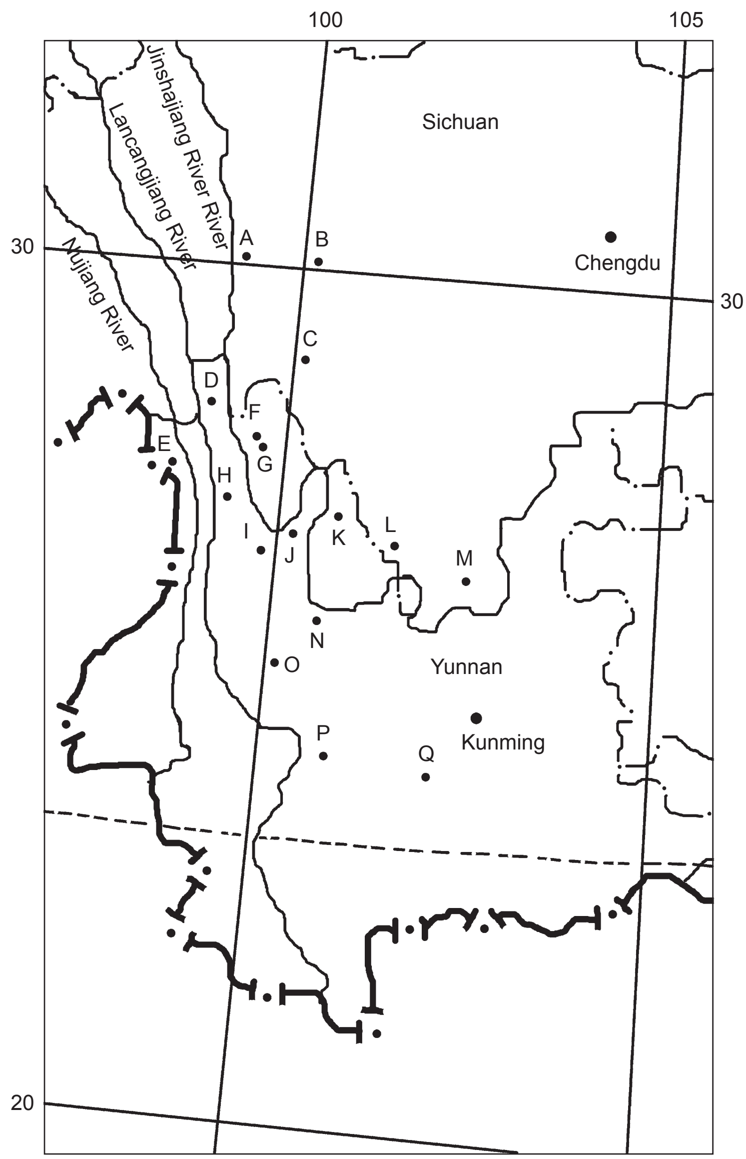

Fig. 4. Geographic distribution of samples examined in this study. A, Batang; B, Litang; C, Daocheng; D, Deqin; E, Gongshan; F, Zhongdian; G, Xiaozhongdian; H, Weixi; I, Jianchuan; J, Lijiang; K, Ninglang; L, Yanyuan; M, Huidong; N, Binchuan; O, Weishan; P, Jingdong; Q, Eshan.

CDs of CBL and ABL were > 1.28 between the central Yunnan and Sichuan populations, while none of CDs of the 14 cranial variables was > 1.28 between the northwestern Yunnan and Sichuan populations. The results suggest that the central Yunnan population should rank as a subspecies apart from the northwestern Yunnan and Sichuan populations.

External and cranial measurements of the 3 populations of *A. chevrieri* are given in table 3.

DISCUSSION

In an earlier study (Ellerman 1941), *A. chevrieri* was regarded as an independent species, and *A. c. chevrieri* (Milne-Edwards) and *A. c. fergussoni* (Thomas) were regarded as subspecies, with the 1st being from Sichuan Province and the 2nd from southern Gansu Province. Further studies performed by Ellerman and Morrison-Scott (1951) and Corbet (1978) reduced it to the status of a subspecies of *A. agrarius*, and geographical variation in this subspecies was not further investigated. Although Xia (1984) re-validated it as a bona fide species, and Corbet and Hill (1992), Musser and Carleton (1993), Wang (2003), and Musser and Carleton (2005) all followed his verdict, they paid no attention to intraspecific geographic variations.

Table 2. Comparison of the coefficient of difference (CD) among the 3 *Apodemus chevrieri* geographic populations: 1, central Yunnan population; 2, northwestern Yunnan population; 3, Sichuan population. Variable codes are explained in figure 1

Variable	1 vs. 2	1 vs. 3	2 vs. 3
GLS	1.27	0.99	0.45
CBL	**1.39**	**1.37**	0.25
ONL	**1.35**	1.24	0.34
UTR	1.10	0.68	0.55
M	0.22	0.50	0.73
ABL	0.99	**1.85**	0.68
DBB	0.03	0.47	0.53
BOO	0.41	0.24	0.58
BFM	0.07	0.77	0.74
HS	0.68	0.21	0.53
ZW	1.19	1.04	0.20
NL	0.66	0.67	0.13
NB	0.56	0.10	0.61
LTR	1.03	0.43	0.59

In our study, results obtained from the PCAs revealed that 18 sampled areas were clustered into 3 distinct geographic populations. The 1st included Batang, Litang, and Daocheng (western and southwestern Sichuan Province). The 2nd included Deqin, Gongshan, Zhongdian, Xiaozhongdian, Weixi, Jianchuan, Lijiang, Binchuan, Weishan, and Ninglang (northwestern Yunnan Province), and Yanyuan, Huidong (southern Sichuan province), and the 3rd included Jingdong, Eshan, and Kunming (central Yunnan Province). The DAs confirmed the above results. Furthermore, the results of the CD analyses indicated that these 3 geographic populations belong to 2 different subspecies, 1 ranging from Sichuan to northwestern Yunnan, and the other occurring in central Yunnan.

Based on these results, it is clear that the central Yunnan *A. chevrieri* population markedly differs from the other populations of the species, strongly suggesting that it should be recognized as a distinct subspecies. As the type locality of *chevrieri* is Moupin (now called Baoxing), in Sichuan, the central Yunnan population requires a new name.

Figure 4 indicates that latitude plays an important role in the intraspecific differentiation of *A. chevrieri*. To confirm this conclusion, more studies, especially molecular data analysis and investigation of additional geographical and other impact factors (such as elevation, climate, seasonality, and vegetation), should be performed to reconstruct their molecular phylogenies and decisively determine the relationships between subspecific differentiation of *A. chevrieri* and geographical evolution in southwestern China.

On the other hand, table 3 shows that mean values of GLS, CBL, ONL, UTR, ABL, HS, ZW, NL, NB, and LTR of the *A. chevrieri* central Yunnan population were larger than those of the northwestern Yunnan and Sichuan populations. Considering their distribution areas (Fig. 4), we believe that our results suggest an interesting pattern of size variation, with *A. chevrieri* being larger at lower latitudes (central Yunnan population) and smaller at higher latitudes (northwestern Yunnan and Sichuan populations). This finding is contrary to Bergmann's rule (Bergmann 1847). In their studies on meadow voles, Snell and Cunnison (1983) found the same phenomenon, and they argued that small size reduces total expenditure of energy, and a smaller body would be less energetically stressful than a larger one. Their explanation may also be applicable to geographical variations of *A. chevrieri* in southwestern China.

Acknowledgments: This work was completed at the Kunming Institute of Zoology, Chinese Academy of Sciences (KIZ, CAS). We are indebted to Drs. J. Yang, M.W. Zhang, Z.M. Zhou, and G.H. Yu, KIZ, CAS, with special thanks to Dr. W.S. Yang, of the University of Pennsylvania, Philadelphia, USA for his critical review of this manuscript. This study was supported by the National Natural Science Foundation of China (30770251), National Science Foundation (DEB-0103795), National Basic Research Program of China (973 Program) (2007CB411600), and Natural Science Foundation of Yunnan Province (2007C099M).

REFERENCES

Allen GM. 1940. The mammals of China and Mongolia. Nat. Hist. Cent. Asia. Vol. 11, Part 2. New York: American Museum of Natural History.

Table 3. External and cranial variable measurements of 3 populations of *Apodemus chevrieri* (mean ± standard deviation)/range. Variable codes are explained in figure 1

External measurements

	HB	TL	HFL	EL
Central Yunnan	104.15 ± 9.22 82-125 (*n* = 34)	83.38 ± 11.41 48-108 (*n* = 32)	20.91 ± 1.07 18-23 (*n* = 33)	15.24 ± 1.78 10-18 (*n* = 34)
Northwestern Yunnan	88.39 ± 8.38 70-120 (*n* = 77)	80.86 ± 9.27 50-107 (*n* = 71)	21.42 ± 1.10 19-24 (*n* = 77)	14.21 ± 1.68 10-18 (*n* = 77)
Sichuan	90.57 ± 4.75 82-100 (*n* = 23)	83.38 ± 5.52 75-95 (*n* = 21)	21.13 ± 0.76 20-23 (*n* = 23)	12.87 ± 1.58 11-17 (*n* = 23)
Total	92.76 ± 10.49 70-125 (*n* = 134)	81.94 ± 9.40 48-108 (*n* = 124)	21.24 ± 1.06 18-24 (*n* = 133)	14.24 ± 1.84 10-18 (*n* = 134)

Cranial variable measurements

	GLS	CBL	ONL	UTR	M	ABL	DBB
Central Yunnan *n* = 34	27.91 ± 0.65 26.69 – 29.01	26.00 ± 0.62 24.89 – 27.30	27.23 ± 0.62 26.21 – 28.44	13.48 ± 0.34 12.61 – 14.40	1.17 ± 0.06 1.03 – 1.29	5.65 ± 0.27 5.22 – 6.31	1.81 ± 0.20 1.45 – 2.25
Northwestern Yunnan *n* = 77	26.02 ± 0.84 23.81 – 27.94	23.92 ± 0.88 21.35 – 25.54	25.29 ± 0.82 23.37 – 27.33	12.58 ± 0.47 11.28 – 13.68	1.14 ± 0.06 0.88 – 1.30	5.14 ± 0.25 4.28 – 5.73	1.80 ± 0.16 1.36 – 2.14
Sichuan *n* = 23	26.67 ± 0.61 25.83 – 28.10	24.30 ± 0.63 23.16 – 26.02	25.75 ± 0.57 24.83 – 27.00	13.03 ± 0.33 12.54 – 13.89	1.23 ± 0.05 1.16 – 1.37	4.85 ± 0.17 4.54 – 5.28	2.01 ± 0.24 1.59 – 2.74
Total *n* = 134	26.61 ± 1.10 23.81 – 29.01	24.51 ± 1.18 21.35 – 27.30	25.86 ± 1.10 23.37 – 28.44	12.89 ± 0.57 11.28 – 14.40	1.16 ± 0.07 0.88 – 1.37	5.22 ± 0.37 4.28 – 6.31	1.84 ± 0.20 1.36 – 2.74

	BOO	BFM	HS	ZW	NL	NB	LTR
Central Yunnan *n* = 34	6.15 ± 0.14 5.86 – 6.42	4.54 ± 0.16 4.27 – 4.94	3.92 ± 0.27 3.37 – 4.52	13.42 ± 0.31 12.83 – 14.07	10.45 ± 0.50 9.47 – 11.78	3.12 ± 0.16 2.73 – 3.49	11.64 ± 0.33 11.01 – 12.36
Northwestern Yunnan *n* = 77	6.02 ± 0.18 5.59 – 6.50	4.57 ± 0.14 4.18 – 4.86	3.51 ± 0.34 2.31 – 4.24	12.57 ± 0.41 11.35 – 13.49	9.82 ± 0.45 8.77 – 10.66	2.95 ± 0.14 2.53 – 3.27	10.81 ± 0.48 9.39 – 11.84
Sichuan *n* = 23	6.23 ± 0.19 6.01 – 6.64	4.79 ± 0.16 4.56 – 5.16	3.81 ± 0.23 3.34 – 4.27	12.73 ± 0.37 12.11 – 13.68	9.92 ± 0.29 9.41 – 10.66	3.09 ± 0.10 2.87 – 3.26	11.33 ± 0.40 10.36 – 12.30
Total *n* = 134	6.09 ± 0.19 5.59 – 6.64	4.60 ± 0.17 4.18 – 5.16	3.66 ± 0.36 2.31 – 4.52	12.81 ± 0.52 11.35 – 14.07	9.99 ± 0.51 8.77 – 11.78	3.02 ± 0.16 2.53 – 3.49	11.11 ± 0.56 9.39 – 12.36

Bergmann C. 1847. Über die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse. Göttinger Studien, **3:** 595-708.

Corbet GB. 1978. The mammals of the Palaearctic region: a taxonomic review. London: British Museum (Natural History), Cornell Univ. Press.

Corbet GB, JE Hill. 1992. The mammals of the Indomalayan region: a systematic review. New York: Oxford Univ. Press.

Ellerman JR. 1941. The families and genera of living rodents. Vol. 2. London: Oxford Univ. Press.

Ellerman JR, TCS Morrison-Scott. 1951. Checklist of Palaearctic and Indian mammals. London: British Museum (Natural History).

Mayr E. 1969. Principles of systematic zoology. New York: McGraw-Hill.

Musser GG, MD Carleton. 1993. Family Muridae. *In* DE Wilson, DM Reeder, eds. Mammal species of the world: taxonomic and geographic reference, 2nd ed. Washington D.C.: Smithsonian Institution Press.

Musser GG, MD Carleton. 2005. Family Muridae. *In* DE Wilson, DM Reeder, eds. Mammal species of the world: taxonomic and geographic reference, 3rd ed. Maryland: Johns Hopkins Univ. Press.

Snell RR, KM Cunnison. 1983. Relation of geographic variation in the skull of *Microtus pennsylvanicus* to climate. Can. J. Zool. **61:** 1232-1241.

Wang YX. 2003. A complete checklist of mammal species and subspecies in China, a taxonomic and geographic reference. Beijing: China Forestry Publishing House.

Xia WP. 1984. A study on Chinese *Apodemus* with a discussion of its relations to Japanese species. Acta Theriol. Sin. **4:** 93-98. (in Chinese)

Zhang YZ, SK Jin, GQ Quan, SH Li, ZY Ye, FG Wang, ML Zhang. 1997. Distribution of mammalian species in China. Beijing: China Forestry Publishing House.

APPENDIX

***Apodemus chevrieri* central Yunnan population: *n* = 34.**

Yunnan Province: Jingdong (640033, 640034, 811614, 811616, 811643, 811646, 811647, 811672, 811677, 811683, and 811687), Kunming (600061, 600063, 600075, 600077, 620570, 620572, 63I-0099, 63I-0105, 63I-0107, 63I-0108, 63I-0128, 63I-0131, 63I-0140, 63I-0142, 6310325, 6310326, 76728, and 85025,); and Eshan (67079, 67092, 67093, 67094, and 67095).

Apodemus chevrieri northwestern Yunnan population: *n* = 77.

Yunnan Province: Xiaozhongdian (810016, 810017, and 810041); Zhongdian (1089, 1093, 810429, 810432, 810433, 810443, 810444, 810462, 810464, 810475, 810476, 810477, 810478, 810479, 810483, 810484, 810485, 810486, 810488, and 810489); Deqin (79610, 79717, 79718, 79720, 79768, 79783, 79798, and 79799); Weishan (650339 and 650341); Ninglang (810719, 810722, 810723, 810742, 810756, 810757, 810759, 810760, 810762, 810764, 810765, 810766, 810767, 810768, and 810769); Binchuan (810633 and 810671); Jianchuan (650356, 650365, 650374, and 650376); Lijiang (79819, 79847, 79849, 79852, 79858, 810015, and 201054); Weixi (1103, 1104, 1105, 810497, 810503, 810530, 810532, 810548, 810554, 810555, 810559, 810572, and 810594); and Gongshan (73326).

Sichuan Province: Yanyuan (889) and Huidong (890).

Apodemus chevrieri Sichuan population: *n* = 23.

Sichuan Province: Batang (1069, 1070, 810331, 810332, 810359, 810360, 810368, 810370, 810372, 810377, 810378, 810379, 810381, 810382, 810383, 810387, 810388, 810389, and 810391); Litang (1053 and 810296); Daocheng (1049 and 810274).