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# Differentiation of Subspecies of Asiatic Striped Squirrels (*Tamiops swinhoei*) (Milne-Edwards) (Rodentia: Sciuridae) in China with Description of a New Subspecies

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**Song Li, Qing Feng, Jun-Xing Yang, and Ying-Xiang Wang (2006)** Differentiation of subspecies of Asiatic striped squirrels (*Tamiops swinhoei*) (Milne-Edwards) (Rodentia: Sciuridae) in China with description of a new subspecies. *Zoological Studies* **45**(2): 180-189. Based on the pelage characteristics and results of multivariate and univariate analyses, a new subspecies is described in this study, and a taxonomic revision of *Tamiops swinhoei* from China is presented. In total, 123 specimens of *Tamiops swinhoei* were investigated, 48 of which had intact skulls that were subjected to multivariate and univariate analyses. Results indicated that 8 subspecies of *T. swinhoei* can be recognized in China: *T. s. swinhoei* of southwestern Sichuan; *T. s. vestitus* broadly distributes from northeastern Sichuan, southern Gansu, southeastern Ningxia, southern Shaanxi, northwestern Hubei, southern Shanxi, northern Henan, and Hebei to Beijing; *T. s. spencei* distributes in Mt. Gaoligong, northwestern Yunnan (from northeastern Myanmar to the Nujiang); *T. s. russeolus* restricts to northwestern Yunnan and southeastern Tibet (between the Lancangjiang and Jinshajiang, south to 27°N); *T. s. forresti* distributes in northern Yunnan (Lijiang, Dali, and Chuxiong areas); *T. s. chingpingensis* of southwestern Yunnan; *T. s. olivaceous* of southern Yunnan; and a new subspecies distributes in northern Sichuan (Markam). *Tamiops s. clarkei*, from western Yunnan (east of the Nujiang) and eastern Yunnan (Mile) is not a subspecies of *T. swinhoei*, but may be a subspecies of *T. maritimus*. http://zoolstud.sinica.edu.tw/Journals/45.2/180.pdf

**Key words:** New subspecies, Multivariate analysis, *Tamiops swinhoei*, Taxonomic revision.

The Asiatic striped squirrel *Tamiops swinhoei* (Milne-Edwards) (Rodentia: Sciuridae) distributes in Yunnan and Sichuan Provinces, North China, and adjacent areas (Shaanxi and Gansu Provinces, and Tibet), as well as in northeastern Myanmar and northern Vietnam. The species distributes in mountainous areas between 1500 and 3500 m in elevation (Corbet and Hill, 1992). It seems to be generally larger than other species of *Tamiops* and to have longer and denser fur, which are diagnostically distinct characters. These 2 tendencies may be related to the fact that the species *T. swinhoei* lives farther north or at higher elevations than other species of *Tamiops*. The outer pair of light lines on the back is less brilliant than those of *T. mcclellandi* (Horsfield) but often broader, and they generally stop at the shoulder instead of being connected with the cheek stripes. Compared with *T. swinhoei*, characters of *T. maritimus* (Bonhote) mainly differ by (1) the pelage which is comparatively short and thin, with the general coloration tending to be nearer the color of the nape; and (2) the outer lighter stripes which are whitish (Moore and Tate 1965).

Milne-Edwards (1874) named this species *Sciurus mcclellandii* var. *swinhoei*, and (J. Allen 1906) established *Tamiops* as an effective genus. Thomas (1911) regarded this species as *T. swin-*

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*hoei*. G. Allen (1940) included *T. mcclellandi* and *T. swinhoei* in *Tamiops* from China; and regarded *T. s. swinhoei*, *T. s. clarkei* (Thomas), *T. s. vestitus* (Miller), *T. s. maritimus*, and *T. s. hainanus* (J. Allen) as subspecies of *T. swinhoei* in China. Ellerman (1940) regarded *Tamiops* as a subgenus in *Callosciurus* (Gray); *C. swinhoei* was regarded as a monotypic species. Ellerman and Morrison-Scott (1951) considered that *C. swinhoei* included 11 subspecies: *C. s. swinhoei*, *C. s. maritimus*, *C. s. formosanus* (Bonhote), *C. s. hainanus*, *C. s. vestitus*, *C. s. clarkei*, *C. s. spencei*, *C. s. laotum* (Robinson and Kloss), *C. s. moi* (Robinson and Kloss), *C. s. russeolus*, and *C. s. olivaceus*. Moore and Tate (1965) listed only *T. s. swinhoei* and *T. s. vestitus* as subspecies of *T. swinhoei*; they considered *T. clarkei*, *T. maritimus forresti* (Thomas), *T. spencei* (Thomas), *T. mcclellandi russeolus* (Jacobi), and *T. monticolus olivaceus* (Osgood) to be junior synonyms of *T. s. swinhoei*. Lu et al. (1965) described a new subspecies *T. s. chingpingensis* (Lu and Qyan) from Chingping, Yunnan Prov. Recently (Wang 2003) summarized the subspecies of *T. swinhoei* from China as including *T. s. swinhoei*, *T. s. vestitus*, *T. s. clarkei*, *T. s. forresti*, *T. s. spencei*, *T. s. chingpingensis*, *T. s. russeolus*, and *T. s. olivaceus*; and he also regarded "*Tamiops swinhoei* Barkam form" as a special group without a nomenclatural description.

As shown above, the subspecific classification has been quite confusing among various authors, but the morphological and geographical boundaries among subspecies have not been well clarified. Therefore, a study of subspecific morphological differentiation is needed. In this paper, we examined morphological variations among the subspecies in China. We describe a new subspecies that was mentioned as the "Barkam form" by Wang (2003), because it became clear that it is morphologically distinct from the other subspecies.

## MATERIALS AND METHODS

This study was based on the mammal collections of the Museum of Vertebrates, Kunming Institute of Zoology, Chinese Academy of Sciences (KIZ,CAS) (Kunming, China), Institute of Zoology, Chinese Academy of Sciences (IOZ,CAS) (Beijing, China), and Museum of Sichuan University (MSU) (Chengdu, China). Numbers and collecting localities of specimens that were examined in the study are listed in Appendix I.

A series of 123 specimens was studied, 48 of which had intact skulls which were suitable for use for numerical analyses. Four external measurements, head and body length (HB), tail length (TL), hind foot length (HFL), and ear length (EL), were recorded from original labels attached to the skins. Skull variables were recorded following Musser (1979) and Musser et al. (1992). All 12 cranial measurements were taken by Song Li with digital calipers graduated to the nearest 0.01 mm, as follows: greatest length of the skull (GLS); condylobasal length (CBL); basal length (BL); palatal length (PL), from the anteriormost edge of the premaxillary to the posterior edge of the palatine; zygomatic breadth (ZOB); interorbital breadth (IOB); mastoid breadth (MTB); length of the nasals (NL); breadth across the molars (BAM); length of the upper cheek tooth (LUCT); length of the lower cheek tooth (LLCT); and palatilar length (PAL), from the posterior edge of the incisive foramen to the posterior edge of the palatine.

The coefficient of the difference (CD) (Mayr 1953) was evaluated: $CD = (M_b - M_a)/(SD_a + SD_b)$; where $M_b$ is the mean of population b, $M_a$ is the mean of population a, $SD_a$ is the standard deviations of population a, and $SD_b$ is the standard deviations of population b. Overall similarities among specimens were assessed through principal component analyses (PCA); no a priori groupings based on putative species identifications were assumed. Based on the results of the PCA, we defined different groups; and univariate and multivariate comparisons were made among groups with the program SPSS vers.11.0. Species and subspecies distribution ranges were determined based on the specimens examined, supplemented by selected literature records.

## RESULTS

### *Tamiops swinhoei markamensis* Li and Wang, subsp. nov.

*Holotype*: KIZ 19381, ♂, adult, collected 12 May 1961 from Markam, northern Sichuan Prov., China, elev. 3700 m.

*Paratype*: IOZ 19383, ♀, adult, collected August 1961, from Markam, northern Sichuan Prov., China, elev. 3800 m.

*Specimens examined*: 4 ♂♂, 3 ♀♀, Markam, northern Sichuan (IOZ 19375~19377, 19380, 21540; KIZ 19382; MSU 60I020).

*Etymology*: The new subspecies is named according to the type locality.

*Diagnosis*: General dorsal color olive-gray, inner light stripes yellowish-brown, narrow, nearly attached to base of tail, flanks gray, backs of feet ocherous-buff mixed with black.

*Description of subspecies*: Subspecies *T. s. markamensis* subsp. nov. quite distinct and apparently fairly stable in the following characteristics: (1) General dorsal color olive-gray (other subspecies all olive-brown, only deeper or paler); (2) Middorsal line black, nearly attached to base of tail; (3) Inner dark stripes brown, and outer dark pair of stripes also brown, but lighter than former, inconspicuous, and almost grading into color of flanks; (4) Inner light stripes yellowish-brown, outer light stripes nearly the same as inner light stripes but lighter than former; (5) Flanks gray; (6) Ears covered with black hair becoming white terminally, producing a contrasting white tuft; (7) Underneath, belly ocherous-buff with base of hair slate-gray, fur on throat and chest thicker than that on belly; (8) Backs of feet ocherous-buff mixed with black; and (9) Tail ocherous-buff mixed with black above and ocherous-buff below. As to external and cranial characteristics, *T. s. markamensis* subsp. nov. relatively bigger among *T. swinhoei* subspecies, with the greatest values for HB, EL, CBL, PL, ZOB, NL, and BAM; and its HFL, GLS, PAL only shorter than those of *T. s. swinhoei*.

*Synonyms*: *Tamiops swinhoei vestitus*, Wang 1984, Sichuan Fauna Economica, vol. 2, p. 195.

*Tamiops swinhoei* Barkam form, Wang 2003, Complete Checklist of Mammal Species and Subspecies of China, p. 145.

*Measurements* (Table 1)

*Remarks*: So far, this subspecies is known only from the Markam area (Sichuan Prov., China) from 3000 to 3900 m in elevation, and its distribution apparently does not overlap with that of any other subspecies. According to Mayr (1953), as long as the CD of any 1 character of 2 samples exceeds 1.28, the samples can be separated as different subspecies. Table 2 indicates that among

**Table 1.** Measurements (mm) of external and skull of type specimens of *Tamiops swinhoei markamensis* subsp. nov

| Specimen | sex | HB | TL | HFL | EL | GLS | CBL | BL | PL |
|---|---|---|---|---|---|---|---|---|---|
| Holotype | male | 145 | 100 | 33.00 | 19.00 | 37.12 | 33.37 | 30.98 | 18.00 |
| Paratype | female | 155 | 112 | 40.00 | 21.00 | 42.61 | 37.92 | 35.22 | 20.54 |

| Specimen | sex | ZOB | IOB | MTB | NL | BAM | LUCT | LLCT | PAL |
|---|---|---|---|---|---|---|---|---|---|
| Holotype | male | 23.69 | 13.21 | 16.21 | 11.30 | 09.30 | 06.42 | 06.49 | 15.87 |
| Paratype | female | 23.75 | 11.17 | 17.85 | 13.69 | 10.57 | 07.02 | 06.76 | 17.48 |

HB, head and body length; TL, tail length; HFL, hind foot length; EL, ear ength; GLS, greatest length of the skull; CBL, condylobasal length; BL, basal length; PL, palatal length; SOB, zygomatic breadth; IOB, interorbital breadth; MTB, mastoid breadth; NL, length of the nasals; BAM, breadth of the molars; LUCT, length of the upper cheek tooth; LLCT, length of the lower cheek tooth; PAL, palatilar length.

**Table 2.** Comparison of the coefficient of difference (CD) of the external and skull measurements between *Tamiops swinhoei markamensis* subsp. nov. and the other subspecies

| | III-I | III-II | III-IV | III-V | III-VI | III-VII |
|---|---|---|---|---|---|---|
| HB | - | 1.43 | 1.35 | - | - | 1.64 |
| EL | 1.63 | 2.83 | 2.28 | 2.23 | 1.60 | - |
| ZOB | - | 1.73 | 1.47 | | - | 1.76 |
| NL | 1.59 | - | - | 1.57 | - | 1.95 |
| BAM | - | - | - | | - | 1.32 |
| LLCT | - | - | - | - | - | 1.41 |

I, *T. s. russeolus*; II, *T. s. spencei*; III, *T. s. markamensis*; IV, *T. s. olivaceus*; V, *T. s. forresti*; VI, *T. s. veatitus*; VII, *T. s. chingpingensis*. Key to measurements is given in the footnotes to table 1.

these 16 variables, at least 1 CD was found that exceeded 1.28 between *T. s. markamensis* subsp. nov. and any of the other known subspecies (except for *T. s. swinhoei*).

The subspecies whose ranges are geographically adjacent to *T. s. markamensis* subsp. nov. are *T. s. vestitus* and *T. s. swinhoei*; *T. s. vestitus* lives to the northeast of *T. s. markamensis*, and *T. s. swinhoei* to the southwest (Fig. 3). *Tamiops s. markamensis* subsp. nov. can clearly be distinguished from these 2 subspecies by the following combinations of characteristics described above: from *T. s. vestitus* by (3), (4), and (7); and from *T. s. swinhoei* by (1), (3), and (7).

**Multivariate analysis**

As noted above, 48 individuals with intact skulls were available for assessment of overall similarity. External and cranial measurements of subspecies of *T. swinhoei* are given in table 3.

Eigenvalues for the first 3 principal components were 10.94, 1.20, and 1.09, respectively, explaining 82.67% of the total variance. Most characteristics had high positive loadings on the first principal component, suggesting that this component (68.40% of the total variance) reflected a size effect. The 2nd principal component (7.47% of the variance) was strongly correlated with HFL,

**Table 3.** Measurements (mm) of external and skull characters of subspecies of *Tamiops swinhoei* (mean ± std. dev. with the range given on the line below)

| | *T. s. russeolus* | *T. s. spencei* | *T. s. markamensis* | *T. s. olivaceus* | *T. s. clarkei* |
|---|---|---|---|---|---|
| | *n* = 6 | *n* = 10 | *n* = 5 | *n* = 6 | *n* = 5 |
| HB | 133.50 ± 5.47 | 122.40 ± 6.35 | 142.60 ± 7.70 | 121.17 ± 8.13 | 129.80 ± 8.04 |
| | 125 - 140 | 115 - 135 | 136 - 155 | 110 - 131 | 120 - 139 |
| TL | 113.83 ± 4.88 | 103.00 ± 3.43 | 96.20 ± 11.43 | 99.50 ± 5.65 | 110.20 ± 7.89 |
| | 107 - 120 | 98 - 110 | 85 - 112 | 90 - 105 | 102 - 119 |
| HFL | 30.50 ± 1.22 | 30.20 ± 1.14 | 32.64 ± 4.49 | 25.67 ± 1.86 | 30.80 ± 1.30 |
| | 29 - 32 | 28 - 32 | 28 - 40 | 23 - 28 | 30 - 33 |
| EL | 12.83 ± 1.47 | 11.90 ± 0.32 | 18.26 ± 1.92 | 11.00 ± 1.26 | 14.00 ± 0.71 |
| | 11 - 15 | 11 - 12 | 16 - 21 | 10 - 12 | 13 - 15 |
| GLS | 35.07 ± 1.54 | 34.63 ± 1.66 | 38.63 ± 2.26 | 35.53 ± 1.90 | 36.68 ± 1.84 |
| | 32.64 - 36.82 | 31.84 - 36.98 | 37.12 - 42.61 | 32.69 - 37.59 | 34.86 - 39.16 |
| CBL | 31.56 ± 1.72 | 31.33 ± 1.42 | 34.66 ± 1.88 | 31.46 ± 1.41 | 32.60 ± 1.61 |
| | 29.34 - 34.06 | 28.89 - 33.56 | 33.37 - 37.92 | 29.33 - 32.86 | 31.53 - 35.29 |
| BL | 28.96 ± 1.63 | 28.85 ± 1.32 | 32.10 ± 1.79 | 29.08 ± 1.28 | 30.35 ± 1.61 |
| | 26.79 - 31.28 | 26.62 - 30.92 | 30.98 - 35.22 | 27.15 - 30.39 | 28.99 - 32.91 |
| PL | 16.50 ± 0.87 | 16.52 ± 0.73 | 18.55 ± 1.11 | 16.62 ± 0.80 | 17.55 ± 0.98 |
| | 15.31 - 17.77 | 15.32 - 17.80 | 18.00 - 20.54 | 15.76 - 17.51 | 16.83 - 19.09 |
| ZOB | 21.55 ± 0.80 | 20.34 ± 1.03 | 23.19 ± 0.62 | 20.70 ± 1.07 | 21.38 ± 1.11 |
| | 20.22 - 22.47 | 18.71 - 21.73 | 22.20 - 23.75 | 19.20 - 21.83 | 20.61 - 23.20 |
| IOB | 11.82 ± 0.50 | 11.54 ± 0.58 | 12.76 ± 0.92 | 11.94 ± 0.54 | 12.14 ± 0.49 |
| | 11.10 - 12.34 | 10.61 - 12.33 | 11.17 - 13.50 | 11.69 - 12.34 | 11.64 - 12.88 |
| MTB | 16.52 ± 0.65 | 15.62 ± 0.70 | 16.67 ± 0.73 | 15.77 ± 0.75 | 16.78 ± 0.98 |
| | 15.41 - 17.13 | 14.44 - 16.78 | 16.10 - 17.85 | 14.57 - 16.56 | 15.94 - 18.38 |
| NL | 9.48 ± 0.44 | 9.94 ± 0.66 | 11.84 ± 1.04 | 10.33 ± 1.09 | 10.84 ± 0.62 |
| | 8.76 - 9.97 | 9.02 - 10.80 | 11.20 - 13.69 | 8.31 - 11.21 | 10.29 - 11.60 |
| BAM | 8.84 ± 0.33 | 8.46 ± 0.41 | 9.47 ± 0.62 | 8.69 ± 0.34 | 8.57 ± 0.41 |
| | 8.28 - 9.20 | 7.80 - 9.06 | 9.10 - 10.57 | 8.34 - 9.12 | 8.26 - 9.28 |
| LUCT | 6.32 ± 0.23 | 5.69 ± 0.32 | 6.43 ± 0.35 | 6.16 ± 0.26 | 6.27 ± 0.34 |
| | 5.94 - 6.60 | 5.21 - 6.05 | 6.10 - 7.02 | 5.78 - 6.52 | 6.00 - 6.84 |
| LLCT | 6.24 ± 0.23 | 5.69 ± 0.25 | 6.37 ± 0.31 | 6.07 ± 0.27 | 6.07 ± 0.32 |
| | 5.85 - 6.50 | 5.27 - 6.12 | 6.00 - 6.76 | 5.61 - 6.43 | 5.83 - 6.60 |
| PAL | 14.56 ± 0.64 | 14.36 ± 0.67 | 15.93 ± 0.92 | 14.34 ± 0.72 | 15.34 ± 0.83 |
| | 13.54 - 15.29 | 13.24 - 15.38 | 15.10 - 17.48 | 13.43 - 15.24 | 14.74 - 16.69 |

EL, BL, NL, and PAL (with factor loadings > 0.60). The 3rd principal component (6.80% of the variance) was primarily correlated with TL and HFL (with factor loadings > 0.50) (Table 4).

Because factor loadings of each variable greatly differed in PC2 and PC3, they were plotted in figure 1. Inspection of figure 1 indicates that *T. s. clarkei* is scattered among *T. s. spencei*, *T. s. swinhoei*, and *T. s. chingpingensis*.

After excluding *T. s. clarkei*, the PCA was performed again. Eigenvalues for the first 3 principal components were 10.98, 1.26, and 1.11 respectively, explaining 83.43% of the total variance. Most characters had high positive loadings on the 1st principal component, suggesting that this component (68.62% of the total variance) reflected a size effect. The 2nd principal component (7.85% of the variance) was strongly correlated with HFL, EL, CBL, BL, NL, and PAL (with factor loadings > 0.60). The 3rd principal component (6.95% of the variance) was primarily correlated with TL and HFL (with factor loadings > 0.50) (Table 5). The graph in figure 2 was produced in the same manner as was figure 1.

## Univariate analysis

A one-way analysis of variance (ANOVA) test for differences revealed that the groups of samples significantly differed ($p \leq 0.001$) in all external and

**Table 3.** (Cont.)

| | *T. s. forresti* | *T. s. swinhoei* | *T. s. veatitus* | *T. s. chingpingensis* |
|---|---|---|---|---|
| | *n* = 3 | *n* = 9 | *n* = 2 | *n* = 2 |
| HB | 142.00 ± 3.61 | 135.78 ± 6.40 | 126.00 ± 8.49 | 130.00 ± 0.00 |
| | 138 - 145 | 130 - 148 | 120 - 132 | 130.00 |
| TL | 107.00 ± 2.65 | 119.11 ± 4.51 | 91.50 ± 0.71 | 104.50 ± 0.71 |
| | 104 - 109 | 115 - 130 | 91 - 92 | 104 - 105 |
| HFL | 26.00 ± 1.00 | 35.00 ± 1.22 | 31.00 ± 0.00 | 30.00 ± 0.00 |
| | 25 - 27 | 33 - 36 | 31.00 | 30 |
| EL | 12.67 ± 0.58 | 16.00 ± 1.00 | 17.50 ± 0.71 | 17.50 ± 3.54 |
| | 12 - 13 | 15 - 18 | 17 - 18 | 15 - 20 |
| GLS | 37.83 ± 0.84 | 39.02 ± 1.30 | 35.01 ± 1.22 | 35.14 ± 0.90 |
| | 36.87 - 38.46 | 37.15 - 40.86 | 34.14 - 35.87 | 34.50 - 35.77 |
| CBL | 34.21 ± 0.95 | 34.81 ± 1.10 | 31.51 ± 1.04 | 33.91 ± 1.10 |
| | 33.21 - 35.09 | 33.17 - 36.28 | 30.77 - 32.24 | 33.13 - 34.69 |
| BL | 31.22 ± 0.98 | 32.29 ± 1.10 | 29.02 ± 1.41 | 30.61 ± 0.47 |
| | 30.33 - 32.27 | 30.72 - 33.95 | 28.02 - 30.02 | 30.28 - 30.94 |
| PL | 18.10 ± 0.45 | 18.34 ± 0.61 | 16.81 ± 0.44 | 15.69 ± 1.54 |
| | 17.58 - 18.40 | 17.63 - 19.41 | 16.50 - 17.12 | 14.60 - 16.78 |
| ZOB | 21.97 ± 0.77 | 22.72 ± 0.38 | 21.17 ± 1.85 | 20.23 ± 1.06 |
| | 21.35 - 22.84 | 22.19 - 23.29 | 19.86 - 22.48 | 19.48 - 20.98 |
| IOB | 12.75 ± 0.33 | 12.96 ± 0.39 | 12.63 ± 0.34 | 11.61 ± 0.54 |
| | 12.38 - 13.03 | 12.49 - 13.73 | 12.39 - 12.87 | 11.23 - 11.99 |
| MTB | 17.12 ± 0.71 | 17.06 ± 0.35 | 16.53 ± 0.57 | 15.84 ± 0.37 |
| | 16.64 - 17.93 | 16.24 - 17.48 | 16.13 - 16.93 | 15.58 - 16.10 |
| NL | 9.74 ± 0.29 | 10.65 ± 0.80 | 10.24 ± 0.65 | 9.09 ± 0.37 |
| | 9.45 - 10.03 | 9.34 - 12.07 | 9.78 - 10.70 | 8.83 - 9.35 |
| BAM | 9.11 ± 0.23 | 9.38 ± 0.20 | 8.76 ± 0.52 | 8.32 ± 0.25 |
| | 8.85 - 9.25 | 9.10 - 9.71 | 8.39 - 9.13 | 8.14 - 8.49 |
| LUCT | 6.71 ± 0.24 | 6.82 ± 0.17 | 6.06 ± 0.35 | 5.69 ± 0.30 |
| | 6.51 - 6.97 | 6.69 - 7.20 | 5.81 - 6.31 | 5.47 - 5.90 |
| LLCT | 6.56 ± 0.23 | 6.79 ± 0.18 | 5.97 ± 0.14 | 5.85 ± 0.06 |
| | 6.37 - 6.81 | 6.49 - 7.10 | 5.87 - 6.07 | 5.80 - 5.89 |
| PAL | 15.59 ± 0.40 | 15.99 ± 0.63 | 14.64 ± 0.35 | 15.25 ± 0.92 |
| | 15.14 - 15.90 | 15.27 - 16.89 | 14.39 - 14.89 | 14.60 - 15.90 |

Data are from intact skulls analyzed in this study. Key to measurements is given in the footnotes to table 1.

cranial characters (Table 6).

## DISCUSSION

### About *Tamiops swinhoei clarkei*

Allen (1940) accepted *clarkei* as a subspecies of *T. swinhoei*, and Moore (1965) considered it to be a junior synonym of *T. s. swinhoei*. Two aspects of its pelage characteristics place it well outside the range of *T. swinhoei*. First, its outer light stripes are whitish with a more or less buffy tint, but those of other subspecies are all yellowish-brown; and second, there is almost no buffy tint on its belly, and the hairs are gray at the base with whitish tips (those of the throat and chest are more whitish than those on the belly), while those of other subspecies are more or less ocherous-buff. We therefore suggest that *T. s. clarkei* is not a subspecies of *T. swinhoei*. According to the characteristics of its outer light stripes, it could perhaps be included in *T. maritimus*. The result of the PCA in this study (Fig. 1) showed that this group could not be separated from 3 other subspecies: *T. s. spencei*, *T. s. swinhoei*, and *T. s. chingpingensis*. This may have resulted from the fact that *T. s.*

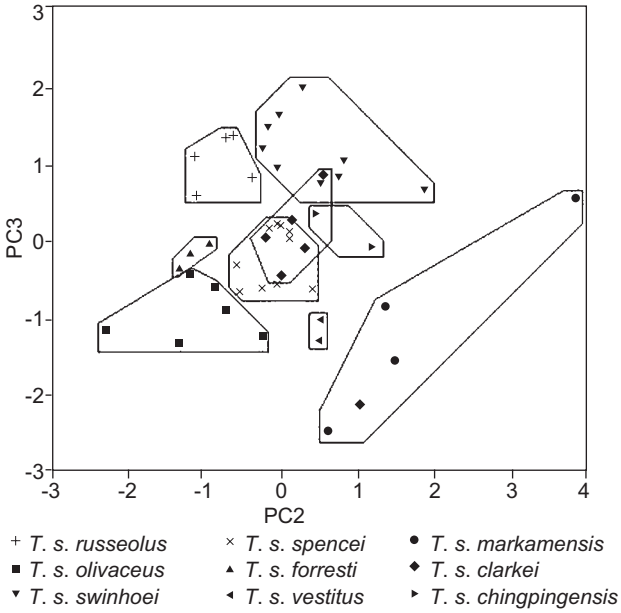


**Fig. 1.** Plots of principal component factors 2 and 3 for subspecies of *Tamiops swinhoei* (including *T. s. clarkei*).

**Table 4.** Factor loadings of each variable for the principal component analysis (including *T. s. clarkei*) (rotated component matrix[a])

| | Component | | |
|---|---|---|---|
| Variable | PC1 | PC2 | PC3 |
| HB | 0.493 | 0.494 | 0.267 |
| TL | 0.273 | 0.079 | 0.899 |
| HFL | 0.076 | 0.745 | 0.562 |
| EL | 0.229 | 0.799 | 0.087 |
| GLS | 0.779 | 0.546 | 0.177 |
| CBL | 0.711 | 0.594 | 0.182 |
| BL | 0.721 | 0.604 | 0.183 |
| PL | 0.783 | 0.509 | 0.125 |
| ZOB | 0.812 | 0.430 | 0.149 |
| IOB | 0.801 | 0.179 | -0.057 |
| MTB | 0.785 | 0.276 | 0.342 |
| NL | 0.450 | 0.677 | -0.175 |
| BAM | 0.795 | 0.446 | 0.207 |
| LUCT | 0.839 | 0.138 | 0.382 |
| LLCT | 0.808 | 0.173 | 0.427 |
| PAL | 0.699 | 0.613 | 0.231 |

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization. [a]Rotation converged in 11 iterations. Key to measurements is given in the footnotes to table 1.

**Table 5.** Factor loadings of each variable for the principal component analysis (excluding *T. s. clarkei*) (rotated component matrix[a])

| | Component | | |
|---|---|---|---|
| Variable | PC1 | PC2 | PC3 |
| HB | 0.480 | 0.505 | 0.260 |
| TL | 0.274 | 0.069 | 0.911 |
| HFL | 0.071 | 0.748 | 0.560 |
| EL | 0.222 | 0.796 | 0.091 |
| GLS | 0.772 | 0.564 | 0.159 |
| CBL | 0.695 | 0.616 | 0.164 |
| BL | 0.706 | 0.625 | 0.163 |
| PL | 0.776 | 0.525 | 0.098 |
| ZOB | 0.805 | 0.444 | 0.128 |
| IOB | 0.809 | 0.179 | -0.058 |
| MTB | 0.804 | 0.283 | 0.322 |
| NL | 0.433 | 0.695 | -0.212 |
| BAM | 0.800 | 0.487 | 0.193 |
| LUCT | 0.846 | 0.148 | 0.364 |
| LLCT | 0.820 | 0.193 | 0.418 |
| PAL | 0.689 | 0.633 | 0.211 |

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization. [a]Rotation converged in 10 iterations. Key to measurements is given in the footnotes to table 1.

*clarkei* is a different species. Future study to reevaluate the specific status for *clarkei* is necessary based on more evidence.

### About *Tamiops swinhoei forresti*

Ellerman and Morrison-Scott (1950) regarded *T. maritimus forresti* (Thomas, 1920) as a junior synonym of what they called *Callosciurus swinhoei clarkei* (Thomas 1920). Peng et al. (1962) restored *T. s. forresti* as a valid subspecies, to which we concur. This is because not only for the multivariate analysis results, but also of its pelage color characteristics that can be readily distinguished from those of *T. s. clarkei*. There are 3 main pelage color differences between *T. s. forresti* and *T. s. clarkei*: (1) the belly of *T. s. clarkei* is whitish but that of *T. s. forresti* is ocherous-buff; (2) the middorsal line of *T. s. forresti* is blacker than that of *T. s. clarkei*; and (3) the outer light line of *T. s. clarkei* (whitish) is narrower than that of *T. s. forresti* (yellowish-brown).

### Morphological differences among subspecies

Figure 2 shows that all subspecies in this analysis could clearly be separated from one another. The specimens fall into 2 groups. The 1st group, with values exceeding 0.5 on PC3, is formed by *T. s. russeolus* and *T. s. swinhoei*, from northwestern Yunnan Prov. and western Sichuan Prov. The 2nd group, with values < 0.5 on PC3, is formed by the other 6 subspecies. In this group, *T. s. spencei*, *T. s. chingpingensis*, *T. s. forresti*, and *T. s. olivaceus*, from western, southwestern, and southern Yunnan Prov., are close to each other, while the other 2 subspecies (*T. s. vestitus*, distributed from eastern Sichuan Prov. to Hebei Prov., and *T. s. markamensis* subsp. nov. from northern Sichuan) are close to each other. This result fits the geographic distributions of these subspecies (Fig. 3).

### Discussion of relationships between geographical differences and differentiation of subspecies in *T. swinhoei*

The study indicates that there are 8 subspecies of *T. swinhoei* in China. Only *T. s. vestitus* broadly distributes from northeastern Sichuan, Hubei, Henan, Hebei, Shanxi, Shaanxi, Gansu, and Ningxia to Beijing, while the other subspecies distribute in Sichuan and Yunnan. In other words, differentiation of subspecies in *T. swinhoei* mainly occurred in Sichuan and Yunnan. Figure 3 shows that the localities of most of these subspecies are in the mountains segregated by deep, north-south river gorges which dissect the general area (Hengduan Mountains). For example, *T. s. spencei* distributes to west of the Nujiang; *T. s. russeolus* distributes between the Lancangjiang and

**Table 6.** One-way analysis of variance of subspecies of *Tamiops swinhoei*

| Variable | d | f | *F* | *p* |
|---|---|---|---|---|
| HB | 7 | 35 | 8.798 | 0.000*** |
| TL | 7 | 35 | 14.559 | 0.000*** |
| HFL | 7 | 35 | 15.539 | 0.000*** |
| EL | 7 | 35 | 25.563 | 0.000*** |
| GLS | 7 | 35 | 7.914 | 0.000*** |
| CBL | 7 | 35 | 7.583 | 0.000*** |
| BL | 7 | 35 | 7.728 | 0.000*** |
| PL | 7 | 35 | 8.267 | 0.000*** |
| ZOB | 7 | 35 | 9.100 | 0.000*** |
| IOB | 7 | 35 | 6.552 | 0.000*** |
| MTB | 7 | 35 | 5.386 | 0.000*** |
| NL | 7 | 35 | 5.273 | 0.000*** |
| BAM | 7 | 35 | 6.849 | 0.000*** |
| LUCT | 7 | 35 | 15.090 | 0.000*** |
| LLCT | 7 | 35 | 17.198 | 0.000*** |
| PAL | 7 | 35 | 6.775 | 0.000*** |

***$p \leq 0.001$. Key to measurements is given in the footnotes to table 1.

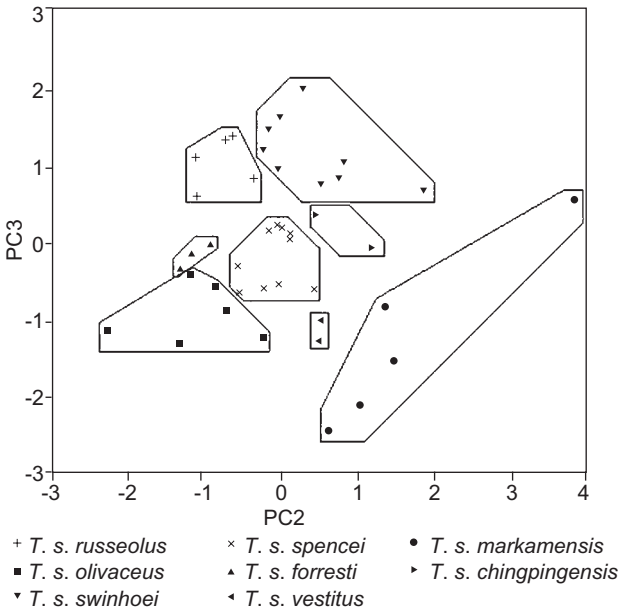


**Fig. 2.** Plots of principal component factors 2 and 3 for subspecies of *Tamiops swinhoei* (excluding *T. s. clarkei*).

Jinshajiang; and *T. s. chingpingensis* distributes between the Nujiang and Lancangjiang. Concerning *T. s. markamensis* subsp. nov., there are the Big Snow Mountain and Dadu River to the southwest of its distribution area, and there is Min Mountain and upstream branches of the Minjiang to the northeast of its distribution area. All these observations indicate that river gorges and high mountains act as obvious barriers resulting in subspecies differentiation. But, on the other hand, *T. s. forresti* distributes on both sides of the Jinshajiang, and *T. s. swinhoei* distributes on both sides of the Yalongjiang. More studies, especially examining molecular phylogenetic relationships, should be performed to clarify why river gorges and high mountains act as obvious barriers to different extents among various subspecies.

### Key to the subspecies of *Tamiops swinhoei*

I. Upperparts olive tinged with olive-gray
1. Inner light stripes yellowish-brown, narrow and attach to base of tail; GLS 38.63 (37.12-42.61) mm, PL 18.55 (18.00-20.54) mm, NL 11.84 (11.20-13.69) mm ..... *T. s. markamensis* subsp. nov.
2. Inner light stripes yellowish-white, attaching or not attaching to base of tail; GLS 35.01 (34.14-35.87) mm, PL 16.81 (16.50-17.12) mm, NL 10.24 (9.78-10.70) mm ..... *T. s. vestitus*

II. Upperparts olive tinged with olive-brown
1. Upperparts thick olive-brown
   (1) Midstripe black and narrow. Remaining stripes all relatively narrow; CBL 31.46 (29.33-32.86) mm, NL 10.33 (8.31-11.21) mm ..... *T. s. olivaceus*
   (2) Midstripe black and wide, remaining stripes all relatively wide; CBL 33.91 (33.13-34.69) mm, NL 9.09 (8.83-9.35) mm ..... *T. s. chingpingensis*
2. Upperparts relatively pale olive-brown
   (1) Midst ripe black and short
   (a): General dorsal color deeper and body relatively smaller. Inner dark stripes wider than other stripes; MTB 15.62 (14.44-16.78) mm, NL 9.94 (9.02-10.80) mm ..... *T. s. spencei*
   (b): General dorsal color paler and body relatively larger. Inner dark stripes nearly the same as other stripes; MTB 16.52 (15.41-17.13) mm, NL 9.48 (8.76-9.97) mm ..... *T. s. russeolus*
   (2) Midstripe black and relatively long
   (a): Inner dark stripes olive-brown; throat and chest ochreous-buff; GLS 39.02 (37.15-40.86) mm, BL 32.29 (30.72-33.95) mm ..... *T. s. swinhoei*
   (b): Inner dark stripes blackish-brown; throat and chest yellowish-white; GLS 37.83 (36.87-38.46) mm, BL 31.22 (30.33-32.27) mm ..... *T. s. forresti*

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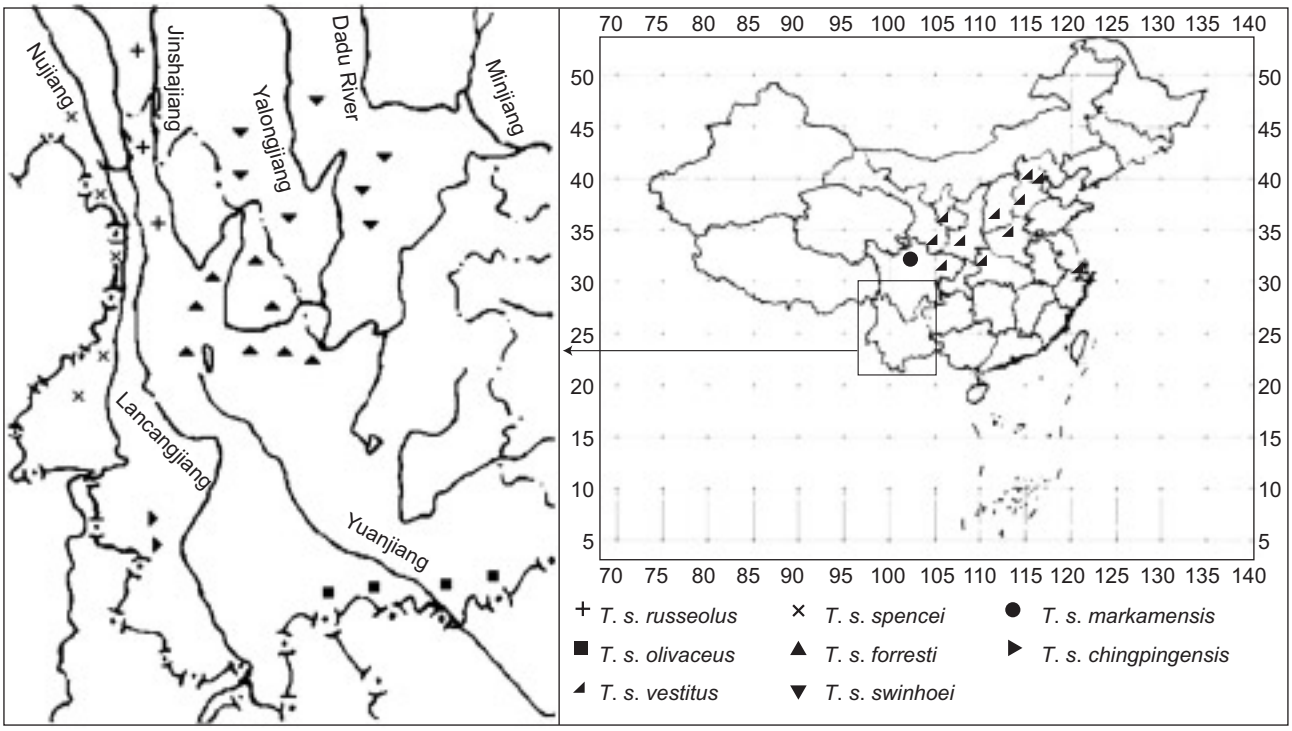


**Fig. 3.** Distribution of subspecies of *Tamiops swinhoei* in China.

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## REFERENCES

Allen GM. 1940. The Mammals of China and Mongolia. Nat. Hist. Cent. Asia. Vol. 11, pt. 2. New York: Amer. Mus. Nat. Hist.

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

Ellerman JR. 1940. The families and genera of living rodents. Vol. 1. Oxford, UK: Oxford Univ. Press.

Ellerman JR, TCS Morrison-Scott. 1951. Checklist of Palaearctic and Indian mammals. London: British Museum (Natural History), 810 pp.

Hu JZ, YZ Wang. 1984. Sichuan Fauna Economica. Vol. 2. Beijing: Science Press, pp. 195. (in Chinese)

Lu CK, ZW Wang, GQ Quan, SK Gin, DH Ma, DH Yang. 1965. On the mammals from Lin-Tsang area, west Yunnan. Acta Zool. Sinica **2:** 279-295.

Mayr E. 1953. Methods and principles of systematic zoology. Translated by ZX Zhen et al. (1965). Beijing: Science Press, pp. 139-172.

Moore JC, GHH Tate. 1965. A study of the diurnal squirrels, Sciurinae, of the Indian and Indochinese subregions. Fieldiana Zool. **48:** 1-351.

Musser GG. 1979. The species of *Chiropodomys*, arboreal mice of Indochina and the Malay Archipelago. Bull. Amer. Mus. Nat. Hist. **162:** 381-445.

Musser GG, Heaney LR. 1992. Philippine rodents: definitions of *Tarsomys* and *Limnomys* plus a preliminary assessment of phylogenetic patterns among native Philippine murines (Murinae, Muridae). Bull. Amer. Mus. Nat. Hist. **211:** 1-138.

Peng HS, YT Gao, CK Lu, ZJ Feng, QX Chen. 1962. Report on mammals from southwestern Sichuan and northwestern Yunnan. Acta Zool. Sinica **14(Supplement):** 105-132.

Wang YX. 2003. A complete checklist of mammal species and subspecies in China, a taxonomic and geographic reference. Beijing, China: China Forestry Publishing House, pp. 143-145.

## APPENDIX I : Specimens examined in the study

***Tamiops swinhoei russeolus* N = 17**

Mangkang, southeastern Tibet: (KIZ 1080, 810401, 810417). Weixi, northwestern Yunnan: (KIZ1106). Adong, northwestern Yunnan: (KIZ 79436-79440, 79452, 79453, 79499, 79588, 79618, 79660, 79801, 79811.

***Tamiops swinhoei spencei* N = 36**

Mt. Gaoligong, western Yunnan: (KIZ 73105, 73441, 73447, 73468, 73499, 73600, 73637, 73638, 73657, 73673, 73684, 73691, 73711, 73736, 73738, 73748, 73806, 73807, 73811, 73813, 73814, 73818, 73820-73822, 73828, 73829, 73836, 73888, 73903, 74223, 74243, 74259, 74685). Lushui, western Yunnan: (KIZ 74332, 74242).

***Tamiops swinhoei markamensis* N = 9**

Markam, northern Sichuan: (KIZ19381, 19382; IOZ 19375-19377, 19380, 19383, 21540; MSU 60I020).

***Tamiops swinhoei olivaceus* N = 19**

Pingbian, southern Yunnan: (KIZ 84103, 84104, 84118, 84124). Jingping, southern Yunnan: (KIZ 84394, 84398, 84400, 84401, 84441, 84446, 84472, 84475). Lvchun, southern Yunnan: (KIZ 72012, 72048, 72049, 72071, 72076, 72094). Jiangchen, southern Yunnan: (KIZ 72186).

***Tamiops swinhoei clarkei* N = 9**

Mile, eastern Yunnan: (KIZ 84202, 84205, 84238, 84239, 84241, 84253, 84263). Bingchuan, central Yunnan: (KIZ 810668, 810708).

***Tamiops swinhoei forresti* N = 11**

Xiaozhongdian, northwestern Yunnan: (KIZ 810067, 810143, 810200, 810201). Zhongdian, northwestern Yunnan: (KIZ 90092). Muli, western Sichuan: (KIZ 820807; IOZ 17272). Yajiang, western Sichuan: (KIZ 820264, 820270). Daofou, western Sichuan: (KIZ 820232). Dajiaotong, eastern Tibet: (IOZ T0707).

***Tamiops swinhoei swinhoei* N = 12**

Yajiang, southwestern Sichuan: (KIZ 820269, 820271, 820273, 820274, 820633, 820657, 820725); Meigu, southwestern Sichuan (IOZ 17264, 17267); Shimian, western Sichuan (IOZ 28081, 28082); Mt. Emei, western Sichuan (IOZ 17262).

***Tamiops swinhoei vestitus* N = 2**

Yuanqi, southern Shanxi: (IOZ 19442); Qinshui, southern Shanxi: (IOZ 19443).

***Tamiops swinhoei chingpingensis* N = 8**

Shuangjiang, southwestern Yunnan: (IOZ 23444, 23446-23452).