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Geographic Variation of Morphometric Characters in Five Subspecies of Korean Field Mice, *Apodemus peninsulae* Thomas (Rodentia, Mammalia), in Eastern Asia

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Four external and 27 cranial characters of Korean field mice (*Apodemus peninsulae*) from nine localities in eastern Asia, representing five subspecies, were analyzed by multivariate statistical methods. Three forms were recognized: a large-size form from Korea (subspecies *peninsulae*), southern Manchuria (*praetor*), and northern Manchuria (*major*); a middle-size form from western Siberia (*tscherga*) and southwestern China (*sowerbyi*); a small-size form from northeastern China (*sowerbyi*). It is also revealed that variations among the three forms are clinal and circular.

It is confirmed that *Apodemus peninsulae* could be classified into two subspecies (*peninsulae* and *sowerbyi*) within the distribution range in the continent of Asia, as noted by Corbet (1978). However, it is found that subspecies *peninsulae* includes *praetor* and *major* and that subspecies *sowerbyi* includes *tscherga*, indicating that subspecies *tscherga* is not the synonym of subspecies *peninsulae*, but that of subspecies *sowerbyi*.

KEY WORDS: Systematics, morphometry, *Apodemus peninsulae*, Asia

The genus *Apodemus* composed of 14 species is confined to the Palaearctic and northern part of the Oriental regions (Corbet & Hill, 1991). Seven species, *A. agrarius, A. argenteus, A. chevrieri, A. draco, A. latronum, A. speciosus,* and *A. peninsulae*, inhabit in eastern Asia and two species, *A. agrarius and A. apeninsulae*, are distributed in Korea.

In morphometric analyses with eight subspecies of striped field mice, *A. agrarius*, in Asia (Koh, 1991), it is confirmed that one subspecies of *A. agrarius* (*A. agrarius chevrieri*) from southern China is a species, *A. chevrieri*, and another subspecies (*A. agrarius chejuensis*) from Cheju island in Korea is also a distinct species, *A. chejuensis*.

Korean field mice, *A. peninsulae* Thomas 1906, are distributed over much of Siberia, China, Manchuria, Korea, and Hokkaido (Corbet & Hill, 1991), and the type locality of *A. peninsulae* is Mungyong, 110 miles southeast of Seoul, Korea (Jones, 1956). *A. peninsulae* was considered as a subspecies of *A. speciosus* (Thomas, 1906; Vinogradov & Argiropulo, 1941; Tate, 1947; Woon, 1967), but Vorontsov *et al.* (1977) claimed on the basis of karyological and morphological analyses with samples of boreal regions of East Asia that all the eastern Asian forms of *A. speciosus* should be transferred to the species, *A. peninsulae*. In chromosomal and morphometric analyses it is confirmed that the Korean field mice from Korea are not *A. speciosus peninsulae*, but

A. peninsulae peninsulae (Koh, 1986). Corbet (1978) summarized eight subspecies (*peninsulae, major, majusculus, praetor, rufulus, tscherga, giliacus,* and *sowerbyi*) of *A. peninsulae* into three ones (subspecies *peninsulae* including five other subspecies; *sowerbyi*; and *giliacus*). Therefore, the taxonomy of *A. peninsulae* is still in doubt, as noted by Xia (1985).

The methods of numerical taxonomy based on equal weighting and overall similarity seemed inapplicable in defining higher categories above the species level (Farris, 1966). On the other hand, Flake and Turner (1968) stated that the numerical approach offers potential for the resolution of taxonomic problems for populations at infraspecific level.

The objective of this paper is to analyze morphometric characters of samples of *A. peninsulae* from nine localities in eastern Asia, representing five subspecies (*peninsulae, praetor, major, tscherga,* and *sowerbyi*), in order to determine the subspecific status of these subspecies within *A. peninsulae*.

Materials and Methods

Materials

Sexual variation was not significant, but age variation was evident with rather slower rate of growth among three age classes of adults in *A. agrarius* (Koh, 1983). Juveniles, subadults, and old adults of *A. peninsulae* were not used, and 79 samples of young and middle-aged adults of *A. peninsulae* from nine localities in eastern Asia, representing five subspecies, were analyzed as shown in Table 1 and Fig. 1.

Multivariate Analyses

Four external and 27 cranial characters were measured (for details see Koh, 1983) and samples from each locality were grouped as Operational Taxonomic Units, OTUs (see Table 1). Sample statistics such as mean and standard deviation were calculated by subprogram DESCRIPTIVE of SPSS/pc$^+$ program. Discriminant and cluster analyses were also performed by subprograms DISCRIMINANT and CLUSTER of SPSS/pc$^+$, respectively. Principal component analysis was carried out using subprograms EIGEN and PROJ of NTSYS/pc program. Minimum spanning tree was also produced by subprogram MST of NTSYS/pc.

Table 1. Subspecies name, locality, and number of samples of *Apodemus peninsulae* from eastern Asia, used for morphometric analyses.

Subspecies	Locality	No. of sample	OTU
peninsulae	Munkyong, Korea	5	1
〃	Mt. Weolak, Korea	29	2
〃	Kumhwa, Korea	9	3
praetor	Kirin, Manchuria	5	4
major	Amur, Manchuria	5	5
sowerbyi	Peking, China	10	6
〃	Shensi, China	4	7
〃	Sikang, China	4	8
tscherga	Altai, Siberia	8	9
		79	

Fig. 1. A map showing nine localities (OTUs) of samples of *Apodemus peninsulae* from eastern Asia. The subspecies name and number of samples in each OTU are given in Table 1. The distribution range of *Apodemus peninsulae* (Corbet, 1978) is shown with oblique lines.

Results

Two dimensional plottings from discriminant analysis with 79 samples of *A. peninsulae* (nine OTUs, five subspecies) are shown in Fig. 2 (numerals indicate centroids of OTUs and minimum spanning tree is superimposed on the plots with minimum distance shown). The correlations between original characters and the discriminant functions are given in Table 2. Four forms were revealed: I, OTUs 1 and 2; II, OTUs 3, 4, and 5; III, OTUs 7, 8, and 9; IV, OTU 6. Furthermore, in the first discriminant axis, clinal variation among the four forms appeared to be evident, although forms I and II are somewhat distinct from forms III and IV.

Two dimensional configurations of nine OTUs, five subspecies, of *A. peninsulae* by principal component analysis are shown in Fig. 3 (minimum spanning tree is superimposed on the plots with minimum distance shown). The correlations between original characters and the principal components are given in Table 3. Three forms were revealed: I, OTUs 1, 2, 3, 4, and 5; II, OTUs 6 and 7; III, OTUs 8 and 9. In the first principal component axis, variation among the three forms was clinal.

Nine OTUs of *A. peninsulae* were also grouped by cluster analyses of complete, average, and single clustering methods, as shown in Fig. 4. Three forms were revealed: I, OTUs 1, 2, 3, 4,

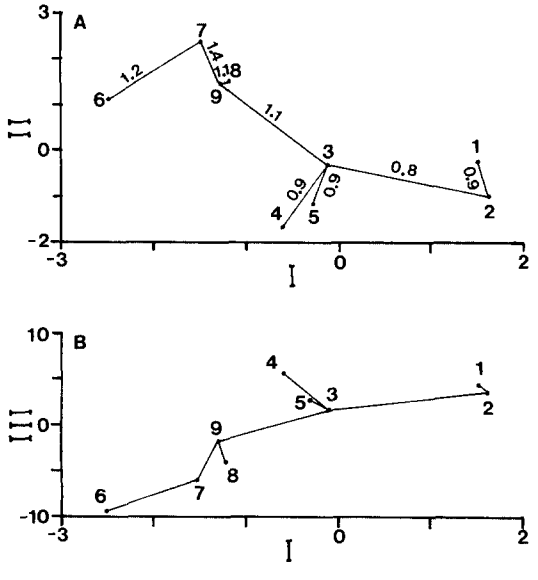

Fig. 2. Plottings of nine OTUs of *Apodemus peninsulae* from eastern Asia by discriminant analysis with 79 samples. Numerals indicate the centroid of each OTU and minimum spanning tree is superimposed on the plots (minimum distance is also given). A, OTUs ordinated with function I vs. function II. B, OTUs ordinated with function I vs. function III.

Table 2. Discriminant functions I, II, and III expressed as correlations between characters and individual functions from the analysis with 79 samples of *Apodemus peninsulae* (nine OTUs) from eastern Asia.

Character	Functions		
	I	II	III
1	0.35	0.40	−0.45
2	−1.91	0.02	0.47
3	0.42	0.13	0.34
4	−0.17	−0.57	0.46
5	0.64	0.22	0.40
6	0.81	0.41	0.38
7	−0.68	0.29	0.01
8	0.84	0.59	−0.23
9	−0.75	0.11	−0.29
10	−1.60	1.28	0.12
11	0.29	−0.37	0.60
12	0.33	−1.03	−0.47
13	0.30	0.13	−0.79
14	0.72	−2.19	−0.59
15	0.11	0.57	0.54
16	0.77	0.50	0.55
17	0.05	0.38	−0.67
18	0.02	0.26	0.47
19	1.03	0.21	−1.00
20	1.00	0.71	−0.10
21	−0.26	0.47	1.18
22	−0.21	−0.43	0.06
23	0.19	−1.23	−0.14
24	−0.04	−0.18	−0.46
25	−0.48	−0.23	0.74
26	−0.04	−0.32	−0.15
27	−0.64	1.09	−0.20
28	0.18	−0.43	−0.07
29	0.30	1.42	−0.31
30	−0.27	−0.19	0.32
31	0.02	−0.93	−0.15
	47.57	26.51	7.69

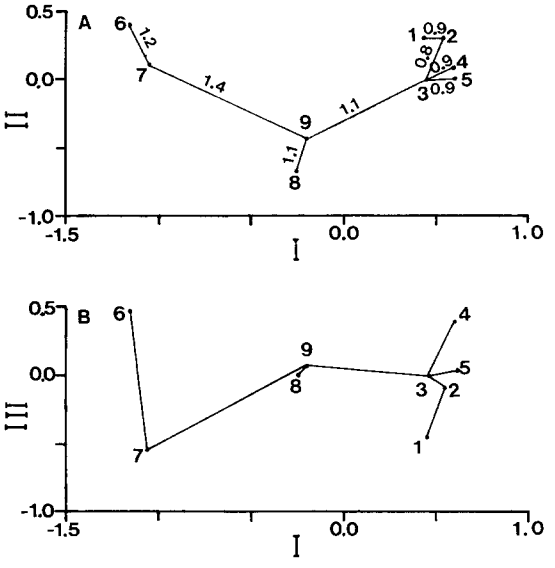

Fig. 3. Projections of nine OTUs of *Apodemus peninsulae* from eastern Asia by principal component analysis. Numerals indicate each OTU. Minimum spanning tree is superimposed on the projections and minimum distance is also given. A, OTUs ordinated with factor I vs. factor II. B, OTUs ordinated with factor I vs. factor III.

and 5; II, OTUs 6 and 7; III, OTUs 8 and 9. Moreover, variation among the three forms was found to be clinal.

In summary, three forms were recognized in the analyses with nine OTUs (five subspecies) of *A. peninsulae:* I, a large-size form, OTUs 1, 2, and 3 from Korea (subspecies *peninsulae*), 4 from southern Manchuria (*praetor*), and 5 from northern Manchuria (*major*); II, a middle-size form, OTUs 9 from western Siberia (*tscherga*) and 8 from southwestern China (*sowerbyi*); III, a small-size form, OTUs 7 and 6 from northeastern China (*sowerbyi*). Moreover, it is found that variation of morphometric characters among the three forms of *A. peninsulae* is clinal and circular from a large-size form in Korea (subspecies *peninsulae*) and Manchuria (*praetor* and *major*) through a middle-size form in western Siberia (*tscherga*) and southwestern China (*sowerbyi*) to a small-size form in northeastern China (*sowerbyi*).

Table 3. Principal components I, II, and III expressed as correlations between characters and individual components from the analysis of nine OTUs of *Apodemus peninsulae* from eastern Asia.

Character	Factors		
	I	II	III
1	0.98	0.08	-0.08
2	0.97	-0.02	0.03
3	0.60	-0.32	0.01
4	0.91	0.02	0.36
5	0.91	0.29	-0.21
6	0.70	-0.17	-0.26
7	-0.01	-0.33	-0.88
8	0.39	0.28	-0.69
9	0.45	-0.73	0.06
10	0.95	-0.13	0.12
11	0.88	0.31	-0.02
12	0.59	0.33	-0.24
13	0.58	-0.43	0.11
14	0.97	0.14	0.10
15	0.76	-0.55	-0.19
16	0.39	-0.71	0.04
17	-0.35	-0.33	-0.51
18	-0.11	0.23	-0.68
19	0.96	0.07	0.01
20	0.84	0.35	-0.12
21	0.34	0.01	-0.71
22	0.89	-0.03	0.12
23	0.66	0.35	0.30
24	0.95	0.19	0.05
25	0.85	0.31	0.17
26	0.19	0.02	0.45
27	0.01	-0.87	0.18
28	0.65	-0.17	0.01
29	0.62	-0.06	-0.41
30	0.56	-0.53	0.09
31	0.64	0.25	0.29
	49.31	12.68	11.57

Discussion

Boyce (1969) noted that average linkage or UPGMA represents a distance matrix of random points better than either complete or single linkage. The relationships between close neighbors are frequently distorted in an ordination, especially one based on principal component analysis, PCA

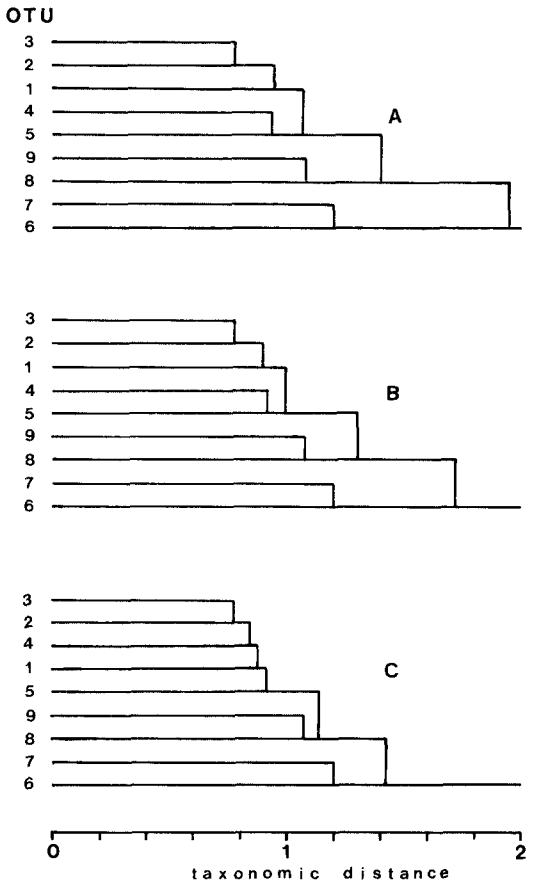

Fig. 4. Groupings of nine OTUs of *Apodemus peninsulae* from eastern Asia by cluster analyses. A, complete linkage. B, average lenkage. C, single linkage.

(Rohlf, 1970), and it is useful to superimpose minimum spanning tree on the plots by ordination methods (Kruskal, 1956). Discriminant ananlysis ordinates two or more *a priori* defined groups as that there is minimum overlap and maximum separation among them, whereas PCA makes no assumption about the existance of grouping among the OTUs (Clifford & Stephenson, 1975). Furthermore, Sneath & Sokal (1973) stated that there are no satisfactory methods for telling whether clustering or ordination is most appropriate.

In this paper based on discriminant analysis (Fig. 2), PCA (Fig. 3) and cluster analyses (Fig. 4) with morphometric characters, it is concluded that samples of five subspecies of *Apodemus peninsulae* from nine localities of eastern Asia are grouped into three forms: I, a large-size form, OTUs 1, 2, and 3, 4, and 5; II, a middle-size form, OTUs 9 and 8; III, a small-size form, OTUs 7 and 6. However, variation among the three forms is found to be clinal.

Miller (1914) stated that a new species, A. *praetor* (= *A. peninsulae praetor*), is greater in its size than *A. speciosus peninsulae* (= *A. peninsulae peninsulae*). Jones (1956) reported that *A. peninsulae* is distinct from *A. spesiosus* and he recognized a new subspecies, *A. peninsulae sowerbyi,* from China, because it is smaller in its external and cranial characters than *A. peninsulae peninsulae* from Korea. In the present analyses with five subspecies of *A. peninsulae* (Figs. 2, 3, and 4), it is revealed that A. *peninsulae peninsulae* (OTUs 1, 2, and 3) and *A. peninsulae praetor* (OTU 4) constitute a large-size form, indicating that two subspecies are similar with each other. And it is confirmed that *A. peninsulae peninsulae* (OTUs 1, 2, and 3) is larger in its size than *A. peninsulae sowerbyi* (OTUs 6, 7, and 8). However, it is found that variation between these two subspecies is circular through the subspecies *praetor* (OTU 4), *major* (OTU 5), and *tscherga* (OTU 9).

Apodemus peninsulae was considered as a subspecies of *A. speciosus* (Thomas, 1906). Vorontsov *et al.* (1977) reported that all the Far Eastern forms of *A. speciosus* should be transferred into *A. peninsulae,* and Corbet (1978) summarized eight subspecies of *A. peninsulae* into three subspecies: subspecies *peninsulae* including five nominal subspecies (*major, majuculus, praetor, rufulus,* and *tscherga*) from Korea, Manchuria, and Siberia, *sowerbyi* from China, and *giliacus* from Hokkaido, Japan. Mayr & Ashlock (1991) noted that terminal populations at the opposite ends of a continum may be rather different phenotypically and may deserve recognition as subspecies.

In this paper (Figs. 2, 3, and 4), five subspecies of *A. peninsuale* are grouped into three forms: I, a large-size form, OTUs 1, 2, and 3 from Korea (subspecies *peninsulae*), 4 from southern Manchuria (*praetor*) and 5 from northern

Manchuria (*major*); II, a middle-size form, OTUs 9 from western Siberia (*tscherga*) and 8 from southwestern China (*sowerbyi*); III, a small-size form, OTUs 7 and 6 from northeastern China (*sowerbyi*). Moreover, variation among the three forms of *A. peninsulae*, is clinal and circular, indicating that only two subspecies, *peninsulae* and *sowerbyi*, should be recognized in continental regions of distribution in *A. peninsuale*, as suggested by Corbet (1978). However, subspecies boundary between the two subspecies is different from Corbet's (1978) decision: in this paper, subspecies *peninsulae* includes *praetor* and *major* and subspecies *sowerbyi* includes *tscherga*, indicating that *tscherga* is not the synonym of *peninsulae*, but that of *sowerbyi*.

Kobayashi (1985) noted that "there still remains the important question that either Vorontsov's *peninsulae* is homologous with the Thomas's *peninsulae*, or he made a mistake in terms of the international naming code." Moreover, it is interesting to analyze whether or not subspecies *peninsulae* and *sowerbyi* are in contact and behave like a species in southwestern Manchuria where the distribution boundary of these two subspecies is located. Hillis & Moritz (1990) noted that geographic variation within species is effectively studied with molecular analyses.

In the present paper, morphometric analyses with samples of five of all eight subspecies in *Apodemus peninsulae* were carried out, and samples of each subspecies are not large. Therefore, morphometric and molecular analyses with additional samples and subspecies are necessary to perform in order to confirm the results of this paper and to solve the taxonomic problems in *A. peninsulae*.

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동부 아시아에 서식하는 흰넓적다리 붉은쥐, ***Apodemus peninsulae*** Thomas (설치목, 포유강), 5 아종의 형태적 형질의 지리적 변이

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동부 아시아에 서식하는 흰넓적다리 붉은쥐(*Apodemus peninsulae*) 5아종의 표본들의 4개 외부형질과 27개 두골형질들을 다변량통계 방법으로 분석하였다. 3개 형(form)으로 나뉘어 졌는데, 한국의 아종 *peninsulae*, 만주 남부의 *praetor*와 만주 북부의 *major*는 큰 형이며, 시베리아 서부의 *tscherga*와 중국 남서부의 *sowerbyi*는 중간 형이고, 중국 북서부의 *sowerbyi*는 작은 형이었다. 이들 3개 형들은 clinal과 circular한 변이를 보였다.

Corbet(1978)가 언급한 바와 같이, 아시아 대륙내의 흰넓적다리 붉은쥐의 분포범위에서는 흰넓적다리 붉은쥐는 2아종(*peninsulae* and *sowerbyi*)으로 분류된다는 것이 확인되었다. 그러나 아종 *peninsulae*에는 *praetor*와 *major*가 포함되며, 아종 *sowerbyi*에는 *tscherga*가 포함되므로, 아종 *tscherga*는 아종 *peninsulae*의 synonym이 아니라 아종 *sowerbyi*의 synonym이다.