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Systematic Studies of Korean Rodents: I. Geographic Variation of Morphometric Characters in Striped Field Mice, *Apodemus agrarius coreae* Thomas

Hung Sun Koh
(Department of Biology, Chungbuk University, Chongju, Korea)

한국산 설치류의 계통분류학적 연구: I. 등줄쥐, *Apodemus agrarius coreae* Thomas의 형태적 형질의 지리적 변이

고 홍 선
(충북대학교 자연대학 생물학과)

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요 약

태백산·월악산·팔공산 및 청주지역에서 채집한 등줄쥐, ***Apodemus agrarius coreae***를 사용하여 형태적 형질의 단변량분석(univariate analysis)과 다변량분석(multivariate analysis)을 행하였다.

채집된 표본들은 서로 유사하여 동일아종임이 재입증되었다.

표본이 채집되었던 지역의 고도와 연관된 clinal variation이 discriminant analysis의 제일축(first axis)과 꼬리의 길이(length of tail vertebrae)에서 나타났다.

INTRODUCTION

Most taxonomic works on Korean rodents were based on the description of pelage colour and external measurements of type specimens (Woon, 1967). Striped field mice ***Apodemus agrarius*** Pallas, inhabit from West Germany to Korea and most of subspecies were designated based on slight differences in pelage colour and/or mean body size (Corbet, 1978).

Thomas (1906) described striped field mice from the Korean peninsular and Cheju-Do as ***Apodemus agrarius coreae***. Jones and Johnson (1965) reported that four subspecies of *A.* ***agrarius*** were recognized in Korea: *A.* ***agrarius manchuria*** in the extreme northern part; *A.* ***agrarius coreae*** throughout the major portion of the peninsular; *A.* ***agrarius pallescens*** in the coastal lowlands of southern and southwestern Korea; and *A.* ***agrarius chejuensis*** in Cheju-do. They also stated that subspeciation of *A.* ***agrarius*** in the Korean mainland was not clearly defined.

Recently, the wide use of computers, the refinements of methods for chromosomal analyses, and new techniques for electrophoretic studies have enabled systematists to interpret evolution through different lines of research, i.e., chromosomal, phenetic, and molecular (Koh, 1981). Among them, computer applications are closely related to the methods of 'numerical taxonomy', and the basic tenets of 'numerical taxonomy' are: (1) acceptance of equal weightings for each character; (2) use of resemblance rather than key characters to compare taxa; and (3) utilization of large numbers of characters rather than a few selected ones (Sneath and Sokal, 1962).

Equal weightings and overall similarity seem inapplicable in defining higher categories above the species level (Farris, 1966). On the other hand, Flake and Turner (1968) noted that the numerical approach offers potential for the resolution of taxonomic problems for populations at infraspecific level.

Evident age variation and no significant secondary sexual dimorphism were found from univariate and multivariate analyses of morphometric characters of *A. agrarius coreae* from Chongju (Koh, 1983).

The objective of this paper is by univariate and multivariate analyses to determine the range of geographic variation in morphometric characters of *A. agrarius coreae* in order to establish a sound basis for a reexamination of geographic variation in *A. agrarius* from Korea.

MATERIALS AND METHODS

Materials

Skins and skulls of 140 striped field mice, *A. agrarius coreae*, were used [11 samples from Mt. Taebaek area (Baeksan-ri, Yonhwa-dong, Taebaek), altitude 700m; 15 from Mt. Wolak area (Songgye-ri, Hansu-myon, Jewon-gun, Chungchongbuk-do), altitude 200m; 12 from Mt. Palgong area (Kongsan-ri, Kongsan-myon, Dalsong-gun, Kyongsangbuk-do), altitude 500m; 102 from Chongju area (Kaesin-dong, Chongju), altitude, 50m]. Altitude of localities were obtained from Topographical maps (National Geography Institute, 1971). All specimens examined are in the collection of the author, Dept. of Biology, Chungbuk University, Chongju, Korea.

Characters

Analyses were based on four external and 27 cranial characters as follows (For details see Koh, 1983): 1. greatest length of the skull; 2. condylobasal length; 3. length between incisor and incisive foramen; 4. length of the nasal bone; 5. zygomatic width; 6. mastoid width; 7. width of brain case; 8. height of brain case; 9. width between infraorbital canals; 10. length of rostrum; 11. length of hard palate; 12. interorbital constriction; 13. width across upper third molars; 14. incisor-upper-first-molar length; 15. width across upper first molars; 16. length of incisive foramen; 17. width of the interparietal bone; 18. length of the interparietal bone; 19. postpalatine length; 20. height of rostrum; 21. bullae-brain case height; 22. greatest length of mandible; 23. length of mandibular tooth row; 24. height of mandible; 25. length of ramus; 26. length of upper third molars; 27. length of upper first molar; 28. length of tail vertebrae; 29. length of hind foot; 30. body length; 31. length of ear.

OTU designation

Although sufficiently large samples were not available for each locality to be used as a basic unit, samples from the same locality were grouped as Operational Taxonomic Units, OTU's (1. Mt. Taebaek area; 2. Mt. Wolak area; 3. Mt. Palgong area; 4. Cheongju area).

Age classification

Each specimen was assigned to one of five age classes (juvenile, subadult, young adult, middle-aged adult, and old adult) based on the eruption of upper third molar, degree of tooth-wear, and pelage colour (for details see Koh, 1983). All samples were classified into 1 juvenile, 32 subadults, 41 young adults, 53 middle-aged adults, and 13 old adults. As the number of specimens classified into the middle-aged adult was the largest, 53 middle-aged adults were used for the analyses of geographic variation (5 samples from OTU 1; 6 from OTU 2; 7 from OTU 3; 35 from OTU 4).

Phenetic analyses for geographic variation

All computations were made using the University of Toronto IBM/37-165 II computer.

For univariate analyses, Gabriel's (1964) Sums of Square Simultaneous Test Procedure (SS-STP) on ranked means (Power, 1970) was applied by UNIVAR program to test significant differences of means among OTU's.

In multivariate analyses with the data from individual measurment or means, clustering and ordination of OTU's were performed by several subprograms of the Numerical Taxonomy System of Multivariate Statistical Program, NT-SYS, by Rohlf *et al.* (1974).

Raw data were first standardized using Sokal's (1961) equation, $(X_i-\bar{X})/S$ (subprogram STAND), where X_i indicates ith measurement, $\bar{X}$ the mean, and S standard deviation, to give equal magnitude to each character to prevent distortion caused by the dominant effect of a few characters of larger magnitude and greater variation. Average taxonomic distance matrices were calculated from standardized data by subprogram SIMINT. The subprogram TAXON was used to group individuals or OTU's by Unweighted Pair Group Method using Arithmatic Averages, UPGMA (Sneath and Sokal, 1973). Principal component analysis (Seal, 1964) was performed using subprogram FACTOR.

Cophenetic correlation coefficient, r, between the original taxonomic matrix and the distance matrix from the dendrogram (Sokal and Rohlf, 1962) was calculated by subprogram MAXCOMP. In UPGMA cluster analysis with the data of individual measurements r was 0.58, indicating that great degree of distortion was occurred when the dendrogram was produced from the taxonomic distance matrix, and the dendrogram was not presented here.

Discriminant analysis was also carried out by subprogram DISCRIM of Statistical Package for the Social Sciences, SPSS (Nie *et al.*, 1975).

RESULTS

SS-STP analysis

Character means of each OTU are shown in Table 1, where the OTU's showing no significant differences are connected by straight lines. In 21 characters (1, 2, 4, 5, 7, 8, 10, 11, 12, 14, 15, 16, 17, 18, 21, 23, 24, 26, 27, 29, and 31) means were not significantly different among the four OTU's. In other ten characters the order of ranked means were variable, but in nine of ten characters means of OTU's 1 and 3 were larger than those of OTU's 2 and 4. Moreover, in character 28 OTU's 1 and 3 were significantly different from OTU's 2 and 4.

Table 1. Geographic variation among four OTU's of *Apodemus agrarius coreae* based on SS-STP analysis. Character means of each OTU are shown with no significant subsets connected by straight lines. The localities of the four OTU's are: 1, Mt. Taebaek area; 2, Mt. Wolak area; 3, Mt. Palgong area; 4, Cheongju area. Means are given in millimetres.

Characters	1. Greatest length of the skull				2. Condylobasal length				3. Length between incisor and incisive foramen			
OTU's	3	1	4	2	3	1	4	2	1	3	4	2
Means(mm)	27.3	27.3	27.0	26.6	25.1	25.1	24.8	24.4	3.41	3.24	3.16	3.14
Subsets												
Characters	4. Length of the nasal bones				5. Zygomatic width				6. Mastoid width			
OTU's	3	1	2	4	3	1	4	2	1	2	3	4
Means(mm)	10.6	10.6	10.5	10.4	13.2	13.1	13.0	12.9	10.0	10.0	9.79	9.74
Subsets												
Characters	7. Width of brain case				8. Height of brain case				9. Width between infraorbital canals			
OTU's	2	1	4	3	4	1	3	2	3	1	2	4
Means(mm)	11.6	11.6	11.5	11.4	8.81	8.76	8.71	8.60	3.23	3.22	3.09	3.05
Subsets												
Characters	10. Length of rostrum				11. Length of hard palate				12. Interorbital constriction			
OTU's	1	3	2	4	3	2	4	1	1	3	2	4
Means(mm)	9.12	9.90	8.99	8.96	5.21	5.04	5.03	4.97	4.41	4.35	4.33	4.31
Subsets												
Characters	13. Width across upper third molars				14. Incisor-upper-first-molar length				15. Width across upper first molars			
OTU's	3	1	2	4	3	1	2	4	1	2	3	4
Means(mm)	4.63	4.58	4.53	4.43	8.77	8.76	8.66	8.62	5.08	5.03	5.03	4.97
Subsets												

Characters	16. Length of incisive foramen				17. Width of the inter-parietal bone				18. Length of the inter-parietal bone			
OTU's	1	3	2	4	1	4	2	3	2	3	4	1
Means(mm)	5.03	4.95	4.89	4.86	10.6	10.3	10.3	10.3	3.19	3.15	2.99	2.97
Subsets												
Characters	**19. Postpalatine length**				**20. Height of rostrum**				**21. Bullae-brain case height**			
OTU's	1	3	4	2	3	1	4	2	1	4	2	3
Means(mm)	9.64	9.59	9.25	9.20	4.35	4.31	4.22	4.07	9.69	9.62	9.60	9.34
Subsets												
Characters	**22. Greatest length of mandible**				**23. Length of mandibular tooth row**				**24. Height of mandible**			
OTU's	3	1	4	2	3	2	1	4	3	1	4	2
Means(mm)	17.6	17.3	16.9	16.9	4.01	3.90	3.88	3.84	7.15	7.06	6.99	6.85
Subsets												
Characters	**25. Length of ramus**				**26. Length of second & third upper molars**				**27. Length of first upper molar**			
OTU's	3	1	4	2	3	2	4	1	2	1	3	4
Means(mm)	7.96	7.66	7.60	7.56	1.89	1.85	1.85	1.81	2.13	2.14	2.02	1.97
Subsets												

Characters	28. Length of tail vertebrae				29. Length of hind foot				30. Body length				31. Ear length			
OTU's	1	3	4	2	3	1	4	2	1	3	2	4	3	1	4	2
Means(mm)	104	98	91	90	21.7	21.6	21.3	21.2	99	95	91	83	13.7	13.7	13.5	13.0
Subsets																

Multivariate analyses with individual measurements

Two dimensional configurations from principal component analysis with 53 samples are shown in Fig. 1 (symbols for samples of each OTU are as follows: OTU 1, shaded triangle; OTU 2, shaded circle; OTU 3, unshaded triangle; OTU 4, unshaded circle). The correlations between original characters and the principal components are given in Table 2 (Factors I, II, and III represented 32, 8, and 7 per cent of the variance, respectively). The first principal component axis scores of 53 samples from the four OTU's are also summarized as a histogram (Fig. 2). The samples of one OTU were found to be similar with those of other OTU's.

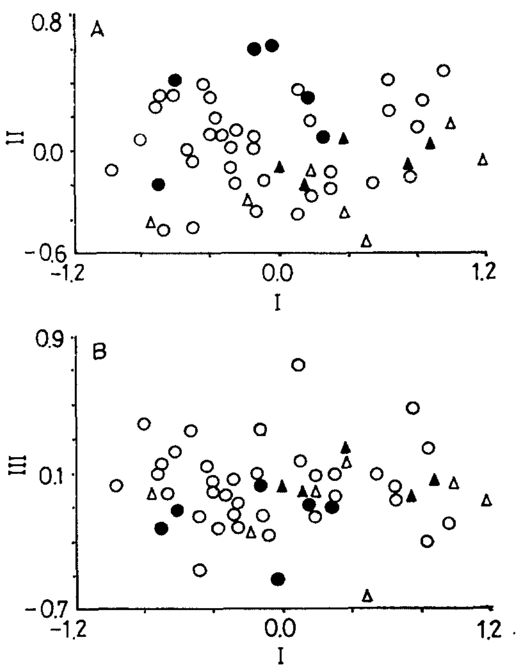
Two dimensional configurations from discriminant analysis with 53 samples grouped into four OTU's are shown in Fig. 3 (for symbols used see the legend in Fig. 2). The correlations between original characters and three canonical discriminant functions are given in Table 3 (functions I, II, and III represented 57, 29, and 20 per cent of the variance, respectively). The first discriminant axis scores of 53 samples from the four OTU's are summarized as a histogram (Fig. 4). The samples of one OTU were different from those of other OTU's. In the first discriminant axis, however, clinal variation from OTU 4 to OTU 1 through OTU 2 and OTU 3 was found and characters 1, 16, and 28 showed higher correlation coefficients with the first axis.

Table 2. Principal components I, II, and III expressed as correlations between characters and individual components from an analysis of striped field mice of *Apodemus agrarius coreae.* Standardized measurements from 53 middle-aged adults were used.

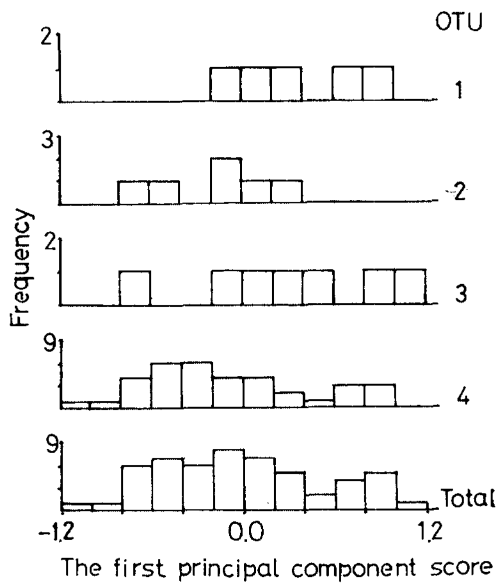
Characters	Factor I	Factor II	Factor III
1	0.89	−0.04	0.14
2	0.89	−0.06	0.14
3	0.64	−0.19	0.00
4	0.71	0.04	0.16
5	0.71	0.19	−0.16
6	0.56	0.44	−0.04
7	0.40	0.73	−0.15
8	0.53	0.32	0.42
9	0.50	−0.20	−0.06
10	0.85	0.04	0.05
11	0.29	−0.02	0.14
12	0.42	0.40	−0.13
13	0.18	−0.04	−0.33
14	0.85	−0.00	0.15
15	0.53	0.11	−0.45
16	0.57	0.14	−0.24
17	0.57	0.21	0.11
18	0.26	0.23	−0.15
19	0.70	−0.30	0.09
20	0.57	−0.28	0.25
21	0.40	0.48	0.24
22	0.81	−0.29	−0.02
23	0.40	−0.21	−0.58
24	0.47	0.13	0.19
25	0.62	−0.23	−0.06
26	0.34	−0.25	−0.36
27	0.23	0.19	−0.70
28	0.48	−0.22	0.04
29	0.38	−0.36	−0.11
30	0.39	−0.25	0.35
31	0.22	−0.39	−0.17
% Trace	32.2	7.7	6.8

Table 3. Canonical discriminant functions I, II, and III expressed as correlations between characters and individual functions from an analysis of striped field mice of *Apodemus agrarius coreae.* Measurements from 53 middle-aged adults were used.

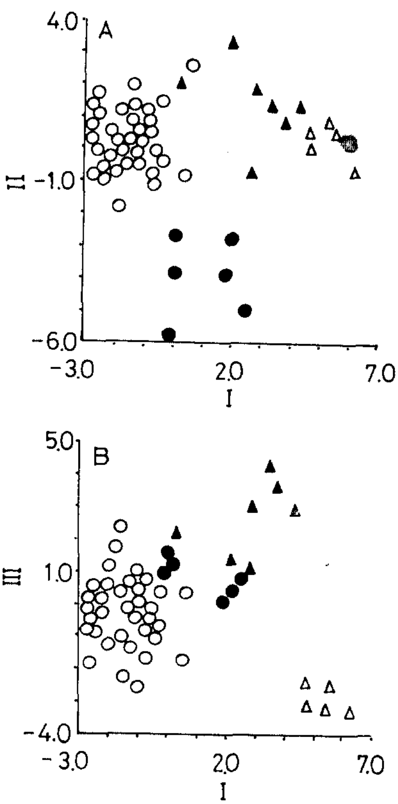
Characters	Function I	Function II	Function III
1	−2.37	0.77	−1.06
2	−0.21	−0.32	−0.09
3	0.49	0.23	−1.41
4	1.17	−0.72	−0.03
5	−0.13	0.81	0.64
6	−0.08	−0.23	1.05
7	0.34	0.00	−0.86
8	−0.64	0.84	0.85
9	0.21	0.59	−0.36
10	0.18	−1.06	0.29
11	0.59	0.98	1.02
12	0.24	−0.03	−1.12
13	0.36	−0.46	0.71
14	−0.83	−2.21	0.65
15	−0.67	0.08	−0.75
16	1.53	0.92	0.62
17	0.32	0.53	0.19
18	−0.23	−0.13	0.30
19	1.04	0.25	−0.09
20	−0.20	0.23	1.05
21	−0.27	−0.29	−1.54
22	0.85	0.44	−0.20
23	−0.62	0.47	−0.55
24	0.09	0.02	0.46
25	0.11	0.35	0.06
26	−0.31	0.02	1.13
27	0.43	−1.50	1.34
28	1.43	0.18	−0.32
29	−0.23	−0.12	−0.44
30	−0.20	−0.05	0.22
31	0.04	0.51	0.03
% Trace	57.1	23.1	19.7



<Fig. 1>



<Fig. 2>



<Fig. 3>

Fig. 1. Projections of 53 samples (four OTU's) of *Apodemus agrarius coreae* based on principal component analysis in three dimensions using standardized individual measurements. Factors I, II, and III represented 32, 8, and 7 per cent of the variance, respectively. Symbols for samples of each OTU are as follows: OTU 1, shaded triangle; OTU 2, shaded circle; OTU 3, unshaded triangle; OTU 4, unshaded circle. A, 53 samples of four OUT's ordinated with factor I vs. factor II. B, 53 samples of four OTU's ordinated with factor I vs. factor III.

Fig. 2. Frequency distribution of the first principal component axis scores of 53 samples from four OTU's of *Apodemus agrarius coreae*. The localities of the four OTU's are: 1, Mt. Taebaek area; 2, Mt. Wolak area; 3, Mt. Palgong area; 4, Chongju area.

Fig. 3. Projections of 53 samples of *Apodemus agrarius coreae* based on discriminant analysis in three dimensions using individual measurements grouped into four OTU's. Functions I, II, and III represented 57, 29, and 20 per cent of the variance, respectively. Symbols for samples of each OTU are as follows: OTU 1, shaded triangle; OTU 2, shaded circle; OTU 3, unshaded triangle; OTU 4, unshaded circle. A, 53 samples of four OTU's ordinated with factor I vs. factor II. B, 53 samples of four OTU's ordinated with factor I vs. factor III.

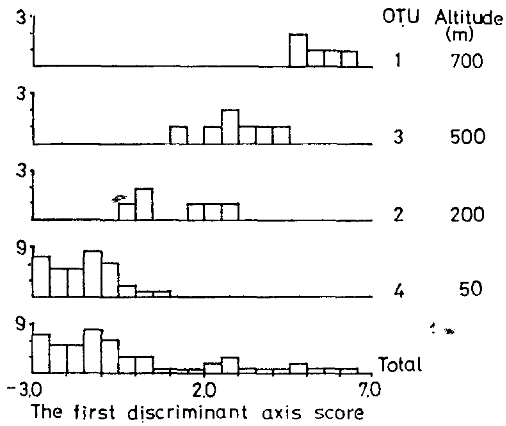
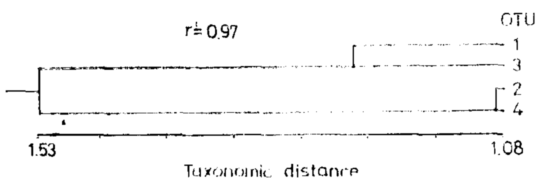


Fig. 4. Frequency distribution of the first discriminant axis scores of 53 samples from four OTU's of ***Apodemus agrarius coreae***. The localities of the four OTU's are: 1, Mt. taebaek area; 2, Mt. Wolak area; 3, Mt. Palgong area; 4, Chongju area. Altitude of localities were obtained from Topographical maps (National Geography Institute, 1971).

Multivariate analyses with means

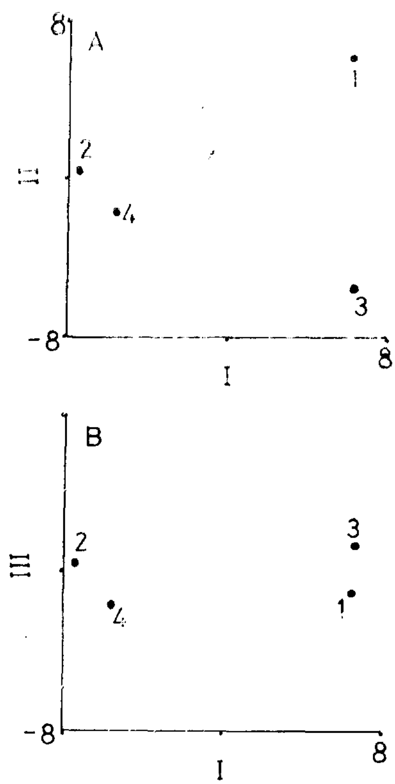
The four OTU's were grouped by UPGMA cluster analysis, as shown in Fig. 5 (r= 0.97). Two dimensional configurations from principal component analysis are shown in Fig. 6 (factors I, II, and III represented 56, 25, and 19 per cent of the variance, respec-



〈Fig. 5〉

Fig. 5. Groupings of four OTU's of ***Apodemus agrarius coreae*** based on UPGAM analysis using average taxonomic distance matrix from standardized means. The cophenetic correlation coefficient, r, was 0.97. The localities of the four OTU's are: 1, Mt. Taebaek area; 2, Mt. Wolak area; 3, Mt. Palgong area; 4, Chongju area.

Fig. 6. Projections of four OTU's of ***Apodemus agrarius coreae*** based on principal component analysis in three dimensions using standardized means. Factors I, II, and III represented 56, 25, and 19 per cent of the variance, respectively. The localities of the four OTU's are: 1, Mt. Taebaek area; 2, Mt. Wolak area; 3, Mt. Palgong area; 4, Chongju area. A, Four OTU's ordinated with factor I vs. factor II. B, Four OTU's ordinated with factor I vs. III.



〈Fig. 6〉

Table 4. Mean body length and ratio of mean hind foot length to mean body length related with altitude of localities of four OTU's. The localities of the four OTU's are: 1, Mt. Taebaek area; 3, Mt. Palgong area; 2, Mt. Wolak area; 4, Chongju area. The altitude of localities given in metres were obtained from Topographical maps (National Geography Institute, 1971). Means of each OTU are given in millimetres with no significant subsets connected by straight lines.

OTU	Mean body length (mm)	Mean hind foot length/mean body length	Altitude(m)
1	99	0.22	700
3	95	0.23	500
2	91	0.24	200
4	83	0.26	50

tively). OTU 1 was grouped with OTU 3, whereas OTU 2 formed another subgroup with OTU 4.

In summary, from the results of univariate and multivariate analyses presented above 53 samples of *A. agrarius coreae* from the four OTU's were similar enough to be grouped into a single subspecies and clinal variation shown in the first discriminant axis and in length of tail vertebrae (character 28) were related with altitude of locality where samples were collected.

DISCUSSION

In striped field mice, *Apodemus agrarius coreae*, Thomas (1906) and Kuroda (1934) noted that there was no difference in external morphology between the specimens from the Korean peninsular and those from Cheju-do. Johnson and Jones (1955) distinguished striped field mice in coastal areas of southwestern Korea as *A. agrarius pallescens* and those in Cheju-do as *A. agrarius chejuensis* from *A. agraries coreae* in other areas of Korea. They compared external and cranial character means of samples from type localities, but they did not consider age and secondary sexual variation of samples.

Evident, significant age variation and no significant secondary sexual dimorphism were found in morphometric characters of *A. agrarius coreae* from Chongju (Koh, 1983): it was concluded that univariate and multivariate analyses using samples of the same age class are necessary to analyze for geographic variation of *A. agrarius coreae* in Korea.

Principal component analysis makes no assumption about the existence or otherwise of grouping among the entities (Clifford and Stephenson, 1975), whereas discriminant function or canonical analysis ordinates two or more a priori defined groups as that there is minimum overlap and maximum separation between them (Thorpe, 1981). Moreover, in order to compare samples the results based on individual measurements and multivariate analyses are more convincing than those based on character means and univariate analyses.

From univariate SS-STP analysis (Table 1) means of 21 of 31 characters were not significantly different among the four OTU's and only in length of tail vertebrae samples from Mt. Wolak and Chongju were significantly different from Mt. Taebaek and Mt. Palgong samples.

Based on the results of principal component analysis with individual measurements (Figs. 1 and 2) samples of the four OTU's were similar. However, from the discriminant analysis using individual measurements (Figs. 3 and 4) samples from the four OTU's were different with one another, although clinal variation was revealed in the first axis. From UPGMA cluster analysis and principal component analysis with means (Figs. 5 and 6) Chongju and Mt. Wolak samples formed one group and Mt. Palgong and Mt. Taebaek samples the other group.

Therefore, it was concluded that samples of striped field mice, *Apodemus agrarius coreae*, were similar enough to be recognized as a single subspecies: a subspecies is an aggregate of phenetically similar populations of a species, inhabiting a geographic subdivisions of the range of a species (Mayr, 1969).

Within species of homeotherms the body size of individuals of different populations is often negatively correlated with environmental temperature, and the relative size of appendages is often positively correlated with environmental temperature: such trends are sufficiently widespread to have been labeled to ecogeographic rules of Bergman and Allen, respectively (Brown and Lee, 1969). In this study I used the altitude as an index to the temperature of the localities, and found that body length was positively correlated with the altitude and the ratio of hind foot to body length was negatively correlated with altitude (Table 4).

Among infraspecific populations different characters show independent trends of geographic variation (Wilson and Brown, 1953). In this study means were not significantly different among the four OTU's in 21 of 31 characters and the order of ranked means were variable in other ten characters, although means of samples from Chongju and Mt. Wolak were smaller than those from Mt. Palgong and Mt. Taebaek (Table 1).

A cline is directional change of character or gene frequency within a species over geographic distance (Johnson, 1976): a graphic plot of characters with distance usually reveals a rather smooth ascending or descending curve. In this study clinal variation was revealed in the first discriminant axis (Fig. 4): the higher correlation coefficient was found in greatest length of the skull, length of incisive foramen, and length of tail vertebrae (Table 3). However, from univariate SS-STP analysis samples from the four OTU's were not significantly different among themselves in greatest length of the skull and length of incisive foramen, but in the length of tail vertebrae Chongju and Mt. Wolak samples were significantly different from Mt. Palgong and Mt. Taebaek samples, i.e., a step cline was revealed.

Fewer examples involve large frequency change over short units of distance, the so-called step cline: the absence of gene flow results in a step cline (Endler, 1977). Some general categories of extrinsic isolating factors for the isolation of infraspecific populations through which dispersal is limited without causing reproductive isolation are geographical, temporal, and ecological barriers (Edwards, 1954). There are no recognizable barriers such as mentioned above in the geographic range of *A. agrarius coreae*, and it will be necessary to increase sample sizes to confirm the presence of a step cline.

When clinal variation is recognized, it is inadvisable to delimit subspecies, except two ends of cline with very different or separated by a pronounced gap (Mayr, 1969). Moreover, Jones and Johnson (1965) noted that they would expect future specimens of *A. agrarius* from Korea to illustrate a rather gradual change in external sizes from north to south.

In future, comparison of *A. agrarius coreae* with *A. agrarius pallescens* and *A, agrarius chejuensis* will be necessary.

SUMMARY

Univariate and multivariate analyses of morphometric characters were performed with samples of striped field mice, *Apodemus agrarius coreae* Thomas, collected from Mt. Taebaek area, Mt. Wolak area, Mt. Palgong area, and Chongju area.

It was confirmed that the samples of *A. agrarius coreae* were similar with one another to be grouped into a single subspecies. Moreover, clinal variation related with the altitude of localities where samples were collected was revealed in the first axis resulted from discriminant analysis and in the length of tail vertebrae.

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