KOREAN JOURNAL OF ZOOLOGY
Vol. 29, No. 4, pp. 272-282 (1986)

Geographic Variation of Morphometric Characters among Three Subspecies of Striped Field Mice, *Apodemus agrarius* Pallas (Muridae, Rodentia), from Korea.

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한국산 등줄쥐, *Apodemus agrarius* Pallas (Muridae, Rodentia), 3아종에 있어서의 형태적 형질들의 지리적 변이

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(Received April 10, 1986)

적 요

한국산 등줄쥐 3아종(*Apodemus agrarius coreae, A. agrarius pallascens,* and *A. agrarius chejuensis*)에 속하는 표본들의 형태적형질들을 단변량 및 다변량 분석방법에 의해서 분석하였다.

제주도산 *A. agrarius chejuensis*는 다른 한반도산 두 아종과 형태적인 차이가 있음이 밝혀졌으므로, 이 아종의 분류학적 위치를 재 규명할 연구가 계속되어야 한다고 결론지워졌다.

또한 *A. agrarius coreae*는 *A. agrarius pallescens*와 형태적으로 유사하다고 밝혀졌으므로, 후자는 전자의 synonym으로 결론내렸다.

INTRODUCTION

Striped field mice, *Apodemus agrarius* Pallas, inhabit from West Germany to Korea and most of subspecies were designated on the basis of slight differences in pelage colour and/or body size (Corbet, 1978).

Thomas (1906) described striped field mice from the Korean peninsular and Jeju-Do as *A. agrarius coreae.* Johnson and Jones (1955) 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 Jeju-Do. They, however, stated that subspeciation of this species in the Korean main land was not clearly

본 연구는 1985년도 한국과학재단 연구비로 수행된 것임.

defined.

Evident age variation and no significant secondary sexual variation were found from univariate and multivariate analyses of morphometric characters of *A. agrarius coreae* from Chongju (Koh, 1983). Based on morphometric analyses with the samples of the same age class in *A. agrarius coreae* from four localities, they were similar with one another enogh to be grouped into a single subspecies (Koh, 1985).

In this paper, specimens of *A. agrarius* from ten localities which were selected to represent samples of three subspecies (*A. agrarius coreae*; *A. agrarius pallescens*; *A. agrarius chejuensis*) were analyzed statistically to determine the range of geographic variation of external and cranial characters in order to reexamine the subspecific status of the three subspecies in *A. agrarius* from Korea.

MATERIALS AND METHODS

Materials

Skins and skulls of 254 striped field mice were used (for localities, number of specimens in each locality, and subspecific names see Table 1).

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 aross upper first molars; 16, length of incisive foramen; 17, width of the interparietal bone; 18, length

Table 1. Specimens used.

Subspecies name	Locality	No. of Specimen
Apodemus agarius chejuensis	Mosulpo	11
	Jeju	6
Apodemus agrarius coreae	Chongju	131
	Mt. Weolak	26
	Mt. Taebaek	19
	Mt. Palgong	21
	Mungyong	22
Apodemus agrarius pallescens	Anmyon Is.	6
	Kunsan	8
	Mokpo	4
Total 3	10	254

Table 2. Age classification of the samples of *Apodemus agrarius* from Korea. SA, YA, MA, and OA indicate subadult, young aduld, middle-aged adult, and old adult, respectively.

Locality	OTU	Age classes				Total
		SA	YA	MA	OA	
Mosulpo	1	—	2	7	2	11
Jeju	2	—	3	3	—	6
Chongju	3	37	43	42	9	131
Mt. Weolak	4	6	4	13	3	26
Mt. Taebaek	5	2	6	8	3	19
Mt. Palgong	6	4	4	9	4	21
Mungyong	7	1	7	12	2	22
Anmyon Is.	8	—	2	4	—	6
Kunsan	9	—	1	6	1	8
Mokpo	10	—	1	2	1	4
Total		50	73	106	25	254

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 molar; 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 avaiable for each locality to be used as a basic unit, samples from the same locality were grouped as Operational Taxonomic Units, OTU's (1, Mosulpo area; 2, Jeju; 3, Chongju; 4, Mt. Weolak; 5, Mt. Taebaek; 6, Mt. Palgong; 7, Mungyong; 8, Anmyon Island; 9, Kunsan; 10, Mokpo).

Age classification

Each specimen was assigned to one of five age classes (juvenile, subadult, young adult, middle-aged adult, and old adult) (for details see Koh, 1983). All samples were classified into 50 subadults, 73 young adults, 106 middle-aged adults, and 25 old adults (for details see Table 2). The specimens of each adult age classes were used for further analyses.

Analyses of geographic variation

All computations were made using HP 3000 computer, Chungbuk University, Chongju.

For univariate analysis, Gabriel's Sums of Square Simultaneous Test Procedure (SS-STP) on ranked means (Power, 1970) was applied with the individual measurements of middle-aged adults in seven OTU's with more than five specimens by UNIVAR program in order to test significant difference of means among OTU's.

For ordination analysis, principal component analysis (Seal, 1964), PCA, was performed from the individual measurements of 31 characters using subprogram PCAS of Interactive

Statistical Packages. However, the data was singular in all analyses. Therefore, the 13 characters (1, 3, 4, 6, 9, 13, 16, 19, 20, 22, 25, 28, and 30), showing significant difference among means from the four OTU's in the analysis with *A. agrarius coreae* (see Koh, 1985) were selected and used for PCA (the means of 13 selected characters were also used). The results based on middle-aged adults with the largest number of specimens were shown here because the same results were obtained even with the data from different age class.

For cluster analysis, the means of 31 characters calculated from samples of ten OTU's (OTU's 9 and 10 with only one specimen were also included) were first standardized using Sokal's (1961) equation, $(X_i-\bar{X})/\text{S.D.}$, where X_i indicates ith measurement, $\bar{X}$ the mean, and S.D. standard deviation. Average taxonomic distance matrices were calculated from the standardized data. To group OTU's Unweighted Pair Group Method using Arithmatic Averages, UPGMA, was used (Sneath and Sokal, 1973).

The means of 13 selected characters in ten OTU's were also used for UPGMA cluster analysis in order to decide whether the result based on 31 characters is similar with the result on the basis of 13 selected characters or not. The results on the basis of middle-aged adults were shown here because the same results were obtained.

RESULTS

SS-STP analysis

Character means of each of seven OTU's are shown in Table 3, where the OTU's showing no significant differences are connected by straight lines. In three characters (23, 26, and 27) means were not significantly different among the seven OTU's tested. In other 28 characters the order of ranked means were variable, but in each character mean of OTU 1 was the largest. Moreover, in ten characters (1, 2, 3, 10, 14, 17, 19, 20, 22, and 25) mean in OTU 1 differ significantly from that in other six OTU's (3, 4, 5, 6, 7, and 9).

Multivariate analyses with individual measurements

Two dimensional configurations from PCA with 106 middle-aged adults are shown in Fig. 1 (numerals indicate the specimens of each OTU, whereas numeral 0 indicates those of OTU 10). The correlations between original characters and the principal components are given in Table 4 (factors I, II, and III represented 46, 9, and 7 per cent of the variance, respectively).

Samples of OTU's 1 and 2 were found to be larger than those of other eight OTU's (3, 4, 5, 6, 7, 8, 9, and 10). The highest coefficient was shown in character 1 (greatest length of the skull).

Multivariate analyses with means

Two dimensional configurations from PCA are shown in Fig. 2 (factors I, II, and III represented 70, 10, and 9 per cent of the variance, respectively). In one UPGMA analysis with means of 31 characters, the ten OTU's were grouped, as shown in Fig. 3. In the

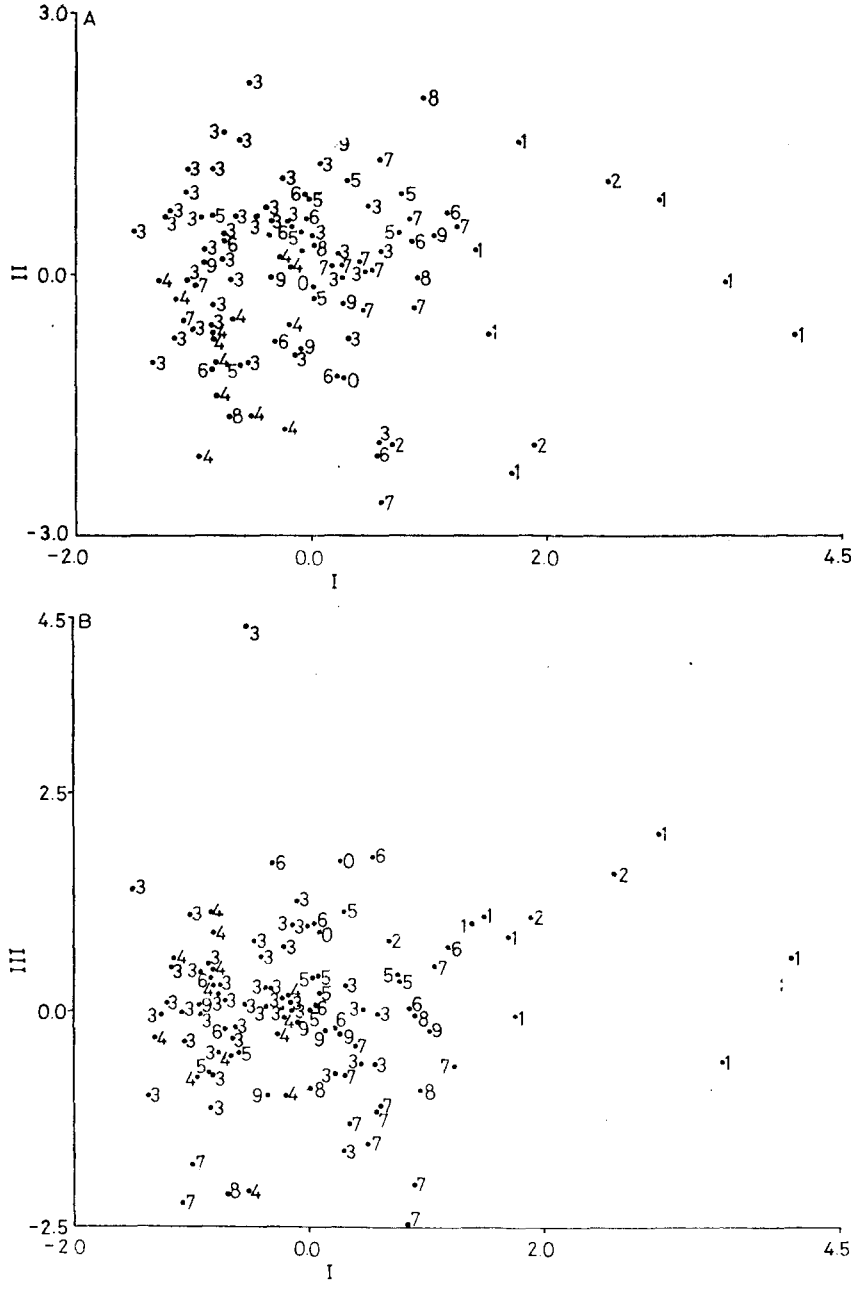

Fig. 1. Projections of 106 middle-aged adults (ten OTU's) of *Apodemus agrarius* based on prinipal component analysis in three dimensions. Factors Ⅰ, Ⅱ, and Ⅲ represented 46, 9, and 7 per cent of the variance, respectively. Individual measurements of 13 selected characters were used. Numerals indicate the specimens of each OTU, whereas numeral O indicate those of OTU 10. For subspecies name, locality, and number of specimens of each OTU see Tables 1 and 2. A, ordination with factor Ⅰ vs. factor Ⅱ. B, ordination with factor Ⅰ vs. factor Ⅲ.

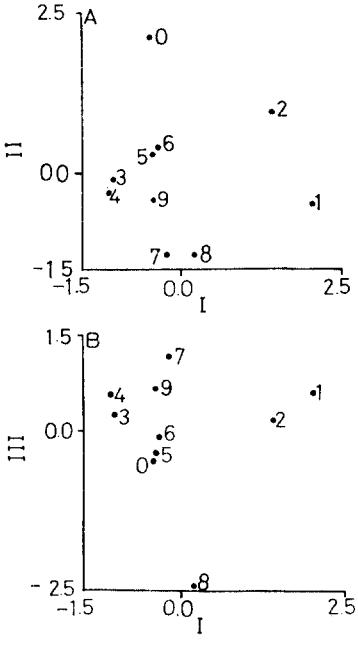

Fig. 2. Projections of ten OTU's of *Apodemus agrarius* based on principal component analysis in three dimensions. Factors Ⅰ, Ⅱ, and Ⅲ represented 70, 10, and 9 per cent of the variance, respectively. The means of 13 selected characters of each OTU were used. Numerals indicate OTU number, but numberal O indicates OTU 10. For subspecies and locality of each OTU see Tables 1 and 2. A, ordination with factor Ⅰ vs. factor Ⅱ. B, ordination with factor Ⅰ vs. factor Ⅲ.

other UPGMA analysis with means of 13 selected characters, the ten OTU's were also clustered, as shown in Fig. 4.

OTU's 1 and 2 formed one subgroup, whereas other eight OTU's (3 to 10) formed the other subgroup.

In summary, *A. agrarius chejuensis* (OTU's 1 and 2) was different from *A. agrarius coreae* (OTU's 3 to 7) and *A. agrarius pallescens* (OTU's 8, 9, and 10): *A. agrarius coreae* was similar with *A. agrarius pallescens.*

DISCUSSION

In striped field mice, *Apodemus agrarius coreae*, there was no difference in external morphology between the specimens from the Korean peninsular and those from Jeju-Do(Thomas, *op. cit.*; Kuroda, 1934). However, Johnson and Jones (*op. cit.*) recognized two more subspecies within *A. agrarius coreae* (*A. a. pallescens* from coastal areas of sowthwestern Korea and *A. a. chejuensis* from Jeju-Do) based on the differences of means in external and cranial characters without the consideration of age variation and secondary sexual dimorphism. Evident age variation and no significant sexual variation were revealed (Koh, 1983) and analysis of geographic variation among samples of *A. agrarius coreae* was conducted (Koh, 1985).

In this report, *A. agrarius chejuensis* was found to be different from other two subspecies, *A. agrarius coreae* and *A. agrarius pallescens* (see Figs. 1, 2, 3, and 4):*A. agrarius pallescens*

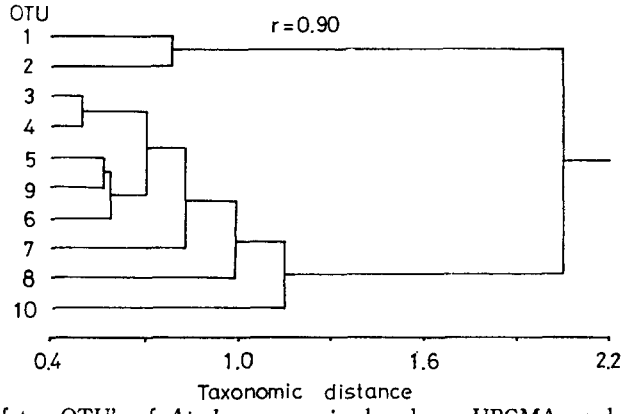

Fig. 3. Groupings of ten OTU's of *Apodemus agrarius* based on UPGMA analysis using average taxonomic distance from standardized means of 31 characters. The cophenetic correlation coefficient, r, was 0.90. For subspecies name and locality of each OTU see Tables 1 and 2.

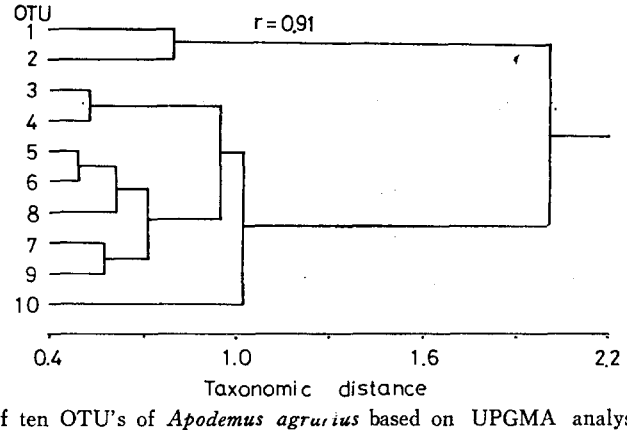

Fig. 4. Groupings of ten OTU's of *Apodemus agrarius* based on UPGMA analysis using average taxonomic distance from standardized means of 13 selected characters. The cophenetic correlation coefficient, r, was 0.91. For subspecies name and locality of each OTU see Tables 1 and 2.

was similar to *A. agrarius coreae*. It was concluded that *A. agrarius pallescens* is a synonym of *A. agrarius coreae* suggested by Thomas (*op. cit.*) and that *A. agrarius chejuensis* is distinct from *A. agrarius coreae* (=*A. agrarius coreae* and *A. a. pallescens*) noted by Johnson and Jones (*op. cit.*): a subspecies is an aggregate of phenetically similar populations of a species, inhabiting a geogrpahic subdivisions of the range of species (Mayr, 1969).

Utilization of large numbers of characters rather than a few selected ones is one of the basic tenets in numerical taxonomy; however, there is neither empirical nor theoretical grounds on the recommendation about the number of characters to use (Sneath and Sokal, 1973).

In this paper, OTU's 1 and 2 (*A. agrarius chejuensis*) formed one subgroup and OTU's 3 to 10 (*A. agrarius coreae*) the other subgroup in UPGMA cluster analysis based on 31 characters (see Fig. 3) and that on the basis of 13 selected characters (see Fig. 4), indica-

Character	OTU's							Character	OTU's						
	1	7	9	6	3	5	4		1	5	7	4	6	3	9
1	30.4	27.8	27.5	27.3	27.3	27.0	26.6	17	11.1	10.4	10.4	10.3	10.3	10.3	10.3
	1	7	9	6	5	3	4		1	4	6	7	3	9	5
2	27.8	25.6	25.3	25.0	24.8	24.7	24.3	18	3.83	3.23	3.15	3.02	2.98	2.92	2.91
	1	5	7	9	3	6	4		1	7	9	6	5	3	4
3	37.0	34.9	34.6	31.7	31.6	31.5	30.2	19	10.6	9.82	9.67	9.55	9.43	9.24	9.11
	1	7	6	5	3	9	4		1	9	6	3	5	7	4
4	11.3	10.5	10.4	10.4	10.3	10.3	10.2	20	4.77	4.31	4.28	4.21	4.14	4.08	4.07
	1	7	6	9	4	3	5		1	9	7	4	3	5	6
5	14.1	13.6	13.2	13.2	13.1	12.9	12.9	21	10.3	9.79	9.76	9.66	9.61	9.59	9.46
	1	7	4	5	9	6	3		1	6	9	7	5	3	4
6	10.5	10.1	10.0	9.97	9.93	9.87	9.75	22	18.9	17.4	17.4	17.3	17.1	16.8	16.8
	1	7	5	4	9	3	6		1	6	9	7	5	3	4
7	12.1	11.8	11.6	11.6	11.5	11.4	11.4	23	4.04	3.95	3.88	3.84	3.84	3.84	3.84
	1	7	9	3	6	5	4		1	6	9	7	5	3	4
8	9.37	9.03	8.90	8.79	8.67	8.66	8.66	24	7.61	7.18	7.16	7.09	7.01	6.97	6.89
	1	6	9	5	7	4	3		1	7	6	9	3	5	4
9	3.31	3.20	3.19	3.18	3.10	3.10	3.07	25	8.54	7.87	7.86	7.75	7.62	7.60	7.57
	1	7	5	6	3	9	4		6	4	3	7	1	9	5
10	10.1	9.33	9.00	8.97	8.96	8.76	8.74	26	1.88	1.88	1.85	1.85	1.83	1.82	1.80
	1	6	4	7	3	9	5		4	1	5	9	6	3	7
11	5.45	5.11	5.07	5.06	5.04	4.97	4.97	27	2.07	2.06	2.04	2.04	2.03	1.97	1.94
	1	9	6	5	4	7	3		1	5	6	9	3	7	4
12	4.76	4.37	4.36	4.36	4.35	4.34	4.31	28	101	100	97	93	92	91	88
	1	6	5	4	3	7	9		1	7	9	6	5	3	4
13	4.88	4.68	4.59	4.56	4.44	4.41	4.40	29	24.0	22.3	21.8	21.8	21.6	21.4	21.1
	1	7	9	6	5	3	4		1	7	5	9	6	3	4
14	9.92	9.04	8.66	8.66	8.64	8.64	8.49	30	106	99	98	97	94	91	88
	1	5	6	7	9	4	3		1	6	5	9	3	4	7
15	5.26	5.11	5.08	5.02	5.00	4.99	4.95	31	15.1	14.0	14.0	13.8	13.6	13.5	13.3
	1	7	9	3	6	4	5								
16	5.45	5.22	5.09	5.09	5.01	4.92	4.89								

Table 3. Geographic variation among seven OTU's of three subspecies in *Apodemus agrarius* (subspecies *chejuensis*, OTU 1; subspecies *coreae*, OTU's 3, 4, 5, 6, and 7; subspecies *pallescens*, OTU 9) based on SS-STP analysis. Character means of each OTU are shown with no significant subsets connected by straight lines. Means are given in milletres. For localities of each OTU see Table 2.

Table 4. Principal components Ⅰ, Ⅱ, and Ⅲ expressed as correlations between characters and individual components from an analysis of three subspecies of *Apodemus agrarius*(subspecies *chejuensis*, *coreae*, and *pallescens*). Individual measurements of 13 selected characters of 106 middle-aged adults were used.

Character	Factor Ⅰ	Factor Ⅱ	Factor Ⅲ
1	0.94	−0.03	−0.07
3	0.75	0.12	0.09
4	0.77	−0.06	−0.07
6	0.67	−0.21	−0.35
9	0.53	−0.45	0.36
13	0.45	−0.44	0.50
16	0.66	−0.18	−0.32
19	0.88	0.05	−0.13
20	0.38	0.29	0.51
22	0.57	0.13	−0.02
25	0.79	−0.14	−0.08
28	0.51	0.56	0.19
30	0.62	0.44	−0.05
% Trace	46	9	7

ting that number of characters does not effect on results, wherever there is a distinct difference between subgroups.

The process of numerical taxonomy include the decision about the selections of clustering methods and ordination techniques to use: there are as yet no satisfactory methods for telling whether clustering or ordination is most appropriate (Sneath and Sokal, 1973). Moreover, the relationship between close neighbors are frequently distorted in an ordination, especially one based on principal component analysis (Rohlf, 1970). Although the primary aims of the methods of numerical taxonomy are repeatability and objectivity (Sneath and Sokal, 1962), Michener (1970), Lidicker (1973), and Dunn (1982) concluded that numerical taxonomic methods must be used cautiously in view of instability.

The result based on PCA (see Figs. 1 and 2) was similar with that by UPGMA cluster analysis (see Figs. 3 and 4), indicating that marked difference between subgroups results in the same conclusion even with different methods.

A cline is directional change of character or gene frequency within a species over geographic distance (Johnson, 1976) and clinal variation corresponds to the Bergman's and Allen's rule (Brown and Lee, 1969).

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 isolaiton of infraspecific populations through which dispersal is limited without causing reproductive isolation are geographical, temporal,

and ecological barriers (Edwards, 1954).

In this study, step cline was revealed in ten of 31 morphometric characters (see Table 3) between *A. agarius chejuensis* from Jeju-Do and *A. agrarius coreae* from the Korean peninsular: a geographic barrier, the South Sea, separates two subspecies of *A. agrarius.*

Geographically isolated populations may be either species or subspecies (Wiley, 1982) and it is preferable for various reasons to treat allopatric populations of doubtful rank as subspecies (Mayr, *op. cit.*). Crowson (1970) noted that a discontinuity in characters of structure will normally show when members of two different species are compared. Jardin and Sibson (1971) noted that the distinct criteria for populations to be recognized as different species are: a) dissimilarity in morphological attributes; b) differences in ecological and/or geographical range; c) degree of interfertility; d) cytological difference; and e) difference of enzymes and proteins.

In future, more specimens are needed for chromosomal, electrophoretic, and phenetic analyses in order to clearify the subspecific status of *A. agrarius chejuensis.*

SUMMARY

Univariate and multivariate analyses of morphometric characters were performed with samples of three subspecies of striped field mice (*Apodemus agrarius coreae, A. agrarius pallescens,* and *A. agrarius chejuensis*).

It was found that the samples of *A. agrarius chejuensis* from Jeju-Do were distintc from those of the other two subspecies from the Korean peninsular, whereas subspecies *coreae* was similar to subspecies *pallescens:* it is concluded that *A. agrarius pallescens* is a synonym of *A. agrarius coreae.*

Further analyses will be needed to clearify the subspecific status of *A. agrarius chejuensis.*

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