

Numerical Taxonomic Study on Five Species of Genus *Apodemus* in East Asia

Hung Sun Koh, Tae Young Chun and Young Ki Kim

(Department of Biology, Chungbuk University, Cheongju 361-763, Korea)

ABSTRACT

Specimens of five species of *Apodemus* (*A. agrarius*, *A. chevrieri*, *A. draco*, *A. latronum*, and *A. peninsulae*) from east Asia (Korea and China) were used for numerical taxonomic analyses with 31 external and cranial characters. Two groups and eight subgroups within them were recognized: [I; a large-size form; (*A. agrarius chejuensis*), (*A. chevrieri*), (*A. draco orestes* and *A. latronum*), and (*A. peninsulae peninsulae* and *A. p. preator*)], [II; a small-size form; (*A. agrarius coreae*), (*A. agrarius manchuricus*, *A. a. ningpoensis*, and *A. a. pallidior*), (*A. draco draco*), and (*A. peninsulae sowerbyi*)]. Conclusions based on morphometric analyses are such as followings: 1) Morphometric characters appeared not to be useful in order to distinguish two subgenera in *Apodemus* (*Apodemus* and *Alsomys*), 2) further analysis is necessary to determine whether or not *A. draco* and *A. latronum* are conspecific, and 3) *A. a. chejuensis* is in morphometric characters the largest form among five species of *Apodemus* studied. Moreover, it is confirmed: 1) *A. agrarius*, *A. chevrieri*, and *A. peninsulae* are distinct species, 2) *A. draco* and *A. latronum* are not conspecific with *A. peninsulae*. 3) Three forms of *A. agrarius* (large-size form, medium-size form, and small-size form) can be recognized as three subspecies [(*A. a. chejuensis*), (*A. agrarius coreae*), and (*A. a. ningpoensis* including *A. a. manchuricus* and *A. a. pallidior*)], 4) *A. draco draco* and *A. draco orestes* are distinct subspecies, 5) *A. peninsulae peninsulae* (including *A. p. preator*) and *A. p. sowerbyi* are distinct subspecies.

Key words: Numerical taxonomy, *Apodemus*, East Asia

INTRODUCTION

The genus *Apodemus* is confined to the Palaearctic and northern part of the Oriental Regions (Tate, 1947; Corbet, 1978). Two species of *Apodemus* (*A. agrarius* and *A. peninsulae*) inhabit in east Russia (Vinogradov and Argirolulo, 1968): five species of it (*A. agrarius*, *A. chevrieri*, *A. draco*, *A. latronum*, and *A. peninsulae*), in east China (Xia, 1984): and two species of it (*A. agrarius* and *A. peninsulae*), in Korea (Jones and Johnson, 1965).

However, classification within genus *Apodemus* is not stable. Ellerman and Morris-Scott (1951) recognized five species in *Apodemus*, *A. agrarius*, *A. flavicolis*, *A. mystacinus*, *A. speciosus*, and *A. sylvaticus*: Corbet and Hill (1991) listed 15 species, *A. agrarius*, *A. alpicola*, *A. argenteus*, *A. chevrieri*, *A. draco*, *A. falzfeini*, *A. flavicolis*, *A. gurkha*, *A. latronum*, *A. microps*, *A. mystacinus*, *A. peninsulae*, *A. speciosus*, and *A. sylvaticus*: and Wilson and Reeder (1993) reclassified this genus to 21 species, *A. agrarius*, *A. alpicola*, *A. argenteus*, *A. arianus*, *A. chevrieri*, *A. draco*, *A. flavicolis*, *A. fulvipectus*, *A. gurkha*, *A. hermonensis*, *A. hyrcanicus*, *A. latronum*, *A. mystacinus*, *A. peninsulae*, *A. ponticus*, *A. rusiges*, *A. semotus*, *A. speciosus*, *A. sylvaticus*, *A. uralensis*, and *A. wardi*. Moreover, these recognized species have been allocated among subgenera *Apodemus*, *Sylvaemus*, *Alsomys*, and *Karstomys* (Corbet, 1978), but Mezhzherin and Kashkova (1992) treated *Sylvaemus* as a separate genus.

Developments in the areas of molecular, cyto-, and numerical taxonomy are enormous (Quicke, 1993), and it was advocated that a classification should be the product of all available characters distributed as widely and evenly possible over the organisms studied (Huelsenbeck *et al.*, 1996).

The purpose of this paper is to compare morphometric characters of five species of *Apodemus* in east Asia, Korea and China [subgenus *Apodemus* (*A. agrarius* and *A. chevrieri*) and subgenus *Alsomys* (*A. draco*, *A. latronum*, and *A. peninsulae*)] in order to confirm taxonomic status of these species and to obtain the results for reclassification of this genus in future.

MATERIALS AND METHODS

Sexual variation was not significant, but age variation was evident in *Apodemus agrarius* (Koh, 1983). Juveniles, subadults, and old adults were not used, and 322 specimens of young and middle-aged adults from nine localities in east Asia (Korea and China), representing five species, *A. agrarius*, *A. chevrieri*, *A. draco*, *A. latronum* and *A. peninsulae*, were used (see Table 1 and Fig. 1).

Four external and 27 cranial characters were measured (for the details of measurements, see Koh, 1983). Sample statistics such as mean and standard deviation were calculated by subprogram DESC of SPSS/pc+ program: discriminant analysis was also performed by subprogram DISCRIMINANT. Principal Component Analysis, PCA, and cluster analysis of Unweighted Pair Group Methods of Arithmetic means, UPGMA, were carried out using subprogram EIGEN and SAHN of NTSYS/pc program, respectively: minimum spanning tree was also produced by subprogram MST.

Table 1. Specimens of five species of *Apodemus* in east Asia (Korea and China).

Species	Locality	No. of Samples	OTU
<i>A. agrarius chejuensis</i>	Cheju island, Korea	45	1
" <i>coreae</i>	Mt. Weolak, Korea	35	2
" <i>manchuricus</i>	Jirin, China	40	3
" <i>pallidior</i>	Sandong, China	29	4
" <i>ningpoensis</i>	Hupeh, China	26	5
<i>A. peninsulae peninsulae</i>	Mt. Weolak, Korea	31	6
" <i>preator</i>	Jirin, China	28	7
" <i>sowerbyi</i>	Xinjiang, China	29	8
<i>A. draco draco</i>	Henan, China	8	9
" <i>orestes</i>	Xixang, China	17	10
<i>A. chevrieri</i>	Yunan, China	19	11
<i>A. latronum</i>	Xixang, China	15	12

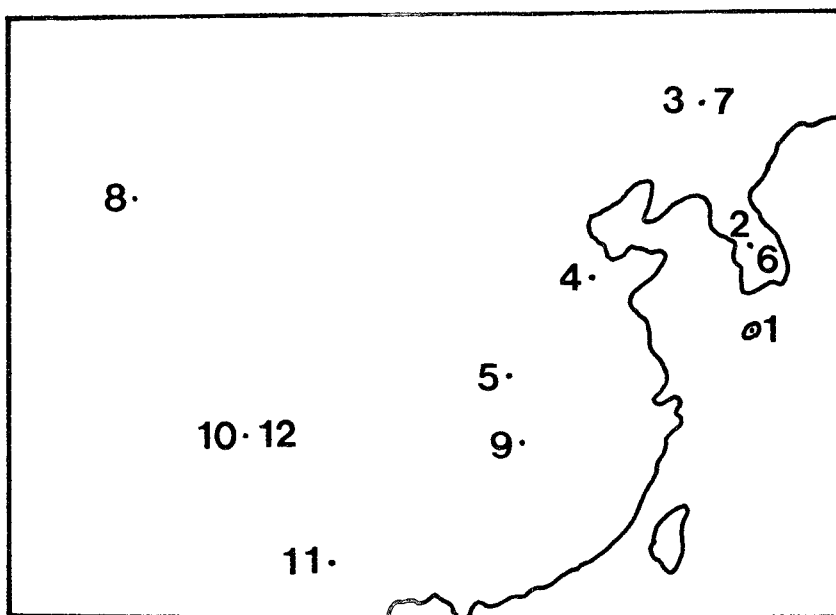


Fig. 1. A map showing 12 OTUs in five species of *Apodemus* in east Asia (Korea and China). The species name and number of specimens in each OTU are given in Table 1.

RESULTS

Twelve OTUs of five species in *Apodemus* were grouped by cluster analysis of UPGMA with taxonomic distances, as shown in Fig. 2. Two dimensional configurations of 12 OTUs in *A.*

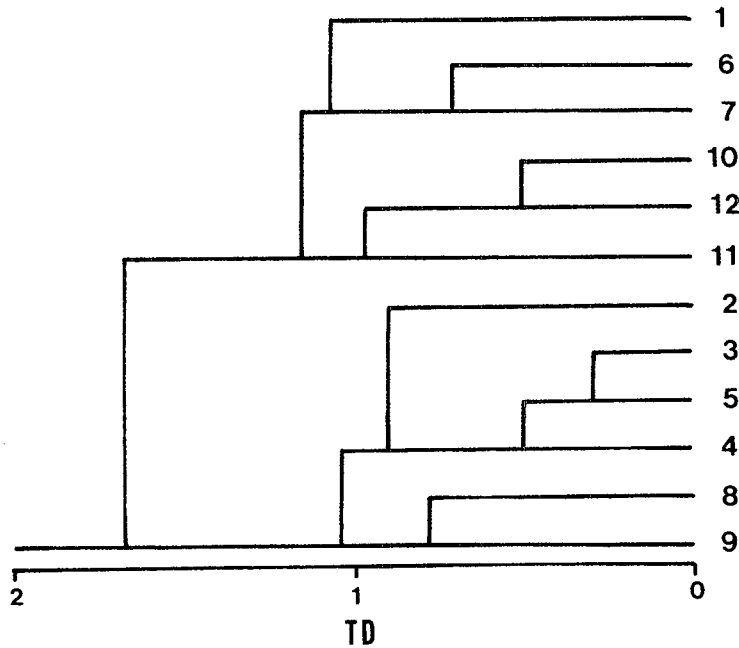


Fig. 2. Grouping of 12 OTUs in five species of *Apodemus* in east Asia (Korea and China) by cluster analysis of UPGMA with taxonomic distances (TD). The species name and locality of each OTU are given in Table 1.

agrarius by PCA are shown in Fig. 3 (minimum spanning tree is superimposed on the plots with minimum distance given). Factors I, II, and III represented 65, 13, and 8 percent of the variance, respectively (86 percent in total). Two dimensional plottings with individual measurements of specimens grouped into 12 OTUs of *A. agrarius* by discriminant analysis are shown in Fig. 4 (minimum spanning tree is superimposed on the plots with minimum distance given). Numerals indicate the centroids of OTUs and functions I, II, and III represented 37, 29, and 12 percent of the variance, respectively (78 percent in total). In summary, two major groups and eight subgroups within them were revealed: [I; (OTU 1), (OTUs 6 and 7), (OTU 10 and 12), and (OTU 11)], [II; (OTU 2), (OTUs 3, 4, and 5), (OTU 8), and (OTU 9)].

In conclusion, two major groups and eight subgroups within them based on their morphometric characters of five species in *Apodemus* were recognized: [I; a large-size form; (OTU 1, *A. agrarius chejuensis*), (OTUs 10 and 12, *A. chevrieri* and *A. draco orestes*), (OTU 11, *A. latronum*), and (OTUs 6 and 7, two subspecies of *A. peninsulae*, subspecies *peninsulae* and *preator*)], [II; a small-size form; (OTU 2, *A. agrarius coreae*), (OTUs 3, 4, and 5; three subspecies of *A. agrarius*, subspecies *manchuricus*, *ningpoensis*, and *pallidior*), (OTU 9, *A. d. draco*), and (OTU 8, *A. peninsulae sowerbyi*)].

DISCUSSION

The classification within genus *Apodemus* is still in confusion. Wilson and Reeder (1993) noted

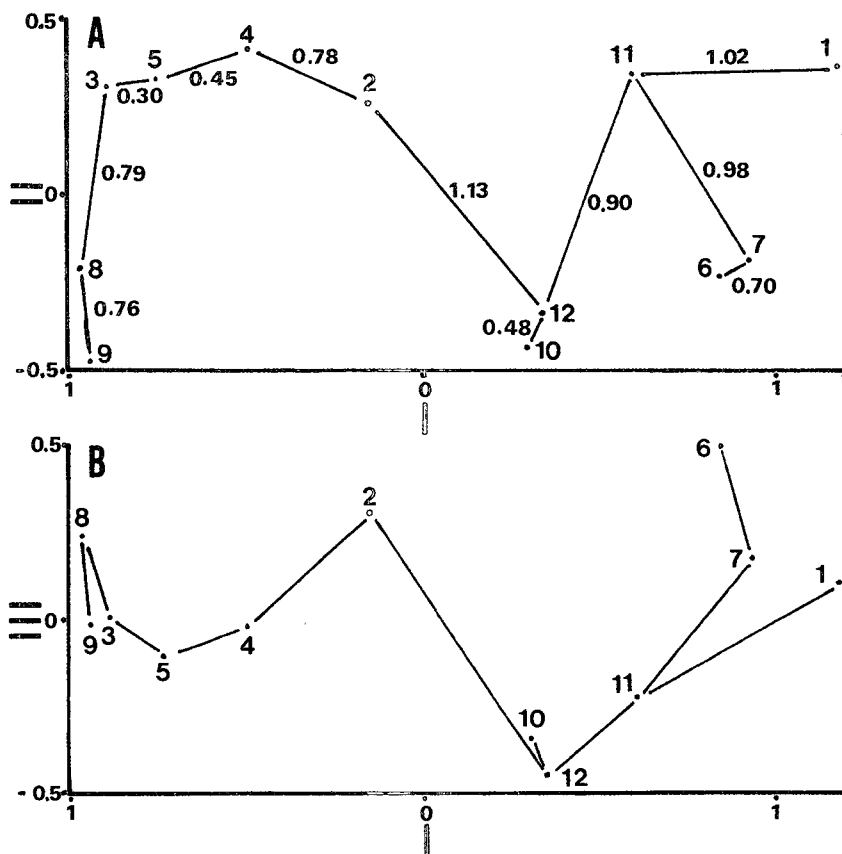


Fig. 3. Projections of 12 OTUs in five subspecies of *Apodemus agrarius* in east Asia (Korea and China) by principal component analysis. Numerals indicate OTUs, and the species name and locality of each OTU are given in Table 1. A, OTUs ordinated with factor I vs. factor II. B, OTUs ordinated with factor I vs. factor III.

that twenty one species of *Apodemus* are classified into four subgenera [*Apodemus* (*A. agrarius* and *A. chevrieri*), *Sylvaemus* (*A. alpicola*, *A. arianus*, *A. flavicolis*, *A. fulvipectus*, *A. hermonensis*, *A. hyrcanicus*, *A. ponticus*, *A. rusiges*, *A. sylvaticus*, *A. uralensis*, and *A. wardi*), *Alsomys* (*A. argenteus*, *A. draco*, *A. gorkha*, *A. latronum*, *A. peninsulae*, *A. semotus*, and *A. speciosus*), and *Karstomys* (*A. mystacinus*)], but he stated that whether these names designated monophyletic clusters and should be retained as subgenera or instead raised to generic rank remains to be answered by critical systematic revision of the entire group, which is currently unavailable. Zimmermann (1962) stated that there was a clear distinction between eastern Asian forms of subgenus *Alsomys* and western Asian and European forms of subgenus *Sylvaemus*, although Kobayashi (1985) noted that most Japanese workers recognize three types in *Apodemus*, 1) *flavicolis* type, 2) *sylvaticus* type, and 3) *agrarius* type.

As subgenus *Apodemus* inhabits across Eurasia, and subgenus *Karstomys* is distributed in Europe, five species of two subgenera [*Apodemus* (*A. agrarius* and *A. chevrieri*) with the third upper molar of 2 internal lobes and *Alsomys* (*A. draco*, *A. latronum*, and *A. peninsulae*) with the

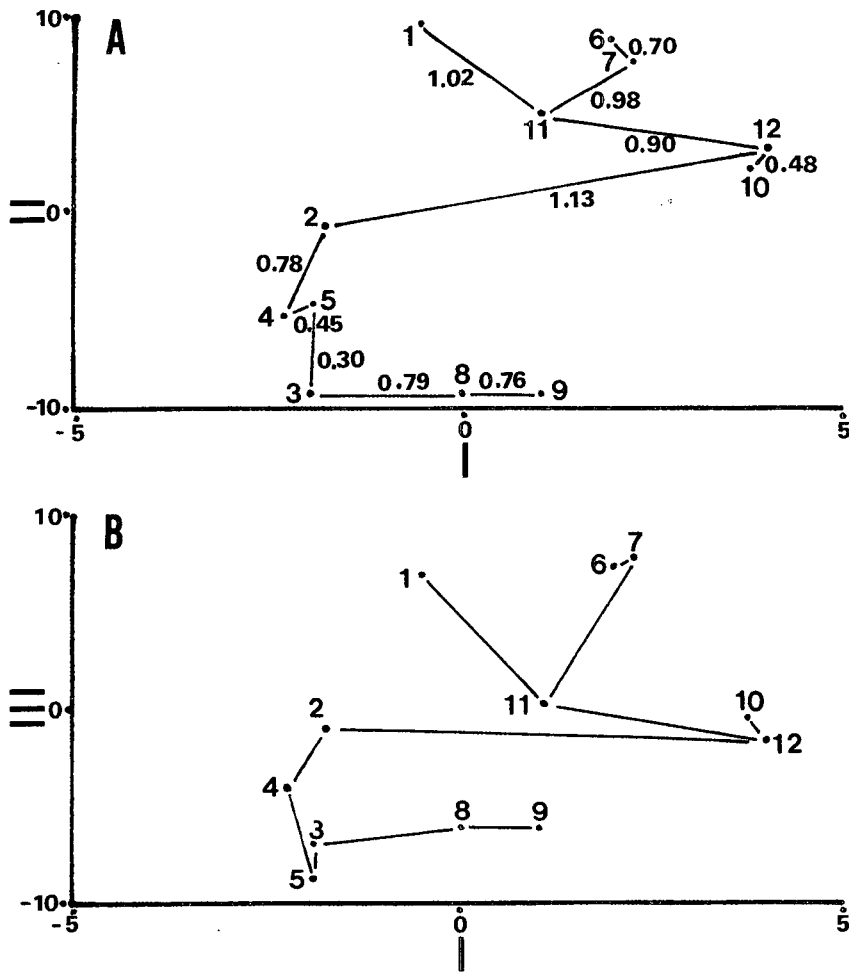


Fig. 4. Plottings of 12 OTUs in five subspecies of *Apodemus* in east Asia (Korea and China) by discriminant analysis. Numerals indicate the centroid of OTUs, and the species name and locality of each OTU are given in Table 1. A, OTUs ordinated with functions I vs. function II. B, OTUs ordinated with function I vs. function III.

third upper molar of 3 internal lobes] are living in east Asia including Korea, east China, and east Russia (Corbet, 1978). Morphometric characters of these five species in two subgenera of *Apodemus* were analyzed in this paper (see Figs. 2, 3, and 4), and two major groups of large-size and small-size forms were revealed: however, these two size groups are not consistent with two subgenera, indicating that 31 morphometric characters used for this paper are not useful to distinguish two subgenera in *Apodemus* (*Apodemus* and *Alsomys*).

Corbet (1978) summarized 24 nominal subspecies of *A. agrarius* into three subspecies [*agrarius*, a western subspecies including 12 named subspecies from western Asia and Europe; *ningpoensis*, an eastern subspecies including eight named subspecies from east Asia; and *chevrieri*, a southern Chinese subspecies including one named subspecies]. Wang (1985) performed the analyses with penile bones, papilla lingualis, and serum proteins of three subspecies (*chevrieri*, *ningpoensis*, and

pallidior) of *A. agrarius*, and concluded that subspecies *chevrieri* is a distinct species: Yang and Fang (1988) also noted that it is a distinct species. Allen (1940) noted that *A. agrarius chevrieri* completely lacks the black dorsal stripe, which is a character to distinguish all other subspecies of *A. agrarius*, and that it is larger in cranial characters than three subspecies of *A. agrarius* (subspecies *manchuricus*, *ningpoensis*, and *pallidior*). Koh (1991) noted on the basis of morphometric analyses with seven subspecies of *A. agrarius* and *A. chevrieri* in Asia that *A. chevrieri* is a distinct large-size form. In this analysis with 31 morphometric characters of five species of *Apodemus* (see Figs. 2, 3, and 4), *A. chevrieri* was found to be a distinct subgroup within a large-size form: it is revealed that *A. chevrieri* (subgenus *Apodemus*) is different in morphometric characters from five subspecies of *A. agrarius*, i.e., *A. a. chejuensis*, *A. a. coreae*, *A. a. manchuricus*, *A. a. ningpoensis*, *A. a. pallidior* (subgenus *Apodemus*) and three species of subgenus *Alsomys* (*A. draco*, *A. latronum*, and *A. peninsulae*), indicating that *A. chevrieri* is a distinct species, as noted by Wang (1985).

Striped field mouse, *A. agrarius*, is widely distributed in Eurasia from Germany to Korea, and it is a distinct species with narrow black mid-dorsal stripe (Vinogradov and Argiropulo, 1968; Corbet, 1978). In this morphometric analyses (see Figs. 2, 3, and 4), five subspecies of *A. agrarius* was different from other four species studied to form different subgroups. It is confirmed that *A. agrarius* is a distinct species.

In the subspecies classification of *A. agrarius*, Koh and Tikhonova (1998) suggested from the morphometric analyses that 15 subspecies can be classified into five; *A. a. chejuensis*, *A. a. coreae* (including subspecies *pallidior*), *A. a. ningpoensis* (including subspecies *manchuricus*, *pallidior*, and *insulaemus*), *A. a. agrarius* (including subspecies *tianschanicus*, *ognevi*, *septentrionalis*, *nikolski*, *caucasicus*, and *karelicus*), and *A. a. volgensis*, although Corbet (1978) noted that 22 named subspecies can be summarized into two subspecies (*A. a. ningpoensis* in the east Eurasia and *A. a. agrarius* in the west Eurasia). In this morphometric analysis including five subspecies of *A. agrarius*, three distinct forms [(large-size form, *A. a. chejuensis*), (medium-size form, *A. a. coreae*), and (small-size form; *A. a. manchuricus*, *A. a. ningpoensis*, and *A. a. pallidior*) were revealed (see Figs. 2, 3, and 5), and it is confirmed that these three forms can be recognized as three subspecies, as noted by Koh and Tikhonova (1998). Moreover, it is revealed that *A. a. chejuensis* is in morphometric characters the largest form among five species of *Apodemus* studied.

In *A. draco*, two subspecies (*A. d. draco* and *A. d. orestes*) are recognized, and this species could conceivably be conspecific with northern *A. peninsulae* (Corbet, 1978): however, Allen (1940) distinguished it from *A. peninsulae* on the basis of its darker ears. In this analysis with morphometric characters of five species in *Apodemus* (see Figs. 2, 3, and 4), *A. d. orestes* is larger than *A. d. draco*, and they are different in its morphometric characters from *A. peninsulae*, *A. agrarius*, and *A. chevrieri* studied. It is confirmed that *A. d. draco* and *A. d. orestes* are distinct subspecies, and that *A. draco* is not conspecific with *A. peninsulae*, as suggested by Allen (1940).

Corbet (1978) also noted that big-eared wood mouse, *A. latronum*, is not conspecific with the smaller, northern *A. peninsulae*. In this analysis (see Figs. 2, 3, and 4), *A. latronum* formed a distinct subgroup with *A. d. orestes*, but it differs in morphometric characters from *A. peninsulae*, *A. agrarius*, and *A. chevrieri* studied. It is confirmed that *A. latronum* is not conspecific with *A.*

peninsulae.

Xia (1985) noted that the classification of *A. latronum* is still obscure, and Wilson and Reeder (1993) noted that *A. latronum* was regarded as a subspecies of *A. draco*, *A. d. latronum*. But Corbet (1978) stated that *A. latronum* is sympatric with *A. d. orestes* in Szechuan, China, and that *A. latronum* is larger than *A. draco* in morphometric characters: however, they are similar in their dark ears. In this analysis (see Figs. 2, 3, and 4), *A. latronum* formed the same subgroup with *A. d. orestes*. It is concluded that further analysis is necessary to determine whether or not *A. draco* and *A. latronum* are conspecific.

Korean field mouse, *A. peninsulae*, is distributed over much of Siberia, China, Manchuria, Korea, Hokkaido (Corbet and Hill, 1991). *A. peninsulae* was considered as a subspecies of *A. speciosus* (Thomas, 1906), but Vorontsov *et al.* (1977) claimed that on the basis of karyological and morphological basis that all eastern forms of *A. peninsulae* should be transferred to the species, *A. peninsulae*. In this morphometric analyses (see Figs. 2, 3, and 4), three subspecies of *A. peninsulae* differs from other four species studied to form different subgroups. It is confirmed that *A. peninsulae* is a distinct species.

In the subspecies classification of *A. peninsulae*, Corbet (1978) recognized only two subspecies (*A. p. peninsulae* and *A. p. sowerbyi*) in the continent of Asia. Koh *et al.* (1996) noted in their morphometric analysis that *A. p. peninsulae* and *A. p. preator* are more or less similar with each other and that these two subspecies are larger than *A. p. sowerbyi*, but *A. p. sowerbyi* might be a heterogeneous group. In this analysis (see Figs. 2, 3, and 4), *A. p. peninsulae* and *A. p. preator* are similar with each other, and they are different from *A. p. sowerbyi*, indicating that *A. p. peninsulae* (including *A. p. preator*) and *A. p. sowerbyi* are distinct subspecies.

In future, it is necessary to use additional samples in order to confirm all of the conclusions in this paper because they are based on the limited number of samples from east Asia. Especially, it is urgent to analyze samples of *A. argenteus* and *A. speciosus* in Japan.

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동아시아산 붉은쥐속 5종의 형태형질의 수리분류학적 연구

고 흥 선 · 천 태 영 · 김 영 기

(충북대학교 생물학과)

동아시아의 한국과 중국에 살고 있는 붉은쥐속 (*Apodemus*) 5종 (*A. agrarius*, *A. chevrieri*, *A. draco*, *A. latronum* 및 *A. peninsulae*)의 표본들을 31개 외부 및 두골형질들의 수리분류학적 연구에 사용하였다. 2군과 각 군내의 8아군 [I: 큰 형; (*A. agrarius chejuensis*), (*A. chevrieri*), (*A. draco orestes*와 *A. latronum*) 및 (*A. peninsulae peninsulae*와 *A. p. preator*)], [II: 작은 형; (*A. agrarius coreae*), (*A. agrarius manchuricus*, *A. a. ningpoensis* 및 *A. a. pallidior*), (*A. draco draco*) 및 (*A. peninsulae sowerbyi*)]이 형성되었다. 형태형질의 분석에서 얻은 결론은 다음과 같다: 1) 형태형질들은 붉은쥐속 *Apodemus*내의 2아속 (*Apodemus*와 *Alsomys*)을 구분하는 데에 유효하지 않다, 2) *A. draco*와 *A. latronum*가 동일한 종인지의 결정을 위한 계속적인 연구가 필요하다, 3) *A. a. chejuensis*는 본 연구에서 분석한 붉은쥐속 5종중에서 형태적 형질에서 가장 크기가 크다. 뿐만 아니라, 다음 사실들이 확인되었다: 1) *A. agrarius*, *A. chevrieri* 및 *A. peninsulae*는 독특한 종들이다, 2) *A. draco*와 *A. latronum*는 흰넓적다리붉은쥐 *A. peninsulae*와 동종이 아니다, 3) 등줄쥐 *A. agrarius*의 3형 (큰 형, 중간 형 및 작은 형)은 3아종 [(*A. a. chejuensis*), (*A. agrarius coreae*) 및 (*A. a. manchuricus*와 *A. a. pallidior*를 포함하는 *A. a. ningpoensis*)]으로 구분된다, 4) *A. draco draco*와 *A. draco orestes*는 독특한 아종이다, 5) *A. peninsulae peninsulae* (*A. p. preator*포함)와 *A. p. sowerbyi*는 독특한 아종이다.