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Morphometric Analyses on 24 Species (13 Families of Six Orders) of Korean Mammals

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Four external and 22 cranial characters of 279 specimens representing 24 species of six orders of Korean mammals were measured. The data were analyzed by phenetic methods such as ordination as well as clustering techniques. Morphological distances were also calculated. Phenetic studies yield taxonomic placements of Siberian mink, Palearctic squirrel, and big white-toothed shrew which are incorrect. Morphological differences among Korean mammals at ordinal level in the taxonomic hierarchy are larger than those among other mammals: morphological differences below ordinal level are comparable to those among other mammals. Average taxonomic distances and morphological differences among Korean mammals at various levels in the taxonomic hierarchy are jointly monotonic, although the value of Pearson's product-moment correlation coefficient between average taxonomic distance matrix and morphological difference matrix is 0.59.

KEY WORDS: ***Systematics, Morphometric, Korean mammals***

Many of the precedented, formal classifications that are familiar and used today were constructed under the view based on the evolutionary school of classification (Mayr, 1969). Partly in reaction to the methodological vagueness of evolutionary classification operational principles, which have come to be known as basic principles of phenetic school, were proposed (Sneath and Sokal, 1973). Another reaction to the methodological vagueness of the evolutionary school of classification was the development of more operational and explicit theory for estimating evolution, i.e., cladistic school (Hennig, 1966). Proponents of the three major schools of taxonomy (evolutionary, cladistic, and phenetic) have each specified that their classifications are superior on philosophical, methodological, and empirical grounds. All three schools have been critisized for not achieving their own stated goals and for not achieving goals deemed significant by opposing schools (Archie, 1984; Estabrook, 1986).

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 and (2) use of resemblance rather than key characters to compare taxa (Sneath and Sokal, 1962). Furthermore, they noted that the primary aims of the methods of numerical taxonomy are repeatability and objectivity.

Michener (1970) concluded, however, that the methods of numerical taxonomy are best seen as tools for data exploration, rather than for the production of a formal classification. Oxnard (1978) also stated that whatever the pattern constructed by a dendrogram, and however good the overall significance, the liability in the system make a number of other dendrograms possible. Dunn (1982) noted that the methods of cluster analyses and ordinations in numerical taxonomy, in practice, do not lead to a purely objective and stable classification.

On systematic works of Korean mammals, Woon (1967) reported that 82 species of mam-

Table 1. Specimens used

Order	Family	Species name	Locality	No.	OTU
Artiodactila	Cervidae	*Hydropotes inermis*	Koesan	3	1
Carnivora	Mustelidae	*Mustela sibirica*	Koesan	10	2
	Canidae	*Nycterreutes procyonoides*	Chongju	1	3
	Felidae	*Felis bengalensis*	Koesan	1	4
Lagomorpha	Leporidae	*Lepus sinensis*	Koesan	3	5
Rodentia	Sciuridae	*Sciurus vulgalis*	Koesan	6	6
	Sciuridae	*Tamias sibiricus*	Jinchon	8	7
	Cricetidae	*Microtis fortis*	Pochon	4	8
	Cricetidae	*Clethrionomys rufocanus*	Mt. Weolak	3	9
	Cricetidae	*Cricetulus triton*	Jeju	2	10
	Muridae	*Apodemus agrarius coreae*	Chongju	102	11
	Muridae	*Apodemus agrarius chejuensis*	Jeju	50	12
	Muridae	*Apodemus peninsulae*	Mungyong	5	13
	Muridae	*Micromys minutes*	Chongju	1	14
	Muridae	*Rattus rattus*	Chongju	17	15
	Muridae	*Rattus norvegicus*	Chongju	26	16
	Muridae	*Mus molosinus*	Chongju	14	17
Insectivora	Erinaceidae	*Erinaceus europaeus*	Chongju	3	18
	Soricidae	*Crocidura lasiura*	Chongju	5	19
	Talpidae	*Talpa robusta*	Chongju	5	10
Chiroptera	Rhinolophidae	*Rhinolopus ferrum-equinum*	Jinju	2	21
	Vespertilionidae	*Myotis mystasinus*	Jinju	1	22
	Vespertilionidae	*Myotis formosus*	Jinju	1	23
	Vespertilionidae	*Pipistrellus abramus*	Chongju	3	24
	Vespertilionidae	*Minioptemis schreibersii*	Muneui	3	25

mals (including 16 species of rodents) are inhabited in Korea and described external features of type specimens. Corbet (1978) noted that 52 species of mammals are distributed in Korea. Jones and Johnson (1960, 1965) reviewed taxonomically Korean insectivorans and Korean lagomorphs and rodents, respectively: they, however, stated that "we have been able to examine only limited materials from northern Korea and the adjacent parts of Manchuria and Siberia, and the present treatment must be ragarded, therefore, as provisional". In order to analyze systematically Korean mammals Koh (1987) analyzed 15 species of small mammals by multivariate methods.

In the present paper, samples of 24 species of Korean mammals were used for phenetic analyses.

Materials and Methous

Materials

Two hundred and seventy nine specimens of Korean mammals (six orders, 13 families, and 24 species) were analyzed statistically (see Table 1 for species name, localities, and number of samples studied).

Characters

Analyses were based on four external and 22 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. incisor-upper-first-molar length; 14. width across upper first molars; 15. length of incisive foramen; 16. width of the interparietal bone; 17. length of the interparietal bone; 18. postpalatine length; 19. height of rostrum; 20. bullae-brain case height; 21. greatest length of mandible; 22. height of mandible; 23. length of tail vertebrae; 24. length of hind foot; 25. body length; 26. length of ear.

OTU designation

Although sufficiently large samples were not available for each locality to be used as a basic unit, samples of the same species from the same locality were grouped as Operational Taxonomic Units, OTU's. Samples of 24 species were grouped into 25 OTU's (see Table 1 for OTU number of each species).

Phenetic analyses

All computations were made by HP-3000/48 computer in Chungbuk University. Sample statistics such as mean, standard deviation, and skewness were calculated by ELEMSTAT program of Interactive Statistical Programs (ISP).

Raw data were first standardized using Sokal's equation (1961). Average taxonomic distances were calculated from standardized data and phenogram was constructed by Unweighted Pair Group Method using Arithmatic Averages, UPGMA (Sneath and Sokal, 1973). Principal component analysis with the means of 12 selected characters (characters 1, 3, 4, 6, 9, 16, 19, 20, 22, 24, 28 and 30) was also carried out by PCAS of ISP. Discriminant analysis was performed by DISCRIM of Statistical Package for the Social Sciences, SPSS (Nie *et al.*, 1975). Morphological distances (Wyles *et al*, 1983) were calculated with the means of 26 characters of 25 OTU's: a phenogram was constructed by UPGMA clustering.

Results

The 25 OTU's of 24 species of Korean mammals were grouped by UPGMA cluster analysis with average taxonomic distance, as shown in Fig. 1. Average taxonomic distances among Korean mammals at various levels in the taxonomic hierarchy are given in Table 2 and Fig. 2. Two dimensional configurations from principal component analysis with 12 character means are shown in Fig. 3. (factors I, II, and III represented 83, 8, and 7 percent of the variance, respectively). Two dimensional configuration from discriminant analysis with 274 samples grouped into 20 OTU's (OTU's 1-2, 5-13, 15-21, and 24-25) is shown in Fig. 4 (functions I and II represented 64 and 14 percent of the variance, respectively).

In summary, the groupings of 25 OTU's based on UPGMA cluster analysis (Fig. 1), principal component analysis (Fig. 3), and discriminant analysis (Fig. 4) are appeared to be similar with the groupings based on conventional classification. However, each of three OTU's (OTU 2, *Mustela sibiricus*, Siberial mink; OTU 6, *Sciurus vulgaris*, Palearctic squirrel; OTU 19, *Crocidura lasiura*, big white-toothed shrew) are distinct in morphometric characters from the other species of the order Carnivora, Rodentia, and Insectivora, respectively.

Morphological distances among 24 species of Korean mammals at various levels in the taxonomic hierarchy are given in Table 3 and Fig. 5.

Table 2. Average taxonomic distances among Korean mammals at various levels in the taxonomic hierarchy

Taxonomic rank	Distance (mean ± S.E.)
Subspecies	0.05
Species	0.08±0.01
Genus	0.33±0.20
Family	0.53±0.32
Order	1.37±1.20

Table 3. Morphological distances among 24 species of Korean mammals at various levels in the taxonomic hierarchy

Taxonomic rank	Distance (mean ± S.E.)
Subspecies	2.05
Species	4.38± 1.26
Genus	8.99± 3.34
Family	18.41± 9.61
Order	33.16±11.81

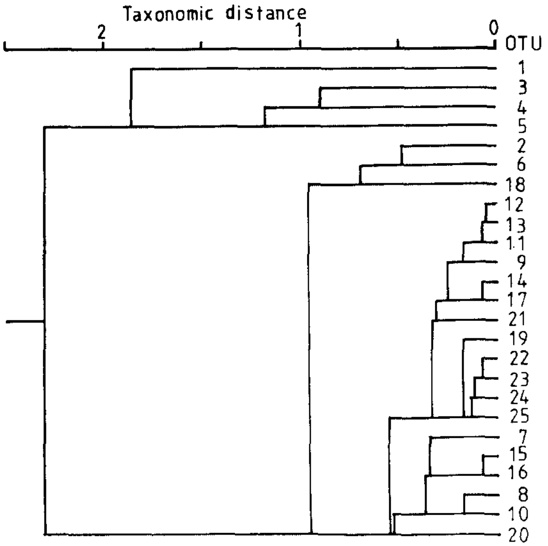

Fig. 1. Groupings of 25 OTU's of 24 species of Korean mammals based on UPGMA analysis using average taxonomic distances from standardized means of 26 characters. The species names and localities of each OTU are shown in Table 1.

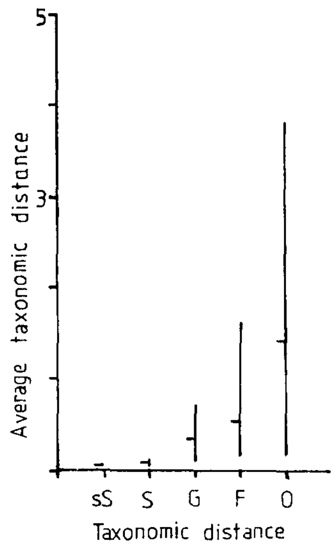

Fig. 2. Average taxonomic distance compared with taxonomic distance in Korean mammals. Vertical lines indicate range of the means. The units of taxonomic distance are expressed in terms of the following categories: sS, subspecies; S, species; G, genus; F, family; O, order.

Morphological distances varied accrding to taxonomic rank.

The grouping of 25 OTU's by UPGMA clustering based on morphological distances, which was shown in Fig. 6, appeared to be similar with the grouping on the basis of conventional classification. However, each of two OTU's (OTU 2, *Mustela sibirca;* and OTU 19, *Crocidula lasiura*) differed from the other species of the order Carnivora and Insectivora, respectively.

Morphological distance matrix and average taxonomic distance matrix were compared by calculating the value of Pearson's product moment correlation coefficient, and the value was 0.59, indicating a little relationship between two matrices.

Discussion

The relationships between close neighbors are frequently distorted in an ordination, especially one based on principal component analysis (Rohlf, 1970), there are as yet no satisfactory methods for telling whether clustering or ordination is most appropriate (Sneath and Sokal, 1973), and Dunn (1982) noted that the methods for cluster and ordination analyses are easy to use and that they are also easy to misuse and misinterpret. In this paper, UPGMA clustering, principal component, and discriminant analyses were used and similar results were obtained (Figs. 1, 3, and 4).

Flake and Turner (1968) stated that the numerical approach offers potential for the resolution of taxonomic problems for populations at infraspecific level. Farris (1966) noted that equal weightings and overall similarity seem inapplicable in defining higher categories above the species level. As shown in Figs. 1, 3, and 4, groupings resulted from UPGMA clustering, principal component, and discriminant analyses seemed to be consistent with the groupings based on conventional taxonomy except each of three OTU's (OTU 2, Siberian mink, *Mustela sibiricus;* OTU 6, Palearctic squirrel, *Sciurus vulgaris;* OTU 19, big white-toothed shrew, *Crocidura lasiura*). It is concluded that careful evaluation is necessary before phenetic results are used for the construction of classification above species level.

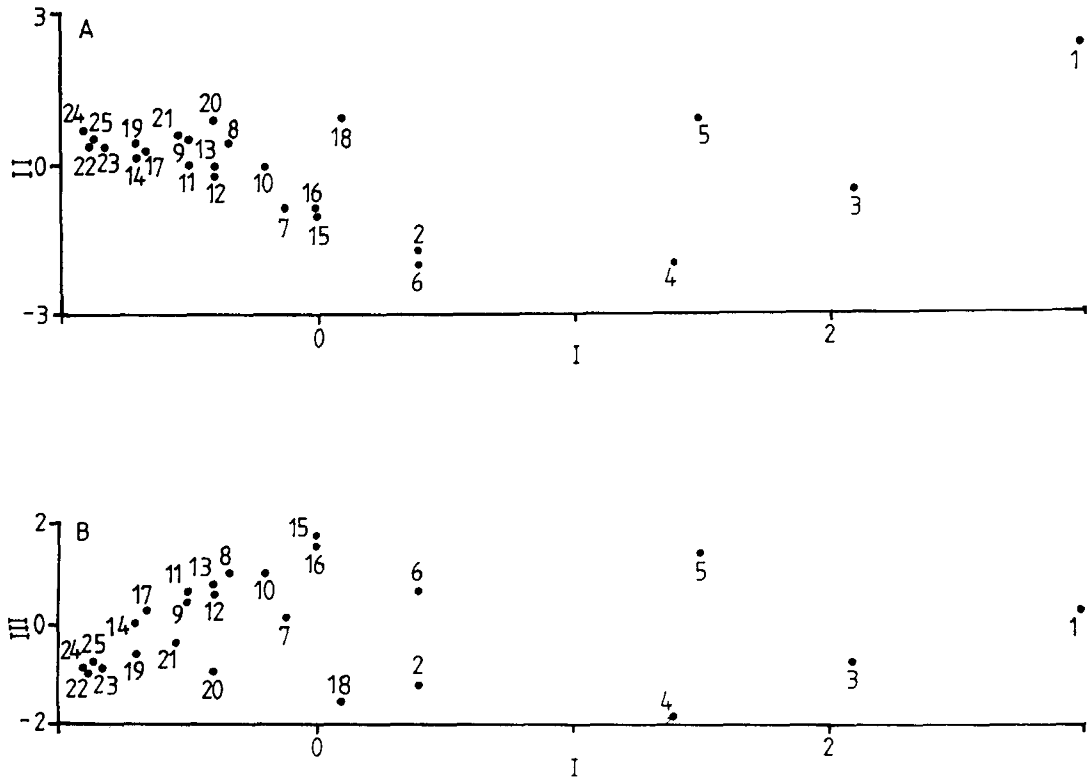

Fig. 3. Projections of 25 OTU's of 24 species of Korean mammals based on principal component analysis in three dimensions using means of 12 characters. Factors I, II, and III represented 83, 8 and 7 percent of the variance, respectively. For species names and localities of each OTU see Table 1. A, OTU's ordinated with factor I vs. factor II. B, OTU's ordinated wth factor I vs. factor III.

Morphological distances among humans and chimpanzees were compared with those among frogs (Cherry *et al.*, 1983). Wyles *et al.* (1983) discussed on the values of morphological distances among the vertebrates at various levels in the taxonomic hierarchy. As shown in Tabel 3, morphological distances among Korean mammals at ordinal level are larger than those among other mammals, although morphological distances below ordinal levels are comparable to those among other mammals.

Cherry *et al.* (1983) and Wyles *et al.* (1983) also noted that morphological distances are the satisfactory means of the concept of how different animals are at the organismal level. As shown in Tables 2 and 3 and Figs. 3 and 5, average taxonomic distances and morphological distances among Korean mammals at various levels in the taxonomic hierarchy are jointly monotonic, although the value of Pearson's product-moment correlation coefficient between these two matrices is 0.59. Dunn (1982) stated that morphological distances will give information concerning, essentially the shape of the organism, whereas average taxono-

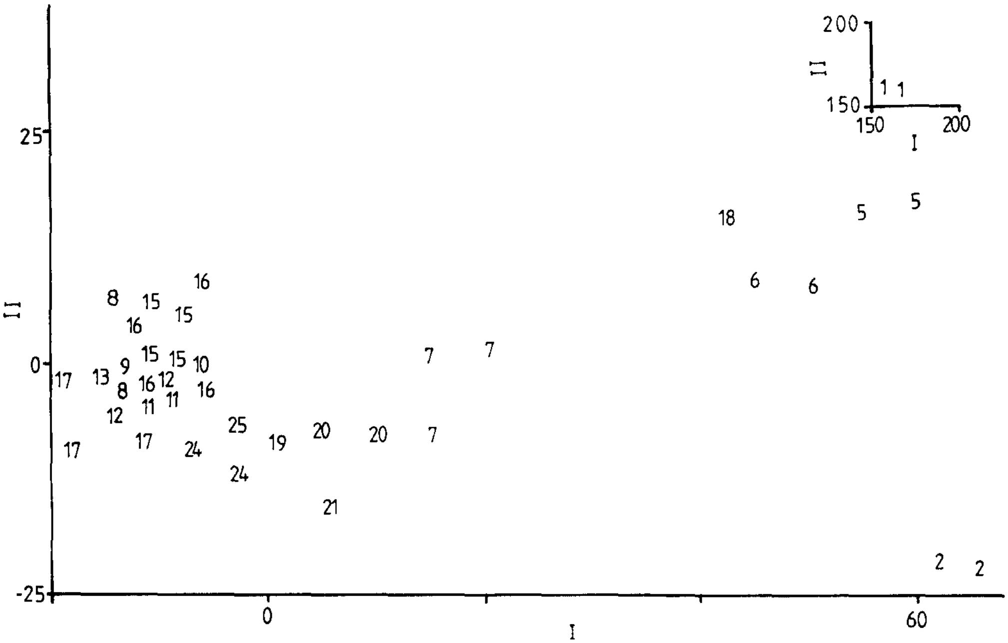

Fig. 4. Projections of 274 samples of Korean mammals based on discriminant analysis in two dimensions using individual measurements. Twenty OTU's are OTU's 1-2, 5-13, 15-21, and 24-25. Functions I and II represented 64 and 14 percent of the variance, respectively. For species names and localities of each OTU see Table 1.

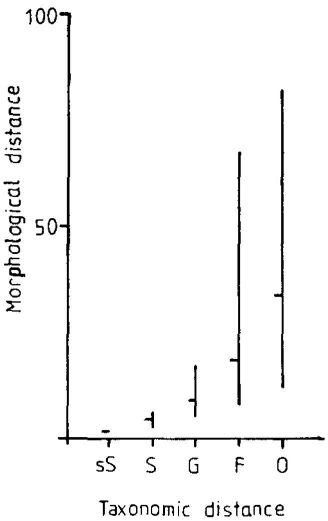

Fig. 5. Morphological distance compared with taxonomic distance in Korean mammals. Vertical lines indicate range of the means. The units of taxonomic distance are expressed in terms of the following categories: sS, subspecies; S, species; G, genus; F, family; O, order.

mic distances reflects the size of the organism. Grouping with the morphological distances seemed to be better than grouping with average taxonomic distances (see Figs. 1 and 6): 12 OTU's of order Rodentia (OTU's 6-17) formed a subgroup and five OTU's of order Chiroptera (OTU's 21-25) formed another subgroup. Furthermore, OTU 6 (*Sciurus vulgaris*) formed a subsubgroup with the other member of family Sciuridae, OTU 7 (*Tamias sibiricus*). Therefore, it was confirmed that speciation resulted in shape difference of morphometric characters rather than size difference, as noted by Cherry *et al.* (1983).

Further analysis including samples of most of Korean mammals will be necessary.

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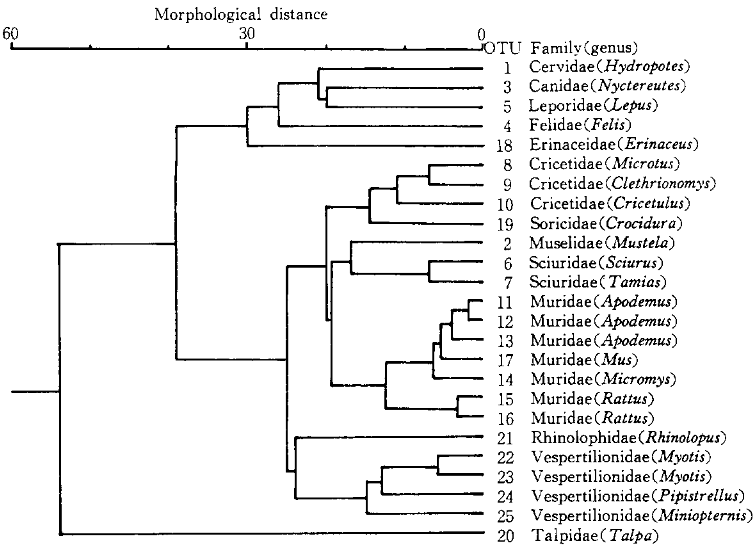

Fig. 6. Groupings of 25 OTU's of 24 species of Korean mammals based on UPGMA cluster analysis using morphological distances. The species names and localities of each OTU are shown in Table 1.

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한국산 포유동물 24종(13과 6목)의 형태적 형질의 분석

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한국산 포유동물 6목 24종 279표본의 4개 외부형질과 22개 두골형질들을 측정하였으며, 측정치를 ordination법과 clustering법에 의해서 분석하였다.

형태적 분석의 결과는 족제비, 청서 및 토마스 땃쥐가 현존 분류체계상의 위치와 다르게 나타났다. 한국산 포유동물의 목 수준에서의 morphological difference는 다른 포유동물보다는 크게 나타났으나, 목 이하의 수준에서는 별 차이가 없었다. 분류학적 체계에서의 단계가 높아질 수록 average taxonomic distance나 morphological difference의 수치는 커졌으며, 두 행렬식 간의 상관계수는 0.59였다.