Iranian Journal of Animal Biosystematics (IJAB)
Vol.7, No.2, 143-155, 2011
ISSN: 1735-434X

Application of outline analysis on fossil and modern specimens of *Apodemus*

Jangjoo, M.[a*], Darvish, J.[a,b], Vigne, J.D.[c]

[a] *Biology Department, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad, Iran*
[b]*Rodentology Research Department, Faculty of Sciences, Ferdowsi Uneversity of Mashhad, Mashhad, Iran*
[c]*UMR 7209 CNRS- National Museum of Natural History, Paris, France*

Wood mice of the genus *Apodemus* are widespread in temperate areas of the Palaearctic region**.** Four species *A. hyrcanicus*, *A. flavicollis*, *A. witherbyi, A. avicennicus* and *A. uralensis* were reported for Iran. The shape variation among three species of the genus *Apodemus* (*A. witherbyi, A. hyrcanicus, A. uralensis*) and a subfossil specimens from Kordestan (Kani Mikaiil cave) dated to 6000-4800 cal. BC, were investigated using outline-based geometric morphometrics of the second lower molar. In a second step, morphological differences among four populations of Iranian wood mice belonging to *A. witherbyi* were studied by the same method. The results indicated that subfossil specimens from Kani Mikaiil belong to *A. witherbyi.* The discriminant analysis also shows that *A. witherbyi* of East Azerbaijan was separated from populations of Tehran, Khorasan and Gorgan, based on variations in the shapes of the second lower molar. Moreover, results of clustering analysis show that those fossil specimens which belong to *A. witherbyi* are ancestral and close to the population of East Azerbaijan.

Key words: *Apodemus*, East Azerbaijan, Fossil, Geometric morphometrics, Iran

INTRODUCTION

Wood mice of the genus *Apodemus* Kaup, 1829 are widespread in temperate areas of the Palaearctic region (Michaux et al., 2002). Twenty one species have been already recorded for this genus (Musser and Carleton, 2005; Darvish et al., 2006), twelve of which being ascribed to the subgenus *Sylvaemus,* distributed in the Western Palaearctic region (Filippucci et al., 1989; Musser and Carleton, 1993, 1996; Musser et al., 1996; Michaux et al., 2002; Darvish et al., 2006). The *Apodemus* species described from Iran are *A. hyrcanicus*, *A. flavicollis*, *A.witherbyi,* *A. avicennicus* and *A. uralensis* and belong to this subgenus (Michaux et al., 2002). Three species (*A. hyrcanicus*, *A. flavicollis* and *A. hermonensis,* Filippucci, Simson and Nevo, 1989) were first reported from Iran by Macholan et al. (2001).
Zagorodnyuk et al. (1997) and Mezhzherin (1997) elucidated the morphological characters and distributional boundaries of *A. witherbyi* Thomas, 1902, and their definition incorporates the names and ranges of *A. fulvipectus* Ognev, 1924, *A. falzfeini* Mezhzherin and Zagorodnyuk, 1989 and *A. hermonensis* Filippucci, Simson and Nevo, 1989, each of them being considered as a good species by various authors (Musser and Carleton, 2005). According to genetic studies, Macholan et al. (2001) confirmed the geographic distribution of *A. hermonensis* up to Eastern Turkey and Iran (Javidkar et al., 2005). Examining the holotype of the species *A. witherbyi*, Krystufek (2002) noted that it might be identical to *A. hermonensis* (Filippucci et al., 1996). Musser and Carleton (2005) used *A. witchery* as the

*Corresponding Author: Jangjoo.maryam@yahoo.com

oldest name for both *A. arianus* Blandford, 1881 and *A. hermonensis*, the name that is also used in this study.

A. witherbyi is distributed in south Ukraine, Crimea, north and south Caucasus, Anatolian Turkish steppe, south to north Palestine and northwest Jordan. It probably occurs in Afghanistan, in the northeast of Iraq and over most of the Central and North Iranian Plateau, in the Zagros and Alborz steppe provinces, including Azerbaijan, Kurdestan and Kopet-Dagh Mountains (Musser and Carleton, 2005). This species exists in syntopy with *A. uralensis* in NW Iran and *A. flavicolis* in the Zagros Mountains, and it is altitudinally parapatric with *A. hyrcanicus* (Frynta et al., 2001; Macholan et al., 2001; Musser and Carleton, 2005; Krystufek and Hutterer, 2006).

In this study, a fossil assemblage from the Kani Mikaiil cave located in the Zagros Mountain, near Saqqez, was studied (Hashemi et al., 2006). The rodent remains hold the greatest potential for archaeologists for monitoring palaeoenvironments because they are more sensitive to changes in the local environments (Redding, 1978). The key of determination of *Apodemus* species are from Corbet (1978), Krystufek (2002), (2002), Javidkar et al. (2005), Darvish et al. (2006), Hosseinpour Feizi et al. (2009), and Darvish et al. (2010).

The aims of this study are to determine the variations in the shape of the molars in the populations of *A. witherbyi* in Northern Iran and to identify the subfossil specimens of Kani Mihaiil. For this purpose, we used geometric morphometric methods based on the molar outline (Renaud et al. 2003, Janzekovitc et al., 2004; Darvish et al., 2006).

MATERIAL AND METHODS

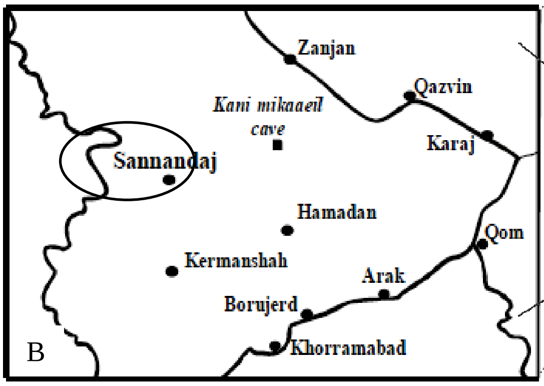
Studies conducted in this research are divided into two parts:

1- Identification of the subfossil specimens using Geometric morphometry (GM) in comparison with modern *Apodemus* specimens that were taxonomically identified in the previous studies (Hosseinpour Feizi et al., 2009; Darvish et al., 2010), based on molecular and morphological analyses.

In this section, the second lower molar (M/2) of subfossil specimens were analyzed (since only M/2s existed within the subfossil specimens) with 34 recent specimens of *Apodemus* of northern Iran which were classified into three haplotypes using RFLP studies and were identified as three species using craniometrric analyses (Darvish et al., 2010): *A. witherbyi*, *A. hyrcanicus* and *A. uralensis* were investigated. The specimens studied belong to three different localities of the Golestan province, five localities of East Azerbaijan province (Table 1 and Fig. 1A) and the two subfossil specimens were collected from Late Glacial / Early Holocene deposits in Kurdistan (Kani Mikaiil) (Fig. 1B, C).

TABLE 1. Museum code (ZMFUM) and sampling locality of the three studied species of the genus *Apodemus*.

Species	Museum code	Locality
A. witherbyi	1816, 1820, 1822, 1823, 1824, 1825, 1826, 1830, 1832, 1839, 1840, 1842, 1855, 1857, 1896, 1897, 1898, 1899, 1900, 1914	Azarbaijan
	1935	Gachian
A. hyrcanicus	1797	Garmabdasht
	1860, 1865, 1910	Tuskahestan
	1926, 1931	Gachian
A. uralensis	1880, 1885, 1906, 1911, 1929, 1932	Tuskahestan



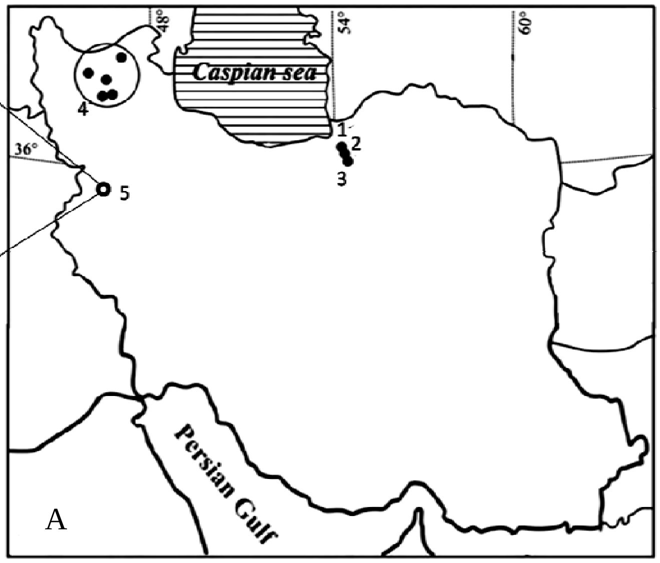


FIGURE 1. A: Map showing the sampling stations of *Apodemus* specimens (closed circles: current specimens, open circle: subfossil specimens). 1- Tuskahestan, 2- Garmabdasht, 3- Gachian, 4- Azarbaijan 5- Sanandaj B: Geographic situation of Kani Mikaiil cave, (Roustaei et al).

TABLE 2. Sampling sites and the number of each sample.

Number of collection site	Locality	Geographic coordinates	Number of specimens
1	Eastern Azarbaijan-Makidi	38°49' N, 46°55' E	1
2	Eastern Azarbaijan- Marand	38°25' N, 45°46' E	4
3	Eastern Azarbaijan- Soufian	-	4
4	Eastern Azarbaijan-Tabriz	38°05' N, 46°17' E	14
5	Eastern Azarbaijan-Lighvan	37°50' N, 46°26' E	8
6	Eastern Azarbaijan-Kandovan	37°48' N, 46°14' E	2
7	Eastern Azarbaijan-Sefidkhan	37°50' N, 46°23' E	2
8	Golestan-Chelcheli	36° 39' N, 54° 34 ' E	9
8	Golestan-Jahannama	36° 40' N, 54° 33 ' E	2
9	Khorasan –Bojnord	37°27' N, 57°19' E	1
10	Khorasan –Shirvan	37°36' N, 57° 55' E	1
11	Khorasan –Dargaz	37°26' N, 59° 6' E	5
12	Khorasan-Mashahad	36°17' N, 59°35' E	5
13	Khorasan –Moghan	36°07' N, 59° 22' E	13
14	Khorasan–Torbate Heidarieh	35°37' N, 59° 18' E	2
15	Tehran-Abnik	35°58' N, 51°42' E	12
16	Tehran-Sorkhehesar	35°41' N, 51°38' E	20
17	Tehran-Fasham	35°56' N, 51°31' E	4
	Total		109

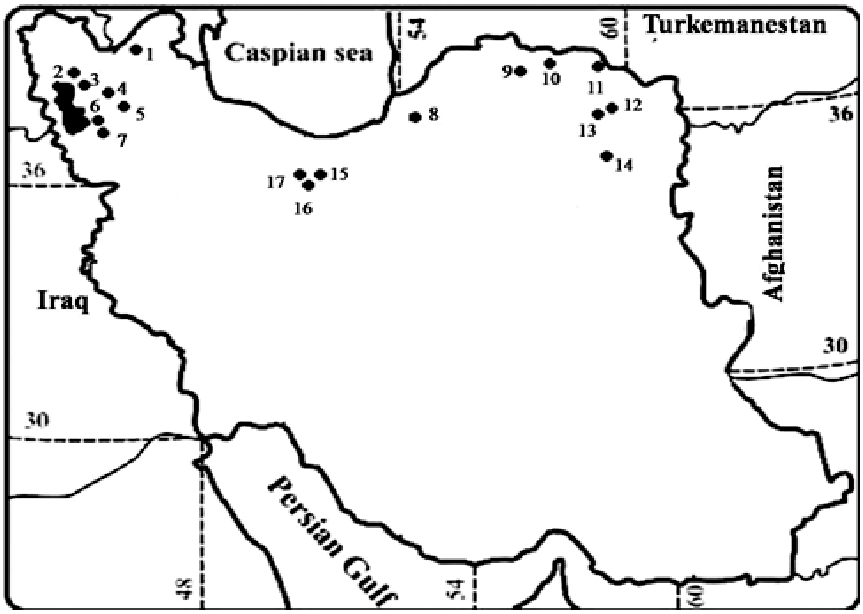


FIGURE 2. Sampling sites in northern part of Iran from which *A. witherbyi* were examined. 1. Makidi, 2. Marand, 3. Soufian, 4. Tabriz, 5. Lighvan, 6. Kandovan, 7. Sefidkhan, 8. Golestan (Chelcheli , Jahannama), 9. Bojnord, 10. Shirvan, 11. Dargaz, 12. Mashhad, 13. Moghan village, 14. Torbate Heidarieh, 15. Abnik, 16. Sorkhehesar National Park, 17. Fasham, (see Table 2 for more details).

2- Study of the systematic status of *A. witherbyi* in the populations of northern parts of Iran using GM analyses on M/2 to determine the status of the subfossil specimens more precisely.

In the second phase, craniometric and GM analyses were carried out on 109 recent specimens. All belong to *A. witherbyi* and were identified in previous studies (Musser and Carleton 1993; Darvish et al., 2010; Javidkar et al., 2005; Hosseinpour Feizi et al., 2009). The GM analysis was carried out to determine the systematic status of *A. witherbyi* in the populations of northern Iran; then the results of this section were exploited to study the subfossil specimens.

The collection sites and number of specimens examined for each population are presented in Table 2 and Figure 2, respectively. Measurements were done only for adults (with complete maxillary teeth). All samples are deposited at the Collection of Rodents in Zoological Museum of Ferdowsi University of Mashhad (ZMFM).

In each section, GM analyses were conducted on the specimens and the related results were interpreted separately.

Geometric morphometrics analyses

The shape of M/2 were digitized using outline approach by its two dimensional projection viewed from occlusal surface. 150 equally spaced points were sampled along the outline. Digital images were captured using digital camera (DP71) connected to stereoscope (Olympus SZH10) with magnification of 30. The digitization was performed using TPSdig 2.12 software (Rohlf, 2008).

Elliptic Fourier Analysis (EFA) was primarily described by Kuhl and Giardinia (1982). The EFAWIN software (Rohlf and Ferson, 1992) was used to conduct EFAs. The program GMTP (Taravati, 2010) was used to adjust the TPSDig output file format, being directly opened in EFAWIN.

The first 12 harmonics were used to describe the shape variations of M/2. Each harmonic corresponds to four coefficients, A_n, B_n for x, and C_n, D_n for y, and defines an ellipse on the XYplane (Hautier et al., 2009). The output file of EFAWIN includes these harmonic coefficients which can be employed as raw data for statistical analyses.

Harmonic coefficients were used as statistical variables in SPSS version 16 and PAST version 1.98 (Hammer et al., 2010). In the first phase, Canonical variate analysis (CVA) was carried out to identify of subfossil specimens.

In the second phase, the populations for which no molecular study had been performed (East Azarbaijan, Khorasan, Tehran, Golestan) were posterior projected on the discriminant space to identify their specific attributions. The cluster analysis was performed on the Euclidean distances between the mean shapes of the taxa computed from DFA to determine the status of subfossil specimens more precisely.

The relationship between shape variables and centroid size was evaluated by multivariate regression analysis (Rolf and Marcus 1993), to investigate the allometric patterns associated with the molar size.

Craniometric studies

In this study, the craniometric analysis was carried out to determine the systematic status of *A. witherbyi* in the populations of northern parts of Iran.

Measurements: The study is based on 12 cranial (Frynta et al., 2001) and 12 dental variables and 4 standard external measurements. Abbreviation used are: , BCH: brain case height, RH: rostral height, ZYGW: zygomatic breadth, RW: rostral width (maximum distance), IOW: interbullar width, BCW: brain case height, FL: facial length, CBL: condylobasal length, IBW: interbullar width, BULL: bulla length, FI: Length of foramen incisivum, M1/L: first upper molar length, M2/L: second upper molar length, M3/L: third upper molar length, M1/W: first upper molar width, M2/W: second upper molar width, M3/W: third upper molar width, M/1L: first lower molar length, M/2L: second lower molar length, M/3L: third lower molar length, M/1W: first lower molar width, M/2W: second Lower molar width, M/3W: third lower molar width (Fig. 3).

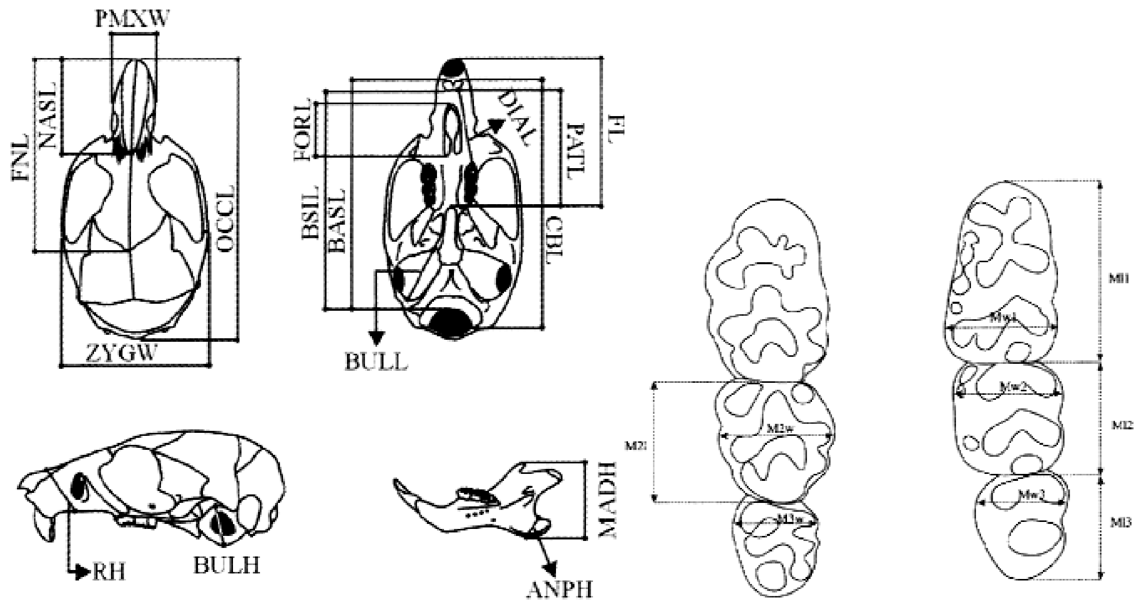


FIGURE 3. The characters measured on skull (left image after Ferynta and Zizkova) and molars (right). See text for abbreviations.

Dental measurements were taken with a measuroscope accurate to 0.001 mm (molars measured based on maximal size). Cranial measurements were taken with the use of a caliper accurate to the nearest 0.05 mm. Standard external measurements were taken with a ruler accurate to the nearest millimeter (BL: body length, TL: tail length, FL: foot length, EL: ear length).

RESULTS

1- Result of GM study of modern and subfossil *Apodemus* specimens, the latter being identified based on molecular analysis in previous studies:

M/2s of subfossil specimens were analyzed on samples of *A. witherbyi, A. hyrcanicus, A. uralensis.* The results of CVA based on First (CV1) and Second (CV2) functions are shown in Fig. 4. The Wilks' Lambda values confirms the significance of the functions (Wilks' Lambda = 0.028) and the two first components gather 84.6% and 15.4% of all variation, respectively. Scatter plot of CVA revealed that recent specimens of *A. witherbyi* and subfossil specimens were completely overlapping and distinction between subfossil specimens and *A. witherbyi* specimens and other species was achieved along CV1 and CV2. The result shows that subfossil specimens belong to *A. witherbyi.*

Morphometric Results

2. Standard descriptive statistics including the mean and standard deviation for 28 external, cranial and dental characters are given in tables 3. The analysis of variance indicated that 9 variables are statistically significant ($p<0.05$). This variable includes: BCH, PAL, RH, FL, CBL, IBW, BULL, M/2L and M/3L (Table 3).

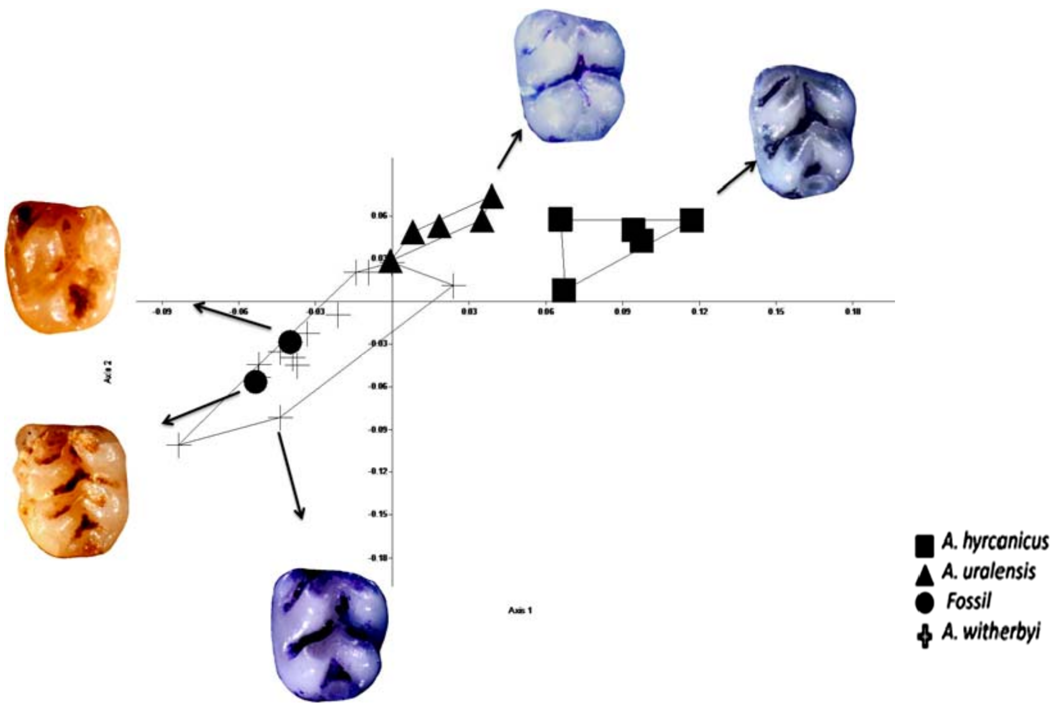


FIGURE 4. CVA scatter plot on shape variables of M/2**.**

TABLE 3. Means (M) and standard deviation (SD) of characters in different population of *A. witherbyi.*

	Tehran N=36	Khorasan N=27	Eastern Azarbaijan N=35	Gorgan N=11	
characters	M±SD	M±SD	M±SD	M±SD	P.V. (ANOVA)*
BL	80.27±5.75	89.15±7.31	84.17±10.6	88.50±10.82	0.000
TL	98.50±8.15	99.15±5.4	91.46±13.1	90.80±8.38	0.001
FL	21.45±1.00	21.64±0.74	21.00±1.17	22.00±1.05	0.041
EL	14.54±1.67	14.28±2.10	13.33±1.98	14.60±1.39	0.041
CBL	25.00±0.95	25.03±1.22	24.63±1.01	25.44±0.79	0.080
FL	13.90±0.50	14.15±0.50	13.70±0.62	14.39±0.50	0.003
PAL	4.65±0.28	4.53±0.24	4.81±0.37	5.05±0.28	0.000
ZYG	13.05±0.49	12.99±0.45	12.80±0.63	13.00±0.50	0.666
RW	4.61±0.32	4.48±0.32	4.43±0.28	4.62±0.17	0.056
IOW	4.22±0.14	4.18±0.23	4.18±0.13	4.23±0.14	0.600
BCW	11.61±0.39	11.73±0.37	11.73±0.37	11.63±0.34	0.570
IBW	9.23±0.28	9.38±0.27	8.94±0.34	9.20±0.21	0.000
RH	4.18±0.24	4.25±0.33	3.96±0.30	4.32±0.16	0.000
BCH	8.46±0.31	8.59±0.34	8.34±0.35	8.79±0.31	0.001
BULL	5.78±0.26	5.89±0.33	4.83±0.31	5.86±0.03	0.000
FI	4.86±0.28	4.97±0.25	4.74±0.23	4.95±0.31	0.600
M1/L	1.83±0.07	1.84±0.07	1.80±0.07	1.84±0.06	0.498
M2/L	1.15±0.05	1.16±0.04	1.15±0.04	1.16±0.04	0.264
M3/L	0.87±0.05	0.88±0.05	0.85±0.05	0.88±0.04	0.084
M1/W	1.18±0.04	1.18±0.01	1.17±0.03	1.18±0.04	0.249
M2/W	1.13±0.04	1.12±0.05	1.13±0.04	1.13±0.04	0.365
M3/W	0.84±0.06	0.83±0.20	0.85±0.01	0.84±0.05	0.141
M/1L	1.64±0.04	1.68±0.13	1.68±0.07	1.72±0.05	0.385
M/2L	1.16±0.04	1.16±0.04	1.14±0.04	1.16±0.03	0.019
M/3L	0.93±0.04	0.92±0.03	94.0±0.01	1.01±0.26	0.019
M/1W	1.02±0.04	1.03±0.04	1.03±0.04	1.05±0.05	0.195
M/2W	1.04±0.04	1.05±0.03	1.05±0.04	1.05±0.04	0.896
M/3W	0.85±0.14	0.86±0.03	0.86±0.09	0.86±0.07	0.932

*: Result of ANOVA

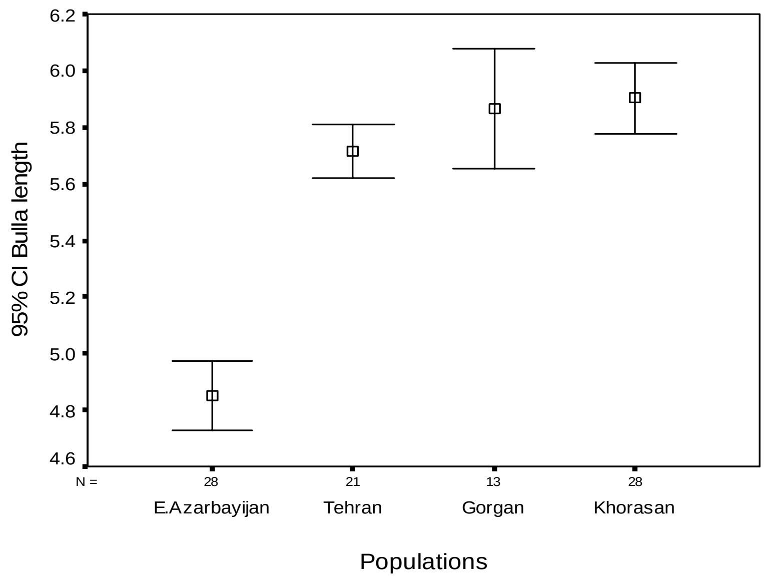


FIGURE 5. Error bar diagrams of variation in tympanic bulla length in different populations of *A. witherbyi*.

Error bar diagrams of tympanic bulla length compared to condylobasale length shows the presence of two groups. The population of East Azerbaijan has the smallest tympanic bulla length and populations of Khorasan, Tehran, Gorgan have the largest tympanic bulla length (Fig. 5). These results confirm the importance of bulla length for determination of *A. witherbyi* population. The test of normality for the samples showed that the samples are normal.

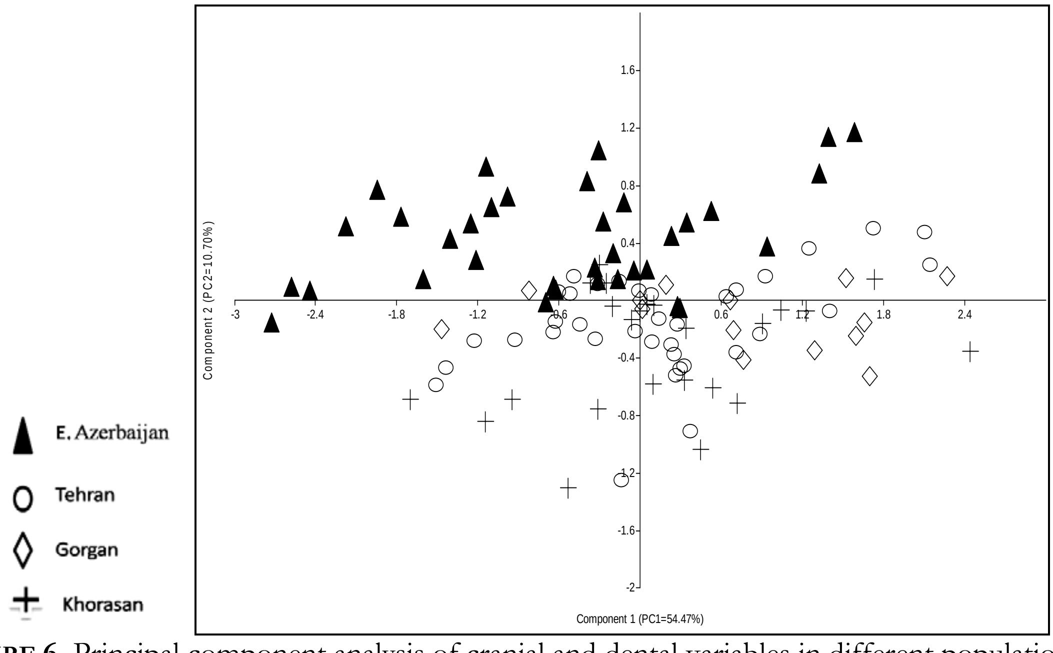


FIGURE 6. Principal component analysis of cranial and dental variables in different populations of *A. witherbyi.*

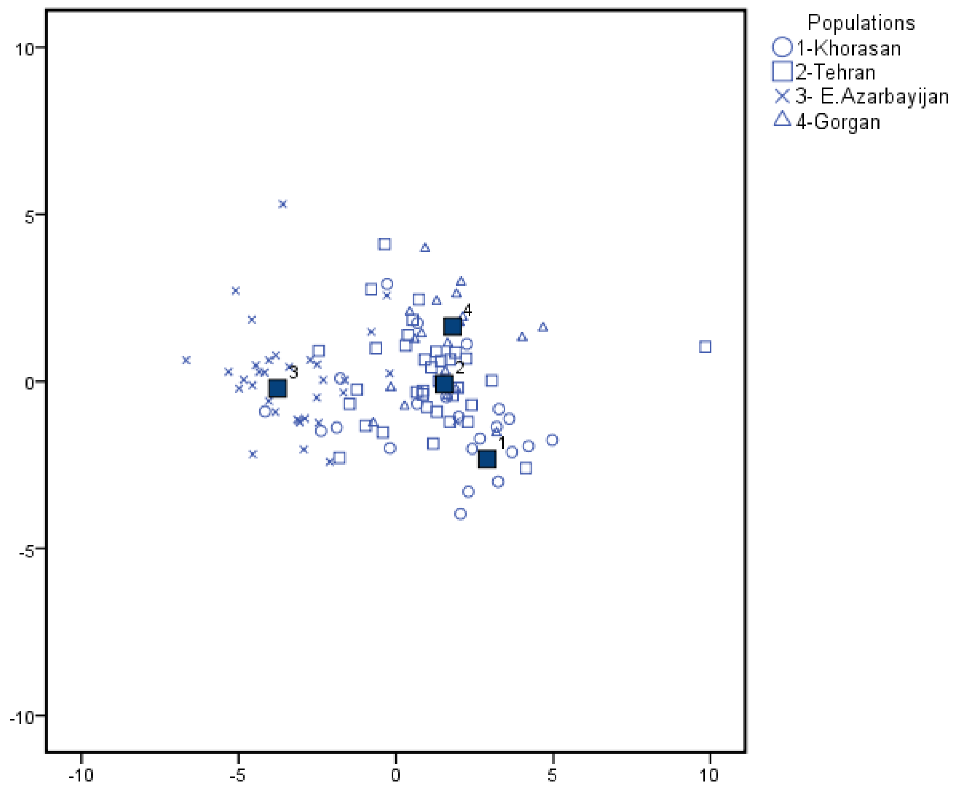


FIGURE 7. DFA based on First (1) and Second (2) Components for the cranial and dental measurements in different populations of *A. witherbyi*. Blue solid squares are the centroids of the four groups.

In Principal component analysis (PCA), based on cranial and dental measurements, the first component (PC1) accounted for 54.5% of total variance and the second component (PC2) accounted for 10.7% (Fig. 6). Scatter plot shows that the separation of the population of eastern. Azerbaijan from the other populations, base on first principle component (PC1). DFA on first (1) and second (2) components are shown in Figure 7. The Wilks' Lambda value confirms the significance of the functions. The two components gather respectively 75.8% and 16.5% of the variance.

Second lower molar (M/2) of the subfossil **specimens**

According to discriminant analysis, the first two discriminant functions explain 92.6% (77.1% and 15.5%. respectively) of the variation among the populations of *A. witherbyi*. Statistical comparisons reveal that based on DF1, the population of E. Azerbaijan and Kani Mikaiil are clearly distinct from the populations of Khorasan and Tehran (Fig. 8). The clustering tree based on harmonic coefficients centroid of all sample are extracted from DFA (Fig. 9).

Discriminant analysis on M/2 shows that the fossil specimens and the East Azerbaijan population plot in a fairly well separated position with the group from southern slopes of Alborz Mountains and northeast of Iran. In clustering analysis, southern slopes of Alborz Mountains and northeast of Iran populations form the same collection while northwest of Iran population clusters far from the other populations. The subfossil samples plot close to the NW population of Iran and grouped together.

The regression between centroid size and shape variables is not significant (p $_{(reg)}$ = 0.186). This showes that the differences of M/2 shape in the studied specimens of *A. witherbyi* are not due to allometry.

DISCUSSION

Discriminant analysis on M/2 shows that the subfossil specimens from Kani Mikaiil belong to *A. witherbyi*. *A. witherbyi* is an interesting species for the study issues such as intraspecific variation, direction of migration and adaptation.

In this study, the results of morphometric show that the studied populations divided into two groups. The population of East Azerbaijan has the smallest tympanic bulla length and southern slopes of Alborz Mountains and northeast of Iran populations have the largest tympanic bulla length. These results confirm the importance of bulla length for determination of *A. witherbyi* groups. Macholan et al. (2001) showed geographic distribution of *A. witherbyi* toward eastern Turkey and western Iran. Moreover, Krystufek and Hutterer (2006) reported *A.witherbyi* from Makidi in NW Iran. They reported the maxillary tooth row of 3.65 to 4.00 mm and bulla length of 4.00 to 4.7 mm. It shows that the size of bulla is smaller compared to the specimens of *A. witherbyi* in E. Azerbaijan, which are studied in this paper, (tooth row 3.68-3.92 mm and bulla length 4.54-5.16 mm).

This is also in agreement with the results obtained from morphology and geometric morphometric analysis on M2/ and M1/ in previous studies (Jangjoo and Darvish, in press). The results demonstrate that studied populations of *A. witherbyi* in Northern Iran divided into two groups. Northwest of Iran population was diagnosed as *A. witherbyi fulvipectus* and southern Alborz and northeast of Iran populations were identified as *A. witherbyi arianus*. Therefore, the application of this technique provides a powerful tool in allowing identification of *Apodemus* specimens and subfossil samples.

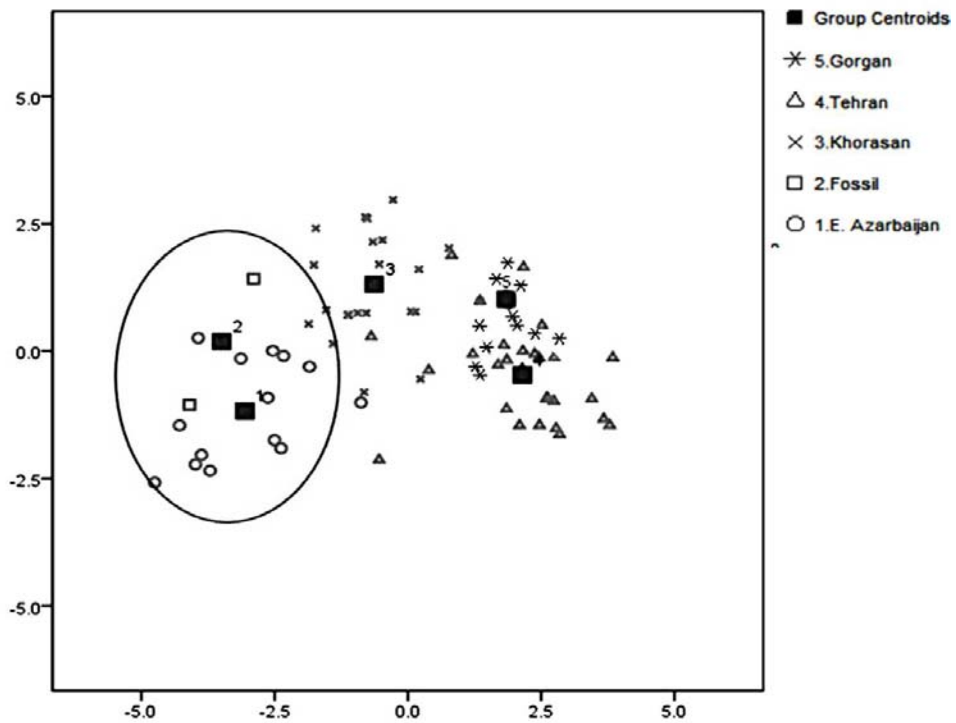


FIGURE 8. Canonical Discriminant Analyses of M/2 based on harmonic coefficient.

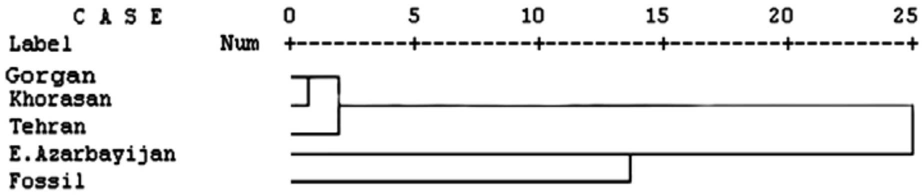


FIGURE 9. Dendogram obtained from harmonic coefficients centroids of all sample extracted from DFA using Euclidean distances between group means

ACKNOWLEDGMENTS
We would like to thanks the members of the Rodentology Research Department, Ferdowsi University of Mashhad. Also, we are grateful to K. Roustaei, H. Rezvani and F. Biglari and M. Mashkour for having provided us with the microvertebrate samples of Kani Mikaiil. This paper was realized in the framework of the Memorandum of Understanding and the cooperation convention between the Ferdowsi University of Mashad and the Muséum national d'Histoire naturelle of Paris.

LITERATURE CITED

Burke, A., Cinq-Mars, J., 1996. Dental characteristics of Late Pleistocene Equus lambei from the Bluefish Caves, Yukon Territory, and their comparison with Eurasian horses. *Geographie physique et Quaternaire* 50, 81-93.

Corbet, G.B., 1978. *The mammals of the Palaearctic region. A taxonomic review*. British Museum of Natural History London pp. 314.

Darvish, J., Javidkar, M., Siahsarvie, R., 2006. New species of wood mouse of genus *Apodemus* (Rodentia: Muridae) from Iran. *Zoology in the Middle East* 38, 5-16.

Darvish, J., Akbary Rad, S., Siahsarvieh, R., Hosseinpour Feizi, M.A., Ghorbani, F., 2010. New record on pigmy field mouse (Muridae, Rodentia) from Northeast Iran, *Hystrix. Italian Journal of Mammalogy* 21, 115-126.

Filippucci, M., Simson, S., Nevo, E., 1989. Evolutionary biology of genus *Apodemus* Kaup, 1829 in Israel. Allozymic and biometric analyses with description of a new species: *Apodemus hermonensis* (Rodentia: Muridae). *Bolletino di Zoologia* 56, 361-376.

Filippucci, M., Storch, G., Macholan, M., 1996. Taxonomy of genus *Sylvaemus* in western Anatolia, morphological and electrophoretic evidence (Mammalia: Rodentia: Muridae). *Senekenbergiana biologica* 75, 1-14.

Frynta, D., Zizkova, M., 1992. Postnatal growth of Wood mouse (*Apodemus sylvaticus*) in captivity. P. 57, 69. In: Horacek, I., Vohralik, V., (Eds.), Prague studies in mammalogy. Prague.

Frynta, D., Mikulava, P., Suchomelova, E., Sadolva, J., 2001. Discriminant analysis of morphometric characters in four species of *Apodemus* (Muridae: Rodentia) from Eastern Turkey and Iran. *Israel Journal of Zoology* 47, 243-258.

Hammer, Q., Harper, D.A.T., Rayan, P.D., 2010. PAST, version 1.98. Stat Univ. At Stony Brook. (Program).

Hashemi, N., Darvish, J., Mashkour, M., Biglari, F., 2006. Rodents and Lagomorphs remains from late Pleistocene and early Holocene Caves and Rochshelter sites in the Zagros region, Iran. *Iranian Journal of Animal Biosystematics* 2, 25-33.

Heaton, T.H., Talbot, Sl., Shields, G., 1996. An ice age refugium for large mammals in the Alexander Archipelago, southeastern Alaska. *Quaternary Research* 46, 186-192.

Hosseinpour Feizi, M., Darvish, J., Pouladi, N., Akbari Rad, S., Siahsarvie, R., 2009. Biosystematic study of steppe field mouse *Apodemus witherbyi* (Rodentia: Muridae) from North,West Iran. *Iranian Journal of Animal Biosystematics* 5, 47-58.

Hautier L., Mackaye, H.T., Lihoreau, F., Tassy, P., Vignaud, P., Brunet, M., 2009. New material of *Anancus kenyensis* (proboscidea, mammalia) from Toros-Menalla (Late Miocene, Chad): Contribution to the systematics of African anancines. *Journal of African Earth Sciences* 53, 171-176.

Janzekovitc, F., Krystufek, B., 2004. Geometric morphometry of upper molars in European wood mice *Apodemus*. *Folia Zoologica* 53(1), 47-55.

Jangjoo, M., Darvish, J., Geometric morphometric analysis of steppe field mouse, *Apodemus witherbyi* (Rodentia: Muridae), from northern parts of Iran. *Iranian Journal of Animal Biosystematics* (In press).

Javikar, M., Darvish, J., Riahi, A., Bakhtiari 2005. Discriminate analysis of dental and cranial characteristics in *Apodemus hyrcanicus* and *A. hermonensis* (Rodentia, Muridae) from Iran. *Zoology in the Middle East* 35, 5-12.

Krystufek, B., 2002. Identity of four *Apodemus* (*Sylvaemus*) types from the Eastern Mediterranean and Middle East. *Mammalia* 66, 43-51.

Krystufek, B., Hutterer, R., 2006. The Urak field mouse *Apodemus uralensis*, a mammal species new to Iran. *Zoology in the Middle East* 38, 111-112.

Kuhl, F.D., Giardina, C.R., 1982. Elliptic Fourier featheres of a closed contour. *Computer graphics and image processing* 18, 236-258.

Macholan, M., Filippucci, M., Benda, P., Frynta, D., Sadolva, J., 2001. Allozyme Variation and Systematics of the genus *Apodemus* (Rodentia: Muridae) in Asia Minor and Iran. *Mammalogy* 82, 799-813.

Mezhzherin, S.V., 1997. Genetic differentiation and phylogenetic relationships among Palaeartic mice (Rodentia, Muridae) [in Russian, English summary]. *Genetika* 33, 78-86.

Michaux , J.R., Chevret, P., Fillippucci, M.G., Macholan, M., 2002. Phylogeny of the genus *Apodemus* with a special emphasis on the subgenus *Sylvaemus* using nuclear IRBP gene and two mitochondrial markers: cytochrome b and 12S Rrna. *Molecular Phylogenetics and Evolution* 23, 123-136.

Musser, G.G., Carleton, M.D., 1993. Family Muridae. In: (Wilson, D.E., Reeder, D.M., eds.) *Mammal species of the world: a taxonomic and geographic refrence*, 2nd ed. Smithsonian Institution Press, Wshington, DC pp. 501-755.

Musser, G.G., Brothers, E., Carleton, M., Hutterer, R., 1996. Taxonomy and distributional records of oriental and European Apodemus, with a review of the *Apodemus Sylvaemus* problem. *Bonner Zoologische Beiträge* 46, 143-190.

Musser, G.G., Carleton, M.D., 2005. In: Wilson D.E. and Reeder D.M., mammal species of the world, A taxonomic and geographic reference. , The Johns Hopkins University Press Baltimore, third edition 2, 1259-1280

Redding, W.R., 1978. Rodents and the archaeological palaeoenvironment: Considerations, problems and future.. In: Meadow, R.H., Zeder, M.A., *Approaches to faunal analysis in the Middle East*. Peabody Museum of Archaeology and Ethnology. Peabody Museum Bulletin 2, 63-68.

Rohlf, F.J., 2008. tpsDig-Thin Plate Spline Digitizer, version 2.12. Computer Program. New York.

Rohlf, F.J., Ferson, S., 1992. EFAW. Version 11794. N. Y. Stat Univ. At Stony Brook (Program).

Rohlf, F.J., Marcus, L., 1993. A revolution in morphometric. *Trend in ecology and evolution* 8, 129-132.

Renad, S., Michaux, J.R., 2003. Adaptive latitudinal trends in the mandible shape of *Apodemus* wood mice. *Journal of Biogeography* 30 (10), 1617–1628.

Taravati, S., 2010. GMTP: Geometric Morphometric Tools Package. Version 2.0 Beta (Program).

Zagorodnyuk, I.V., Boyeskorov, G.G., Zykov, A.Ie., 1997. Variation and taxonomic status of the steppe forms of the genus *Sylvaemus* "*sylvaticus*" (*falzfeini, fulvipectus, hermonensis, arianus*). *Vestnik Zoologii* 31(1), 37-56 (in Russian, with a summary in English).