Over the last few decades, many studies have done to clarify the taxonomy of water voles (genus Arvicola Lacépede, 1799). Recent studies showed that water voles divided into three species; A. sapi-dus (Miller, 1908), A. amphibius (Linnaeus, 1758) (formerly known as A. terrestris) and A. scherman (Musser and Carleton, 2005). The first records of water vole (A. amphibious) from the Turkey reported by Steiner and Vauk (1966) around Lake Beyşehir. Depend on morphological differentiation, we conclude that these two populations, classified within two subspecies: Arvicola amphibius persicus and Arvicola amphibius cernjavskii respectively.

A total of 116 specimens of the genus Arvicola were collected from western part of Turkey (Western part of Anatolia and Turkish Thrace) and examined based on geometric morphometrics and traditional morphometrics. Morphometrical analyses showed that A. amphibius populations in western part of Turkey are highly differentiated as Anatolian and Thrace populations. Depend on morphometrical differentiation, we conclude that these two populations, classified within two subspecies; Arvicola amphibius persicus and Arvicola amphibius cernjavskii respectively.

Keywords:
Arvicola; Geometric morphometrics; Morphology; Thrace; Anatolia; Taxonomy.

INTRODUCTION

Over the last few decades, many studies have done to clarify the taxonomy of water voles (genus Arvicola Lacépede, 1799). Recent studies showed that water voles divided into three species; A. sapi-dus (Miller, 1908), A. amphibius (Linnaeus, 1758) (formerly known as A. terrestris) and A. scherman (Musser and Carleton, 2005). The first records of water vole (A. amphibious) from the Turkey reported by Steiner and Vauk (1966) around Lake Beyşehir.

Depend on morphological and biomechanical features, three water vole subspecies identified in Turkey; Arvicola amphibius persicus (Anatolia), Arvicola amphibius hintoni (Southeastern Anatolia Region), Arvicola amphibius cernjavskii (Thrace) (Mursaloğlu, 1975). amphibius comprises two ecological types which are aquatic and fossorial forms, each with different living habits and these ecotypes are often morphologically distinct (Meylan, 1977). And also recent studies lowerline that, water voles are characterized by an extraordinary morpho-
MATERIALS AND METHODS

Water voles were collected from 9 localities Western part of Anatolia between 2004-2007 (Fig. 1). Skulls of 85 adult individuals of two subspecies were examined.

Thrace samples were collected from Kırklareli at around 41° 67’ N and 27° 07’ E associated with temperate conditions. Anatolian samples were collected from western part of Anatolia vary at 40° 81’ N and 32° 83’ E and 38° 53’ N and 28° 64’ E (Table 1).

The skull images were taken with Leica MZ 16 stereomicroscope. Photographs were first input to TpsUtil1.34 and then 2D coordinates of each landmark were digitized using the Tps-Dig1.40 (Rohlf, 2004). The landmark configurations were superimposed to the same reference form by generalized least squares (Rohlf, 1999) in Morpheus (Slice, 2002).

Geometric morphometric data consisted of four sets; one referring to 11 landmarks on the dorsal side (Fig. 2A), 18 landmarks on the ventral side (Fig. 2B) and the other to 8 landmarks on the lateral side of the skull (Fig. 2C).

Depend on their close geographic position, some localities are combined and then 6 group defined; trak (Thrace), beys (Beyşehir), deus (Denizli-Uşak), abes (Ankara-Bolu-Eskişehir), kirs (Kırşehir), eber (Eber) (Table 2.).

4 external and 35 internal characters are measured. Table 2 shows that average measurements of morphometrical characters, minimum, maximum and standard deviations of Anatolian populations of Arvicola terrestris persicus(Table 3).

4 external and 35 internal morphometric characters are measured. Table 2 shows that average measurements of morphometrical characters, minimum, maximum and standard deviations of Thrace populations of Arvicola terrestris cernjavskii.

All statistical analyses to identify shape variations of water voles were performed using the SPSS 13.0 (SPSS, 2004).
Table 2. External and internal lineer measurement characters of *Arvicola terrestris persicus*

| Measurements Characters | N  | avg. | Min. | Max. | SS (+/-) |
|--------------------------|----|------|------|------|----------|
| 1. Total length          | 79 | 305.20 | 213.00 | 378.00 | 34.23    |
| 2. Tail                  | 79 | 125.96 | 81.00 | 153.00 | 14.39    |
| 3. Hind leg              | 79 | 36.78  | 27.00 | 42.00  | 2.47     |
| 4. Ear length            | 79 | 16.88  | 9.00  | 21.00  | 2.62     |
| 5. Weight                | 79 | 142.14 | 59.00 | 237.00 | 38.09    |
| 6. Zygomatic width       | 79 | 23.05  | 19.35 | 25.94  | 1.62     |
| 7. Least breadth of skull| 79 | 4.85   | 3.96  | 6.10   | 0.37     |
| 8. Condylorbasale length | 79 | 37.53  | 31.26 | 41.48  | 2.24     |
| 9. Condylorbasale length | 79 | 39.86  | 33.59 | 43.80  | 2.31     |
| 10. Occipitonasale length| 79 | 38.11  | 19.55 | 42.71  | 3.67     |
| 11. Basale               | 79 | 36.39  | 29.26 | 40.17  | 1.14     |
| 12. Nasal length         | 79 | 10.92  | 8.72  | 12.70  | 0.98     |
| 13. Nasal width          | 79 | 4.77   | 3.65  | 6.99   | 0.64     |
| 14. Perietal suture uzunluğu | 79 | 7.96   | 6.16  | 9.04   | 0.56     |
| 15. Face area length     | 79 | 24.02  | 10.26 | 34.01  | 2.49     |
| 16. Brain area length    | 79 | 15.47  | 11.09 | 17.43  | 1.12     |
| 17. Mastoid width        | 79 | 11.01  | 9.11  | 12.48  | 0.70     |
| 18. Bulla tympanica length | 79 | 12.20  | 11.61 | 14.80  | 0.68     |
| 19. Bulla tympanica width | 79 | 11.88  | 9.82  | 70.93  | 6.81     |
| 20. Occipitale width     | 79 | 15.65  | 12.42 | 17.48  | 1.06     |
| 21. Brain capsule width  | 79 | 14.57  | 12.60 | 15.65  | 0.59     |
| 22. Diestama length      | 79 | 12.29  | 10.34 | 15.54  | 1.12     |
| 23. Palatal length       | 79 | 21.69  | 17.31 | 24.09  | 1.47     |
| 24. Insisiva length      | 79 | 6.68   | 4.46  | 9.76   | 0.74     |
| 25. Bulla tympanica length | 79 | 9.88   | 7.66  | 11.27  | 0.54     |
| 26. Bulla tympanica width | 79 | 7.04   | 6.12  | 8.36   | 0.35     |
| 27. Mandibulae length    | 79 | 26.29  | 22.21 | 29.15  | 1.64     |
| 28. Mandibulae height    | 79 | 6.45   | 5.16  | 8.84   | 0.57     |
| 29. Upper molar alveoli length | 79 | 9.13   | 7.72  | 10.44  | 0.62     |
| 30. Upper molar length   | 79 | 10.13  | 9.02  | 11.90  | 0.61     |
| 31. Length of lower teeth alveoli | 79 | 9.24   | 7.82  | 10.55  | 0.64     |
| 32. Lower molar length   | 79 | 9.98   | 8.54  | 11.68  | 0.58     |
| 33. Coronoid process height | 79 | 13.99  | 11.45 | 16.09  | 1.05     |
| 34. First upper molar length M1 | 79 | 8.59   | 7.63  | 10.26  | 0.62     |
| 35. Second upper molar length M2 | 79 | 6.25   | 5.00  | 7.36   | 0.55     |
| 36. Third upper molar length M3 | 79 | 6.22   | 3.16  | 7.63   | 0.68     |
| 37. First lower molar length M4 | 79 | 9.26   | 7.63  | 11.05  | 0.73     |
| 38. Second lower molar length M5 | 79 | 6.00   | 5.00  | 8.94   | 0.59     |
| 39. Third lower molar length M6 | 79 | 5.95   | 4.73  | 8.94   | 0.63     |

N: number of sample, avg: avarage, min: minimum, max: maksimum, SS: Standart deviation
Table 3. External and internal linear measurement characters of *Arvicola terrestris cernjavskii*

| Measurements Characters | N  | avg. | Min.  | Max.  | SS (+/-) |
|-------------------------|----|------|-------|-------|----------|
| 1. Total length         | 6  | 314,67 | 297,00 | 340,00 | 16,79 |
| 2. Tail                 | 6  | 211,17 | 194,00 | 230,00 | 9,43 |
| 3. Hind leg             | 6  | 34,50  | 33,00  | 36,00  | 1,05 |
| 4. Ear length           | 6  | 17,17  | 14,00  | 19,00  | 1,83 |
| 5. Weight               | 6  | 273,50 | 252,00 | 193,00 | 16,28 |
| 6. Zygomatic width      | 6  | 23,45  | 22,95  | 24,54  | 0,68 |
| 7. Least breadth of skull| 6  | 4,77   | 4,52   | 5,04   | 0,27 |
| 8. Condylorbase length  | 6  | 37,81  | 36,15  | 39,76  | 1,51 |
| 9. Condylorbase length  | 6  | 39,73  | 38,27  | 42,06  | 1,61 |
| 10. Occipital length    | 6  | 38,83  | 37,41  | 41,45  | 1,67 |
| 11. Basal length        | 6  | 32,59  | 27,65  | 37,91  | 8,41 |
| 12. Nasal length        | 6  | 10,55  | 9,08   | 11,58  | 0,35 |
| 13. Nasal width         | 6  | 4,51   | 4,11   | 5,07   | 0,40 |
| 14. Perietal suture uzunluğu | 6  | 7,97  | 7,07  | 8,88  | 0,69 |
| 15. Face area length    | 6  | 24,28  | 23,34  | 26,28  | 1,17 |
| 16. Brain area length   | 6  | 15,60  | 15,06  | 16,14  | 0,52 |
| 17. Mastoid width       | 6  | 11,71  | 11,12  | 12,20  | 0,45 |
| 18. Bulla tympanica length | 6  | 12,69  | 12,08  | 13,12  | 0,40 |
| 19. Bulla tympanica width | 6  | 11,08  | 10,72  | 11,36  | 0,26 |
| 20. Occipital width     | 6  | 15,77  | 15,12  | 16,47  | 0,60 |
| 21. Brain capsule width | 6  | 14,80  | 14,44  | 15,42  | 0,42 |
| 22. Diestama length     | 6  | 13,33  | 12,08  | 14,25  | 0,92 |
| 23. Palatal length      | 6  | 22,65  | 20,29  | 23,73  | 1,23 |
| 24. Insisiva length     | 6  | 6,51   | 5,81   | 7,01   | 0,47 |
| 25. Bulla tympanica length | 6  | 9,78  | 9,16  | 10,62  | 0,53 |
| 26. Bulla tympanica width | 6  | 7,02  | 6,90  | 7,12  | 0,10 |
| 27. Mandibulae length   | 6  | 26,42  | 24,76  | 28,00  | 1,14 |
| 28. Mandibulae length   | 6  | 6,46   | 6,02   | 6,55   | 0,14 |
| 29. Upper molar alveoli length | 6  | 9,07  | 8,71  | 9,55  | 0,37 |
| 30. Upper molar length  | 10  | 10,11  | 9,56  | 10,81  | 0,47 |
| 31. Length of lower teeth alveoli | 6  | 9,26  | 8,92  | 9,94  | 0,40 |
| 32. Lower molar length  | 10  | 10,16  | 9,61  | 10,35  | 0,61 |
| 33. Coronid prossess height | 10  | 13,27  | 11,86  | 14,22  | 0,93 |
| 34. First upper molar length M1 | 6  | 8,77  | 8,15  | 9,47  | 0,52 |
| 35. Second upper molar length M2 | 6  | 6,49  | 6,31  | 6,84  | 0,21 |
| 36. Third upper molar length M3 | 6  | 6,00  | 5,79  | 6,05  | 0,12 |
| 37. First lower molar length M1 | 6  | 8,90  | 8,15  | 10,52  | 0,92 |
| 38. Second lower molar length M2 | 6  | 5,74  | 5,26  | 6,31  | 0,39 |
| 39. Third lower molar length M3 | 6  | 5,84  | 5,52  | 6,32  | 0,43 |

N: number of sample, avg: average, min: minimum, max: maximum, SS: Standard deviation
RESULTS

Based on shape analysis of dorsal view of water vole UPGMA dendogram (Fig.3A) we find no significant differentiation basis for Turkish Thrace and Western part of Anatolia populations.

Our UPGMA dendogram results indicate clear confirmation of the subspecies-level status of Arvicola amphibius persicus (Anatolia) and Arvicola amphibius cernjavskii (Thrace) depend on ventral and lateral view of water vole skull (Fig. 3B, C). Fig. 3C also indicates that Beyşehir population is different from all other populations, and Thrace population is much closer to the other populations. Comparing to Arvicola terrestris subspecies populations; tail, ear, condylobasal length, basale length, nasal length, parietal suture length, mastoid, width, diestama length, damak length, bulla tympanica length, bulla tympanica width, mandibul length, Mandibulae height, under molar alveoli length, under molar length, coronoid process height, under M2, under M3 ve upper M2 measurements are quite different within 2 subspecies.

Comparison of Arvicola terrestris populations depend on measurements of external and internal characters shown on Fig. 4.

DISCUSSION

The shape of organs or structures are important in the interaction between the organism and its environment. It is quite common to associate taxonomic differentiation with morphological divergence (Renaud and Michaux, 2003; Rohlf, 1990).

Arvicola subspecies; Arvicola amphibius persicus, Arvicola amphibius armenius and Arvicola amphibius hintoni which are recorded from Anatolia and those subspecies are investigated in a previous study (Mursaloğlu, 1975) and only persicus and hintoni accepted as a subspecies because of differentiation of populations depend on morphological and biometrical features. And armenius noticed as a synonym of persicus. Consequently Mursaloğlu (1975) defined Arvicola amphibius cernjavskii from Turkish Thrace and Arvicola amphibius persicus from Central Anatolia. Again, this review stops more than 40 years ago. For example, the data and statements presented by Krystufek & Vohralik (2005) are not considered.

In this study, in Anatolian populations; average head-body length 179 mm, tail length 125 mm, hind length 27-42 mm, condylobasal length 39,26-41,48 mm, in Thrace populations; average head-body length 193,5 mm, tail length 121.17 mm, hind length 33-36 mm, condylobasal length 36,15-39,76 mm are measured. Depend on these measurements except tail measurements of Anatolian populations are consistent with Miller (1912) and the other differences is head and body length of Thrace populations.

Mursaloğlu (1975) recorded Arvicola terrestris cernjavskii from Trakya, and Arvicola terrestris persicus subspecies from Central Anatolia. According to Mursaloğlu (1975), the average and minimum - maximum measurements of 11 Arvicola terrestris persicus samples obtained from Central Anatolia; the length of the whole length is 297,5 mm (229 - 318), the head - body length is 180.2 mm (115 - 200) and the weight is 170.6 g (130 - 209). Measurements of Western Anatolian Arvicola terrestris persicus specimens examined in this study compared with the samples obtained from Central Anatolia by Mursaloğlu, whole length, head-body length and weight measurements were found to be smaller. These average whole length values are greater than the maximum value given by the researcher for the whole length (318 mm) and head - body length (200 mm). In addition, the mean value of the weight measurements of Arvicola terrestris persicus subspecies samples of Mursaloğlu (1975) is 170.6 gr. The average weight of the samples collected in this study is larger.

In our study, it is first time we analysed geometric morphometrics on Turkish Arvicola samples distributed on
western part of Anatolia. A total of 37 landmarks on dorsal, ventral and lateral view of the skull were used to identified differentiation level of Arvicola populations in western part of Anatolia. We found any evidence of differentiation between Thrace and Anatolia populations according to dorsal view of water vole skull. However ventral and lateral view of water vole skull strongly support that Turkish Thrace and Western part of Anatolia water vole populations are highly differentiated two subspecies of water vole Arvicola amphibius persicus and Arvicola amphibius cerncavskii distributed through Western part of Turkey by using landmark based geometric morphometrics.

Thus, ventral and lateral view of skull is quite efficient to determine intraspecies variations of water vole by using geometric morphometrics. On the other hand, dorsal view of water vole skull is not informative to explain intraspecific variations of water vole subspecies throughout Western part of Turkey.

In addition to these, during field study, we observed that the distribution area of Arvicola amphibius is highly limited by water pollution, anthropogenic impact and climate change.

References

1. Castiglia R, Aloise G, Amori G, Annesi F, Bertolino S, Capizzi D, Mori E, Colangelo P. The Italian peninsula hosts a divergent mtDNA lineage of the water vole, Arvicola amphibius s.l., including fossorial and aquatic ecotypes. (2016) 27, doi:10.4404/hystrix-27.2-11588.
2. Kryštufek B, Vohralík V. Mammals of Turkey and Cyprus: Rodentia I: Sciuridae, Dipodidae, Gliridae, Arvicolinae. Zgodovinsko družtvo za južno Primorsko, Koper. 2005
3. Miller G.S. Catalogue of the Mammals of Western Europe in the collection of the British Museum. British Museum: (Nat. Hist), London. 1912
4. Meylan A. Fossorial Forms of the Water Vole, Arvicola terrestris (L.), in Europe. EPPO Bulletin 7, 209–218, doi:10.1111/j.1365-2338. (1977) tb02723.x.
5. Mursaloğlu B. Türkiye su sıçanlarının, Arvicola, coğrafik varyasyonları. Tübitak V. Bilim Kongresi Tebliği, (1975) 353–368.
6. Musser GG, Carleton MD. Family Muridae. In: Wilson, D.E., Reeder, D.M. (Eds.), Mammal Species of the World. A Taxonomic and Geographic Reference. The Johns Hopkins University Press, Baltimore. 2005
7. Renaud S, Michaux JR. Adaptive latitudinal trends in the mandible shape of Apodemus wood mice. Journal of Biogeography 30, (2003) 1617–1628, doi:10.1046/j.1365-2699.2003.00932.x.
8. Rohlf FJ. Fitting curves to outlines. In: Rohlf FJ, Bookstein FL, eds. The University of Michigan Museum of Zoology. 1990
9. Rohlf FJ. Shape statistics: Procrustes superimpositions and tangent spaces. J. Classif 16, (1999) 197–223.
10. Rohlf FJ. Tps Series. State University of New York, Stony Brook, Department of Ecology and Evolution. 2004
11. Slice DE. Morphos, Software for Morphometric Research. Department of Biomedical Engineering Wake Forest University School of Medicine, Winston-Salem, NC, USA. 2002
12. SPSS, SPSS for Windows, Release 13.0. Standard Version. SPSS Inc., Chicago, IL, USA. 2004
13. Steiner H, Vauk G. Saugetiere aus dem Beyşehir Gebiet (vil. Konya, Kleinasien). Zoologischer Anzeiger 176, (1966) 97–102.
14. Zelditch M. L., Swiderski D. L., Sheets H. D. and Fink, W. L. 2004. Geometric morphometrics for biologists: a primer, Elsevier, 443 p.