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Review of the earthworm biodiversity of Turkey and its neighbouring countries (Clitellata, Megadrili)

M. MISIRLIOĞLU[1], H. VALCHOVSKI[2], & M. STOJANOVIĆ[3]

[1]*Mete Mısırlıoğlu, Eskişehir Osmangazi University, Faculty of Science and Letters, Department of Biology, 26480 Eskişehir, Turkey. E-mail: metem@ogu.edu.tr*

[2]*Hristo Valchovski, Department of Soil Microbiology, Institute of Soil Science, Agrotechnologies and Plant Protection "N. Poushkarov", 7 Shosse Bankya Str., 1080 Sofia, Bulgaria.*

[3]*Mirjana Stojanović, University of Kragujevac, Faculty of Science, Institute of Biology and Ecology, Kragujevac, Serbia.*

Abstract. This paper presents the combined list of earthworms from Turkey and its neighbouring countries: Syria, Iran, Georgia, Armenia, Azerbaijan, Cyprus, Greece and Bulgaria. Turkey has one of the richest earthworm biodiversities among the Eurasian countries. Its interesting geographic position on the conjunction of three continents (Asia, Europe and Africa) and the close proximity of three different biodiversity hotspots (Caucasus, Mediterranean and Iran-Anatolia) are the primary influence on the large number species as well as the different climatic conditions and major biogeographical barriers in the country. Till now 83 species and subspecies has been recorded and the earthworms of Turkey is characterized by the highest rate of endemism in the region (30 taxa = 36.14%). Taking into account the whole dataset (autochtonous + peregrine species) Turkish earthworms shows strong similarity to the fauna of Georgia (34 taxa = 40.96%) and Greece (32 taxa = 38.55%).

Keywords. Biodiversity, earthworms, clitellata, megadrili, fauna of Turkey.

INTRODUCTION

Turkey is a vast country (783 356 km^2) composed of two lands located in two different continents. The waterway consisting of Bosporus, the Sea of Marmara, and the Dardanelles Strait divides the European part (called East Thrace and constitutes 3% of the country) from the Asian one (called Anatolia and constitutes 97% of the country). Besides the three seas – Mediterranean, Aegean and Black Sea – surrounding the country, it has eight bordering neighbour countries: Bulgaria, Greece, Syria, Iraq, Iran, Azerbaijan, Armenia and Georgia (Figure 1).

Seven geographic regions distinguished by different climatic conditions and large barriers such as the Anatolian Diagonal, Taurus and North Anatolian mountains and the waterways mentioned above play an important role in contributing to the various species compositions. In addition to this, its closeness to three biodiversity hotspots – the Mediterranean, Caucasus and Iran-Anatolia – has a major effect on its rich biodiversity (Mısırlıoğlu 2017a, 2017b, Mısırlıoğlu *et al*. 2017).

Earthworm research in Turkey was started by Rosa at the end of the nineteenth century with the first earthworm record of *Allolobophora syriaca* Rosa, 1893 from Samsun, North Anatolia. After that, only a few studies (Rosa 1905, Pop 1943, Omodeo 1952, 1955, Zicsi 1973, 1981, 1985) which are based on sporadic collections which have been carried out over ninety years.

The research published by Omodeo & Rota (1989, 1991) are the most comprehensive studies on Turkish fauna in the whole of the 20th century. They identified several taxa and reported new records for the country in two separate papers (Csuzdi *et al*. 2006, Mısırlıoğlu 2017, Szederjesi & Mısırlıoğlu 2017).

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Figure 1. The number of earthworm taxa in Turkey and adjacent countries reported in the literature.

Since then Csuzdi *et al*. (2006) combined all Turkish faunistic results in an annotated checklist. It was the most important step to understanding the whole earthworm fauna of Turkey and followed by considerable faunistic research containing new taxa and new records (*e.g.* Csuzdi *et al.* 2007, Szederjesi *et al.* 2014a, Szederjesi & Mısırlıoğlu 2017, Mısırlıoğlu 2018)

As a result of this research, Turkey is the richest country in terms of earthworm taxa in the region. Although there are still large unsampled areas in the country, more than 80 earthworm taxa have been recorded so far and most probably the number will be in the hundreds in the future (Mısırlıoğlu 2017b, Reynolds & Mısırlıoğlu 2018).

The aim of this the paper is to summarise current knowledge on the earthworm fauna of Turkey and its neighbouring countries.

MATERIAL AND METHODS

The data treated herein comes from the incorporation of all available literature records concerning the distribution of earthworms in Turkey and its neighbouring countries, except for Iraq, for which there is no confident knowledge on species occurrence. The valid taxa names are given according to the online database of Csuzdi (2012).

The species listed are assigned to the following zoogeographic categories: Peregrine, Atlanto-Mediterranean, Circum-Mediterranean, Trans-Aegean, Moesian, Illyric, Balkanic-Alpine and different groups of endemics (distributed in the Balkans, Anatolia, Caucasus, Caucaso-Anatolian or Levantine-Anatolian or Balkanic-Anatolian areas) (Zicsi 1973, Csuzdi & Zicsi 2003, Csuzdi *et al*. 2006, Kvavadze 1985, Mısırlıoğlu 2017a, 2017b, Perel 1979, 1997, Stojanović *et al*. 2012, Stojanović & Milutinović 2013, Stojanović *et al*. 2013, Trakić *et al*. 2016, Reynolds and Mısırlıoğlu 2018).

Faunistic similarity was computed with PAST 3.2 software package (Hammer *et al.* 2001) using Jaccard index which expresses similarity in the lists of species of two country areas as follows $C = j / (a + b - j)$ where a and b are the number of species in area A and B, respectively, and j is the common number of species found in both areas. The maximum value (1, 100%) is reached when the species lists are identical for two areas, the minimum value (zero) when the lists are completely different.

RESULTS

The list of earthworm taxa recorded in Turkey and in neighbouring countries comprises 164 species and subspecies (Appendix 1), of which 153 (in 18 genera) belong to family Lumbricidae, one species belong to Criodrilidae, and ten species are from the families Acanthodrilidae (three species in two genera), Megascolecidae (five species in three genera) and Ocnerodrilidae (two species in two genera).

Presence of some species in Turkey is uncertain, probably due to misidentification. Omodeo & Rota (1989) reported the Alpine species *Aporrectodea smaragdina* (Rosa, 1892) from Turkey without detailed description. However, according to Csuzdi *et al.* (2006) because of the absence the characteristic green colour of the specimens, they were probably belonging to *Allolobophora brunnecephala* and not the Central -European *Ap. smaragdina*.

On the other hand, Omodeo & Rota (1991) mentioned the presence of species *Allolobophora bellicosa* (Ude, 1922) (synonym *Perelia nematogena*) in Turkey. However, Csuzdi *et al.* (2006) consider that the short description of this species is also more similar to *Allolobophora brunnecephala*. Other authors (Pavliček *et al* 2010, Szederjesi 2017b) have accepted this view.

The presence of *Dendrobaena samarigera* in Turkey is mentioned in the papers of Csuzdi *et al* (2006), Pavliček *et al*. (2010) and Szederjesi (2017b). However, in Csuzdi *et al.* (2006) authors express their suspicion in the presence of this species in Turkey due to the incomplete description of the juvenile specimen found in Turkey by Omodeo (1952). Therefore the presence of this species in Turkey requires confirmation (Csuzdi *et al* 2006; Szederjesi 2017b).

DISCUSSION

So far, eighty-three taxa have been registered from Turkey, a greater number than for the 7 neighbouring countries (Mısırlıoğlu 2017b, 2018, Reynolds & Mısırlıoğlu 2018).

The earthworm fauna of Turkey is characterized also by the highest rate of endemism. According to Csuzdi *et al*. (2006), the country has a distinctive specialized earthworm fauna. The largest number of Turkish endemics belong to the Anatolian endemics (30 taxa) with 13 taxa from the genus *Dendrobaena* and seven taxa from *Healyella* genus.

Out of 31 *Dendrobaena* species and subspecies registered in Turkey, 13 taxa belong to Anatolian endemics, 12 taxa are Caucaso-Anatolian, five are Levantine-Anatolian and one taxon is Balkanic-Anatolian. Therefore, 41.93 % of *Dendrobaena* species and subspecies are endemics for this region of Turkey (Omodeo and Rota 2008, Szederjesi *et al*. 2014a). Besides, *Dendrobaena orientalis orientalis*, *D. semitica, D. hauseri*, *D. samarigera*, *Healyella syriaca, Perelia galileana* are Levantine-Anatolian species which were registered both in Anatolia and the Levant and indicate the connection between two regions.

Some of the species which belong to the genera *Spermophorodrilus* or *Perelia* could not disperse over the Taurus Mountains. For example, *Perelia galileana* was found in Israel and Hatay Province of Turkey (Csuzdi & Pavlíček 2005, Pavlíček *et al*. 2006, Csuzdi *et al*. 2007, Mısırlıoğlu *et al*. 2008).

The second largest portion of the endemic group belongs to genera *Spermophorodrilus* and *Healyella*. The genus *Healyella* and *Spermophorodrilus* species are almost all endemic to the country. *Healyella* is distributed throughout Anatolia and Middle East. Of the nine *Healyella* species, eight are registered in Turkey, and only two species, *He. syriaca* and *He. jordanis* are recorded outside of Turkey (Pavlíček *et al.* 2003, Mısırlıoğlu & Stojanovic 2018). Only *He. syriaca,* occupies a broader area, (Anatolia, Iran, Syria, Lebanon and Israel). Eight *Healyella* species are registered in the central part of Northern Anatolia which represents the distri-

bution centre of the genus (Omodeo & Rota 1999). Caucaso-Anatolian endemic Turkish earthworms are distributed mainly in the North-Eastern region of the country (Csuzdi *et al*. 2006). Besides, five *Dendrobaena* endemics show clear Levantine connection: *D. orientalis, D. hauseri, D. samarigera* (if present)*, D. semitica* and *D. szalokii* (Appendix 1).

There are several endemic groups that are present in a large area of Turkey and neighbouring countries. The greatest number is the Anatolian endemics which represent 28.30% (30 taxa) of the total endemic lumbricid species. Then follow Balkanic endemics (29 taxa = 27.35%), Caucasian endemics (23 taxa = 21.69%), Caucaso-Anatolian (9 taxa = 8.49%), Levantine-Anatolian (7 taxa = 6.6%), Iranian endemics (3 taxa = 2.83%), Levantine and Balkanic-Anatolian with two taxa each (1.88%) and one Cypriot endemic.

The zoogeographical composition of the earthworm fauna in the whole study area appears as follows: Endemics (106 taxa = 64.63%), Peregrine (29 taxa = 17.68%), Trans-Aegean (7 taxa = 4.26%), Central-European (5 taxa = 3.04%), and Circum-Mediterranean (4 taxa = 2.43%), three taxa for each of Balkanic-Alpine and Caucasian-East-Mediterranean, two taxa for Atlanto-Mediterranean and one taxon for each of Moesian, Illyric and Alpine-East-Mediterranean.

The Caucasus is the center of relatively young genera such as *Allolobophora, Eisenia, Eiseniella, Helodrilus* and *Dendrobaena*. The connection between Transcaucasia and Turkey has been important for speciation especially for the genus *Dendrobaena*. *Dendrobaena alpina armeniaca, D. attemsi decipiens*, *D. kurashvilii*, *D. montana*, *D. pentheri*, *D. ressli, D. schmidti marinae*, *D. schmidti tellermanica*, *Di. grandis grandis, Di. hydrophilicus*, *Di. polysegmenticus* and *Allolobophora brunnecephala* are Caucaso-Anatolian species.

The list of earthworms from Bulgaria represents 49 confirmed species and subspecies. Unfortunately, the fauna of Bulgaria is still incompletely known despite the efforts of the recent investigations (Zicsi & Cszudi 1986, Valchovski & Szederjesi 2016, Valchovski & Mısırlıoğlu 2017b, Valchovski 2017), but it appears highly peregrine. Of the 49 species, 17 (34.69%) belong to peregrines. Endemic species follow with 14 taxa = 28.57% (Balkanic and large endemics 10 taxa = 20.40%, Bulgarian endemics 4 taxa = 8.16%). Next are the Trans-Aegean (6 taxa = 12.24%), Central European (5 taxa = 10.20%) and Balkanic-Alpine (3 taxa = 6.12%). Mediterranean (3 taxa = 6.12%) and Moesian (1 taxon = 2.04%) are less numerous. Except for the peregrine worms, 9 taxa are registered both in Turkey and Bulgaria. *Allolobophora leoni*, *Aporrectodea dubiosa*, *Aporrectodea handlirschi*, *Aporrectodea jassyensis, Dendrobaena attemsi, Octodrilus transpadanus* and *Proctodrilus tuberculatus* are Trans-Aegean, while *Murchieona minuscula, Octodrilus complanatus* and *Dendrobaena byblica byblica* are Circum-Mediterranean.

Of the 66 earthworm taxa recorded from Greece 57 belong to the family Lumbricidae, one to the Criodrilidae, four to the Megascolecidae, two to the Acanthodrilidae and two to the Ocnerodrilidae. Nine species within the family Lumbricidae are strict endemics and 18 taxa are recorded both in Turkey and Greece: 5 Trans-Aegean, 4 Circum-Mediterranean, 3 Caucasus-East Mediterranean, 2 Balkan-Anatolian species, 2 Balkan-Anatolian, one Balkanic-Alpine-East Mediterranean, and one Alpin-East Mediterranean (Szederjesi 2017a, 2017b, Szederjesi *et al*. 2017).

Twenty-one earthworm species (19 lumbricid and two acanthodrilid species) are known from Cyprus so far (Szederjesi 2017a); 11 of them are autochtonous: one Circum-Mediterranean (*Dendrobaena byblica*)*,* one Alpine-East-Mediterranean (*Dendrobaena pantaleonis*)*,* one Levantine (*Dendrobaena semitica*), one Trans-Aegean (*Proctodrilus tuberculatus*), two Caucasian-East Mediterranean (*Helodrilus patriarchalis, Dendrobaena pentheri*)*,* and three Circum-Mediterra-

nean (*Eiseniella neapolitana, Murchieona minuscula, Octodrilus complanatus*) are distributed in Turkey and Cyprus. Among them only *Dendrobaena pentheri* shows Anatolian affinity being distributed in the Caucasus region, Anatolia and Cyprus (Szederjesi *et al*. 2016, Szederjesi 2017b).

According to Szederjesi (2017a), the earthworm fauna of Crete comprises 20 species. Out of them nearly 45% are peregrine and nearly 14% are Circum-Mediterranean and only two are Balkanic endemics (*D. byblica olympiaca*, *E. ebneri*). Turkey and Crete have seven species registered on the territory of both lands and none of them are peregrine. Among these species, there are three from Circum-Mediterranean and one each for the Atlanto-Mediterranean, Alpine-East Mediterranean Caucasian-East Mediterranean and Trans-Aegean categories.

Of the 28 taxa of Iranian earthworms, 24 belong to the family Lumbricidae, three to Acanthodrilidae and one to Megascolecidae. Nine of the lumbricid taxa are endemic (Szederjesi *et al.* 2014b, Latif *et al*. 2016).

Iranian earthworms have more zoogeographic affinities with the Levantine than with the Anatolian fauna; in fact only seven taxa (apart from peregrines) are recorded both in Iran and Turkey: *Aporrectodea jassyensis, Dendrobaena byblica, D. orientalis, D. pentheri, D. semitica, Healyella syriaca*, *Helodrilus patriarchalis*. However, there are large unsampled areas in both countries and high similarity of earthworms between northern Iran, Eastern Turkey and Transcaucasus were observed by Mısırlıoğlu *et al*. (2008).

Of the 58 species and subspecies of Georgian earthworms, 54 belong to the Lumbricidae, one to Criodrilidae, two to Acanthodrilidae and one to Megascolecidae (Bakhtadze *et al*. 2003, 2008, Kvavadze 1985, Kvavadze *et al* 2007). 23 taxa (39.65%) are strict Georgian endemics belonging to the family Lumbricidae, while 18 taxa are peregrine (31.03%). There are seven (12.06%) Trans-Aegean and ten (17.24%) Caucaso-Anatolian and three Caucasian-East-Mediterranean species. Of the 18 species and subspecies distributed both in Georgia and Turkey the majority belongs to Caucaso-Anatolian, Trans-Aegean, Circum-Mediterranean and Caucasian-East-Mediterranean categories. Caucaso-Anatolian endemics are one of the most important groups. Those are: *Dendrobaena attemsi decipiens, D. kurashvilii, D. schmidti marinae*, *D. schmidti tellermanica*, *Dendrodriloides grandis grandis, Dendrodriloides hydrophilicus* and *Dendrodriloides polysegmenticus*. All of them belong to genera *Dendrobaena* and *Dendrodriloides* that make this region one of the most important centres of endemism of thesw genera (Omodeo & Rota 1999, Csuzdi *et al*. 2006). The Caucaso-Anatolian species are distributed particularly in the North-Eastern region of Turkey.

Unfortunately, there is only sporadic data for Armenia and Azerbaijan (Szederjesi 2017b). 11 autochthonous taxa are registered both in Armenia and Turkey and the most important group is formed by Caucaso-Anatolian species (*Allolobophora brunnecephala, Dendrobaena alpina armeniaca*, *D. kurashvilii*, *D. montana*, *D. schmidti tellermanica Dendrodriloides grandis grandis*). Two species are Trans-Aegean and Caucasian-East- Mediterranean and one Levantine endemic. A similar situation occurs between Azerbaijan and Turkey with only nine autochthonous shared taxa with four Caucaso-Anatolian species (*Allolobophora brunnecephala, Dendrobaena alpina armeniaca, D. schmidti tellermanica, Dendrodriloides grandis grandis*) two Trans-Aegean and Caucasian-East-Mediterranean and one Levantine endemic.

Based on sporadic investigations in Syria (Kvavadze 1985, Omodeo & Rota 1989, (Pavlíček *et al*. 2003), there exists 14 taxa with only two species, *Dendrobaena semitica* and *Healyella syriaca*, distributed both on the territory of Syria and Turkey.

Unfortunately, there are no confident earthworm records from Iraq. It is expected that the Upper Mesopotamia and the eastern part of Turkey could show similarities with the earthworm fauna of Iraq especially in its Northern part.

It is interesting that in the neighbouring Trans-Caucasian area, there is a noticeable high proportion of earthworm endemics: in Georgia (46.56%), Azerbaijan (41.37%) and Armenia (45.16%).

The earthworm fauna of Turkey including Peregrines has high percentage similarities with the faunas of Greece (32 taxa = 38.55%) and Georgia (34 taxa = 40.96%). Then follow Bulgaria (22 taxa=26.50%), Armenia (21 taxa = 25.30%), Azerbaijan (20 taxa = 24.09%), Iran (19 taxa = 22.89%), Cyprus (17 taxa = 20.48%), Crete (15 taxa = 18.07%), and Syria (12 taxa = 14.45%).

Conversely, our data shows the degree of endemism for Turkey and its neighbouring countries as extremely high, exceeding 64.63%. Summing up the endemics, the Trans-Anatolian and Mediterranean taxa, 73.17% of the total lumbricid fauna of this complex area shows strong autochthonous character.

Jaccard index indicates a higher overall earthworm similarity between the area of Turkey and the area of Georgia (Cj = 31.78%) and Greece (Cj = 27.35%), than between Turkey and the rest neighbouring countries (Table 1.). However, it should be taken into account that the values of Jaccard index (and all the above comparisons) are influenced by the differences in the level of knowledge on earthworm diversity in the compared areas and by the differences in the size of the compared areas.

If we take into account only the autochthonous species the highest similarities can be found among Turkey and Georgia (Cj = 22.35%), Greece (Cj = 16.3) and Armenia (Cj = 15.07%) which highlights the two main regions showing strong influence on the Anatolian earthworm fauna; the Balkan and the Caucasian region. However, the UPGMA dendrograms generated using Jaccard similarity on the full and the autochthonous datasets (Figs. 2–3) unanimously place Turkey into the cluster composed of the Caucasian countries. The other main clusters consist of Bulgaria together with Greece and an other Iran, Syria and the Mediterranean Islands. It is worth noting that using the autochthonous dataset Syria and Cyprus form a sister-clade with high similarity (Cj = 33.33%); this recalls the theory of Pavlíček & Csuzdi (2008) that the Cypriote earthworm fauna has originated through immigration from the Levantine coast in the Messinian period.

Table 2. Jaccard similarity coefficients (Cj) comparing Turkey and neighbouring countries (using the whole dataset and peregrines removed).

	Cj (%) for total taxa	Cj (%) for autochthonous taxa
Bulgaria	20	11.63
Greece mainland	27.35	16.30
Cyprus	19.54	11.76
Crete	17.05	7.27
Iran	20.65	10.29
Georgia	31.78	22.35
Syria	14.12	9.09
Armenia	22.58	15.07
Azerbaijan	21.74	13.89

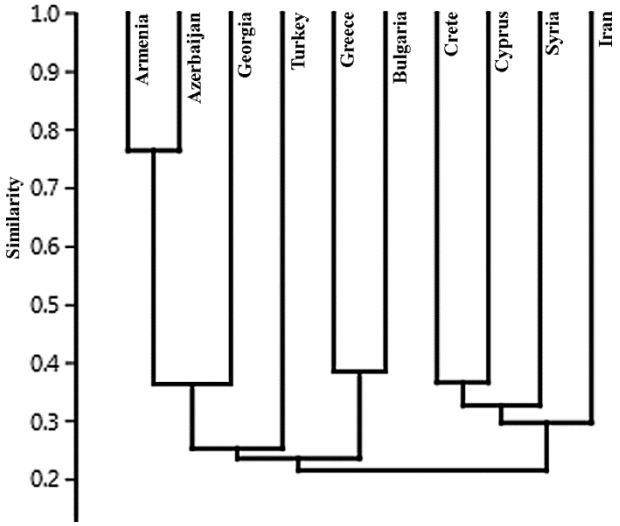

Figure 2. Faunistic similarity of Turkey and the neighbouring countries using Jaccard index and UPGMA clustering on the whole dataset.

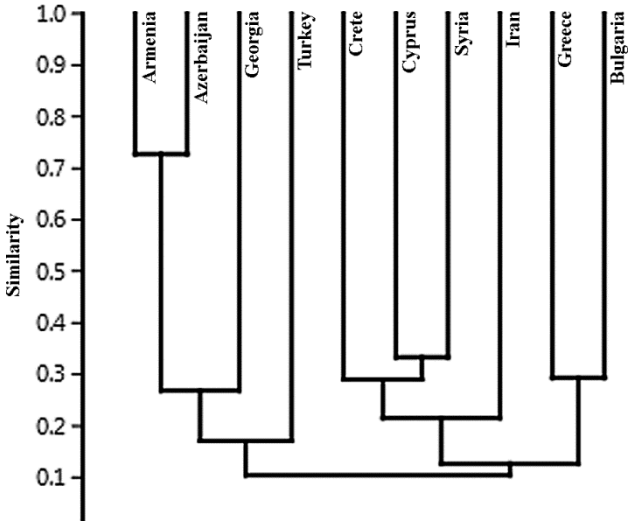

Figure 3. Faunistic similarity of Turkey and the neighbouring countries using Jaccard index and UPGMA clustering on the autochthonous dataset.

Our knowledge about the diversity and distribution of earthworms in Turkey and its neighbouring countries is far from complete; due to the fact that we still have limited data concerning the East and South-East parts of Turkey and some eastern neighbours of Turkey. Thus to compare the faunistic data with these countries is almost impossible. It is reasonable that the eastern part of Turkey will include a large number of endemic species in addition to Oriental and Levantine species. To fill this gap in our knowledge on the earthworm fauna of the studied region more detailed investigations are needed which will result in finding many more new earthworm species in this area.

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