

Article

Contribution to the Knowledge on Distribution of Tardigrada in Turkey

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Abstract: Tardigrades have been occasionally studied in Turkey since 1973. However, species number and distribution remain poorly known. In this study, distribution of Tardigrades in the province of Karabük, which is located in northern coast (West Black Sea Region) of Turkey, was carried out. Two moss samples were collected from the entrance of the Bulak (Mencilis) Cave. A total of 30 specimens and 14 eggs were extracted. Among the specimens; *Echiniscus granulatus* (Doyère, 1840) and *Diatorbiotus islandicus islandicus* (Richters, 1904) are new records for Karabük. Furthermore, this study also provides a current checklist of tardigrade species reported from Turkey, indicating their localities, geographic distribution and taxonomical comments.

Keywords: cave; *Diatorbiotus islandicus islandicus*; *Echiniscus granulatus*; Karabük; Tardigrades; Turkey

1. Introduction

Caves are not only one of the most important forms of karst, but also one of the most unique forms of karst topography in terms of both size and formation characteristics, which are formed by mechanical melting and partly chemical erosion of water [1]. Most of the caves in Turkey were developed within the Cretaceous and Tertiary limestone, metamorphic limestone [2], and up to now ca. 40 000 karst caves have been recorded in Turkey. Although, most of these caves are found in the karstic plateaus zone in the Toros System, important caves, such as Kızılelma, Sofular, Gökgöl and Mencilis, have also formed in the Western Black Sea [3].

Some invertebrate communities can adapt well to these interesting underground formations, whose habitats are found rarely on earth [4,5]. Tardigrades, also known as water bears, are microscopic invertebrates that are one of these invertebrates that can survive in this environment with its harsh conditions. In general, tardigrades inhabit marine, freshwater and terrestrial environments (deserts, soil and leaf litters, mosses, lichens and liverworts, underground and marine caves throughout the world [6,7]. Until now, 30 families, 142 genera and nearly 1300 tardigrade species and 34 subspecies have been reported worldwide [8].

The tardigrade fauna of Turkey remains poorly known [9], with only few papers published since 1973. The most comprehensive studies were carried out by Maucci [10–16], Morgan [17], Binda [18], Kaczmarek et al. [9], Kharkevych and Sergeeva [19] and Ürkmez et al. [20]. To date 54 species and one subspecies have been reported from Turkey. Among them, eleven species and one subspecies belong to the genus *Echiniscus* C.A.S Shultz, 1840 [21] whereas only one species belongs to the genus *Diatorbiotus* Guidetti, Rebecchi, Bertolani, Jönsson, Kristensen and Cesari, 2016 [22].

This paper reports two tardigrade species, which were discovered for the first time from the Bulak (Mencilis) Cave, in Karabük. In addition, we also provide a full checklist of tardigrade species reported from Turkey with their localities, geographic distributions and taxonomical comments.

2. Materials and Methods

In March 2017, two moss samples were collected from the entrance of Bulak (Mencilis) Cave ($41^{\circ}16'30.1836''$ N; $32^{\circ}37'28.4628''$ E), which is located nearly 8.5 km northwest of Safranbolu, the largest and most developed province of Karabük [23]. Bulak (Mencilis) Cave is the fourth largest cave in Turkey with a length of approximately 6 km [24,25].

One moss sample was collected from a rock which was found around the entrance of the Cave and the other from the wall of the entrance. Both samples were put into paper bags and let dry in the laboratory. They were later examined for terrestrial tardigrades using a standard method described by Dastych [26] with modifications described by Stec and Smolak [27]. The samples were placed in a beaker for rehydration with tap water in the laboratory. One day later after stirring, the water containing moss particles were poured into a 200 ml cylinder. After precipitation, approximately 50 ml of remaining sediment was taken into a glass petri dish. Tardigrades and eggs were placed from the sediment under the stereomicroscope (Leica MZ16 A). Tardigrades and their eggs were mounted on microscopic slides in Hoyer's medium and observations and the photomicrographs were made using a phase-contrast microscope (Zeiss Axio Imager M1). The species were identified using the monograph published by Ramazotti and Maucci [7] and according to Guidetti et al. [22]. For genus abbreviations we referred to Perry et al. [28]. All slides, which were secured with a transparent nail polish, were stored in the Ankara University, Department of Biology, Aquatic Animals Research Laboratory.

3. Results

In total, 30 specimens and 14 eggs were found. Within those specimens, 10 belong to the genus *Paramacrobiotus* Guidetti, Schill, Bertolani, Dandekar and Wolf, 2009 [29] and they have not been identified to species level due to the absence of eggs. The remaining 20 specimens and 14 eggs were identified as *Ech. granulatus* (Doyère, 1840) [30] and *Dia. i. islandicus* (Richters, 1904) [31], which are new records for the province of Karabük.

Taxonomic Accounts

Phylum: Tardigrada Spallanzani, 1777 [32]

Class: Heterotardigrada Marcus, 1927 [33]

Order: Echiniscoidea Richters, 1926 [34]

Family: Echiniscidae Thulin, 1928 [35]

Genus: Echiniscus C.A.S. Schultze, 1840 [21]

Echiniscus granulatus (Doyère, 1840) [30]

Material examined: Seven specimens.

Remarks: It has dorsal sculpture of polygonal shape (Figure 1C) that is composed of granules. Lateral appendices cirri A, C and D present (Figure 1A,B), which are in the form of long filaments, lateral cirri B absent. Cirri E in shape of spines. The dorsal appendices C^d and D^d as long spines. Fourth pair of legs with dentate collar (Figure 1D). All characteristics properties of this species correspond with the description in Ramazotti and Maucci [7]. The species is known from many localities in Europe, Turkey, North America, Africa and Asia [36].

Type locality: France [7]

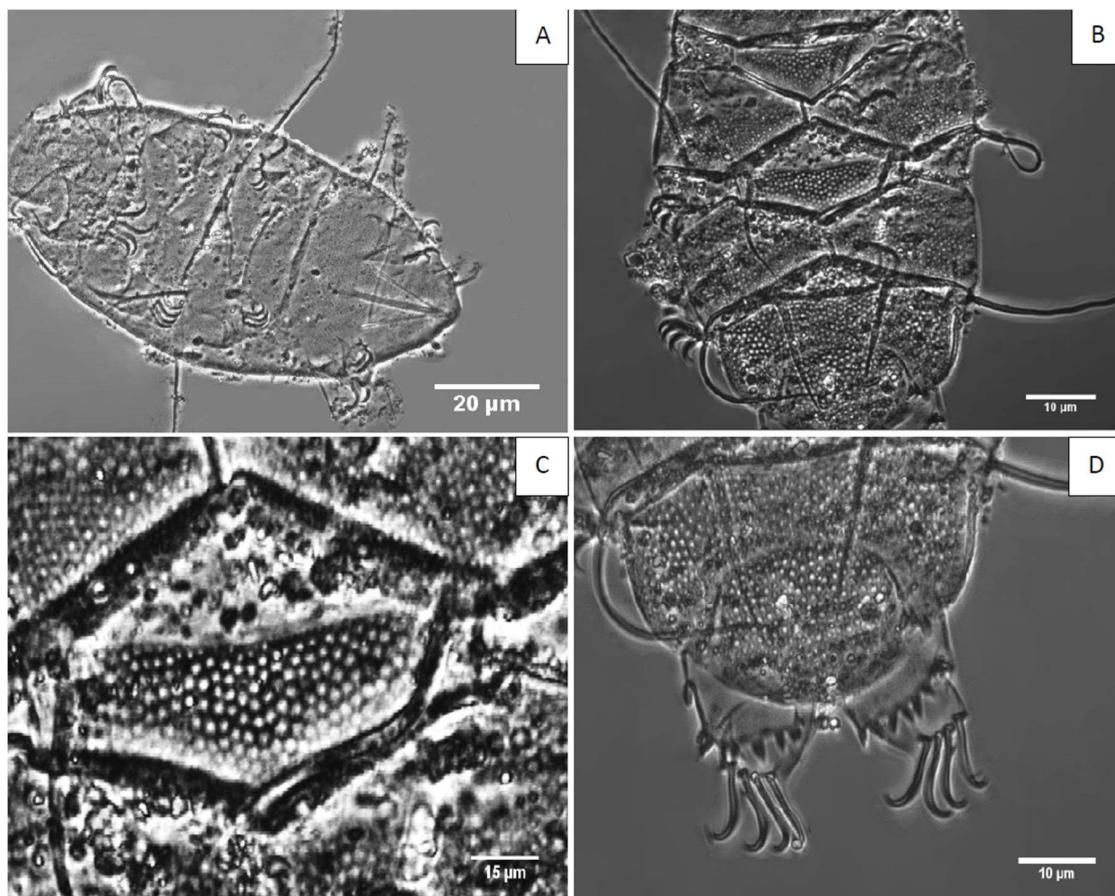


Figure 1. *Echiniscus granulatus*: (A) Habitus, (B) dorsal plates, (C) detail of the cuticular ornamentation, (D) claws of the fourth pair of legs; using phase contrast microscopy.

Class: Eutardigrada Richters, 1926 [34]

Order: Macrobiotoidea Guil, Jørgensen and Kristensen, 2019 [37]

Family: Richtersiidae Guidetti, Rebecchi, Bertolani, Jönsson, Kristensen and Cesari, 2016 [22]

Genus: Diaforobiotus Guidetti, Rebecchi, Bertolani, Jönsson, Kristensen and Cesari, 2016 [22]

Diaforobiotus islandicus islandicus (Richters, 1904) [31]

Material examined: In total 13 specimens and 14 eggs.

Remarks: Their body length is varied from 550 to 665 µm (Figure 2A). Buccal tube is thin and pharynx oval with two macroplacoids (Figure 2B); the first is longer than the second. Lunulas present and dentate (Figure 2C). The projections of the eggs are thin cones, almost spine-like (Figure 2D). Measurements of selected morphological characters for the smallest and largest examined specimens are given in Table 1. All characteristics properties of the species correspond with the description in Guidetti et al. [22]. *Diaforobiotus i. islandicus* (Richters, 1904) [31] was reported in Italy, Switzerland, Crete, Carpathians, Sweden, Norway, Iceland, Faroe Islands, Spitzbergen Archipelago, Greenland, America and Turkey [7,36]

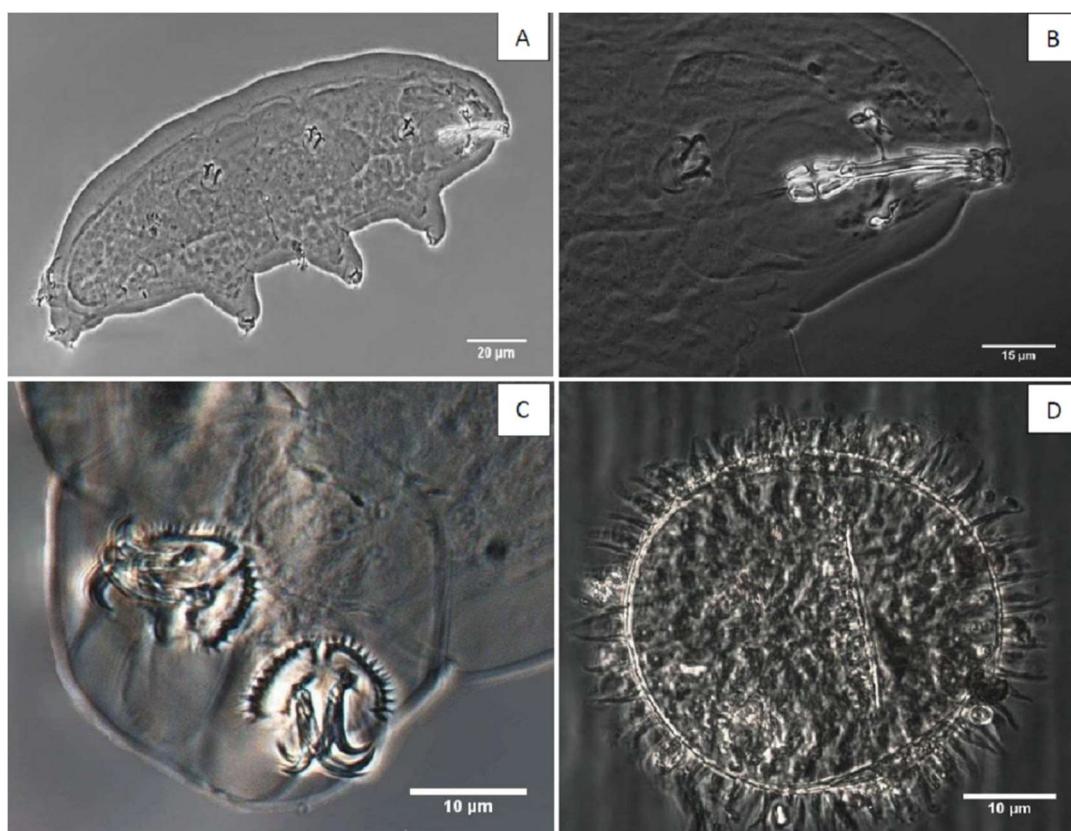


Figure 2. *Diaforobiotus islandicus islandicus*: (A) Habitus, (B) bucco-pharyngeal apparatus (lateral view), (C) claws of legs IV with large dentate lunula, (D) egg shell (midsection); using phase contrast microscopy.

Table 1. Measurements of selected morphological characters of largest and smallest specimens of *Dia. i. islandicus* and eggs (all values in μm , pt ratios in brackets).

Character	Smallest Specimen	Largest Specimen
Body	550	665
Buccal tube length	56.0	62.0
Buccal tube external width	4.2 [7.5]	5.2 [8.4]
Buccal tube internal width	2.0 [3.6]	2.3 [3.7]
Stylet support insertion point	16.9 [30.2]	21.8 [35.2]
Macroplacoid row	13.4 [23.9]	20.0 [32.3]
First macroplacoid	5.8 [10.4]	9.3 [15.0]
Second macroplacoid	4.0 [7.1]	6.7 [10.8]
External claw I	9.0 [16.1]	13.2 [21.3]
Internal claw I	14.5 [25.9]	18.7 [30.2]
External claw II	9.9 [17.7]	14.0 [22.6]
Internal claw II	15.2 [27.1]	22.3 [36.0]
External claw III	10.7 [19.1]	14.3 [23.1]
Internal claw III	16.1 [28.8]	23.0 [37.1]
External claw IV	15.8 [28.2]	18.1 [29.2]
Internal claw IV	22.6 [40.4]	25.7 [41.5]
Egg diameter without processes	94	103
Diameter with processes	133	140
Process height	9.6–11.7	11.9–12.1

Type locality: Iceland [7]

With our study, we added Karabük to the provinces in Turkey in which tardigrades have been recorded and thus, increased the number from 31 to 32 (see Figure 3 and Table 2 for details).

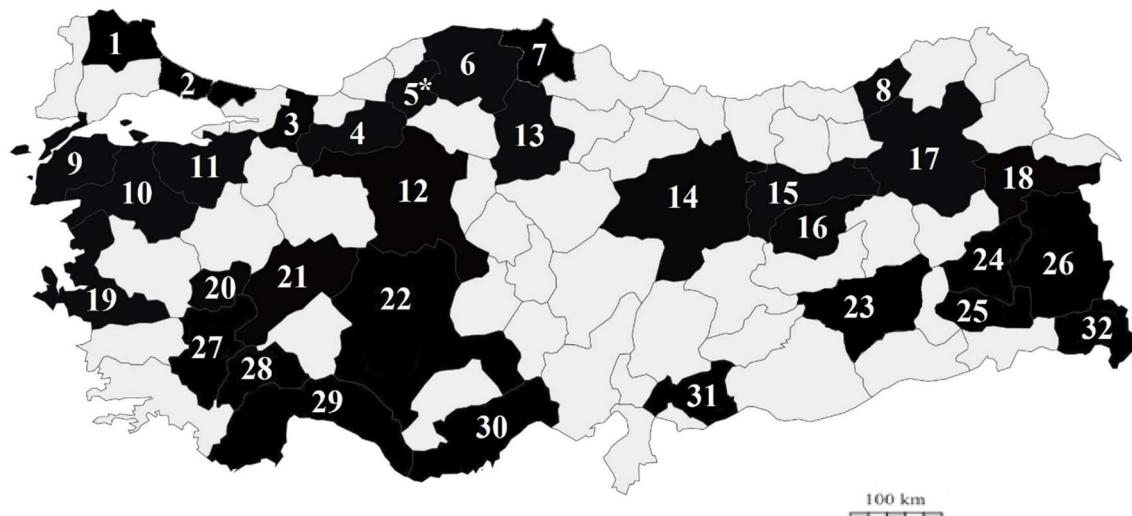


Figure 3. The map of Turkey including all tardigrade species were reported from 32 provinces (marked in dark) From left to right: 1—Kırklareli, 2—Istanbul, 3—Sakarya, 4—Bolu, 5—Karabük *, 6—Kastamonu, 7—Sinop, 8—Rize, 9—Çanakkale, 10—Balıkesir, 11—Bursa, 12—Ankara, 13—Çorum, 14—Sivas, 15—Erzincan, 16—Tunceli, 17—Erzurum, 18—Ağrı, 19—İzmir, 20—Uşak, 21—Afyonkarahisar, 22—Konya, 23—Diyarbakır, 24—Bitlis, 25—Siirt, 26—Van, 27—Denizli, 28—Burdur, 29—Antalya, 30—Mersin, 31—Gaziantep, 32—Hakkari. Kaczmarek et al. [9]’s map is revised by adding the new provinces according to new records. * New province, which was added to the map with present study.

Table 2. The final list of all reported tardigrade species (marine and terrestrial) from Turkey.

Taxa	Geographic Distribution	Localities in Turkey
1. <i>Acanthechiniscus victor</i> (Ehrenberg, 1853) [38]	Reported from many localities in Europe, North America and Greenland [36].	This species was reported from Rize/Verçenik Mountain (2606 m asl) from Turkey [39]. And is described as an alpine taxon [7].
2. <i>Bryodelphax parvulus</i> Thulin, 1928 [35]	Europe, Asia, Indonesia, Africa and N. America, S. America [36].	It was recorded from Van, Turkey [12,14].
3. <i>Cornechiniscus ceratophorus</i> (Maucci, 1973) [10]	Turkey [36].	It is endemic to Turkey. It was reported in Burdur, Antalya [10–13].
4. <i>Crn. cornutus</i> (Richters, 1907) [40]	Europe, Africa, Russia, Asia and N. America [36].	Reported from Afyonkarahisar and Erzurum [11,13].
5. <i>Crn. lobatus</i> (Ramazzotti, 1943) [41]	Europe, Russia, Asia and N. America [36].	Reported from many localities in Çorum and Sivas [11,12].
6. <i>Diaforobiotus islandicus islandicus</i> (Richters, 1904) [31]	Europe, Arctic, Africa, Asia, Indonesia and N. America [36].	This species was reported from İzmir (Dikili) [10].
7. <i>Dipodarctus subterraneus</i> (Renaud-Debyser, 1959) [42]	Faroe Islands, Malta, Bahamas, in Indian Ocean near Seychelles Maldivian Island [43,44], and Black Sea [19].	This marine species has numerous reports from the Mediterranean Sea. In Turkey, it was found the Bosphorous at İstanbul in Black Sea [19].
8. <i>Diphascon nobilei</i> (Binda, 1969) [45]	Europe, Russia, Australia and N. America [36].	It was found in İzmir (Dikili) [12].
9. <i>Doryphoribus flavus</i> (Iharos, 1966) [46]	Europe, Africa, Asia and Central America [36].	Recorded at Ankara, Turkey [10].

Table 2. Cont.

Taxa	Geographic Distribution	Localities in Turkey
10. <i>Echiniscus blumi blumi</i> Richters, 1903 [47]	Reported from a few localities in Europe (Italy, Spain, Scotland, Switzerland, Turkey, Hungary, Greece) and N. America [36].	It was reported from Ankara, Erzincan, and Van, Turkey [10,12,16]. As <i>Ech. blumi blumi</i> and as <i>Ech. medianus</i> Marcus, 1930 [48] which is synonym of <i>Ech. blumi blumi</i> according to Gasiorek et al. [49].
11. <i>Ech. canadensis</i> Murray, 1910 [50]	Europe, Africa, Asia, North and South America [36].	It was reported from many localities from Turkey. Afyonkarahisar, Ağrı, Ankara, Bitlis, Çanakkale, Erzincan, İzmir, Kırklareli, Uşak, Van [10–12,16].
12. <i>Ech. columinis</i> Murray, 1911 [51]	Europe and China [36].	This palearctic species. It was only reported from Küçükkyü/Çanakkale, Turkey [12].
13. <i>Ech. dikenli</i> Maucci, 1973 [10]	Turkey [36].	This endemic species was originally collected in Afyonkarahisar, Turkey [10–12].
14. <i>Ech. granulatus</i> (Doyère, 1840) [30]	Europe, Africa, Asia, Indonesia and N. America [36].	This species, reported from mountain and submountain regions [52] has been recorded from Bolu, Burdur, Çorum, Erzurum, Kastamonu, Sivas, Van [10–12,14], and now, in addition, from Karabük (this study).
15. <i>Ech. merokensis merokensis</i> Richters, 1904 [53]	Europe, Africa, Asia, Russia, N. America and S. America [36].	It was reported from İzmir, Turkey [10,12].
16. <i>Ech. merokensis suecicus</i> Thulin, 1911 [54]	Reported from many localities in Europe, Africa and N. America [36].	Reported from Bursa/Uludağ Mountain at 2200 m asl [10,12].
17. <i>Ech. osellai</i> Maucci, 1975 [11]	Turkey [36].	This endemic species has only reported from Antalya, Turkey [11,12].
18. <i>Ech. testudo</i> (Doyère, 1840) [30]	Europe, Africa, Asia, N. America and S. America [9,12,36,55,56].	It is cosmopolitan species. It was found in several localities in Afyonkarahisar, Ağrı, Antalya, Bitlis, Burdur, Çorum, Denizli, Diyarbakır, Erzincan, Erzurum, Gaziantep, Hakkari, Kastamonu, Mersin, Siirt, Sivas, Van and Konya, Turkey [10,11,17].
19. <i>Ech. trisetosus</i> Cuénot, 1932 [57]	Europe, Africa, Asia and N. America [36].	It was reported from Afyonkarahisar, Ağrı, Ankara, Balıkesir, Çanakkale, Çorum, Diyarbakır, Erzurum, Hakkari, İzmir, Kırklareli, Siirt, Uşak, Van, Turkey [10–12,16,17].
20. <i>Ech. trojanus</i> Maucci, 1973 [10]	Turkey [36].	This endemic species\was originally reported from Çanakkale, İzmir, Turkey [10–12].
21. <i>Grevenius sismicus</i> (Maucci, 1978) [12]	Turkey and India [36].	It was reported from Van, Turkey [12,14].
22. <i>Hypsibius convergens</i> (Urbanowicz, 1925) [58]	Reported from many localities all over the world [36].	This cosmopolitan species group requires the majority of records to be confirmed [9,59]. It has been reported from İzmir, Turkey [11,12].
23. <i>Hys. microps</i> Thulin, 1928 [35]	Widespread throughout the world [36].	This species is considered cosmopolitan, but a species group the majority of records need to be confirmed [9,59]. It has been reported from İzmir and Mersin, Turkey [11,12].
24. <i>Isohypsibius macrodactylus</i> (Maucci, 1978) [12]	Italy, Turkey, Cyprus, Caucasus and Africa [36,60].	A holarctic species was reported from Ağrı and Van, Turkey [9,12,14,36].
25. <i>Iso. prosostomus</i> Thulin, 1928 [35]	Reported from many localities in Europe, Russia, Africa, Indonesia, N. America and S. America [36].	Considered cosmopolitan, this species need to be re-described [9]. Reported from Ankara, Bolu, İzmir, Erzincan and Kastamonu, Turkey [10–12].
26. <i>Itaquascon placophorum</i> Maucci, 1973 [10]	A few localities from Europe [36].	It was originally described from Ankara and Sakarya, Turkey [10–12].

Table 2. Cont.

Taxa	Geographic Distribution	Localities in Turkey
27. <i>Macrobiotus crenulatus</i> Richters, 1904 [53]	Europe, Russia and N. America [36].	Reported from Ankara. However, this species' presence in Turkey needs to be confirmed [9,18,61].
28. <i>Mac. echinogenitus</i> Richters, 1904 [53]	Europe, Russia, Arctic, Africa, Asia, Indonesia, Australia, New Zealand, N. America, Central America, S. America, Atlantic and Antarctica [36].	Considered a cosmopolitan species group, it was reported from Ankara [12]. This species' presence in Turkey needs to be verified [61].
29. <i>Mac. hufelandi</i> C.A.S. Schultze, 1834 [62]	Europe, Russia, Africa, Asia, Indonesia, Australia, New Zealand, Pacific, N. America, Central America, S. America and Antarctica [36].	A cosmopolitan species group that has been reported from Afyonkarahisar, Ankara, Antalya, Balikesir, Bolu, Burdur, Denizli, Izmir, Kırklareli, Sakarya, Turkey [10,11].
30. <i>Mac. pallarii</i> Maucci, 1954 [63]	Europe, Asia and N. America [36].	Reported from three localities: Bolu, Kastamonu, Tunceli, Turkey [10–12].
31. <i>Mac. persimilis</i> Binda and Pilato, 1972 [64]	Europe, Africa, Australia and N. America [36].	Recorded from Balikesir, Bolu, Diyarbakır, Erzincan, Sakarya, Uşak, Van, Turkey [12,14]. (Needs to be confirmed) [9].
32. <i>Mac. spectabilis</i> Thulin, 1928 [35]	Europe, Turkey, Russia, N. America and S. America [36].	Reported from the Verçenik Mountain/Rize, Turkey [39].
33. <i>Megastygarctides sezginii</i> Ürkmez, Ostrowska, Roszkowska, Gawlak, Zawierucha, Kristensen and Kaczmarek, 2017 [20]	Black Sea in Turkey [20].	Originally described from Sinop Bay, Turkey (Southern Black Sea) [20].
34. <i>Mesobiotus harmsworthi</i> (Murray, 1907) [65]	Europe, Russia, Africa, Asia, Australia, Indonesia, New Zealand, N. America, Central America, S. America, Atlantic, Pacific and Antarctica [36].	Cosmopolitan species, known from many localities throughout the world. It was found from Ağrı, Antalya, Bolu, Burdur, Bursa, Çorum, İzmir Kastamonu and Rize, Turkey [10–12,39].
35. <i>Meb. nuragicus</i> (Pilato and Sperlinga, 1975) [66]	Europe, Asia and Indonesia [36].	Reported from Gaziantep, Turkey [12].
36. <i>Meb. reinhardtii</i> (Michalczyk and Kaczmarek, 2003) [67]	Cyprus and Turkey [9,67].	Reported from Konya, Turkey [9].
37. <i>Meb. stellaris</i> (du Bois-Reymond Marcus, 1944) [68]	Turkey, Greece and S. America (Brazil) [36].	Recorded from Antalya, Turkey [11,12].
38. <i>Milnesium beasleyi</i> Kaczmarek, Jakubowska and Michalczyk, 2012 [9]	Turkey [9].	It is endemic species which was originally reported from Konya, Turkey [9].
39. <i>Minibiotus intermedius</i> (Plate, 1888) [69]	Europe, Russia, Africa, Asia, Indonesia, Australia, New Zealand, Pacific, N. America, Central America, S. America, Indian and Antarctica [36].	A cosmopolitan species group that has been reported from Ankara, Turkey [10–12].
40. <i>Paramacrobiotus areolatus</i> (Murray, 1907) [65]	Europe, Africa, Asia, Indonesia, Australia, New Zealand, N. America, Central America and Atlantic [36].	A cosmopolitan species group with an obscure their geographic distribution. It was reported from Uşak, Turkey [12].
41. <i>Pam. richtersi</i> (Murray, 1911) [51]	Europe, Africa, Asia, Australia, New Zealand, N. America, Central America and S. America [36].	A cosmopolitan species group reported from many localities in Turkey, including the provinces: Ankara, Antalya, Burdur, Çanakkale, Konya, Rize, İzmir, Van [9–11,14,39].
42. <i>Parechiniscus chitonides</i> Cuénot, 1926 [70]	Europe, Russia and Africa [36].	This palearctic species has been reported from Burdur and Antalya, Turkey [10–12].
43. <i>Pilatobius patanei</i> (Binda and Pilato, 1971) [71]	Reported from Sicily and Turkey [36].	This species was reported from an unidentified area in Anatolia [72].

Table 2. Cont.

Taxa	Geographic Distribution	Localities in Turkey
44. <i>Pseudochiniscus facettalis</i> Petersen, 1951 [73]	Europe, Africa, New Zealand, N. America and S. America [36].	Reported from İzmir, Turkey [10–12].
45. <i>Pse. megacephalus</i> Mihelčič, 1951 [74]	Turkey and Austria [36].	Only reported from Ankara, Turkey [10–12].
46. <i>Pse. ramazzottii ramazzottii</i> Maucci, 1952 [75]	Europe, Russia, North and South America [36].	Recorded from the Verçenik Mountain/Rize, Turkey [39].
47. <i>Pse. suillus</i> (Ehrenberg, 1853) [38]	Europe, Arctic, Africa, Asia, Indonesia, Indian, Australia, New Zealand, Pacific, N. America, Canada, Central America, S. America and Antarctica [36].	Described as a cosmopolitan species group, this species was reported from Ankara and İzmir, Turkey [10].
48. <i>Ramazzottius oberhaeuseri</i> (Doyère, 1840) [30]	Europe, Greenland, the Arctic and Antarctic, North and South America, Africa and New Zealand [36].	A cosmopolitan species group that has been reported, from numerous locations in Turkey, including the provinces: Afyonkarahisar, Ağrı, Ankara, Antalya, Bolu, Çorum, Erzincan, Erzurum, Hakkari, Gaziantep, Kastamonu, Kırkareli, Uşak, Konya, Tunceli, Van and Rize [9–12,17,39]. However older records of this species need to be verified [9].
49. <i>Richtersius coronifer</i> (Richters, 1903) [47]	Europe, Arctic, Africa, Asia, N. America and S. America [36].	Reported from Ağrı, Çorum, İzmir and Van, Turkey [11,14].
50. <i>Tanarctus ramazzottii</i> Renaud-Mornant, 1975 [76]	Gulf of Biscaglia, Coast of Britain, Mediterranean Sea [7,43] and Black Sea in Turkey [19].	In Turkey, it has been reported from the Bosphorus of İstanbul in the Black Sea [19].
51. <i>Tenuibiotus hystricogenitus</i> (Maucci, 1978) [12]	Turkey, Germany, Greece [36].	It was recorded from Çorum and Erzurum, Turkey [12].
52. <i>Ursulinius duranteae</i> (Maucci, 1978) [12]	Turkey [36].	This endemic species was originally reported from Ağrı, Erzurum and Gaziantep, Turkey [12].
53. <i>Urs. josephi</i> (Iharos, 1964) [77]	Europe [36].	It was only recorded from Van, Turkey [12,14].
54. <i>Urs. leithaicus</i> (Iharos, 1966) [46]	A few localities in Europe (Austria, Finland, Hungary) and Turkey [36].	Reported from Van, Turkey [12].
55. <i>Urs. torulosus</i> (Mihelčič, 1959) [78]	Turkey and Austria [36].	Reported from İzmir, Turkey [11,12].

4. Discussion

We found *Dia. i. islandicus* (Richters, 1904) [31] in the province of Karabük, which is located in the Black Sea Region. It had previously been reported from İzmir, located in the Aegean Region of Turkey. This species has been identified from many localities in Europe, Africa, Indonesia, and North America [36].

Generally associated with limestone and alkaline bedrock, *Ech. granulatus* (Doyère, 1840) [30] has been reported from many localities in Europe, Africa, Caucasus, Georgia, Asia, Indonesia and North America [10–12,14,36,79]. Before our study, it had previously been reported from the provinces of Burdur, Bolu, Çorum, Erzurum, Kastamonu, Sivas, and Van in Turkey [36]. In the Poland, the species has been reported as a mountainous and sub-mountainous species and recorded between 500 and 1000 m asl on alkaline bedrocks [52]. In Turkey, this species was found in Çeltikçi Beli, Ilgaz Mountain, Boğazkale, Yıldızeli and Horasan regions [12]. Mostly usually recorded from 1000 m asl or above [10], this species has also been reported from the Trestede Karst plateau, in Italy, at between 200 to 300 m asl [10].

Although taxonomic and biogeographic studies on caves harboring tardigrades have been conducted for many years, there is still poor knowledge of their patterns of diversity. Only a

few published papers center upon investigation for cave tardigrades. In 1996, *Astatatum trinacriae* (Arcidiacono, 1962) [80] was collected from the entrance of a cave located in Menglun, China [81]. *Doryphoribus smokiensis* Bartels, Nelson, Kaczmarek and Michalczyk, 2007 [82], *Dor. longistipes* Bartels, Nelson, Kaczmarek and Michalczyk, 2008 [83], and *Dor. minimus* Bartels, Nelson, Kaczmarek and Michalczyk, 2008 [83] were reported from the caves in the Great Smoky Mountains National Park in North America. In 2008, *Minibiotus formosus* Zawierucha, Dziamięcki, Jakubowska, Michalczyk and Kaczmarek, 2014 [84] has been collected from Gutmana Cave in the Gauja National Park [84]. In addition, Bartels et al. [85] described *Mac. martini* Bartels, Pilato, Lisi and Nelson, 2009 [86] from Gregorys Cave, North America. Nevertheless, one could think that cave invertebrates are more suitable for analysis, as the number of species is very low in comparison with to above ground habitats [5].

Up to now, tardigrades have been reported from 32 of the 82 Turkish provinces (see Table 2 for details). Among them, ten species have been described as endemic to Turkey (i.e., *Cor. ceratophorus* (Maucci, 1973) [10], *Ech. dikenli* Maucci, 1973 [10], *Ech. osellai* Maucci, 1975 [11], *Ech. trojanus* Maucci, 1973 [10], *Urs. duranteae* (Maucci, 1978) [12], *Iso. macrodactylus* (Maucci, 1978) [12], *Gre. sismicus* (Maucci, 1978) [12], *Mil. beasleyi* Kaczmarek, Jakubowska and Michalczyk, 2012 [9], *Ita. placophorum* Maucci, 1973 [10] and *Ten. hystricogenitus* (Maucci, 1978) [12]). In total, 54 valid species and one subspecies have been reported from Turkey. This number is quite inadequate when compared with other countries of smaller area (e.g., Romania ca 128, Poland ca. 102 and Italy ca. 233) [9,86–89]. Therefore, more samples are required to increase knowledge about distribution of tardigrades in Turkey.

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References

1. Uzun, A.; Zeybek, H. Akçakale Mağarası (Gümüşhane). *TCD* **1996**, *31*, 39–53. [[CrossRef](#)]
2. Aygen, T.; Demirel, S. *Mağaralar ve Yeraltı Irmakları*; DSİ Matbaası: Ankara, Turkey, Speleoloji, 1959.
3. Sür, A. Karstik Yerçekilleri ve Türkiye'den örnekler. *TÜCAUM* **1994**, *3*, 1–28.
4. Novak, T.; Perc, M.; Lipovšek, S.; Janžekovič, F. Duality of terrestrial subterranean fauna. *Int. J. Speleol.* **2012**, *41*, 181–188. [[CrossRef](#)]
5. Culver, D.C.; Deharveng, L.; Bedos, A.; Lewis, J.J.; Madden, M.; Reddell, J.R.; Sket, B.; Trontelj, P.; White, D. The mid-latitude biodiversity ridge in terrestrial cave fauna. *Ecography* **2006**, *29*, 120–128. [[CrossRef](#)]
6. Nelson, D.R.; Guidetti, R.; Rebecchi, L. Phylum Tardigrada. In *Thorp and Covich's Freshwater Invertebrates*, 4th ed.; Thorp, J.H., Rogers, D.C., Eds.; Elsevier: Amsterdam, The Netherlands, 2015; pp. 347–380.
7. Ramazzotti, G.; Maucci, W. Il Phylum Tardigrada. Terza edizione riveduta e corretta. *Mem. Ist. Ital. Idrobiol. Dott. Marco Marchi* **1983**, *41*, 1–1012.
8. Degma, P.; Guidetti, R.; Bertolani, R. *Actual Checklist of Tardigrada Species*, 36th ed.; Università di Modena e Reggio Emilia: Modena, Italy, 2019. [[CrossRef](#)]
9. Kaczmarek, Ł.; Jakubowska, N.; Michalczyk, Ł. Current knowledge on Turkish tardigrades with a description of *Milnesium beasleyi* sp. nov. (Eutardigrada: Apochela: Milnesiidae, the *granulatum* group). *Zootaxa* **2012**, *3589*, 49–64. [[CrossRef](#)]
10. Maucci, W. Tardigradi muscoli della Turchia. *Mem. Mus. Civ. St. Nat. Verona* **1973**, *20*, 169–221.
11. Maucci, W. Tardigradi muscoli della Turchia (secondo contributo). *Boll. Mus. Civ. St. Nat. Verona* **1975**, *1*, 255–275.

12. Maucci, W. Tardigradi muscoli della Turchia (Terzo contributo). *Boll. Mus. Civ. St. Nat. Verona* **1978**, *5*, 111–140.
13. Maucci, W. I *Pseudechiniscus* del gruppo *cornutus*, con descrizione di una nuova specie (Tardigrada, Echiniscidae). *Zesz. Nauk. Univ. Jagellon. Prace Zool.* **1979**, *25*, 107–124.
14. Maucci, W. Analisi preliminare di alcuni dati statistici sulla ecologia dei tardigradi muscolari. *Boll. Mus. Civ. St. Nat. Verona* **1980**, *7*, 1–47.
15. Maucci, W. Analisi di alcune biocenosi relative a tardigradi muscolari. *Boll. Mus. Civ. St. Nat. Verona* **1981**, *8*, 67–83.
16. Maucci, W. Materiali per una revisione del genere *Echiniscus* Schultze, 1840. I: Il complesso *blumi* (Heterotardigrada, Echiniscidae). *Boll. Mus. Civ. St. Nat. Verona* **1985**, *12*, 109–139.
17. Morgan, C.I. *An Annotated Catalogue of Tardigrada in the Collections of the Royal Scottish Museum, Edinburgh*; Royal Scottish. Museum Information Series, Natural History: Edinburg, Scotland, 1977; Volume 5, pp. 1–29. ISSN 0307-5036.
18. Binda, M. Redescrizione di *Macrobiotus echinogenitus* Richters, 1904 e sul valore di buona specie di *Macrobiotus crenulatus* Richters, 1904 (Eutardigrada). *Animalia* **1988**, *15*, 201–210. [CrossRef]
19. Kharkevych, K.O.; Sergeeva, N. Deep-water Tardigrada of the Istanbul Strait's (Bosporus) outlet area of the Black Sea. *Vestn. Zool.* **2013**, *47*, 17–27. [CrossRef]
20. Ürkmez, D.; Ostrowska, M.; Roszkowska, M.; Gawlak, M.; Zawierucha, K.; Kristensen, R.M.; Kaczmarek, Ł. Description of *Megastygarctides sezginii* sp. nov. (Tardigrada: Arthrotardigrada: Stygarctidae) from the Turkish Black Sea coast and a key to the genus *Megastygarctides*. *Mar. Biol. Res.* **2018**, *14*, 1–16. [CrossRef]
21. Schultze, C.A.S. *Echiniscus bellermannii*, Animal Crustaceum, *Macrobiotus hufelandii* Affine. *Apud G. Reimer Berl.* **1840**, 1–8.
22. Guidetti, R.; Rebecchi, L.; Bertolani, R.; Jönsson, K.I.; Møbjerg Kristensen, R.; Cesari, M. Morphological and molecular analyses on *Richtersius* (Eutardigrada) diversity reveal its new systematic position and lead to the establishment of a new genus and a new family within Macrobiotoidea. *Zool. J. Linn. Soc. Lond.* **2016**, *178*, 834–845. [CrossRef]
23. Haner, B.; Yılmaz, A.; Kürkçüoğlu, M.E.; Karadem, A. Mencilis (Bulak) mağarasında radon seviyesi ölçümleri. *SDÜFENBED* **2010**, *14*, 218–224. [CrossRef]
24. Özdemir, Ü. Mencilis Mağarası. *DCD* **2005**, *10*, 135–150.
25. Cetin, M.; Sevik, H.; Saat, A. Indoor air quality: The samples of Safranbolu Bulak Mencilis Cave. *Fresen. Environ. Bull.* **2017**, *26*, 5965–5970.
26. Dastych, H. *Niesporczaki (Tardigrada) Tatrzanskiego Parku Narodowego*; Naukowe, W.P., Ed.; Polska Akademia. Nauk. Monografie. Fauna Polski: Kraków, Poland, 1980; Volume 9, pp. 1–232.
27. Stec, D.; Smolak, R. An integrative description of *Macrobiotus paulinae* sp. nov. (Tardigrada: Eutardigrada: Macrobiotidae: *Hufelandi* group) from Kenya. *Zootaxa* **2015**, *4052*, 501–526. [CrossRef] [PubMed]
28. Perry, E.; Miller, W.R.; Kaczmarek, Ł. Recommended abbreviations for the names of genera of the phylum Tardigrada. *Zootaxa* **2019**, *4608*, 145–154. [CrossRef] [PubMed]
29. Guidetti, R.; Schill, R.; Bertolani, R.; Dandekar, T.; Wolf, M. New molecular data for tardigrade phylogeny, with the erection of *Paramacrobiotus* gen. nov. *J. Zool. Syst. Evol.* **2009**, *47*, 315–321. [CrossRef]
30. Doyère, L.M.F. Mémoire sur les Tardigrades. *Ann. Sci. Nat. Zool.* **1840**, *14*, 269–362.
31. Richters, F. Isländische Tardigraden. *Zool. Anz.* **1904**, *28*, 373–377.
32. Spallanzani, L. *Opuscules de Physique Animale et Végétale*; Chirol, B., Ed.; Geneva, 1777; Volume 1, pp. 1–220. Available online: <https://archive.hshsl.umaryland.edu/handle/10713/3327> (accessed on 5 March 2020).
33. Marcus, E. Zur Anatomie und Ökologie mariner Tardigraden. *Zool. Jahrb. Abt. Syst. Ökol. Geogr. Tiere* **1927**, *53*, 487–558.
34. Richters, F. Tardigrada. In *Handbuch der Zoologie*. Vol. by Kükenthal, W. and Krumbach, T.; de Gruyter, W., Ed.; Walter de Gruyter & Co.: Leipzig/Berlin, Germany, 1926; Volume 3, pp. 58–61.
35. Thulin, G. Über die Phylogenie und das System der Tardigraden. *Hereditas* **1928**, *11*, 207–266. [CrossRef]
36. McInnes, S.J. Zoogeographic distribution of terrestrial/freshwater tardigrades from current literature. *J. Nat. Hist.* **1994**, *28*, 257–352. [CrossRef]
37. Guil, N.; Jørgensen, A.; Kristensen, R. An upgraded comprehensive multilocus phylogeny of the Tardigrada tree of life. *Zool. Scripta* **2019**, *48*, 120–137. [CrossRef]
38. Ehrenberg, C.G. Diagnoses novarum formarum. *Ber. Akad. Wiss. Berl.* **1853**, *8*, 526–533.

39. Cagri, T.; Duygu, B.; Seyda, E.F.; Gurbuzer, P.; Altindag, A. New Records for Tardigrada Species from the High Mountain Region in Turkey (Mount Verçenik, Rize). *J. Limnol. Freshw. Fish. Res.* **2019**. [[CrossRef](#)]
40. Richters, F. Zwei neue *Echiniscus*-Arten. *Zool. Anz.* **1907**, *31*, 197–202.
41. Ramazzotti, G. Nuova varietà del Tardigrado *Pseudechiniscus cornutus*. *Riv. Sci. Nat. Nat.* **1943**, *34*, 89–90.
42. Renaud-Debyser, J. Études sur la faune interstitielle des Iles Bahamas. III. Tardigrades. *Bull. Lab. Arago. Univ. Paris* **1959**, *10*, 296–302.
43. De Zio Grimaldi, S.; D'Addabbo, M.G.; Sandulli, R.; D'Addabbo, R. Checklist of the Italian marine Tardigrada. *Meiofauna Mar.* **2003**, *12*, 97–135.
44. Gallo, M.; D'addabbo, R.; De Leonardi, C.; Sandulli, R.; Grimaldi, S.D.Z. The diversity of Indian Ocean Heterotardigrada. *J. Limnol.* **2007**, *66*, 60–64. [[CrossRef](#)]
45. Binda, M.G. Nuovi dati su tardigradi di Sicilia con descrizione di due nuove specie. *Boll. Accad. Gioenia Sci. Nat. Catania* **1969**, *9*, 623–633.
46. Iharos, G. Neue Tardigraden-Arten aus Ungarn. *Acta Zool. Acad. Sci. Hung.* **1966**, *12*, 111–122.
47. Richters, F. Nordische Tardigraden. *Zool. Anz.* **1903**, *27*, 168–172.
48. Marcus, E. Beiträge zur Tardigraden systematik. *Zool. Jahrb. Abt. Anat. Ontog. Tiere* **1930**, *59*, 363–386.
49. Gašiorek, P.; Vončina, K.; Michalczyk, Ł. *Echiniscus testudo* (Doyère, 1840) in New Zealand: Anthropogenic dispersal or evidence for the ‘Everything is Everywhere’ hypothesis? *New Zealand J. Zool.* **2019**, *46*, 174–181. [[CrossRef](#)]
50. Murray, J. British Antarctic expedition 1907–1909, Reports on the scientific investigations. *Biology* **1910**, *1*, 83–187.
51. Murray, J. Arctiscoidea. *Proc. R. Ir. Acad.* **1911**, *31*, 1–16.
52. Dastych, H. The Tardigrada of Poland. *Monogr Fauny Pol.* **1988**, *16*, 1–255.
53. Richters, F. Arktische Tardigraden. *Fauna Arct.* **1904**, *3*, 495–508.
54. Thulin, G. Beitrag zur Kenntnis der Tardigraden fauna Schwedens. *Ark. Zool.* **1911**, *7*, 1–60.
55. Jørgensen, A.; Møbjerg, N.; Kristensen, R.M. A molecular study of the tardigrade *Echiniscus testudo* (Echiniscidae) reveals low DNA sequence diversity over a large geographical area. *J. Limnol.* **2007**, *66*, 77–83. [[CrossRef](#)]
56. McInnes, S.J.; Michalczyk, Ł.; Kaczmarek, Ł. Annotated zoogeography of non-marine Tardigrada: Part IV: Africa. *Zootaxa* **2017**, *4284*, 1–74. [[CrossRef](#)]
57. Cuénot, L. Tardigrades. In *Faune de France*; Lechevalier, P., Ed.; Fédération Française des Sociétés de Sciences Naturelles: Paris, Frances, 1932; Volume 24, pp. 1–96.
58. Urbanowicz, C. Sur la variabilité de *Macrobiotus oberhaeuseri*. *Bull. Biol. Fr.* **1925**, *59*, 124–142.
59. Kaczmarek, Ł.; Michalczyk, Ł. Redescription of *Hypsibius microps* Thulin, 1928 and *H. pallidus* Thulin, 1911 (Eutardigrada: Hypsibiidae) based on the type material from the Thulin collection. *Zootaxa* **2009**, *2275*, 60–68. [[CrossRef](#)]
60. Tekatli, C.; Altindag, A. New Records for Tardigrada from Cyprus. *North West. J. Zool.* **2017**, *13*, 356–358.
61. Maucci, W. Tardigrada. *Fauna Ital. Bologna Calderini* **1986**, *24*, 1–388.
62. Schultze, K.A.S. *Macrobiotus Hufelandii, Animal e Crustaceorum Classe Novum, Reviviscendi Post Diurnam Asphyxiā et Ariditatem Potens*; Curths, C.A., Ed.; Apud Carolus Curths: Berlin, Germany, 1834; pp. 165–169.
63. Maucci, W. Tardigradi nuovi della fauna italiana. *Boll. Soc. Geol. Ital.* **1954**, *93*, 576–585.
64. Binda, M.G.; Pilato, G. Tardigradi muscicoli di Sicilia (IV Nota). *Boll. Sedute. Accad. Gioenia. Sci. Nat. Catania* **1972**, *11*, 47–60.
65. Murray, J. XXV—Arctic Tardigrada, collected by Wm. S. Bruce. *Earth Environ. Sci. Trans. R. Soc. Edinb.* **1907**, *45*, 669–681. [[CrossRef](#)]
66. Pilato, G.; Sperlinga, G. Tardigradi muscicoli di Sardegna. *Animalia* **1975**, *2*, 79–90.
67. Michalczyk, Ł.; Kaczmarek, Ł. A description of the new tardigrade *Macrobiotus reinhardtii* (Eutardigrada: Macrobiotidae, *harmsworthi* group) with some remarks on the oral cavity armature within the genus *Macrobiotus* Schultze. *Zootaxa* **2003**, *331*, 1–24. [[CrossRef](#)]
68. Du Bois-Reymond Marcus, E. Sobre tardigrados Brasileiros. *Com. Zool. Mus. Montev.* **1944**, *1*, 1–19.
69. Plate, L. Beiträge zur Naturgeschichte der Tardigraden. *Zool. Jahrb.* **1888**, *3*, 487–550. [[CrossRef](#)]
70. Cuénot, L. Description d'un tardigrade nouveau de la faune française. *C. R. Acad. Sci. III* **1926**, *182*, 744–745.
71. Binda, M.; Pilato, G. Nuove osservazioni sui Tardigradi delle Isole Eolie. *Boll. Sedute Accad. Gioenia Sci. Nat. Catania* **1971**, *10*, 766–774.

72. Binda, M.G.; Pilato, G. Le attuali conoscenze sulla fauna tardigradologica di alcune piccole isole circumsiciliane. *Lav. So. Ital. Biogeogr.* **1973**, *3*, 1–7.
73. Petersen, B. The Tardigrade fauna of Greenland. A faunistic study with some few ecological remarks. *Medd. Grønl.* **1951**, *150*, 5–94.
74. Mihelcic, F. Beitrag zur Systematik der Tardigraden. *Arch. Zool. Ital.* **1951**, *36*, 57–103.
75. Maucci, W. Un nuova *Pseudechiniscus* del Carso Triestino (Tardigrada, Scutechiniscidae). *Atti Soc. Ital. Sci. Nat.* **1952**, *91*, 127–130.
76. Renaud-Mornant, J. Occurrence of the Genus *Tanarctus* Renaud-Debyser, 1959 in North Eastern Atlantic waters with a description of *T. ramazzottii* n. sp. (Arthrotardigrada). *Mem. Ist. Ital. Idrobiol. Pallanza* **1975**, *32*, 325–332.
77. Iharos, G. Neuere Beiträge zur Kenntnis der Tardigraden-Fauna Ungarns. V. *Opusc. Zool. Bp.* **1964**, *5*, 57–67.
78. Mihelcic, F. Zwei neue Tardigraden aus der Gattung *Hypsibius* Thulin aus Osttirol (Österreich). Systematisches zur Gattung *Hypsibius* Thulin. *Zool. Anz.* **1959**, *163*, 254–261.
79. Zawierucha, K.; Kolicka, M.; Cytan, J. Contribution to the knowledge on the distribution of *Echiniscus granulatus* (Doyère, 1840) (Heterotardigrada) in Poland. *Bad. Fizjogr. Ser. C. Zool.* **2013**, *53*, 39–43. [[CrossRef](#)]
80. Arcidiacono, R. Contributo alla conoscenza dei Tardigradi dei Monti Nebrodi e descrizione di una nuova specie di *Itaquascon*. *Boll. Sedute Accad. Gioenia Sci. Nat. Catania* **1962**, *7*, 123–134.
81. Beasley, C.W.; Cleveland, A. Tardigrada from southern Yunnan province, People's Republic of China. *Zool. J. Linn. Soc.* **1996**, *116*, 239–243. [[CrossRef](#)]
82. Bartels, P.J.; Nelson, D.R.; Kaczmarek, Ł.; Michalczyk, Ł. *Doryphoribus smokiensis*, a new species of Eutardigrada (Hypsibiidae) from the Great Smoky Mountains National Park, TN, USA (North America). *Zootaxa* **2007**, *1646*, 59–65. [[CrossRef](#)]
83. Bartels, P.J.; Nelson, D.R.; Kaczmarek, Ł.; Michalczyk, Ł. Three new species and one new record of the genus *Doryphoribus* Pilato, 1969 (Tardigrada: Eutardigrada: Hypsibiidae) from the Great Smoky Mountains National Park (Tennessee, USA). *J. Nat. Hist.* **2008**, *42*, 2595–2608. [[CrossRef](#)]
84. Zawierucha, K.; Dziambięcki, J.; Jakubowska, N.; Michalczyk, Ł.; Kaczmarek, Ł. New tardigrade records for the Baltic states with a description of *Minibiotus formosus* sp. n. (Eutardigrada, Macrobiotidae). *ZooKeys* **2014**, *408*, 81–105. [[CrossRef](#)]
85. Bartels, P.J.; Pilato, G.; Lisi, O.; Nelson, D.R. *Macrobiotus* (Eutardigrada, Macrobiotidae) from the Great Smoky Mountains National Park, Tennessee/North Carolina, USA (North America): Two new species and six new records. *Zootaxa* **2009**, *2022*, 45–57. [[CrossRef](#)]
86. Ciobanu, D.A.; Moglan, I.; Zawierucha, K.; Kaczmarek, Ł. New records of terrestrial tardigrades (Tardigrada) from Ceahlău National Park with zoogeographical and taxonomical remarks on Romanian water bears. *North West. J. Zool.* **2014**, *10*, 5–21.
87. Nowak, B.; Stec, D. The first record of *Macrobiotus vladimiri* Bertolani, Bisarov, Rebecchi and Cesari, 2011 (Tardigrada: Eutardigrada: Macrobiotidae: *Hufelandi* group) from Poland. *Turk. J. Zool.* **2017**, *41*, 558–567. [[CrossRef](#)]
88. Kaczmarek, Ł.; Gołdyn, B.; Czyż, M.; Michalczyk, Ł. First records of *Isohypsibius pushkini* Tumanov, 2003 (Tardigrada, Eutardigrada, Hypsibiidae) from Poland. *Biol. Lett.* **2010**, *47*, 81–85. [[CrossRef](#)]
89. Roszkowska, M.; Ostrowska, M.; Grobys, D.; Kmita, H.; Kaczmarek, Ł. Some Tardigrades from Italy, with an updated checklist of limno-terrestrial species from the country. *Acta. Zool. Bulg.* **2019**, *71*, 167–174.



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