

NEW EARTHWORM SPECIES FROM JORDAN (OLIGOCHAETA, LUMBRICIDAE)

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Elaborating a new material from Jordan resulted in describing two species *Dendrobaena alexandrii* and *Dendrobaena transjordanica* new to science and a new record for the country. The updated list of earthworms reports 20 species recorded in the Hashemite Kingdom of Jordan. Out of all recorded species 9–12 species (45–60%) are autochthonous and 8–11 species (40–55%) are introduced.

Key words: earthworms, Jordan, *Dendrobaena*, new species, new records.

INTRODUCTION

The earthworm fauna of the Hashemite Kingdom of Jordan is poorly-known. The first earthworm records from here were published by ROSA (1893). Since ROSA's publication only two short papers dealt with the earthworms of Jordan written by CSUZDI and PAVLÍČEK (2005a) and PAVLÍČEK and CSUZDI (2006). In these two papers occurrence of 18 species was reported. Among them, nine species represented new records for the country and a new subspecies *Dendrobaena orientalis karak* Csuzdi et Pavlíček, 2005 was also described. The small number of earthworm species present in Jordan, especially in a comparison with the 33 species recorded for Israel, could result either from the extinctions caused by severe and increasing aridisation in the last several thousand years in the Saharo–Syrian desert belt and/or by lack of proper sampling in the region (PAVLÍČEK & CSUZDI 2006). Here, we demonstrate that the lack of proper sampling is at least partially responsible for the seemingly impoverished earthworm fauna of Jordan. The short collecting trip organised to collect earthworms in NW Jordan in the spring of 2007 resulted in discovering two earthworm species new to science and new records of several little known endemic earthworm species hereinafter presented.

MATERIAL AND METHODS

Earthworms were collected by the diluted formalin method (RAW 1959) and by digging and hand-sorting. A combination of these methods provides more efficient sampling of lumbricid earthworms. Specimens gathered were immediately killed in 75% ethanol, fixed in 4% formalin, and transferred to 75% ethanol after several days. The collecting sites com-

prised a mixture of the natural and semi-natural (i.e., pastures) semiarid and arid biotopes of the Hashemite Kingdom of Jordan. The field collections were carried out by T. Pavlíček.

Histological studies were conducted on several postclitellar segments. The analysed 10 µm wide microscopic cross-sections, stained with hematoxylin and eosin (KRUTSAY 1980), were sliced, by using a Microm rotary-microtome, from segments embedded in paraffin. The genital setae were removed by dorsal dissecting of the studied specimens and mounted in Euparal for light microscopic study. Microscopic photos were taken by a Nikon Coolpix 990 digital camera attached to a Nikon E660 DIC microscope.

Valid names of earthworms used follow CSUZDI (2012). The graphical presentation of the setal arrangements in a form of pie diagrams follows methodology proposed by MORENO *et al.* (2007). All material is deposited in the Soil Zoology Collection, Hungarian Natural History Museum, Budapest (HNHM).

TAXONOMY

Family Lumbricidae Rafinesque-Schmaltz, 1815

Aporrectodea caliginosa (Savigny, 1826)

Enterion caliginosum SAVIGNY, 1826: 180.

Allolobophora (Allolobophora) caliginosa: ROSA 1893: 7.

Aporrectodea caliginosa: CSUZDI & PAVLÍČEK 2005a: 71., PAVLÍČEK & CSUZDI 2006: 183.

Material examined. HNHM/16307 1 ex., Jerash, bank of the Zarqa River, 32°16'N 35°53'E, 24.02.2007, leg. T. Pavlíček.

Aporrectodea rosea (Savigny, 1826)

Enterion roseum SAVIGNY, 1826: 182.

Allolobophora (Notogama) rosea: ROSA 1893: 2.

Aporrectodea rosea: CSUZDI & PAVLÍČEK 2005a: 72., PAVLÍČEK & CSUZDI 2006: 184.

Material examined. HNHM/16310 1 ex., Jerash, bank of the Zarqa River, 32°16'N 35°53'E, 24.02.2007, leg. T. Pavlíček; HNHM/16693 1 ex., Zarqa main branch, 200 m, 16.01.2004, leg. T. Pavlíček.

***Dendrobaena alexandrii* sp. n.**

(Figs 1–4)

Dendrobaena sp. PAVLÍČEK & CSUZDI 2006: 185.

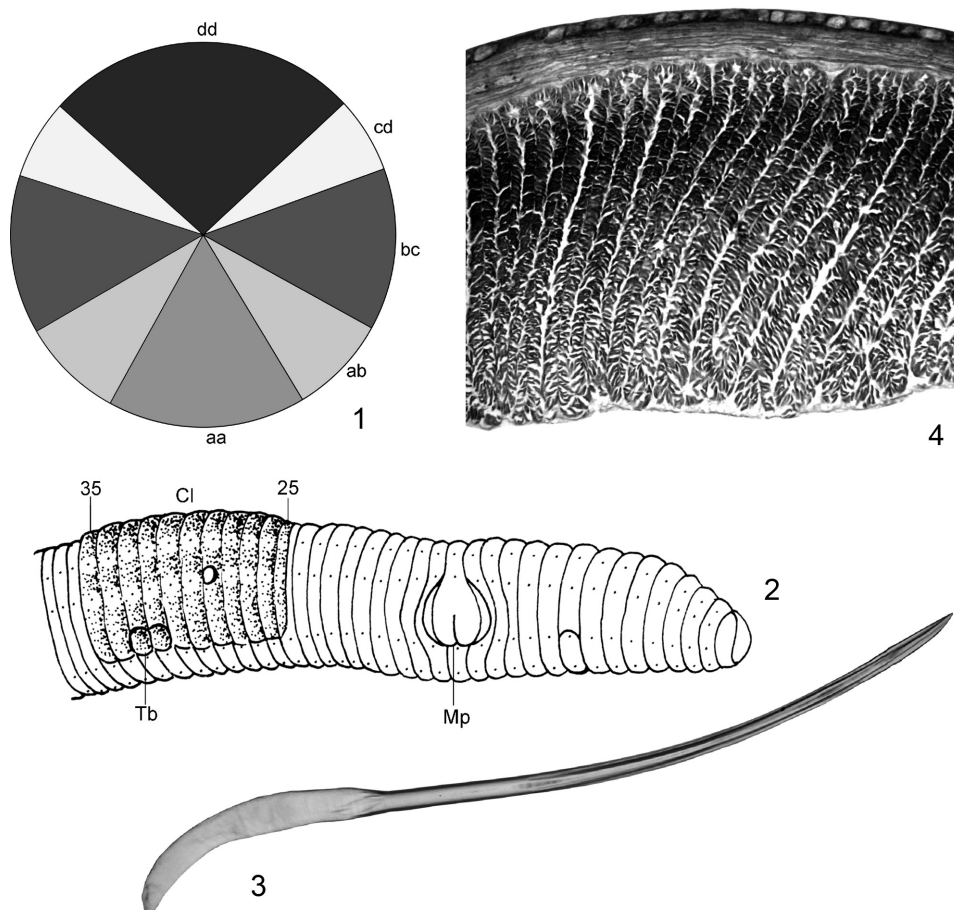
Holotype. HNHM/14882 Umm Qais, small valley, 03.13.2005, leg. T. Pavlíček.

Paratype. HNHM/16351 1 ex., hills near of the road from Jerash to Irbid, 32°23'N 35°49'E, 25.02.2007, leg. T. Pavlíček.

Etymology. The new species is named in honour of the late Sándor Mahunka the world renowned Oribatida taxonomist (Αλέξανδρος Greek = Sándor in Hungarian).

Diagnosis. Length 54–65 mm, diameter 4.5–5 mm, setae distant. Pigmentation red-violet. First dorsal pore in 5/6. Clitellum on ½25–35, tubercles on 32–33. Male pore on 15, surrounded by a glandular crescent. Nephridial pores irregularly alternate between setal line *b* and above *d*. Three pairs of vesicles in 9, 11, 12; spermathecae two pairs in 9/10, 10/11 in *d*. Calciferous glands in 11 and 12. Hearts in segments 6–11, nephridial bladders sausage-shaped.

External characters. Holotype: 65 mm long and 5 mm wide; number of segments 125. Paratype: 54 mm long and 4.5 mm wide; number of segments 133. Colour red-violet. Prostomium tanylobous. First dorsal pore in intersegmental furrow 5/6. Setae distant. Setal arrangement behind the clitellum: $aa:ab:bc:cd:dd = 2.6:1.3:2.1:1:4.1$ (Fig. 1). Male pore large on 15, between setae *b*–*c*, surrounded by a glandular crescent protruding into the neighbouring segments. Nephridial pores irregularly alternate between setal line *b* and above



Figs 1–4. *D. alexandrii* sp. n.: 1 = setal arrangement, 2 = clitellar region (Cl = clitellum, Tb = tubercle, Mp = male pore), 3 = genital setae from segment 9, 4 = longitudinal musculature.

d. Clitellum on segments ½25–35, tubercula pubertatis on segments 32–33, hardly visible (Fig. 2). Genital papillae surround setae *a*, *b* on segment 9. Genital seta of *9b* 1.15 mm long and 0.025 mm wide, spear-shaped (Fig. 3).

Internal characteristics. Dissepiments 11/12–13/14 slightly thickened. Testes and funnels free, paired in segments 10–11. Seminal vesicles present in 9, 11 and 12. Spermathecae two pairs in 9/10 and 10/11 with external openings in setal line *d*. Calciferous glands in 11 and 12. Paired hearts in segments 6–11, extraoesophageals lacking. Nephridial bladders simple, sausage-shaped. Crop in segments 15–16, and gizzard in segments 17–18. Typhosolis multilobed. Longitudinal muscle layer of pinnate type (Fig. 4).

Remarks. *Dendrobaena alexandrii* sp. n. is most similar to *D. samarigera* (Rosa, 1893), however, differs from it in the position of the clitellum (½25–35 vs 28–34, 35) the presence of spermathecae and tubercles. Probably, *D. alexandrii* is the sister species of *D. samarigera* retaining the thecal means of sperm exchange while *samarigera* moved completely to phoral insemination.

Dendrobaena byblica byblica (Rosa, 1893)

Allolobophora (*Dendrobaena*) *byblica* ROSA, 1893: 4.

Dendrobaena byblica: CSUZDI & PAVLÍČEK 2005a: 72.

Material examined. HNHM/16341 4 ex., Malka, wadi dominated by oak, 32°39'N 35°45'E, 25.02.2007, leg. T. Pavlíček; HNHM/16692 1 ex., Zarqa main branch, 200 m, 16.01.2004, leg. T. Pavlíček.

Dendrobaena negev Csuzdi et Pavlíček, 1999 (Figs 5–6)

Dendrobaena negev CSUZDI & PAVLÍČEK, 1999: 482, PAVLÍČEK & CSUZDI 2006: 184.

Material examined. HNHM/16330 3 ex., Al Manshiyya, 31°11'N 35°43'E, 03.03.2007, leg. T. Pavlíček; HNHM/16331 1 ex., HNHM/16333 4 ex., HNHM/16334 1 ex., hill near of the road from Jerash to Irbid, 32°23'N 35°49'E, 25.02.2007, leg. T. Pavlíček; HNHM/16336 11 ex., near Sail Hisban, pine forest and garrigue plant association, 31°50'N 35°46'E, 04.03.2007, leg. T. Pavlíček; HNHM/16338 12 ex., HNHM/16343 2 ex, Ajloun, oak garrigue, 23.02.2007, leg. T. Pavlíček ; HNHM/16339 3 ex., 5km W of Jerash, olive orchards, 24.02.2007, leg. T. Pavlíček; HNHM/16344 11 ex., near Sail Hisban, stone steppe, 31°51'N 35°45'E, 02.03.2007., leg. T. Pavlíček; HNHM/16345 1 ex., wadi Al Hasa, 30°59'N 35°43'E, 03.03.2007, leg. T. Pavlíček; HNHM/16412 4 ex., Mount Nebo, limestone hills with grass vegetation, 31°45'N 35°45'E, 29.01.2005., leg. T. Pavlíček; HNHM/16695 6 ex., Mount Nebo, limestone hills with grass vegetation, 31°45'N 35°44'E, 29.01.2005, leg. T. Pavlíček.

Remarks. *D. negev* was described from the border region between the mesic and desert (northern part of the Negev Desert) regions in Israel. It has first been already recorded from Jordan by PAVLÍČEK and CSUZDI (2006) from a single locality in Mt. Nebo. The present material contains many specimens

from different localities in central and northern regions of Jordan. All collected specimens of *D. negevis* were in a good agreement with the characters as described in the original description with the exception of body size in a part of them. Since some of the collected specimens were much larger than those reported from Israel and showed some external similarity with *D. veneta* (Rosa, 1886) we investigated the longitudinal musculature of these specimens that is a suitable diagnostic differentiating feature between both species. However, the musculature type proved to be identical with those of the Israeli specimens of *D. negevis* (Figs 5–6) as described in the original description.

Dendrobaena semitica (Rosa, 1893)

Allolobophora (*Dendrobaena*) *semitica* ROSA, 1893: 3.

Dendrobaena semitica: CSUZDI & PAVLÍČEK 2005a: 73., PAVLÍČEK & CSUZDI 2006: 184.

Material examined. HNHM/16304 13 ex., Umm Qais, garrigue plant association with oak and *Ceratonia* in wadi, 32°38'N 35°41'E, 25.02.2007, leg. T. Pavlíček; HNHM/16312 7 ex., Malka, garrigue with oak in wadi, 32°39'N 35°45'E, 25.02.2007, leg. T. Pavlíček; HNHM/16337 1 ex., Ajloun, oak garrigue, 23.02.2007., leg. T. Pavlíček.

Dendrobaena transjordanica sp. n.

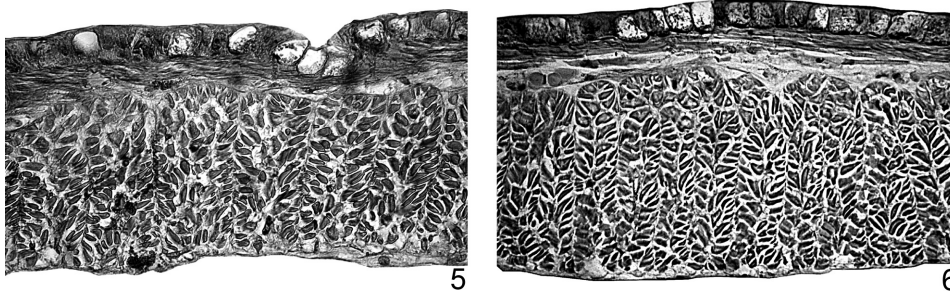
(Figs 7–10)

Holotype. HNHM/16347 Ajloun, oak garrigue, 23.02.2007, leg. T. Pavlíček.

Paratypes. HNHM/16348 2 ex., locality and date same as that of the holotype; HNHM/16349 3 ex., near Tall al Araba'im, wadi entering Jordan Valley, 23.02.2007, leg. T. Pavlíček.

Etymology. The specific epithet refers to the type locality.

Diagnosis. Length 41–55 mm, diameter 4–5 mm, setae distant. Pigmentation red-violet. First dorsal pore in 5/6. Clitellum on 28, 29–36, ½ 37; tubercles on 32–36. Male pore on 15, surrounded by a glandular crescent. Nephridial



Figs 5–6. Longitudinal musculature of *D. negevis*: 5 = Jordan (NHMM/16345), 6 = Israel (NHMM/15143).

pores irregularly alternate between setal line *b* and above *d*. Three pairs of vesicles in 9, 11, 12; spermathecae three pairs in 8/9–10/11 in *d*. Calciferous glands with well-developed diverticula in 12. Hearts in segments 6–11, nephridial bladders sausage-shaped.

External characters. Holotype: 47 mm long and 4 mm wide; number of segments 134. Paratypes: 41–55 mm long and 4–5 mm wide; number of segments 86–143. Colour red-violet, especially dark on dorsum. Prostomium tanylobous. First dorsal pore in intersegmental furrow 5/6. Setae distant. Setal arrangement behind the clitellum: *aa:ab:bc:cd:dd* = 2.5:1.1:2.1:1:4.6 (Fig. 7). Male pore large on 15, between setae *b*–*c*, surrounded by a glandular crescent protruding into the neighbouring segments. Nephridial pores irregularly alternate between setal line *b* and above *d*. Clitellum on segments 1/n 28, 29–36, ½ 37; tubercula pubertatis on segments 32–36 (Fig. 8). Genital papillae surround setae *c*, *d* on segments 11, 12. Genital setae of 11 *cd* 1–1.1 mm long and 0.022–0.025 mm wide, spear-shaped (Fig. 9).

Internal characteristics. Dissepiments 8/9–14/15 slightly thickened. Testes and funnels free, paired in segments 10, 11. Seminal vesicles present in 9, 11 and 12. Spermathecae three pairs, in 8/9, 9/10 and 10/11 with external openings in setal line *d*. Calciferous glands with well-developed diverticula in 12. Paired hearts in segments 6–11, extraoesophageals lacking. Nephridial bladders simple, sausage-shaped. Crop in segments 15–16, and gizzard in segments 17–18. Typhosolis T-shaped. Longitudinal muscle layer of pinnate type (Fig. 10).

Remarks. The new species is similar to *D. rothschildae* Csuzdi et Pavlíček, 1998 but differs from it in the backward shifted position of the tubercles (30–34 vs. 32–36) and furthermore in the setal arrangement (Figs 7, 11).

Dendrobaena veneta veneta (Rosa, 1886)

Allolobophora veneta ROSA, 1886: 674.

Allolobophora (Notogama) veneta: ROSA 1893: 2.

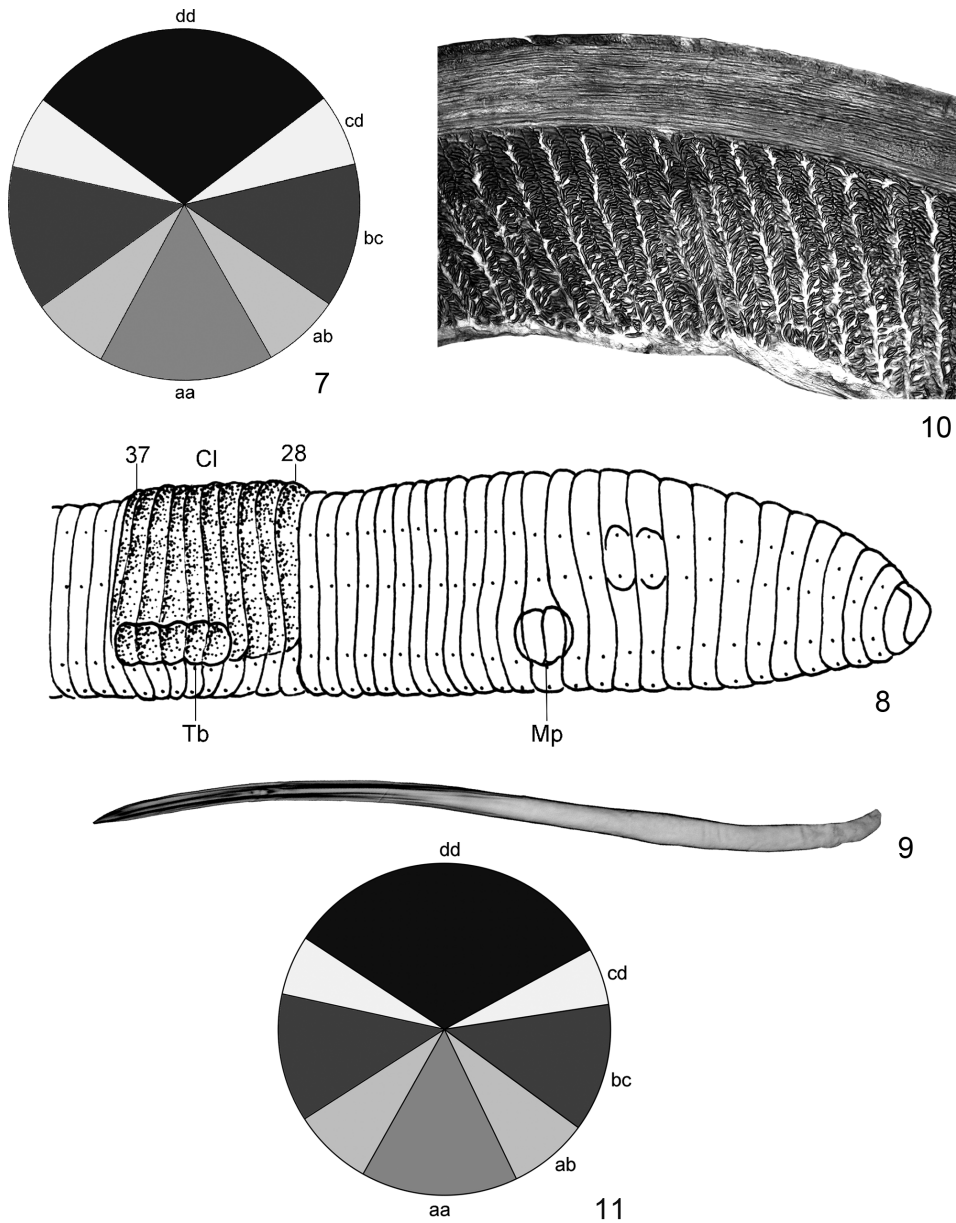
Dendrobaena veneta veneta: CSUZDI & PAVLÍČEK 2005a: 75.

Dendrobaena veneta: PAVLÍČEK & CSUZDI 2006: 184.

Material examined. HNHM/16305 3 ex., Umm Qais, garrigue with oak and *Cearatonia* in wadi, 32°38'N 35°41'E, 25.02.2007, leg. T. Pavlíček; HNHM/16309 4 ex., HNHM/16315 3 ex., Jerash, bank of the Zarqa River, 32°16'N 35°53'E, 24.02.2007, leg. T. Pavlíček; HNHM/16329 5 ex., Al Manshiyya, 31°11'N 35°43'E, 03.03.2007, leg. T. Pavlíček; HNHM/16313 8 ex., HNHM/16340 2 ex., Malka, garrigue with oak in wadi, 32°39'N 35°45'E, 25.02.2007, leg. T. Pavlíček, HNHM/16346 1 ex., wadi Al Hasa, 30°59'N 35°43'E, 03.03.2007, leg. T. Pavlíček; HNHM/16694 1 ex., Mount Nebo, limestone hills with grass vegetation, 31°45'N 35°44'E, 29.01.2005, leg. T. Pavlíček.

Remarks. *Dendrobaena veneta veneta* is quite widely spread all over the Levant and possibly endemic in the region. The Levantine specimens differ from the widely introduced forms by their paler coloration and missing the striped appearance of the pigmentation. They are also frequently found in the open

park forests with dominant oaks. Further DNA studies are needed to clear the taxonomic position of the different *veneta* forms.



Figs 7–11. 7–10. *D. transjordanica* sp. n.: 7 = setal arrangement, 8 = clitellar region (Cl = clitellum, Tb = tubercle, Mp = Male pore), 9 = genital setae from segment 11, 10 = longitudinal musculature. 11. Setal arrangement of *D. rothschildae* Csuzdi & Pavlíček, 1998.

Eiseniella neapolitana (Örley, 1885)

Allurus neapolitanus ÖRLEY, 1885: 12.

Allurus ninnii: ROSA 1893: 11.

Eiseniella tetraedra neapolitana: CSUZDI & PAVLÍČEK 2005a: 76.

Eiseniella neapolitana: PAVLÍČEK & CSUZDI 2006: 185.

Material examined. HNHM16311 2 ex., HNHM/16342 2 ex., Malka, garigue with oak in wadi, 32°39'N 35°45'E, 25.02.2007, leg. T. Pavlíček.

Eiseniella tetraedra (Savigny, 1826)

Enterion tetraedrum SAVIGNY, 1826: 184.

Allurus tetraedrus: ROSA 1893: 10.

Eiseniella tetraedra tetraedra: CSUZDI & PAVLÍČEK 2005a: 76.

Eiseniella tetraedra: PAVLÍČEK & CSUZDI 2006: 185.

Material examined. HNHM/16308 1 ex., Jerash, bank of the Zarqa River, 32°16'N 35°53'E, 24.02.2007, leg. T. Pavlíček.

Healyella syriaca (Rosa, 1893)

Allolobophora syriaca ROSA, 1893: 461.

Bimastos syriacus: CSUZDI & PAVLÍČEK 1999: 471.

Healyella syriaca: OMODEO & ROTA 1989: 173.

Material examined. HNHM/16332 1 ex., HNHM/16335 1 ex. hill near of the road from Jerash to Irbid, 32°23'N 35°49'E, 25.02.2007., leg. T. Pavlíček.

Remarks. This is the first record of *He. syriaca* in Jordan. Due to its extensive Levantine–Anatolian distribution type, its possible occurrence in Jordan has yet been suggested by PAVLÍČEK and CSUZDI (2006).

Helodrilus patriarchalis (Rosa, 1893)

Allolobophora patriarchalis ROSA, 1893: 9.

Helodrilus patriarchalis: CSUZDI & PAVLÍČEK 2005a: 76., PAVLÍČEK & CSUZDI 2006: 185.

Material examined. HNHM/16314 2 ex., wadi Borbita, near of the stream, 30°59'N 35°39'E, 03.03.2007, leg. T. Pavlíček; HNHM/16350 1 ex., near Tall al Araba'im, wadi entering Jordan Valley, 23.02.2007, leg. T. Pavlíček.

Octodrilus transpadanus (Rosa, 1884)

Allolobophora transpadana ROSA, 1884: 45.

Octodrilus transpadanus: CSUZDI & PAVLÍČEK 2005: 76., PAVLÍČEK & CSUZDI 2006: 185.

Material examined. HNHM/16306 3 ex., Jerash, bank of the Zarqa River, 32°16'N 35°53'E, 24.02.2007, leg. T. Pavlíček.

DISCUSSION

Elaborating a new material from Jordan resulted in describing two species new to science and a few new records for the country. The updated list of earthworms reports 20 species recorded in the Hashemite Kingdom of Jordan (Table 1). Out of all recorded species 9–12 species (45–60%) are autochthonous and 8–11 species (40–55%) are introduced. Taking into account that the larger part of Jordan is desertic and inhospitable for earthworm survival, the high level of the local endemism indicates that the earthworm fauna here consist

Table 1. Updated list of earthworm species recorded from Jordan.

Name	Source of data	Comments
<i>Aporrectodea caliginosa</i> (Savigny, 1826)	1, 2, 3	Introduced in Jordan
<i>Ap. jassyensis</i> Michaelsen, 1891	1, 2	Possibly autochthonous in Jordan
<i>Ap. rosea</i> (Savigny, 1826)	2, 3, 4	Introduced in Jordan
<i>Bimastos parvus</i> (Eisen, 1874)	3	Introduced in Jordan
<i>Dendrobaena alexandrii</i> sp. n.	3, 4	Autochthonous in Jordan
<i>Dendrobaena byblica</i> (Rosa, 1893)	2, 4	Autochthonous in Jordan
<i>D. negevii</i> Csuzdi et Pavlíček, 1999	3, 4	Autochthonous in Jordan
<i>D. orientalis karak</i> Csuzdi et Pavlíček, 2005	2	Autochthonous in Jordan
<i>D. semitica</i> (Rosa, 1893)	1, 2, 3, 4	Autochthonous in Jordan
<i>D. transjordanica</i> sp. n.	new record	Autochthonous in Jordan
<i>D. veneta veneta</i> (Rosa, 1886)	2, 3, 4	Possibly autochthonous in Jordan
<i>Eisenia fetida</i> (Savigny, 1826)	2	Introduced in Jordan
<i>Eiseniella neapolitana</i> (Örley, 1855)	1, 2, 4	Autochthonous in Jordan
<i>Eis. tetraedra</i> (Savigny, 1826)	2, 4	Introduced in Jordan
<i>Healyella syriaca</i> (Rosa, 1893)	new record	Autochthonous in Jordan
<i>Helodrilus patriarchalis</i> (Rosa 1893)	1, 2, 4	Autochthonous in Jordan
<i>Metaphire californica</i> (Kinberg, 1867)	3	Introduced in Jordan
<i>Microscolex dubius</i> (Fletcher, 1887)	2, 3	Introduced in Jordan
<i>Ocnerodrilus occidentalis</i> Eisen, 1878	2	Introduced in Jordan
<i>Octodrilus transpadanus</i> (Rosa, 1884)	2, 4	Possibly autochthonous in Jordan

1 = ROSA 1893; 2 = CSUZDI & PAVLÍČEK 2005; 3 = PAVLÍČEK & CSUZDI 2006; 4 = present paper

of highly specialized semi-desertic forms and that only a few common European/Asian peregrine species could manage to conquer this hostile region.

The comparison of the species richness of Jordan to that of the much smaller Israel (33 vs 20 recorded earthworm species) point to the underestimation of the Jordanian earthworm fauna (CSUZDI & PAVLÍČEK 2005b, 2006) and to the prediction that a thorough cross-country sampling could yield more new species for science and new records for the country.

REFERENCES

- CSUZDI, Cs. (2012) Earthworm species, a searchable database. *Opuscula Zoologica, Budapest* **43**(1): 97–99.
- CSUZDI, Cs. & PAVLÍČEK, T. (1999) Earthworms from Israel. I. Genera *Dendrobaena* Eisen, 1874 and *Bimastos* Moore, 1891 (Oligochaeta: Lumbricidae). *Israel Journal of Zoology* **45**: 467–486.
- CSUZDI, Cs. & PAVLÍČEK, T. (2005a) Earthworms of Jordan. *Zoology in the Middle East* **34**: 71–77.
- CSUZDI, Cs. & PAVLÍČEK, T. (2005b) Earthworms from Israel. II. Remarks on the genus *Perelia* Easton, 1983 with description of a new genus and two new species. *Acta Zoologica Scientiarum Hungaricae* **51**: 75–96.
- KRUTSAY, M. (1980) Szövettani technikák. [*Histological techniques.*] Medicina Kiadó, Budapest, 202 pp. [In Hungarian]
- MORENO, A., TEISAIRE, E. S. & BORGES, S. (2007) *An initial study on the relative distance between setae*. Pp. 79–85. In: PAVLÍČEK, T. & CARDET, P. (eds): *Advances in earthworm taxonomy III. (Annelida: Oligochaeta)*. En Tipis Ltd., Nicosia.
- OMODEO, P. & ROTA, E. (1989) Earthworms of Turkey. *Bollettino di Zoologia* **56**: 167–199.
- ÖRLEY, L. (1885) A palaearktikus övben élő Terrikoláknak revíziója és elterjedése. *Értekezések a Természettudományok Köréből* **15**: 1–34. [In Hungarian]
- PAVLÍČEK, T. & CSUZDI, Cs. (2006) *Earthworm fauna of Jordan – A review*. Pp. 183–188. In: POP, V. V. & POP, A. A. (eds): *Advances in earthworm taxonomy II. (Annelida: Oligochaeta)*. University Press, Cluj.
- RAW, F. (1959) Estimating earthworm populations by using formalin. *Nature* **184**: 1661–1662.
- ROSA, D. (1884) *Lumbricidi del Piemonte*. Torino 54 pp.
- ROSA, D. (1886) Note sui lombrici del Veneto. *Atti del Reale Istituto Veneto di Scienze* **4**: 673–687.
- ROSA, D. (1893) Viaggi del Dr. E. Festa in Palestina nel Libano e regioni vicine. *Bollettino del Museo regionale di Scienze Naturali Torino* **8**(160): 1–14.
- SAVIGNY, J. C. (1826) In G. Cuvier: *Analyse des Travaux de l'Académie royale des Sciences, pendant l'année 1821, partie physique. Mémoires de l'Académie des Sciences de l'Institut de France Paris* **5**: 176–184.

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