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On the presence of *Lumbricus terrestris* Linnaeus 1758 (Oligochaeta, Lumbricidae) on the Balkan Peninsula: some aspects of ecology and distribution

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Abstract: In this paper we summarize the current knowledge on the distribution of *Lumbricus terrestris* on the Balkan Peninsula. For this purpose we reviewed all published data on its distribution in addition to original data from our old institute collection and recent field investigations. The objective of this paper is to analyze the whole list of records in order to present a general overview of the distribution of *Lumbricus terrestris* on the Balkan Peninsula. Based on literature data, we also give some possible explanations of ecological influences on the current range characteristics. It belongs to peregrine species native to the Palearctic but has been introduced all over the world. During the last 30 years this species has been recorded from many localities in Serbia, Bulgaria, Bosnia and Herzegovina, and continental parts of Croatia and Slovenia, while it is not present in the Mediterranean part of the Balkans (Turkey, Greece, southern Croatia, southern Montenegro, and Albania). Until the present, the southernmost findings of *Lumbricus terrestris* have been in the southwestern part of Macedonia.

Key words: *Lumbricus terrestris*, distribution, Balkan Peninsula, Turkey, Bosnia and Herzegovina, Bulgaria, Macedonia, Serbia, Croatia, Slovenia

Lumbricus terrestris was the first earthworm described by Carl Linnaeus in his Systema Naturae (1758). It is a large, multisegmented annelid that typically ranges from 8 to 15 cm in length (occasionally up to 35 cm) (Blakemore, 2012). The earthworm *L. terrestris* is an anecic species, meaning that it lives in deep vertical burrows of 2 m and generally only emerges to feed on surface litter. Because of this characteristic burrowing, anecic species such as *L. terrestris* are associated with the mixing of soil horizons in the areas that they invade (Postma-Blaauw et al., 2006). When feeding, this earthworm prefers fresh litter rather than accumulated organic matter in the upper soil horizon (Hale et al., 2005). *L. terrestris* can inhabit all soil types except coarse sands, bare rock, and acidic peat (*Sphagnum*). It has been found to be constrained by the –15 °C isotherm. It tolerates soils with pH values as low as 3.5–3.7 and as high as about 8, normally in alkaline soils of pH 6.2–10.0. *L. terrestris* is not frost-tolerant, indicating that it hibernates in deep soil layers during the winter (Tiunov et al., 2006; Wironen and Moore, 2006). Although the species prefer grasslands, pastures orchards, and deciduous forests, being especially abundant in clay and often present in agricultural fields, it fares poorly due to herbicides, mechanical damage, and lack of leaf litter (Frelich et al., 2006; Blakemore, 2012, 2014).

L. terrestris is a reciprocally mating simultaneous hermaphrodite, which reproduces sexually with individuals mutually exchanging sperm. It leaves its burrow to copulate on the soil surface. The lifespan of *L. terrestris* is approximately 5–9 years in culture (Satchell, 1967; Lakhani and Satchell, 1970; Edwards and Bohlen, 1996) and probably less in the field. Sexual reproductivity is usually reached within 1 year (Evans and Guild, 1948; Wilcke, 1952; Satchell, 1967), but the duration of the prereproductive phase is strongly influenced by environmental factors (Lee, 1985). Adult and immature earthworms can be distinguished by the development of a clitellum when reaching sexual reproductivity. *L. terrestris* grows rapidly for approximately 3 years, with short seasonal pauses in midsummer and midwinter, and reaches an average weight of approximately 9.5–11 g in culture and 5–6.25 g in field populations (Satchell, 1967; Lakhani and Satchell, 1970). After 3 years, the average weight of the earthworms begins to decrease. Often

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their weight does not change greatly for the next 4 years, although not many earthworms survive 7 years in the field (Lightart, 1997; Zwahlen et al., 2003).

In the checklist of Lumbricidae by Qiu and Bouche (1998), the total number of species and subspecies amounted to about 700. According to Blakemore (2012), the total number amounted to about 670 valid names from a total of 1130 nominal lumbricid taxa out of a global total of 7000 described megadrile Oligochaeta (i.e. Lumbricidae is just about 10% of all earthworms). For the territory of the Balkan Peninsula and neighboring countries, 231 listed species and subspecies are registered, 167 of them being registered as fauna of the former Yugoslavia. The abundance of earthworms on the Balkan Peninsula is conditioned by the diversity of its climatic and edaphic factors (overlapping of various zoogeographic regions), as well as by great orogenic changes in the past. This is why the Balkan Peninsula is an important center of earthworm development.

L. terrestris was first described from Scandinavia in 1758, but it was living for millions of years as a European species before glaciation. This earthworm is one of the most frequent species in Europe, especially in agricultural soils (Bundesamt für Umwelt Wald und Landschaft, 1997). Latitudes between 65°N and 40°N and continental climates with wet soils (cultivated, agricultural and urban, periurban) are the most suitable areas for this species. Therefore, the primary limiting factor of its distribution within the climate range could be access to sites. Self-propelled spread is slow at 6.3 m/year or about 6 km/1000 years (Lightart et al., 1997). This species is capable of moving 4–19 m in a single night (Mather and Christensen, 1988) but this is a random movement, not directed towards unoccupied areas.

The earthworm *L. terrestris* is thought to be native to West Europe, but it is now globally distributed in temperate to mild boreal climates. It is an invasive species. Furthermore, its invasive range includes North Europe. Most of the invasion can be attributed to human activity (Tomlin et al., 1992; Hale et al., 2005). Once present in an environment, its activities can radically alter forest floor litter decomposition regimes and the soil-litter communities based on forest floor litter. It is considered invasive as it is widespread globally and tolerant to a range of transport and climatic conditions, and, being a hermaphrodite, only two individuals are needed in a founding population.

On the other hand, earthworms are known to be slow dispersers, especially *L. terrestris* or other anecic species with sedentary-like behavior, inhabiting their vertical burrow systems for longer times. Populations of the species spread at a speed of 25.4 cm/year (Edwards and Bohlen, 1996). Active dispersal of *L. terrestris* is too slow to explain today's range of the species. Even if a twofold dispersal speed of populations of 20 m/year is assumed, it could only have traveled 200 km in the last approximately 10,000 years. This leads to the suggestion that the species is strongly dependent on any mode of passive dispersal, as suggested for the Tasmanian populations.

L. terrestris is a problematic species, because recently it was divided into two species, *L. terrestris* and *L. herculeus* (James et al., 2010). There was no type species of *L. terrestris*; this was replaced by a neotype by Sims in 1973, but James et al. (2010) designated a new neotype to comply with their molecular results. This action was rejected by Blakemore (2013) and a redescription of the Sims neotype was given by him (Blakemore, 2014).

In this paper we summarize the current knowledge on the distribution of *L. terrestris* on the Balkan Peninsula. For this purpose, we reviewed all published data on its distribution in addition to original data from our old institute collection and recent field investigations. The objective of this paper is to analyze the whole list of records in order to present a general overview of distribution of the species on the Balkan Peninsula. Based on literature data, we also give some possible explanations of ecological influences on the current range characteristics.

The study was carried out in 2002–2014 and included the Balkan countries of Bosnia and Herzegovina, Bulgaria, Macedonia, Serbia, and Turkey. Data on the species were obtained from the literature, from fieldwork, and from an old institute collection. As far as possible, we included all published data presently known. Field data were collected at more than 100 sites in the Balkans, situated at altitudes between 300 and 1700 m. Earthworms were collected from various habitats in the area of the Balkan Peninsula (Table) like meadows, pastures, peaty silts, hills, and mountains, as well from mixed forests, under rocks, and even in caves. Most of the localities were in areas rich in organic waste and moisture, a typical feature preferred by *L. terrestris*.

A large number of earthworm genera and species were found, but in this paper we have only analyzed data relating to *L. terrestris*. Data from several authors (Mršić, 1991; Csuzdi et al., 2006, 2007; Mısırlıoğlu, 2011; Szederjesi and Csuzdi, 2012a, 2012b; Hackenberger and Hackenberger, 2013; Stojanović and Milutinović, 2013; Stojanović et al., 2013; Mısırlıoğlu and Szederjesi, 2015) were used to complete the distribution map of *L. terrestris* for the whole Balkans (Figure). Based on our investigation, the examined literature records, and the institute's collection, our database includes localities, collecting dates, and the number of sample sites.

The specimens were obtained by the diluted formaldehyde method complemented with digging and hand sorting as well as by turning over rocks, debris, and logs. The earthworms were killed in 70% ethanol,

Table. List of localities from the entire territory of the Balkan Peninsula.

Countries	Localities	Habitat	Sources
Bulgaria	Sliven		Černosvitov, 1937
			Plisko, 1963
			Šapkarev, 1986
	Slivnitza		Šapkarev, 1986
	Sofia		Šapkarev, 1986
	Rila Mountain		Zicsi and Csuzdi, 1968
	Sofia Valley		Valchovski, 2012
	Sofia-Central park	Meadow	Authors' data, 2010
	Sofia-Boyana	Meadow	Authors' data, 2014
	Vladaya	Meadow	Authors' data, 2014
	Dragichevo	Meadow	Authors' data, 2014
	Sarajevo, Visoko, Mostar,	Pasture	Mršić, 1991
Bosnia and	Jajce, Vratnik		
Herzegovina	Dinarsko polje, Berkovici	Meadow	Authors' data, 2014
	Rudine Mt., Bjeljane	Pasture	Authors' data, 2014
	Veliko selo, Gromizelj	Peaty silt	Authors' data, 2012
	Ohrid, Štip	Pasture	Mršić, 1991
Macedonia	Gostivar	Under rock	Authors' data, 2012
	Mavrovo, Alilica cave	Cave	Authors' data, 2012
	Šara Mt.	Under rock	Authors' data, 2012
Serbia	Jastrebac	Under rock	Authors' data, 1996
	Morava, Ibar	Meadow	Authors' data, 1993
	Aleksinac	Meadow	Authors' data, 1995
	Belgrade, Bela Crkva,	Forest	Mršić, 1991; Stojanović
	Niška Banja, Soko Banja,	Meadow	and Milutinović, 2013
	Avala, Topola, Zaječar		
Montenegro	Kolašin, Bjelasica Mt.	Mountain	Stojanović and
		Pastures	Milutinović, 2013
			Stojanović and
			Karaman, 2003
Slovenia	Ljubljana, Brežice,	Mountain	Mršić, 1991
	Zidani Most, Hrastovlje,	Pastures	
	Jakovec		
Croatia	Maksimir, Sljeme,	Meadow	Mršić, 1991;
	Novska, Slavonski Brod		Hackenberger and
			Hackenberger, 2013
Albania	Absent		Szederjesi and Csuzdi,
			2012a
Greece	Absent		Szederjesi and Csuzdi,
			2012b
Turkey	Absent		Mısırlıoğlu 2002, 2009,
			2011; Mısırlıoğlu and
			Szederjesi, 2015

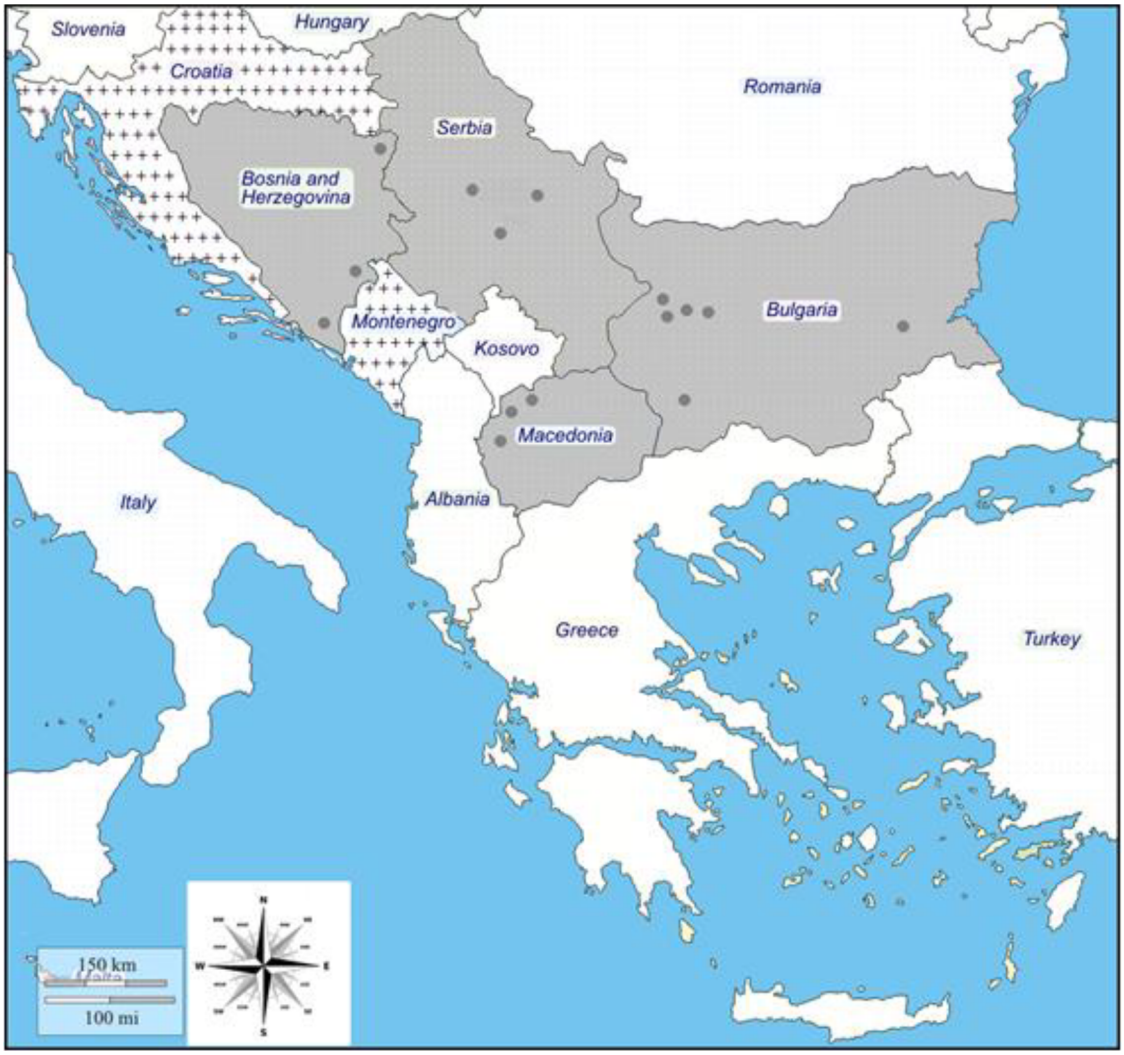

Figure. Distribution of the recent localities of *Lumbricus terrestris* on the Balkan Peninsula (plus marks indicate other Balkan countries where *L. terrestris* also lives).

fixed in 4% formalin solution, and stored in 90% ethanol. Identification of species was done in accordance to Šapkarev (1978), Zicsi (1982), Mršić (1991), Csuzdi and Zicsi (2003), Blakemore (2004), and Mısırlıoğlu (2011).

During the earthworm investigations between 2002 and 2014 in the western part of Bulgaria, we recorded *L. terrestris* in 4 of 10 sample sites (central park of Sofia, Boyana, Boyana Lake, Pancharevo Lake, Vitosha Mountain, Dragichevo, Vladaya, Pirin Mountain-Senokos Village, Rila Mountain-Parangalitza Nature Reserve, and Vidin), all presented in the Table. We found the species only in the urban localities with medium-high altitudes, between 520 and 850 m. The species showed resistance to anthropogenic impact and farming. All of the collected individuals were present in the autumn samplings, possibly due to a slow rate of reproduction, and in the alluvial soils. The species was not found in the typical mountain localities with altitudes of more than 1000 m, probably because of the soil texture and the low soil depth; the species is known to inhabit deeper soil layers (Stojanović and Karaman, 2003). The investigation of the distribution of *L. terrestris* in Bulgaria confirmed that the species is one of the most adaptable synanthropic earthworms, which can be found in all of the urban localities in Europe where the species is adapted to the climate and the soil characteristics, as well as suitable sites overseas after transportation.

On the Balkan Peninsula, it has a wide distribution. In Croatia it is the most common species in the continental region (Hackenberger and Hackenberger, 2013). It is similar in Slovenia (Mršić, 1991). However, the situation in Serbia and Montenegro is different. In the Pannonian part of Serbia *L. terrestris* is more present than in its Balkanic area (Stojanović et al., 2013). In Montenegro it is registered only in the eastern part of the mountainous region.

According to Mršić (1991), the locality near Lake Ohrid in Macedonia is the southernmost point of its distribution in the Balkans, which led us to think that we could find some individuals in different places lying along the same latitude, like the European northern part of Turkey.

Only 3% of the territory of Turkey is part of the Balkan Peninsula. Not all of the territory of the country is situated in the Mediterranean region south of 40°N, which makes the spread of the species look possible. Omodeo (1952) first said that *L. terrestris* is a peregrine species that does not occur in Turkey or in the Mediterranean region south of 40°N.

In the literature data the southernmost point reached by this species is 40°S. Although the species widely occurs in the Balkans, *L. terrestris* does not belong mainly to the Balkan distributive type. It is a peregrine species native to the Palearctic, introduced all over the world (Csuzdi and Zicsi, 2003; Blakemore, 2012).

However, during extensive earthworm investigations and from all the sampled localities in Turkey, we could not find any *L. terrestris* specimens (Mısırlıoğlu, 2002, 2004, 2007a, 2007b, 2008a, 2008b, 2009, 2010, 2011; Csuzdi et al., 2006, 2007; Mısırlıoğlu et al., 2008; Pavlíček et al., 2010; Mısırlıoğlu and Szederjesi, 2015).

Additionally, studies on Turkish earthworms, which were done by different oligochaetologists between 1893 and 2014, did not contain any *L. terrestris* records, either (Rosa 1893, 1905; Michaelsen, 1910; Pop, 1943; Omodeo, 1952, 1955; Zicsi, 1973; Zicsi and Michalis, 1981; Omodeo and Rota, 1989, 1991, 1999; Szederjesi et al., 2014a, 2014b). The unsuitable soil and weather conditions such as high temperatures and moisture levels could probably be the answer. Namely, Nordström and Rundgren (1974) observed a strong relationship between earthworms and high soil content of clay. Soil clay content is also correlated with factors such as water-holding capacity and cationic exchange capacity, which directly influence earthworm distribution (but earthworms also modify their habitat due to their burrowing and soil mixing activities). Water is better retained in clay-rich parts. Soil abrasiveness and susceptibility to drought also affect earthworms and *L. terrestris* in particular. Soil moisture is known to be one of the most important factors interfering with earthworm distribution (even though the presence of earthworms increases soil moisture capacity) (Blakemore, 2000). Environmental factors alone do not determine the distribution of earthworms. Some authors (González et al., 1999) observed that plant species composition could produce differences in earthworm abundance and distribution in tropical areas. Nuutinen et al. (1998) mentioned that disjunctive distribution of *L. terrestris* could be due to competitive interactions.

On the other hand, the ecotopic European territory in Turkey is separated from the Asian portion of Turkey by a series of waterways that connect the Black Sea with the Aegean Sea, which also might be a reason for the absence of the species.

L. terrestris is listed in the Global Invasive Species Database (http://www.issg.org/database). The absence of it from a particular habitat within its climatic range it is not an indication that the site is safe from invasion nor that adequate soil surveys have been conducted.

Further research is needed to determinate the importance of environmental factors on the distribution of *L. terrestris*. The coupling of more detailed climatological analysis to biological processes will help identify the impacts of specific facets of a complex climatic regime on natural systems. Identifying exactly which species, or groups of species, are most vulnerable to climatic conditions represents an important first step towards developing climate adaptation plans for biodiversity.

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