SOIL ORGANISMS 90 (3) · December 2018 pp. 171–185

Distribution and diversity of earthworms (Lumbricidae) in Hesse (Central Germany): current knowledge

Jörg Römbke[1]*, Wolfgang H. O. Dorow[2] and Stephan Jänsch[1]

[1] ECT Oekotoxikologie, Böttgerstr. 2-14, 65439 Flörsheim am Main, Germany
[2] Senckenberg Research, Project Strict Forest Reserves in Hesse, Senckenberganlage 25, 60325 Frankfurt am Main, Germany
* Corresponding author, e-mail: j-roembke@ect.de

Received 17 November 2018 | Accepted 27 November 2018
Published online at www.soil-organisms.de 1 December 2018 | Printed version 15 December 2018
DOI 10.25674/bmwx-qs58

Abstract

In 2016 the first Red List of German earthworms was compiled, listing 46 species. However, little is known about the biodiversity and distribution of Lumbricidae in the individual federal states of Germany. In some of them (e.g. Schleswig-Holstein) earthworm monitoring programs were performed (or are still running). In others no such soil-focused program has been performed so far. The aim of this contribution is to compile the available information on the distribution of earthworms (Lumbricidae) in the state of Hesse, using data from literature including own investigations. The main source is a long-term faunistic inventory made in Strict Forest Reserves, in which different traps were used over a period of two years for each site. Earthworms have also been sampled at other Hessian sites, for different reasons and with various methods within the last 50 years. This information was already compiled in the database Edaphobase. In total, we found data from 43 sites, mainly located in the north-eastern and eastern part of this state as well as around the city of Frankfurt in the south. In total, 25 species have been recorded representing 54 % of the German earthworm fauna. Noteworthy is *Allolobophoridella eiseni* (Levinsen, 1884), a species which is often overlooked since it lives on and below the bark of living and dead trees. In comparison to neighbouring countries such as The Netherlands or France, our knowledge on Hessian earthworms is considered to be poor. Thus, we recommend to perform an earthworm sampling program, using standard methods and assessment tools in order to get a detailed overview on the diversity and distribution of this functionally important group of soil invertebrates.

Keywords Soil invertebrates | Annelida | Strict Forest Reserves | Monitoring

1. Introduction

Within the last ten years the public interest in soil organisms in general and earthworms in particular has slowly increased, probably because their functional role as providers for an impressive list of ecological services became better known, especially at agricultural sites (e.g. Van Groenigen et al. 2014). In addition, awareness on the importance and the vulnerability of the soil ecosystem increased as well as a general recognition of (soil) biodiversity (Lavelle et al. 2006). Earthworms are the 'flagships' within the high number of species from various soil invertebrate groups, most notably mites, springtails, pot worms, isopods, snails and myriapods, not to mention the even higher number of micro-fauna species such as nematodes or protozoans. In addition, earthworms have a good reputation, being considered to be beneficial to soils. Therefore, earthworms have been recommended to be included in German soil monitoring programs (Barth et al. 2000). However, in reality they are sampled only in few German federal states, e.g. in Schleswig-Holstein (Beylich & Graefe

ISSN 1864-6417 (print) · ISSN 2509-9523 (digital)

2009) or Mecklenburg-West Pomerania (Höser 2013). An overview on the current knowledge of earthworms in Germany is given by Jänsch et al. (2013) and Lehmitz et al. (2014). Standardized sampling methods (ISO 2018) and identification keys are available (Graff 1953, Bouché 1972, Sims & Gerard 1999, Csuzdi & Zicsi 2003).

In Hesse there is no monitoring program on soil biodiversity in general or on earthworms in particular. The largest single source of information is a long-term survey of the fauna in Strict Forest Reserves (= 'Naturwaldreservate'; i.e. areas which are allowed to mature without direct human influence), which was set up in 1990 by the Government of Hesse, in cooperation with the Senckenberg Institute (Frankfurt). In order to achieve an as-complete-as-possible faunal inventory, many different sampling methods were applied (Dorow et al. 1992), among them pitfall traps and eclectors at standing and lying trees. Surprisingly, already with these two methods a high number of earthworm species and individuals was collected, the dominant species being *Allolobophoridella eiseni* (Levinsen, 1884) (Römbke et al. 2017).

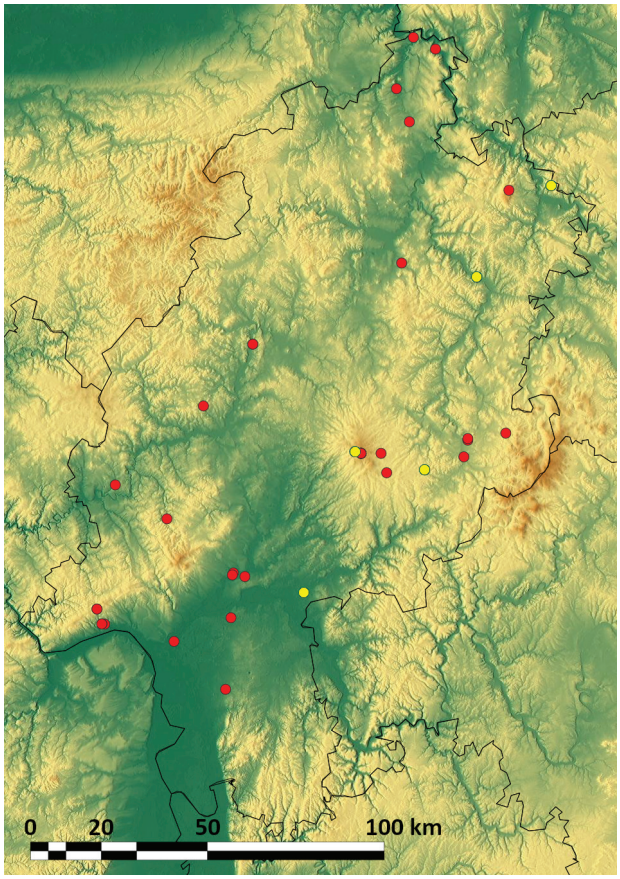

Figure 1. Distribution of the Hessian sites at which earthworms were sampled so far.

Due to the loose sampling history and the lack of a soil monitoring program, our current knowledge of the lumbricid fauna in Hesse in general and the conservation status of these worms in particular is poor at best. However, the relatively high percentage of species found in this medium-sized federal state indicates that further samplings are recommendable. However, when doing so, it should be performed in a way that the main habitats and soil types of this state are adequately covered, using standardized and up-to-date sampling and assessment methods. In addition, there should be a regular repetition in order to notice changes in abundances and community composition.

In summary, this paper has the main aim to compile and review the currently available information on the occurrence of earthworms (Lumbricidae, Clitellata) in the state of Hesse. In this context the knowledge on this ecologically important group of soil invertebrates is discussed, including proposing an earthworm monitoring program.

2. Material and Methods

2.1 Sampling sites

An overview on the sites sampled in Hesse so far is given in Table 1 and their geographical distribution is given in Figure 1.

2.1.1 Strict Forest Reserves

Most of the Hessian earthworms were collected in the Strict Forest Reserves of Hesse and their adjacent managed sites (IBV 2016, Dorow et al. 1992). Four of the six sites are beech forests (dominating: *Fagus sylvatica*) in low mountain ranges, and one (Kinzigaue) is a Pedunculate oak-hornbeam forest (dominating: *Quercus robur*) located in a flooding area of a brook. The fauna of these sites was investigated over a period of two years (24 months) each, using diverse techniques, focusing on aboveground arthropods, especially insects: pitfall traps (filled with a mixture of 70 % Ethanol (67 %) and Glycerine (33 %); different types of trunk eclectors on standing, lying, dead and living tree trunks, stumps, dead branches. No earthworm-specific sampling technique was used. Further details on these sites are given in Römbke et al. (2017) and the references therein. The earthworm samples from the Strict Forest Reserves is stored at the Senckenberg Research Institute and Natural History Museum (Frankfurt am Main), Collection 'Project Hessische Naturwaldreservate'.

Table 1. Description of the Hessian sites at which earthworms were sampled so far. The Code-No refers to the biotope type given by Riecken et al. (2003).

No.	Investigation site	Habitat	Biotope-Type (BfN, Riecken et al. 2003)	Reference
1	Darmstadt, periphery	Human settlements	Small unpaved areas in human settlements (Code: 51)	Wurst et al. (2005)
2	Frankenhausen, Hessian state domains	Arable land	Farmed and fallow land on loess, loam or clay soil (Code: 33.04)	Metzke et al. (2007)
3	Bad Vilbel	Deciduous forest	Deciduous and mixed woodlands and forest plantations (deciduous share > 50%) (Code: 43)	Federschmidt (1994)
4	Flörsheim	Grassland	Natural dry grasslands and grassland of dry to humid sites (Code: 34)	Römbke et al. (2004)
5	Frankfurt, municipal woods	Deciduous forest	Beech (mixed) forest on moist, base-deficient sites (Code: 43.07.04)	Lennig (1989)
6	Fulda, Akazienweg	???	No details known	Pieper (1969)
7	Fulda	???	No details known	Pieper (1969)
8	Gieselwerder	Grassland	Natural dry grasslands and grasslands of dry to humid sites (Code: 34.08)	Baltzer (1956)
9	Gießen, between Königsberg and Dünsberg	Deciduous forest	Oak-hornbeam forest on waterlogged to moist site (Code: 43.07.02)	Pieper (1969)
10	Weilrod, Gießen University trial site (Institut für Phytopathologie)	Arable land	Arable and fallow land (Code: 33)	Westernacher-Dotzler (1988)
11	Helmarshausen	Woodland mantle	Woodland mantles and pioneer stages of woodlands; special forms of woodland use (Code: 42)	Baltzer (1956)
12	Hofgeismar	Arable land	Farmed and fallow land on loess, loam or clay soil (Code: 33.04)	Baltzer (1956)
13	Hoher Meißner, bei Kassel	Unknown	Unknown	Museum für Naturkunde, Berlin
14	Homberg (Ohm)	Grassland	Natural dry grasslands and grassland of dry to humid sites (Code: 34)	Stegger (2011)
15	Ilbeshausen-Hochwaldhausen, Neuwiesenwald	Deciduous forest	Alder carr woodland on nutrient rich sites (Code: 43.02.02)	Pieper (1969)
16	Limburg, Gladbacherhof	Arable land	Arable and fallow land (Code: 33)	Gnan (2002)
17	Limburg, Gladbacherhof	Deciduous forest	Deciduous and mixed forest on damp to moist site (Code: 43.07)	Gnan (2002)
18	Limburg, Gladbacherhof	Grassland	Deciduous and mixed woodlands and forest plantations (deciduous share > 50%) (Code: 43)	Gnan (2002)
19	Marburg	Unknown	Unknown	Museum für Naturkunde, Berlin
20	Schotten, Strict Forest Reserve 'Niddahänge östlich Rudingshain'	Deciduous forest	Beech (mixed) forest on moist, base-deficient sites (Code: 43.07.04)	Römbke (2000), Römbke et al. (2002)
21	Wehretal, Strict Forest Reserve 'Hohestein'	Deciduous forest	Beech (mixed) forest on moist, base-deficient sites (Code: 43.07.04)	Römbke (2006)
22	Fulda, Strict Forest Reserve 'Schönbuche'	Deciduous forest	Beech (mixed) forest on moist, base-deficient sites (Code: 43.07.04)	Römbke (2001)

Continued Tab. 1.

No.	Investigation site	Habitat	Biotope-Type (BfN, Riecken et al. 2003)	Reference
23	Wine region Rheingau	Vineyard	Vineyards and fallow vineyards (Code: 41.08)	Hommel (2017)
24	Rotenburg/Bad Hersfeld, Strict Forest Reserve 'Goldbachs- und Ziebachsrück'	Deciduous forest	Deciduous (beech) and mixed forest on damp to moist site (Code: 43.07)	Römbke (2009)
25	Schlangenbad	Unknown	Unknown	Museum für Naturkunde, Berlin
26	Schlangenbad	Deciduous forest	Deciduous and mixed woodlands and forest plantations (deciduous share > 50 %) (Code: 43)	Museum für Naturkunde, Berlin
27	Hanau-Wolfgang, , Strict Forest Reserve 'Kinzigaue'	Floodplain forest	Pedunculate oak-hornbeam forest (Code: 43.04)	Römbke et al. 2012
28	Langenbieber, Kugelberg (castle Bieberstein)	???	No details known	Pieper (1969)
29	Vogelsberg, Rothenbach Teich	???	No details known	Pieper (1969)
30	Ziegel	???	No details known	Pieper (1969)
31	Frankfurt, Harheim	Arable land	Farmed and fallow land on loess, loam or clay soil (Code: 33.04)	Römbke et al. (2002)
32	Frankfurt, Harheim	Orchard	Sparse orchard on grassland (Code: 41.06.01)	Federschmidt (1994)
33	Frankfurt, Harheim	Grassland	Species-rich moist grassland of the planar to submontane zone (Code: 34.07.01)	Römbke et al. (2002)
34	High Vogelsberg Nature Park, area I	Forest fringe	Riparian and forest fringe communi-ties, tall (perennial) herbs (Code: 39)	Eggert (1982)
35	High Vogelsberg Nature Park, area II	Coniferous forest	Coniferous (mixed) plantations with native tree species (Code: 44.04)	Eggert (1982)
36	High Vogelsberg Nature Park, area III	Coniferous forest	Coniferous (mixed) plantations with native tree species (Code: 44.04)	Eggert (1982)
37	High Vogelsberg Nature Park, area IV	Deciduous forest	Deciduous and mixed woodlands and forest plantations (deciduous share > 50 %) (Code: 43)	Eggert (1982)
38	High Vogelsberg Nature Park, area V	Deciduous forest	Deciduous and mixed woodlands and forest plantations (deciduous share > 50 %) (Code: 43)	Eggert (1982)
39	High Vogelsberg Nature Park, area VI	Arable land	Farmed and fallow land on loess, loam or clay soil (Code: 33.04)	Eggert (1982)
40	High Vogelsberg Nature Park, area VII	Grassland	Natural dry grasslands and grassland of dry to humid sites (Code: 34)	Eggert (1982)
41	High Vogelsberg Nature Park, area VIII	Deciduous forest	Carr woodland (Code: 43.02)	Eggert (1982)
42	High Vogelsberg Nature Park, area IX	Clear-cutting/ forest clearing	Clear-cutting and forest clearing vegetation (with predominantly herbaceous vegetation, planar to montane) (Code: 39.02)	Eggert (1982)
43	High Vogelsberg Nature Park, area X	Calcareous slope, dry	???	Eggert (1982)

2.1.2 Further sites

All other samplings were done using standard earthworm-specific methods such as hand-sorting and/or extraction via chemical expellant, mainly formalin solutions or, in recent years, Allyl isothiocyanate (AITC). Actually, these samplings followed more or less current ISO standards (in particular ISO 23611-1 (2018)), since these guidelines were developed based on the experience in research activities. Some individual records refer to non-standard methods such as random sampling by hand. These samplings were performed with different aims at different times and using different methods, meaning that occurrence, abundance and biomass data are difficult to compare. Therefore, in this contribution only the occurrence of the individual species is listed.

2.3 Earthworm determination

Lumbricid worms collected in Hesse were determined according to the following keys: Graff (1953), Bouché (1972), Sims & Gerard (1999) and Csuzdi & Zicsi (2003). These sources were also used when compiling the geographical distribution of the individual species. All our findings have been put into the database 'Edaphobase', which is hosted by the Senckenberg-Museum in Görlitz (Burckhardt et al. 2014).

2.4 Data evaluation

Due to the very heterogenous nature of the data set available for Hesse no further quantitative evaluation could be made.

3. Results

3.1 Listing of Hessian earthworm species

In Table 2 the earthworm species found in Hesse so far and their number of records are listed.

3.2 Taxonomic status of the species and their occurrence in Hesse

In the following, the geographical distribution and partly the ecological profile (Bouché 1977) of the earthworm species found in Hesse so far are briefly discussed. This discussion is mainly based on the national lists compiled by Graff (1953), Bouché (1972), Sims & Gerard (1999), Csuzdi & Zicsi (2003) and Jänsch et al. (2013).

Allolobophora chlorotica (Savigny, 1826) is a name standing for five different genetically-defined lineages, probably cryptic species (King et al. 2008). They can partly be separated by their body colour, i.e. a yellow (= lineages 1, 4 and 5) and a green (lineages 2 and 3) morph exist. No geographical pattern to these lineages was found; in fact, many populations are polymorphic. Despite some indications of different ecological roles of the different morphs usually this species is classified as endogeic. *A. chlorotica* occurs mostly at open sites and higher than average soil moisture (Jänsch et al. 2013). It has been found all over Germany (Lehmitz et al. 2014) and is native in the Western Palaearctic. In Hesse, this species has been found at 11 sites:

- It occurred at various crop sites near the towns of Gießen (Westernacher-Dotzler 1988) and Limburg (Gnan 2002) in Central Hesse
- It was regularly found in the Western wine-growing area of Hesse (Rheingau) during a governmental monitoring campaign (B. Hommel, Database of the Julius-Kühn-Institute, Berlin);
- Stegger et al. (2011) found it at grassland sites near Homberg (Central Hesse);
- Finally, it has been found regularly during qualitative samplings in the Vogelsberg mountains, in deciduous forests but also in grassland, arable land and close to creeks (Eggert 1982).

Sites in Hesse (Tab. 1): 10, 14, 16, 19, 23, 25, 34, 37, 38, 39, 40

Allolobophoridella eiseni (Levinsen, 1884) is a species which was put in various genera before finally an own genus was erected for it (Mrsic 1991). It is classified as an epigeic, predominantly arboreal and/or corticolous species. Probably it is native to Western Europe, except for the Mediterranean region. Krück (2018), citing Wilcke (1939), states that this species did not cross the Elbe River about 80 years ago, but she found some specimen in Brandenburg. In Hesse it has been found in high numbers in different traps at living and dead trees (but rarely on the ground) at various Hessian Forest Reserves (four beech forests, one lowland floodplain forest) (Römbke et al. 2017; and further references therein), including a floodplain forest in south-east Hesse (Römbke et al. 2012). Quite regularly it did occur in the litter layer of forests and under the bark of trees in the Central Hessian Vogelsberg region. In one case it was living on an apple tree two meters up the trunk (Eggert 1982). Rarely it has been reported from other parts of Germany. Due to its very specific lifestyle it has almost never been found with 'typical' earthworm

sampling methods focusing on soil, such as hand-sorting or chemical extraction. Thus, it can be assumed that it is much more widely distributed than indicated by the few findings in the literature.

Sites in Hesse (Tab. 1): 20, 21, 22, 24, 27, 28, 29, 34, 35, 37, 38, 39, 40, 42, 43

Aporrectodea caliginosa s.l. (Savigny, 1826) is the name for a group of closely related species which can partly be distinguished morphologically (even belonging to different ecological groups), partly only by using genetical methods (Perez-Losada et al. 2009). Most often four 'morphs' have been identified (Sims & Gerard 1999): *A. caliginosa* s.s., *A. turgida*, *A. trapezoides*, *A. tuberculata*, (all of them endogeic ones) and *A. nocturna*, a dark-coloured type, classified as an anecic species. According to recent genetic investigations these are all valid species which can be divided into two groups: *A. caliginosa* s.str. and *A. tuberculata* versus *A. trapezoides* and *A. nocturna* – plus *A. longa*. (Perez-Losada et al. 2009). Further research will clarify whether in particular the inclusion of *A. longa* in this complex is agreeable.

The species of the *A. caliginosa*-group are very common all over Europe; they are probably the most common species-group at crop sites in the Palaearctic (Perez-Losada et al. 2009), but the occurrence of the individual species depends on several factors and, thus, differs considerably geographically. In Hesse, this species group was found mainly in agricultural land:

- It occurred at various crop sites near the towns of Gießen (Westernacher-Dotzler 1988) and Limburg (Gnan 2002) in Central Hesse as well as near Frankenhausen in northern Hesse (Metzke et al. 2007); single individuals were found by different researchers at various crop sites all over Hesse.
- It is widespread in different types of grassland, e.g. in apple plantations around Frankfurt am Main (Federschmidt 1994) but also in dry meadows in different parts of Hesse, e.g. Eggert (1982), Stegger et al. (2011) and Baltzer (1956);
- It occurs in the wine-growing region ('Rheingau') along the Rhine river, both in fallows and between the wine plants (B. Hommel, Database of the Julius-Kühn-Institute, Berlin);
- Finally, this species is also common in – especially mixed – forests (not in acid soils) all over Hesse, e.g. in the Vogelsberg area (Eggert 1982) or around Frankfurt (Federschmidt 1994) and even in a floodplain forest in south-east Hesse (Römbke et al. 2012).

Sites in Hesse (Tab. 1): 2, 3, 4, 5, 10, 12, 14, 16, 18, 19, 20, 21, 23, 24, 25, 27, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43

Aporrectodea handlirschi (Rosa, 1897) is a well-defined species, preferring forests. It is classified as epigeic (Lehmitz et al. 2014), but also as 'hemi-edaphic' (Meyer & Plankensteiner 1995). Details of its ecology are unknown. It is native in the southern parts of Eurasia, roughly between Switzerland and Iran. According to Csuzdi & Zicsi (2003), in Germany it has only been found in its south-eastern corner, i.e. parts of Bavaria. In Hesse it was found only twice, in a floodplain forest in south-east Hesse (Römbke et al. 2012) and in a deciduous forest in the Vogelsberg area of Central Hesse (Eggert 1982). These two findings extend the range of this species by several hundred kilometres to the North.

Sites in Hesse (Tab. 1): 27, 38

Aporrectodea icterica (Savigny, 1826) is also a well-defined endogeic species, which is known from various places in Central Europe plus England, Portugal and Italy, but seems to be rare. However, according to Krück (2018) these worms can be seen at cool and moist days in high numbers on the soil surface. In Hesse it was found only once at crop sites near the town of Limburg (Central Hesse) (Gnan 2002).

Sites in Hesse (Tab. 1): 16

Aporrectodea jassyensis (Michaelsen, 1891) is a well-defined endogeic species which rarely seems to be abundant. According to Csuzdi & Zicsi (2003) it is native in the Palaearctic, mainly in south-western Eurasia (i.e. between Switzerland and Italy in the west and the Caucasus as well as Jordan in the east). It is also quite common in the coastal areas of Libya and Egypt. The species has been found in Hesse just once, in an open area within the town of Darmstadt (Wurst et al. 2005).

Sites in Hesse (Tab. 1): 1

Aporrectodea limicola (Michaelsen, 1890) is an endogeic species occurring in grasslands and forests with a preference for moist habitats (Graff 1953). In the past it has regularly been overlooked, possibly due to confusion with *A. caliginosa* (Sims & Gerard 1999). It has been found in Sweden, England, Belgium, Switzerland, and Western Germany. According to Krück (2018), the most eastern findings have been made in the East German state of Thuringia. It has rarely been found in Hesse, mainly in the Vogelsberg area where it does regularly occur at moist sites (Eggert 1982). Interestingly, the few findings were made in very different land use types: deciduous and coniferous forests, as well as crop and grassland sites. Baltzer (1956) found it once in the far North of Hesse near the border to Westphalia at a grassland site. Recently, it was also sampled in a floodplain forest in south-east Hesse (Römbke et al. 2012).

Sites in Hesse (Tab. 1): 8, 20, 27, 30, 33, 34, 36, 37, 38, 39, 40, 41

Aporrectodea longa (Ude, 1885) is, after *L. terrestris*, the most common anecic species in the Palaearctis. In the older literature it was often cited as *A. terrestris*. Morphologically, young individuals cannot be separated from dark-coloured juvenile specimens of *A. caliginosa* (Krück 2018). This species was found between north-eastern Spain and Germany, England and Scandinavia. While Sims & Gerard (1999) report that it can be found eastwards of Germany up to Siberia, Csuzdi & Zicsi (2003) state that there are only a few scattered findings in eastern Europe (e.g. in Hungary at only two sites). It has rarely been found in Hesse, mainly at crop sites (e.g. near Gießen (Westernacher-Dotzler 1988), Limburg (Gnan 2002) and in Frankenhausen (Metzke et al. 2007). This species occurs also in wine-growing areas in the Rheingau (B. Hommel, Database of the Julius-Kühn-Institute, Berlin). Rarely it has been found in beechwood forests with acid soils (Römbke 2000, 2001).

Sites in Hesse (Tab. 1): 2, 10, 16, 20, 22, 23, 31, 33, 34, 39

Aporrectodea rosea (Savigny, 1826) is an endogeic parthenogenetic species, which has frequently been divided into different morphs, sub-species or species, with currently unresolved taxonomic status (e.g. Bouché 1972, Vlasenko et al. 2011, Porco et al. 2018). For example, in the literature one 'form' is sometimes called *A. jenensis* (Fuller, 1953) (e.g. Eggert 1982). However, this very demanding complex has so far not been resolved into named and identifiable species. *A. rosea* is very common in many soils of the Western Palaearctic. In Hesse, it is common, too, especially at crop sites together with *A. caliginosa*:

- It occurred at various crop sites near the towns of Gießen (Westernacher-Dotzler 1988) and Limburg (Gnan 2002) in Central Hesse as well as near

Table 2. List of earthworm species (partly genera) found so far in Hesse (the names of the nine most common species are coloured in grey (Jänsch et al. 2013)). Species being non-common for specific reasons are underlined, while those which are only occurring in compost heaps are indicated by squared brackets.

Genus	Species	Author and year	Taxon. status	No. of records
Allolobophora	*chlorotica*	(Savigny, 1826)	Valid	108
Allolobophoridella	*eiseni*	*(Levinsen, 1884)*	Valid	19
Aporrectodea	*caliginosa*	(Savigny, 1826)	Not clear	160
Aporrectodea	*handlirschi*	(Rosa, 1897)	Valid	1
Aporrectodea	*icterica*	(Savigny, 1826)	Valid	7
Aporrectodea	*jassyensis*	(Michaelsen, 1891)	Valid	1
Aporrectodea	*limicola*	(Michaelsen, 1890)	Valid	11
Aporrectodea	*longa*	(Ude, 1885)	Valid	86
Aporrectodea	*rosea*	(Savigny, 1826)	Valid	149
Dendrobaena	*octaedra*	(Savigny, 1826)	Valid	22
Dendrobaena	*pygmaea*	(Savigny, 1826)	Valid?	3
[*Dendrobaena*	*veneta*	(Rosa, 1886)	Valid	1]
Dendrodrilus	*rubidus*	(Savigny, 1826)	Valid	22
[*Eisenia*	*fetida/andrei*	(Savigny, 1826)	Not clear	3]
Eiseniella	*tetraedra*	(Savigny, 1826)	Valid	5
(*Fitzingeria*	sp.	Zicsi, 1978	Species unclear	1)
Helodrilus	*oculatus*	Hoffmeister, 1845	Valid	4
Lumbricus	*castaneus*	(Savigny, 1826)	Valid	89
Lumbricus	*friendi*	Cognetti, 1904	Valid	1
Lumbricus	*meliboeus*	Rosa, 1884	Valid	1
Lumbricus	*rubellus*	Hoffmeister, 1843	Not clear	96
Lumbricus	*terrestris*	Linnaeus, 1758	Two species	170
Octolasion	*cyaneum*	(Savigny, 1826)	Valid	30
Octolasion	*tyrtaeum*	(Savigny, 1826)	Valid	58
Proctodrilus	*antipae*	(Michaelsen, 1891)	Valid	18

Frankenhausen in northern Hesse (Metzke et al. 2007); single individuals were found by different researchers at various crop sites all over Hesse (e.g. Eggert 1982, Römbke et al. 2002);

- *A. rosea* occurs also in the wine-growing region ('Rheingau') along the Rhine river, both in fallows and between the wine plants (B. Hommel, Database of the Julius-Kühn-Institute, Berlin);
- Less often but still regularly it is found at different grassland sites all over Hesse, both with trees (e.g. in apple plantations (Federschmidt 1994) or without them (e.g. Eggert 1982), even at dry sites in northern and central Hesse (Baltzer 1956, Stegger et al. 2011);
- Finally, it is regularly found in Hessian deciduous forests (Eggert 1982, Federschmidt 1994, Römbke 2000, Römbke et al. 2002), including a floodplain forest in south-east Hesse (Römbke et al. 2012). Once it was even found in a coniferous forest of the Vogelsberg region (Eggert 1982); quite strange for a species which is certainly not acidophil.

Sites in Hesse (Tab. 1): 2, 3, 4, 10, 12, 14, 16, 20, 23, 24, 27, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41

Dendrobaena octaedra (Savigny, 1826) is an epigeic species which is quite easily identifiable due to the octagonal cross section of its posterior body. However, different polyploid and parthenogenetic races have been found (Hansen et al. 2006), which explains that the morphological features of this species are quite variable (Sims & Gerard 1999). It is a typical inhabitant of acid soils, mainly in forest but also in moors. *D. octaedra* is common in the Western Palaearctic, including the far North (e.g. Greenland) and the Mediterranean. In Hesse, it was regularly – but not in very high numbers – found in the pitfall traps and eclectors of the Strict Forest Reserves, i.e. in deciduous forests (Römbke 2000, 2001, 2006, 2009, Römbke et al. 2000). Accordingly, most of the records are from acidic forests, including some isolated samplings from different parts of Hesse (e.g. Baltzer 1956, Eggert 1982).

Sites in Hesse (Tab. 1): 5, 11, 20, 21, 22, 24, 25, 34, 35, 36, 37, 38, 40, 41, 42, 43

Dendrobaena pygmaea (Savigny, 1826) is an epigeic species, often overlooked due to its small size. Sims & Gerard (1999) consider *D. cognettii* as a synonym of *D. pygmaea*, but Csuzdi & Zicsi (2003) list both as valid species. Not much is known about the distribution of this species, but it has been found in Spain, France, England, Germany and Hungary (Sims & Gerard 1999). In Hesse, this species was found just three times, always at moist forest sites in Central Hesse around Gießen (Pieper 1969). Since no additional information has been provided by the author this record should be classified as doubtful.

Sites in Hesse (Tab. 1): 9, 15

Dendrobaena veneta (Rosa, 1886), often cited as belonging to the genus *Eisenia* (e.g. Sims & Gerard 1999) is an epigeic species with high morphological variability. Despite some old documentation in the field *D. veneta* is regularly found only in compost heaps and similar places such as worm-breeding companies. Originally, it is of East-Mediterranean origin, probably in the Caucasus region (Perel 1979). This species was found once near Fulda (further details are not known) (Pieper 1969).

Sites in Hesse (Tab. 1): 7

Dendrodrilus rubidus (Savigny, 1826) is the name of a species which is divided in three subspecies: *D. rubidus rubidus*, *D. rubidus tenuis* and *D. rubidus subrubicundus*, all of them classified as epigeic. However, the validity of these three subspecies is questioned by Csuzdi & Zicsi (2003), who point out that especially *D. r. tenuis* is only a parthenogenetic form. Interestingly, these subspecies have different chromosome numbers (Sims & Gerard 1999). The origin of this species is somewhere in the Holarctic, but no further details are known, but fossil cocoons – 10,000 years old – have been found in Canadian river sediments (Schwert 1979). With very few exceptions (one crop site and two dry grassland sites (Eggert 1982, Gnan 2002)) this species was always found in different Strict Forest Reserves (mainly beech forests on acid soil, e.g. Römbke 2000, 2001, 2006) and many similar forests (including at least one very moist site) in the Vogelsberg region (Eggert 1982). Only once it was sampled in a beech forest on basic soil, near Frankfurt in southern Hesse (Lennig 1989). In south-east Hesse *D. rubidus* did occur in a floodplain forest (Römbke et al. 2012).

Sites in Hesse (Tab. 1): 5, 11, 18, 20, 21, 22, 24, 27, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43

Eisenia fetida (Savigny, 1826) and *Eisenia andrei* Bouché 1972 (no direct finding of the latter but very probably occurring in Hesse due to its mixing-up with *E. fetida* and its use in several laboratories in Hesse (Römbke, pers. data)). Well-known as compost worms these two closely related epigeic species are difficult to distinguish morphologically, but using DNA barcoding they are well discriminable (Römbke et al. 2016). There are indications that *E. fetida* consists of two different species (Römbke et al. 2016), meaning that the *Eisenia fetida/andrei*-complex consists of three species. However, Latif et al. (2017) state that the *Eisenia fetida/*

andrei-complex consists of only two cryptic sibling species and that the classical morphological distinction between *E. fetida* and *E. andrei* does not fit with their phylogenetic structure. Recently, Martinsson & Erseus (2018) showed that within this complex there are just lineages. In breeding experiments in the laboratory, a very complex hybridization pattern was found both within and between individuals belonging to both *E. fetida* and *E. andrei* (Plytycz et al. 2018). Due to their affiliation to compost heaps and, recently, their establishment as a standard test species in ecotoxicological laboratories, worms belonging to the *Eisenia fetida/andrei*-complex are distributed worldwide. In Hesse, it has been found four times, in different habitats but at least twice in accumulations of organic material made by humans (Eggert 1982) or not far away from human settlements (Römbke 2009). For the other two findings (Pieper 1969, Gnan 2002) the same is highly probable.

Sites in Hesse (Tab. 1): 6, 18, 24

Eiseniella tetraedra (Savigny, 1826), being classified as a highly specialized epigeic, is an amphibious species which does occur in or very close to small rivers or lakes. It consists of a number of parthenogenetic clones (e.g., Terhivuo & Saura 2008) which may show morphological differences. However, a recognition of different morphs as varieties (Bouché 1972) is no longer accepted (Sims & Gerard 1999). The origin of this species is probably the Western Palaearctic. In Hesse, its occurrence has been reported from soil-related studies six times, once from a beechwood forest (Römbke 2000), once from a coniferous forest, twice close to a shoreline and once in a grassland – but it has been reported always close to open water or at least very moist areas. This is especially true for a floodplain forest in south-east Hesse (Römbke et al. 2012). Eggert (1982) assumes that it is much more common than these few records indicate, probably all over Hesse. This view is supported by the fact that *E. tetraeda* is regularly found in limnological studies, both in small rivers (e.g. Schwank 1981) as well as in the Rhine river (Schmelz & Schöll 1992).

Sites in Hesse (Tab. 1): 20, 27, 34, 36, 38, 40

Fitzingeria sp. Zicsi, 1978. The very few specimens caught in Hesse could only be assigned to the genus level. Since all species in this genus have been classified as endogeic it is likely that these Hessian worms also represent this ecotype. According to Csuzdi & Zicsi (2003) most of the *Fitzingeria* species have been found in Central to south-eastern Europe. Further samplings in Hesse are necessary in order to clarify whether this single observation made at a grassland site in Central Hesse (Stegger et al. 2011) do indicate a wider distribution of this genus. So far, only the species *Fitzingeria platyura* (Fitzinger, 1833) has previously been found in Germany (Bavaria) (Lehmitz et al. 2014).

Sites in Hesse (Tab. 1): 14

Helodrilus oculatus Hoffmeister, 1845 is a well-defined species which has not been classified ecologically since it is mainly occurring near or even in limnic waters, at least in very wet soils. Strangely, according to Sims & Gerard (1999), populations almost always consist of juveniles, which makes the identification of these worms difficult. It has been found in various Central European countries as well as in Italy and several East-European regions. In Hesse, it has been found at four forest sites, mostly close to moist sites or even open water (Eggert 1982, Römbke 2006, 2009).

Sites in Hesse (Tab. 1): 21, 24, 34, 38

Lumbricus castaneus (Savigny, 1826) is a well-defined epigeic species, which prefers humid soils but can be found regularly in grasslands, and rarely at agricultural sites. It has been found in all over western and central Europe, except of its most southern areas (e.g. southern Spain, or Sicily). In northern and eastern Europe, it has been found at various sites, but according to Csuzdi & Zicsi (2003) it does not occur area-wide. In Hesse, it has been most often found in agricultural soils around Gießen, Central Hesse (Westernacher-Dotzler 1988). Also, quite regularly Eggert (1982) and Gnan (2002) found this species both at crop and grassland sites – a finding which Stegger et al. (2011) confirmed. It is also common at wine-growing areas in the Rheingau (B. Hommel, Database of the Julius-Kühn-Institute, Berlin) and in apple tree plantations north of Frankfurt (Federschmidt 1994). Finally, it is regularly found in deciduous forests in southern Hesse (Federschmidt 1994) as well as in beech wood and coniferous forests in the mountainous Vogelsberg region (Eggert 1982; Römbke 2000; Römbke 2001; Römbke 2006). Remarkably is its occurrence in a floodplain forest in south-east Hesse (Römbke et al. 2012).

Sites in Hesse (Tab. 1): 3, 10, 14, 16, 18, 19, 20, 21, 22, 23, 24, 27, 32, 34, 36, 37, 38, 39, 40

Lumbricus friendi Cognetti, 1904 is a well-defined anecic species which seems to play in Western Europe the ecological role which is exemplified by *Lumbricus terrestris* in the rest of the continent. The 'giant earthworm' *L. badensis*, found only in a very small region in South-West Germany, was considered a sub-species of *L. friendi*. (Lehmitz et al. 2016). This species has been found in Portugal, Spain, France, Italy, Switzerland, Austria, Ireland and, rarely, in England, but in Germany

only few records are known from central and southern sites (Lehmitz et al. 2014). In Hesse, this species was only found once, at a moist meadow site in the Vogelsberg region (Eggert 1982).

Sites in Hesse (Tab. 1): 40

Lumbricus meliboeus Rosa, 1884 is a well-defined epigeic species but seems to be rare in general: despite being found in many European countries there are not many reports in the literature. This impression might be caused by the fact that it prefers mountainous regions. Milutinovic et al. (2013) assume that there at least three 'centres of diffusion', being the Alps, the Iberian mountains and the Balkans, but single records are also known as far away as Sweden (Lehmitz et al. 2014). In Germany it was found once in the South-eastern Black Forest (Lamparski 1985). In Hesse, two specimens were found in pitfall traps in the Strict Forest Reserve Hohestein in a mixed beechwood forest (Römbke 2006).

Sites in Hesse (Tab. 1): 21

Lumbricus rubellus Hoffmeister, 1843 seems to be a group of up to seven cryptic species which can be separated by genetic methods (Martinsson & Erseus 2017). However, even deeply divergent mitochondrial lineages are not always reproductively isolated in this species (Giska et al. 2015). Based on nuclear DNA markers (microsatellites) Donnelly et al. (2013) confirm at least the existence of two different lineages, probably cryptic species, within the *L. rubellus* complex. All worms determined as *L. rubellus* could be classified ecologically as epigeic (Bouché 1972), epi-endogeic (Tiunov et al. 2006, Krück 2018) or as epi-anecic (Vos et al. 2014, Hoeffner et al. 2018). In general, the ecological range of this species is quite broad, e.g. in terms of soil properties and stress factors in general (Spurgeon et al. 2016). It is occurring all over the Holarctic, meaning that it is one of the most common lumbricids. In Hesse, this species is common but not so regularly found as, for example, *A. caliginosa*. Most often this species has been found at deciduous forest sites, e.g. in the Vogelsberg region (Eggert 1982), near Gießen (Westernacher-Dotzler 1988) and near Limburg (Gnan 2002). In addition, these worms are quite common in the soil of apple tree plantations and other grassland sites (Federschmidt 1994), but also well-adapted to a wide range of forest types, including very moist to swampy ones (Eggert 1982; Federschmidt 1994; Römbke et al. 2012).

Sites in Hesse (Tab. 1): 5, 10, 11, 13, 16, 17, 20, 21, 22, 24, 25, 26, 27, 32, 34, 35, 36, 37, 38, 39, 40, 41, 43

Lumbricus terrestris Linnaeus, 1758 was described by Linné from Sweden in 1758. Later on, Savigny (1826) described similar-looking worms from France as *Enterion herculeum*. This species was placed in synonymy with *L. terrestris* (Michaelsen 1900). Only recent DNA-investigations revealed that there are two clearly robust species, which, however, can be distinguished unequivocally only with DNA methods. Since so far all records of *L. terrestris* from Hesse are based on morphological structures, it is not yet established, which of the two species do occur here. *L. terrestris* includes the original Swedish population, while *L. herculeus* includes the original French population (James et al. 2010, Martinsson & Erseus 2017). *L. terrestris* is considered to be the 'model' earthworm, very well-known due to its big size, its distinctive burrow openings at the soil surface and its large influence on organic matter breakdown and nutrient cycling (Turbé et al. 2010). The species is native in the Palaearctic, but might have been introduced by man in some regions [e.g. Hungary (Csuzdi & Zicsi (2003)]. In Germany this species-group (not considering the distinction into the two species) is very widespread, but reacts negatively to mechanical and chemical soil disturbance (Pelosi et al. 2013, Krück 2018). In Hesse, it is quite common:

- At crop and grassland sites, it is regularly found, e.g. in Central Hesse around Gießen (Westernacher-Dotzler 1988), near Limburg (Gnan 2002) or Homberg (Ohm) (Stegger et al. 2011), but also in northern Hesse (near Kassel) (Metzke et al. 2007);
- This species is also common in wine-growing regions such as the Rheingau in Western Hesse (B. Hommel, Database of the Julius-Kühn-Institute, Berlin) or in the region north of Frankfurt, where apple plantations and deciduous forests as well as meadows are common (Federschmidt 1994, Römbke et al. 2002);
- Finally, the species-group has been found in almost all land use types, as indicated by Eggert (1982) who found it within the Vogelsberg region at crop sites, grasslands (including dry ones) and different forest types, even one coniferous stand, as well as in a very moist floodplain forest in south-east Hesse (Römbke et al. 2012).
- In summary, further samplings are clearly needed in order to get a better impression of the distribution of the two species.

Sites in Hesse (Tab. 1): 2, 3, 4, 10, 12, 14, 16, 17, 18, 19, 20, 21, 22, 23, 27, 32, 33, 34, 36, 37, 38, 39, 40.

Octolasion cyaneum (Savigny, 1826) is a well-defined endogeic species, which contains different parthenogenetic morphs (Csuzdi & Zicsi 2003). Ecologically, it has no specific preferences regarding soil type etc. This species is found all over Western Europe (including Ireland and the British Isles), but not in Scandinavia and most of Italy.

Its distribution in eastern Europe is not clear, but it seems that it has not been found (yet) in Greece, the Balkan and Russia. In Hesse, it has been found in all three land use forms (forests, grasslands, crop sites) regularly, but with clear preferences and less commonly than *O. tyrtaeum* (see below):

- Findings at crop sites are documented from northern Hesse e. g. by Baltzer (1956) near Hofgeismar and Metzke et al. (2007) at Frankenhausen, but single samplings are known from Central Hesse (Eggert 1982, Stegger et al. 2011) as well. Regularly the species was found in vine-growing areas (B. Hommel, Database of the Julius-Kühn-Institute, Berlin);
- Especially from southern Hesse there are several findings reported from different grassland types, especially apple plantations (Federschmidt 1994, Römbke et al. 2004);
- Samplings in forests are rare – right now it is known from two deciduous forests in Central Hesse, one of them with a low soil pH (Römbke 2001, Gnan 2002) and from one floodplain forest located in south-east Hesse (Römbke et al. 2012).

Sites in Hesse (Tab. 1): 2, 4, 12, 14, 17, 22, 23, 27, 31, 32, 33, 38, 39, 40

Octolasion tyrtaeum (Savigny, 1826) is a species whose taxonomy has been discussed for quite some time (Csuzdi & Zicsi 2003), mainly because the original description was not very detailed. Therefore, Michaelsen (1900) accepted the species name *O. lacteum* (Örley, 1881). However, in the international literature mainly the name *O. tyrtaeum* is used (Sims & Gerard 1999). To complicate matters further Bouché (1972), based on his experience in France, distinguishes two subspecies: *O. l. lacteum* and *O. lacteum gracile*, which are separated geographically within Europe. Krück (2018) mentions that there is a 'big' form of *O. tyrtaeum* which in its outer appearance cannot be distinguished from *O. cyaneum*. In any case it is ecologically classified as an endogeic species (Sims & Gerard 1999). In Hesse this species (no division in subspecies was made) has been found regularly in the three land use forms (crop sites, grasslands, forests). Findings are strongly biased by the land use under investigation, meaning that this species is probably very widespread:

- Metzke et al. (2007) found *O. tyrtaeum* regularly at crop sites around Frankenhausen in northern Hesse. This species is also common in the wine-growing region of the Rheingau in Western Hesse (B. Hommel, Database of the Julius-Kühn-Institute, Berlin).
- Other authors, especially Federschmidt (1994) and Römbke et al. (2004) sampled *O. tyrtaeum* at various grassland sites, especially apple plantations in southern Hesse.
- It was found very often in different forest types, partly even in acid soils (in general this species seems to have few preferences regarding soil properties, except high moisture levels) (Eggert 1982, Römbke et al. 2000, Römbke 2001, Federschmidt 1994).
- Especially Eggert (1982) points out that at least in the Vogelsberg region the species is more or less equally abundant at grassland and forest sites (both coniferous and deciduous).

Sites in Hesse (Tab. 1): 2, 3, 4, 12, 20, 21, 22, 23, 32, 33, 34, 36, 37, 38, 39, 40, 42

Proctodrilus antipae (Michaelsen, 1891) is a well-defined endogeic species but does not fit well into one of the existing lumbricid genera, so that it was put either in *Allolobophora* or *Helodrilus.* After the erection of the genus *Proctodrilus* in 1985 the taxonomic situation has been clarified. *P. antipae* strongly prefers moist soils near rivers and in floodplains (Höser & Zicsi 2009, Höser 2018). This species is distributed widely in Central Europe, i.e. between France, northern Italy, the Baltic sea and the Black Sea (Csuzdi & Zicsi 2003). This is an uncommon pattern and may change if its preferred habitats were sampled more intensively. In Germany it has been found especially near the river Elbe and its tributaries (Krück 2018). In Hesse, it was found only at grassland sites, including apple plantations in southern Hesse around Frankfurt (Federschmidt 1994). However, it might be that this small species has been overlooked in the past.

Sites in Hesse (Tab. 1): 4, 32, 33

4. General discussion

So far, out of 46 earthworm species found in Germany (Lehmitz et al. 2016) 25 (including one reference to a genus) have been found in Hesse, which is 54 % of the total number. Jänsch et al. (2013) in their review on the state-of-the-art of earthworm distribution identified the following 10 species as the most common ones in Germany:

Allolobophora chlorotica (Savigny, 1826)

Aporrectodea caliginosa (Savigny, 1826)

Aporrectodea longa (Ude, 1885)

Aporrectodea rosea (Savigny, 1826)

Dendrobaena octaedra (Savigny, 1826)

Dendrodrilus rubidus (Savigny, 1826)

Lumbricus castaneus (Savigny, 1826)

Lumbricus rubellus (Hoffmeister, 1843)

Lumbricus terrestris Linnaeus, 1758

Octolasion tyrtaeum (Savigny, 1826)

As expected, all of them have been found in Hesse at least once. More interestingly, these ten species were almost always those species which have been found most often in Hesse (Tab. 2). So, despite the completely different methods used and the uncoordinated sampling efforts the knowledge on the earthworm fauna of Hesse is not bad. However, in relation to the efforts made in neighbouring countries such as France, Ireland or the Netherlands the earthworm fauna of Hesse is not well known (Rutgers et al. 2016).

But what about the other 14 less common species (omitting the single record of *Fitzingeria* sp.)? Here, two groups can be distinguished. One would consist of species whose rareness is a result of sampling bias:

- *A. eiseni* occurs mainly on dead or living wood, meaning that the standard earthworm sampling methods, which focus on the soil habitat, are simply not adapted to discover this species;
- *A. limicola, E. tetraeda, P. antipae,* and possibly also *O. cyaneum* prefer very moist soils to even limnic habitats. These sites are more rarely sampled in comparison to 'normal' soil sites, thus species preferring those are underrepresented.

Three species have to be excluded from further discussions since they usually do not occur in the 'wild' but are restricted to compost heaps and/or worm breeding facilities: *E. fetida* (including *E. andrei*), and *D. veneta*.

For the last seven species (*A. handlirschi, A. icterica*, *A. jassyensis*, *D. pygmaea*, *H. oculatus*, *L. friendi*, *L. meliboeus*) different reasons for their low number of records have to be considered. For example, in some cases biological or ecological reasons might be responsible for their low findings: e.g., for *L. meliboeus* the Hessian mountains may not be high enough and the size of *D. pygmaea* is very small so that these worms are often overlooked. In addition, in some cases misidentifications might have occurred, but since usually no voucher specimen have been stored this question cannot be solved. In other cases, it is not known why these species are rarely found.

Summarising the experiences made in this compilation we recommend to set up an earthworm monitoring program for Hesse, which is based on standardized sampling methods (e.g. ISO 23611-1 2018). In addition – referring here to our findings of *A. eiseni* on trees – specific methods have to be used for specific habitats on a case-by-case basis. Monitoring sites should be well characterized – in fact, already installed 'Bodendauerbeobachtungsflächen = Permanent Soil Monitoring Sites' should be used for this purpose. In addition, besides traditional morphological methods for species identification also advanced DNA methodology should be used (Taberlet et al. 2012). The results of such monitoring efforts will be used for an assessment of the biological quality of Hessian soils (forests, grasslands, crop sites, 'special' sites such as flooded areas) as well as a means to evaluate soil biodiversity. Details of an earthworm monitoring program for Hesse are presented in Römbke et al. (2013).

4. References

Baltzer, R. (1956): Die Regenwürmer Westfalens. – Zoologisches Jahrbuch **84**: 355–413.

Barth, N., W. Brandtner, E. Cordsen, T. Dann, K.-H. Emmerich, D. Feldhaus, B. Kleefisch, B. Schilling & J. Utermann (2000): Boden-Dauerbeobachtung - Einrichtung und Betrieb von Boden-Dauerbeobachtungsflächen. – In: Rosenkranz, D., G. Bachmann, W. König & G. Einsele (eds): Bodenschutz. Kennziffer **9152**. – E. Schmidt Verlag, Berlin. Germany.

Beylich, A. & U. Graefe (2009): Investigations of annelids at soil monitoring sites in northern Germany: reference ranges and time-series data. – Soil Organisms **81**: 175–196.

Bouché, M. B. (1972): Lombriciens de France. Écologie et systématique. – Annales de zoologie. Ecologie animale, hors série **72(2)**: 1–671.

Bouché, M. B. (1977): Stratégies lombriciennes. – In: Lohm, U. & T. Persson (eds): Soil organisms as components of ecosystems. – Ecological Bulletins NFR **25**: 122–132.

Burkhardt, U., D. J., Russell, R. Buryn, P. Decker, M. Döhler, H. Höfer, J. Römbke, C. Trog, J. Vorwald, E. Wurst & W. E. Xylander (2014): The Edaphobase Project of GBIF-Germany – A new online soil-organism zoological data warehouse. – Applied Soil Ecology **83**: 5–12.

Csuzdi, C. & A. Zicsi (2003): Earthworms of Hungary (Annelida: Oligochaeta, Lumbricidae). – Pedozoologica Hungarica **1**: 1–272.

Donnelly, R. K., G. L. Harper, A. J. Morgan, P. Orozco-Terwengel, G. A. Pinto-Juma, & M. W. Bruford (2013): Nuclear DNA recapitulates the cryptic mitochondrial lineages of *Lumbricus rubellus* and suggests the existence of cryptic species in an ecotoxicological soil sentinel. – Biol. J. Linnean Soc. **110**: 780–795.

Dorow, W. H. O., G. Flechtner & J.-P. Kopelke (1992): Zoologische Untersuchungen — Konzept. Naturwaldreservate in Hessen 3. – Mitteilungen der Hessischen Landesforstverwaltung **26**: 1–159.

Eggert, U. J. (1982): Vorkommen und Verbreitung der Regenwürmer (Lumbricidae) des Naturparks „Hoher Vogelsberg“. – Beiträge zur Naturkunde in Osthessen **18**: 61–103.

Federschmidt, A. (1994): Die Oligochaetenfauna zweier Ökosysteme auf Lößlehm unter Berücksichtigung der Auswirkungen von Chemikalienstress. - Dissertation, Doctoral thesis, Universität Frankfurt: 319 pp.

Giska, I., P. Sechi & W. Babik (2015): Deeply divergent sympatric mitochondrial lineages of the earthworm *Lumbricus rubellus* are not reproductively isolated. – BMC evolutionary biology **15**: 13 pp.

Gnan, R. (2002): Analyse und Bewertung der Abundanz und des Artenspektrums von Regenwürmern (Lumbriciden) in den ackerbaulich genutzten Böden des Lehr- und Versuchsbetriebes Gladbacherhof. – Diploma thesis, University of Gießen, Germany: 96 pp.

Graff, O. (1953): Die Regenwürmer Deutschlands. – Schriftenreihe des Forschungsinstituts für Landwirtschaft **7**: 1–70.

Hansen, P. L., M. Holmstrup, M. Bayley & V. Simonsen (2006): Low genetic variation for *Dendrobaena octaedra* from Greenland compared to populations from Europe and North America: Refuge or selection? – Pedobiologia **50**: 225–234.

Hoeffner, K., C. Monard, M. Santonja & D. Cluzeau (2018): Feeding behavior of epi-anecic earthworm species and their impacts on soil microbial communities. – Soil Biology and Biochemistry **125**: 1–9.

Höser, N. (2018): Interrelation of *Proctodrilus* species (Oligochaeta: Lumbricidae) with lessivage and layering in European soil profiles. – Zootaxa **4496**: 96–110.

Höser, N. (2013): Zur Regenwurmfauna (Oligochaeta: Lumbricidae) in Wäldern Mecklenburgs. – Archiv der Freunde der Naturgeschichte Mecklenburgs **52**: 75–85.

Höser, N. & A. Zicsi (2009): Eine neue *Proctodrilus*-Art (Oligochaeta: Lumbricidae) und ihr spezifisches Ökotop. - Contributions to Natural History (Bern) **12**: 651–658.

IBV (Informations- und Koordinierungszentrum für Biologische Vielfalt) (2016): Datenbank Naturwaldreservate in Deutschland. – Bundesanstalt für Landwirtschaft und Ernährung [http://www.naturwaelder.de].

ISO (International Organization for Standardization) (2018): Soil quality – sampling of soil invertebrates. Part 1: Hand-sorting and formalin extraction of earthworms. – ISO 23611-1: 1–26. Genève, Switzerland.

James, S.W., D. Porco, T. Decaens, B. Richard, R. Rougerie & C. Erseus (2010): DNA Barcoding reveals Cryptic Diversity in *Lumbricus terrestris* L., 1758 (Clitellata): Resurrection of *L. herculeus* (Savigny, 1826). – PLOS One, **5, 12,** e15629: 1–8.

Jänsch, S., L. Steffens, H. Höfer, F. Horak, M. Roß-Nickoll, D. Russell, A. Toschki, & J. Römbke (2013): State of knowledge of earthworm communities in German soils as a basis for biological soil quality assessment. – Soil Organisms **85**: 215–232 + Electronic Supplement.

King, R.A., A. L. Tibble & O. C. Symondson (2008): Opening a can of worms: unprecedented sympatric cryptic diversity within British lumbricid earthworms. – Molecular Ecology **17**: 4694 – 4698.

Krück, S. (2018): Bildatlas zur Regenwurmbestimmung. – Natur + Text, Rangsdorf: 196 pp.

Lamparski, F. (1985): Der Einfluss der Regenwurmart *Lumbricus badensis* auf Waldböden im Südschwarzwald. Freiburger Bodenkundliche Abhandlungen **15**: 205 pp.

Latif, R., M. Masoumeh & C. Csuzdi (2017): When morphology and DNA are discordant: Integrated taxonomic studies on the *Eisenia fetida/andrei* complex from different parts of Iran (Annelida, Clitellata: Megadrili). European Journal of Soil Biology **81**: 55-63.

Lavelle, P., T. Decaëns, M. Aubert, S. Barot, M. Blouin, F. Bureau, P. Margerie, P. Mora & J-P. Rossi (2006): Soil invertebrates and ecosystem services. – European Journal of Soil Biology **42**: S3–S15.

Lehmitz, R., J. Römbke, U. Graefe, A. Beylich & S. Krück (2016): Rote Liste und Gesamtartenliste der Regenwürmer (Lumbricidae et Criodrillidae) Deutschlands. – Naturschutz und Biologische Vielfalt **70**(4): 565–590.

Lehmitz, R., J. Römbke, S. Jänsch, S. Krück, A. Beylich & U. Graefe (2014): Checklist of earthworms (Oligochaeta: Lumbricidae) from Germany. – Zootaxa **3866**: 221–245.

Lennig, A. (1989): Lumbricidenfauna im Frankfurter Stadtwald an Buchenwald-standorten unterschiedlicher Schädigung. - Project thesis/Semester thesis/Term paper, State examination thesis, University of Frankfurt, Germany: 69 pp.

Martinsson, S. & C. Erséus (2017): Cryptic speciation and limited hybridization within *Lumbricus* earthworms (Clitellata: Lumbricidae). – Molecular Phylogenetics and Evolution **106**: 18–27.

Martinsson, S. & C. Erséus (2018): Hybridisation and species delimitation of Scandinavian *Eisenia* spp. (Clitellata: Lumbricidae). – European Journal of Soil Biology **88**: 41–47.

Metzke, M., M. Potthoff, M. Quintern, J. Heß & R. Joergensen (2007): Effect of reduced tillage systems on earthworm communities in a 6-year organic rotation. – European Journal of Soil Biology **43**: 209–215.

Meyer, E. & U. Plankensteiner (1995): Regenwürmer (Luinbricidae) in Waldböden Vorarlbergs (Österreich). – Berichte Naturwissenschaftlich-Medizinischer Verein Innsbruck **82**: 95–103.

Michaelsen, W. (1900): Oligochaeta. - Das Tierreich **X**. – Friedländer & Sohn, Berlin: 575 pp.

Milutinovic, T., R. Tsekova, J. Milanovic & M. Stojanovic (2013): Distribution, biogeographical significance and status of *Lumbricus meliboeus* Rosa, 1884 (Oligochaeta, Lumbricidae) at the European scale: first findings in Serbia and in Bulgaria. – North-Western Journal of Zoology **9**: 63–69.

Mršić, N. (1991): Monograph on earthworms (Lumbricidae) of the Balkans I–II. – Slovenska Akademija Znanosti in

Umetnosti, Zazred za Naravoslovne Vede Opera, Ljubljana **31**: 1–757.

Pelosi, C., L. Toutous, F. Chiron, F. Dubs, M. Hedde, A. Muratet, A., Ponge, J-F., Salmon, F. & D. Makowski (2013): Reduction of pesticide use can increase earthworm populations in wheat crops in a European temperate region. – Agriculture, Ecosystems & Environment **181**: 223–230.

Perel, T. S. (1979): Range and regularities in the distribution of earthworms in the USSR fauna. - Nauka, Mosow: pp. 272 (in Russian).

Pérez-Losada, M., M. Ricoy, J. C. Marshall & J. Domínguez (2009): Phylogenetic assessment of the earthworm *Aporrectodea caliginosa* species complex (Oligochaeta: Lumbricidae) based on mitochondrial and nuclear DNA sequences. – Molecular Phylogenetics and Evolution **52**: 293–302.

Pieper, H. (1969): Zur Verbreitung der Regenwürmer in einigen Landschaften Hessens. – Beiträge zur Naturkunde in Osthessen **1**: 103–106.

Plytycz, B., J. Bigaj, A. Osikowski, S. Hofman, A. Falniowski, T. Panz, P. Grzmil & F. Vandenbulcke (2018): The existence of fertile hybrids of closely related model earthworm species, *Eisenia andrei* and *E. fetida*. - PLoS ONE **13(1)**: e0191711, 18 pp.

Porco, D., C-H. Chang, L. Dupont, S. James, B. Richard & T. Decaëns, T. (2018): A reference library of DNA barcodes for the earthworms from Upper Normandy: Biodiversity assessment, new records, potential cases of cryptic diversity and ongoing speciation. - Applied Soil Ecology **124**: 362–371.

Riecken, U., P. Finck, U. Raths, E. Schröder & A. Ssymank (2003): Standard-Biotoptypenliste für Deutschland, 2. Fassung - Schriftenreihe für Landschaftspflege u. Naturschutz **75**: 65 S. + Anhänge.

Römbke, J. (2000): Lumbricidae (Regenwürmer). – In: Niddahänge östlich Rudingshain. Zoologische Untersuchungen 1990-1992. Teil 1. - Naturwaldreservate in Hessen 5/2.1. – Mitteilungen der Hessischen Landesforstverwaltung **32/1**: 57–83.
[http://www.senckenberg.de/root/index.php?page_id=16851]

Römbke, J., P. Dreher, L. Beck, W. Hammel, K. Hund, H. Knoche, W. Kördel, W. Kratz, T. Moser, S. Pieper, A. Ruf, J. Spelda & S. Woas (2000): Bodenbiologische Bodengüte-Klassen. - Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, **Texte 6/00**, 276 pp.

Römbke, J. (2001): Lumbricidae (Regenwürmer). – In: Schönbuche. Zoologische Untersuchungen 1990-1992. Teil 1. Naturwaldreservate in Hessen 6/2.1. – Hessen-Forst – FIV Ergebnis- und Forschungsbericht **28/1**: 27–52 [http://www.senckenberg.de/root/index.php?page_id=16851].

Römbke, J., P. Dreher, L. Beck, K. Hund-Rinke, S. Jänsch, W. Kratz, S. Pieper, A. Ruf, J. Spelda & S. Woas (2002): Entwicklung von bodenbiologischen Bodengüteklassen für Acker- und Grünlandstandorte. - Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit. - Texte **20** 273.

Römbke, J., C. A. M. van Gestel, S. E. Jones, J. E. Koolhaas, J. M. L. Rodrigues & T. Moser (2004): Ring-Testing and Field-Validation of a Terrestrial Model Ecosystem (TME) – An Instrument for Testing Potentially Harmful Substances: Effects of Carbendazim on Earthworms. – Ecotoxicology **13**: 105–118.

Römbke, J. (2006): Lumbricidae (Regenwürmer). – In: Hohestein. Zoologische Untersuchungen 1994-1996, Teil 1. Naturwaldreservate in Hessen 7/2.1. – Mitteilungen der Hessischen Landesforstverwaltung **41**: 29–59 [http://www.senckenberg.de/root/index.php?page_id=16851].

Römbke, J. (2009): Die Regenwürmer (Lumbricidae) des Naturwaldreservats Goldbachs- und Ziebachsrück (Hessen). Untersuchungszeitraum 1994–1996. – Mitteilungen der Hessischen Landesforstverwaltung **45**: 25–55 [http://www.senckenberg.de/root/index.php?page_id=16851].

Römbke, J., T. Blick & W. H. O. Dorow (2012): Die Regenwürmer (Lumbricidae) des Naturwaldreservats Kinzigaue (Hessen). Untersuchungszeitraum 1999–2001. In: Blick, T., Dorow, W.H.O. & Kopelke, J.-P.: Kinzigaue. Zoologische Untersuchungen 1999–2001, Teil 1. Naturwaldreservate in Hessen **12**: 23–51.

Römbke, J., U. Burkhardt, H. Höfer, F. Horak, S. Jänsch, M. Roß-Nickoll, D. Russell, H. Schmitt & A. Toschki (2013): Beurteilungsansätze für die Boden-Biodiversität: Ergebnisse eines UBA-Vorhabens. – Bodenschutz **3/13**: 100–105.

Römbke, J., M. Aira, T. Backeljau, K. Breugelmans, J. Domínguez, E. Funke, N. Graf, M. Hajibabaei, M. Pérez-Losada, P.G. Porto, R. M. Schmelz, J. Vierna, A. Vizcaíno & M. Pfenninger (2016): DNA barcoding of earthworms (*Eisenia fetida/andrei* complex) from 28 ecotoxicological test laboratories. – Applied Soil Ecology **174**: 3–11.

Römbke, J., W. Dorow & T. Blick (2017): *Allolobophoridella eiseni* (Lumbricidae), a truly arboreal earthworm in the temperate region of Central Europe. – Soil Organisms **89**: 74–83.

Rutgers, M., A. Orgiazzi, C. Gardi, J. Römbke, S. Jänsch, A. Keith, R. Neilson, B. Boag, O. Schmidt, A.K. Murchie, R.P. Blackshaw, G. Pérès, D. Cluzeau, M. Guernion, M. J. I. Briones, J. Rodeiro, R. Piñeiro, D. Díaz-Cosin, J. P. Sousa, M. Suhadolc, I. Kos, P.H. Krogh, J. Faber, C. Mulder, J. J. Bogte, H. J. van Wijnen, A.J. Schouten & D. de Zwart (2016): Mapping earthworm communities in Europe. – Applied Soil Ecology **97**: 98–111.

Savigny, J. C. (1826): Analyse des Travaux de l'Académie royale des Sciences, pendant l'année 1821, partie physique. - In: Cuvier, G. (ed.), Mémoires de l'Académie des Sciences de l'Institut de France. Vol. **5**. Paris: 176–184.

Schmelz, R. & F. Schöll (1992): Über die Oligochaetenfauna an der Stromsohle des Rheins. – Lauterbornia **12**: 1–10.

Schwank, P. (1981): Turbellarien, Oligochaeten und Archianneliden des Breitenbachs und anderer oberhessischer Mittelgebirgsbäche. II. Die Systematik und Autökologie der einzelnen Arten. – Archiv für Hydrobiologie Supplement **62**: 86–147.

Schwert, D.P. (1979): Description and significance of a fossil earthworm (Oligochaeta: Lumbricidae) cocoon from postglacial sediments in Southern Ontario. – Canadian Journal of Zoology **57**: 1402–1405.

Sims, R. W. & B. M. Gerard (1999): Earthworms. In: Kermack, D. M. & Barnes, R.S.K. (eds): Synopses of the British Fauna (New Series) **No. 31**. – E. J. Brill / W. Backhuys, London, UK: 1–171.

Spurgeon, D. J., M. Liebeke, C. Anderson, P. Kille, A. Lawlor, J. G. Bundy & E. Lahive (2016): Ecological drivers influence the distributions of two cryptic lineages in an earthworm morphospecies. – Applied Soil Ecology **108**: 8–15.

Stegger, P., K. P. Ebke & J. Römbke (2011): Boric acid as alternative reference substance for earthworm field tests. – Journal of Soils Sediments **11**: 330–335.

Taberlet, P., E. Coissac, M. Hajibabaei & L. H. Rieseberg (2012): Environmental DNA. – Molecular Ecology **21**: 1789–1793.

Terhivuo, J. & A. Saura (2008): Clone distribution of the earthworm *Eiseniella tetraedra* (Sav.) (Oligochaeta: Lumbricidae) across an altitudinal gradient on subarctic mountains of NW Europe. – Pedobiologia **51**: 375–384.

Tiunov, A.V., C. M. Hale, H. M. Holdsworth & T. S. Vsevolodova-Perel (2006): Invasion patterns of Lumbricidae into the previously earthworm-free areas of northeastern Europe and the western Great Lakes region of North America. – Biological Invasions **8**: 1223–1234.

Turbé, A., De Toni, A., Benito, P., Lavelle, P., Ruiz, N., Van der Putten, W. H., Labouze, E. & Mudgal, S. (2010): Soil biodiversity: functions, threats and tools for policy makers. Bio Intelligence Service, IRD, and NIOO, Report for the European Commission (DG Environment). 250 p.

Van Groenigen, J. W., I. M. Lubbers, H. M. J. Vos, G. G. Brown, G. B. De Deyn & K. J. van Groenigen (2014): Earthworms increase plant production: a meta-analysis. – Scientific Reports **4**: 6365 | DOI: 10.1038/srep06365.

Vlasenko, R. P., S. V. Mezhzherin, A. V. Garbar & Y. Kotsuba (2011): Polyploid races, genetic structure and morphological features of earthworm *Aporrectodea rosea* (Savigny, 1826) (Oligochaeta, Lumbricidae) in Ukraine. – Comparative Cytogenetics **5**: 91–103.

Vos, H. M., M. B. Ros, G. F. Koopmans & J. W. van Groenigen (2014): Do earthworms affect phosphorus availability to grass? A pot experiment. – Soil Biology and Biochemistry **79**: 34–42

Westernacher-Dotzler, E. (1988): Abundanz von Regenwürmern (Lumbricidae, Oligochaeta) unter verschiedenen Kulturpflanzen. - Doctoral thesis, University of Braunschweig, Germany: 149 pp.

Wilcke, D. E. (1939): Der gegenwärtige Stand unserer Kenntnis der märkischen Lumbricidenfauna. – Märkische Tierwelt **4**: 34–50.

Wurst, S., R. Langel & S. Scheu (2005): Do endogeic earthworms change plant competition? – A microcosm study. Plant and Soil **271**: 123–130.