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Article

Diversity of earthworm communities in the European part of Russia: field data and model estimations

N.V. Ivanova[1*], M.P. Shashkov[1], S.A. Ermolov[1, 2]

[1] *Institute of Mathematical Problems of Biology RAS – the Branch of Keldysh Institute of Applied Mathematics, Russian Academy of Sciences, Professor Vitkevich St. 1, Pushchino, Moscow Oblast, 142290 Russia*

[2] *Centre for Forest Ecology and Productivity, Russian Academy of Sciences, Profsoyuznaya St. 84/32 bldg. 14, Moscow, 117997 Russia*

**natalya.dryomys@gmail.com*

Abstract. The predictions of the global earthworm community diversity spatial model, published by H.R.P. Phillips et al. (2019), and field data for earthworm surveys available for the European part of Russia were compared. We analyzed early literature dataset comprised 271 surveys. According to the literature data, 25 earthworm species are reported in the European part of Russia, total of 1 to 9 species were recorded per survey. The greatest species richness was recorded in the broad-leaved forests (on average, 5 ± 2 species) and in the urbanized areas (5 ± 2 species), the lowest (2 ± 0 species) was in larch forests. The highest earthworm population density was observed in broad-leaved forests (217 ± 168 ind./m^2), the lowest (5 ± 0 ind./m^2), in larch forests. The field assesments considerably exceeded the modelling results. According to the model, species richness calculated for the sampling sites was 1 ± 1 species on average, population density, 2 ± 1 ind./m^2. These discrepancies were due to an insufficient volume of input data for modelling; the latter, in turn, was due to strict criteria for data selection.

Keywords: biodiversity, spatial model, data digitization, GBIF

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ORCID:
N.V. Ivanova, https://orcid.org/0000-0003-4199-5924
M.P. Shashkov, https://orcid.org/0000-0002-1328-8758
S.A. Ermolov, https://orcid.org/0000-0002-0634-7641

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Научная статья

Разнообразие сообществ дождевых червей в Европейской России: полевые данные и модельные оценки

Н.В. Иванова[1]*, М.П. Шашков[1], С.А. Ермолов[1, 2]

[1] *Институт математических проблем биологии РАН – филиал ИПМ им. М.В. Келдыша РАН, 142290, Россия, Московская область, г. Пущино, ул. проф. Виткевича, д. 1*

[2] *Центр по проблемам экологии и продуктивности лесов РАН, 117997, Россия, г. Москва, ул. Профсоюзная, д. 84/32, стр. 14*

**natalya.dryomys@gmail.com*

Аннотация. В работе представлены результаты сравнения глобальной пространственной модели разнообразия сообществ дождевых червей, опубликованной H.R.P. Phillips et al. в 2019 г., с доступными для Европейской России полевыми данными. Материалы полевых исследований (271 сбор) взяты из ранее обобщенного нами массива литературных данных. На их основе показано, что всего в регионе учтено 25 видов дождевых червей, в сборах отмечено от 1 до 9 видов. Среди биотопов разных типов наибольшее число видов зафиксировано в широколиственных лесах (в среднем 5 ± 2 видов) и на урбанизированных территориях (5 ± 2 видов), наименьшее – в лиственничных лесах (2 ± 0 вида). Максимальная численность дождевых червей отмечена в широколиственных лесах (217 ±168 экз./м^2), минимальная – в лиственничных лесах (5 ± 0 экз./м^2). Полученные показатели значительно превышают модельные оценки. Согласно последним, среднее значение видового богатства в точках проведения полевых исследований составляет 1 ± 1 вид, численности – 2 ± 1 экз./м^2. Расхождения вызваны недостаточным объемом исходных данных для моделирования, что, в свою очередь, обусловлено строгими критериями их отбора.

Ключевые слова: биоразнообразие, пространственная модель, оцифровка данных, GBIF

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ORCID:
Н.В. Иванова, https://orcid.org/0000-0003-4199-5924
М.П. Шашков, https://orcid.org/0000-0002-1328-8758
С.А. Ермолов, https://orcid.org/0000-0002-0634-7641

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Introduction

Earthworms from the orders Crassiclitellata, Moniligastrida, and Opisthopora (with the most widely distributed species of the family Lumbricidae) are the most abundant group of soil invertebrates in terms of biomass in many biotopes of the temperate zone (Edwards and Bohlen, 1996; Lee, 1985). Nevertheless, despite the great importance of this group in ecosystem processes (Blouin et al., 2013; Bouché, 2014; Eisenhauer et al., 2007; Eisenhauer, 2010; Frouz et al., 2011; Lavelle et al., 1997, Ponge et al., 2014), the data on earthworm distribution and community structure are still fragmentary and insufficient at the global scale (Cameron, 2018; Phillips et al., 2019, 2021; Rutgers et al., 2016). Filling existing knowledge gaps is complicated due to the laborious and geographically restricted character of the field surveys (Coja et al., 2008; Eisenhauer et al., 2008; Ghilarov, 1975; Hackenberger et al., 2017). This issue is accompanied by the difficulty of accessing the published data. Much of these data is provided in "gray" literature: these are reports on technical and research projects, theses and dissertations, conference proceedings, journals published in limited editions in hard copies only and thus unavailable through the Internet, etc.

The modelling approach is prospective for solving this issue. Mathematical models enable one to predict the probability of particular species occurrence, community structure and composition for the areas, where no field studies have been conducted. Such models are based on known data on the distribution of certain species or community composition at certain locations around the globe and environmental properties (Guisan and Thuiller, 2005; Phillips et al., 2006). The number of models of the earthworm community distribution is very limited. Earthworm abundance and species richness models were built for Western Europe, considering various environmental factors (Rutgers et al., 2016). The only model known so far that includes the territory of Russia has been developed by Helen R.P. Phillips et al. (2019). They predict the species richness, abundance, and biomass of earthworm communities on a global scale. Model predictions led to a controversial response from the scientific community (James et al., 2021). Therefore, comparison of model estimates of earthworm community diversity reported by Phillips et al. (2019) with the results of field surveys is of particular interest. However, such comparisons were hardly possible for the territory of Russia until recently, because the data on the composition and community structure of this taxonomic group remained scattered. Previously, our team digitized and generalized the data on earthworm’s species occurrences and their communities based on Russian-language publications (Shashkov et al., 2023, 2024).

The study aims to compare the model estimates of earthworm community diversity for the European part of Russia against the summarized literature data.

Materials and methods

The dataset on the earthworm distribution was collected from 159 papers of Russian researchers. The dataset includes 5304 occurrences of 110 earthworm species recorded for 27 countries. Most of the information relates to the territory of Russia. The compiled data are available through the GBIF global biodiversity portal (Shashkov, 2023). The methodology for data searching, processing, and standardization has been described earlier (Shashkov et al., 2024). The earthworm species list follows the actual taxonomy (Brown et al., 2023), presenting also scientific names according to the original papers. The data include the details both on occurrences and surveys. We define "survey" as the data on species composition and abundance of earthworm communities obtained by the standard method of soil sampling at a certain geographic point (Ghilarov, 1975).

The data analysis comprised the part of the collected dataset that covered the European part of Russia (excluding islands, exclaves, and Caucasus mountains). We have chosen this area, because almost all of the input data for Russia used in the model by Phillips et al. (2019) derived from its European part, and because the published information for this region is the most represented. For the study area, the number of considered earthworm surveys was 271, the number of occurrences 1051 (Fig. 1**A**).

During the data analysis the total number of earthworm species in the European part of Russia was estimated. Information on the habitat types provided by the authors was then aligned to the classification used by Phillips et al. (2019). No habitat information was available for 14 records. A list of habitat types and literature sources analized in this study is provided in Table 1. The frequency and abundance of species belonging to various morpho-ecological groups (Geras'kina, 2020; Perel', 1979) were then analyzed in these habitat types. Since the number of surveys in different habitat types varied considerably, calculations were performed only for the most represented habitat types.

Primary data on surveys used for the model were obtained through the iDiv portal (Phillips et al., 2020). The number of these surveys for the European part of Russia was 171 (Fig. 1**B**). Raster layers that provide community abundance estimates, based on spatial interpolation of the regression models by Phillips et al. (2019), were obtained upon request to the authors. The spatial resolution of the layers was ~1 km/pixel, the geographic coordinate system was WGS 84.

Literature data were compared with the model estimates using species richness (number of species in a particular survey), and abundance (ind./m²); the latter was specified for 180 surveys out of 271. Biomass estimates were not considered in our study, as it was not reported in most papers, although this community metric was predicted in the model by Phillips et al. (2019). The mean and standard deviation (± SD) were calculated both for number of species and for total abundance of earthworms in the survey for each habitat type. The obtained metrics of earthworm community diversity were then compared for the published model estimates at the same geographical points. Information from raster layers was obtained using the *terra* package in the R environment. The results were visualized in the form of "violin" diagrams (*ggplot2* package), which allowed plotting the shape of variable distribution. Due to the obvious differences, their statistical significance was not assessed.

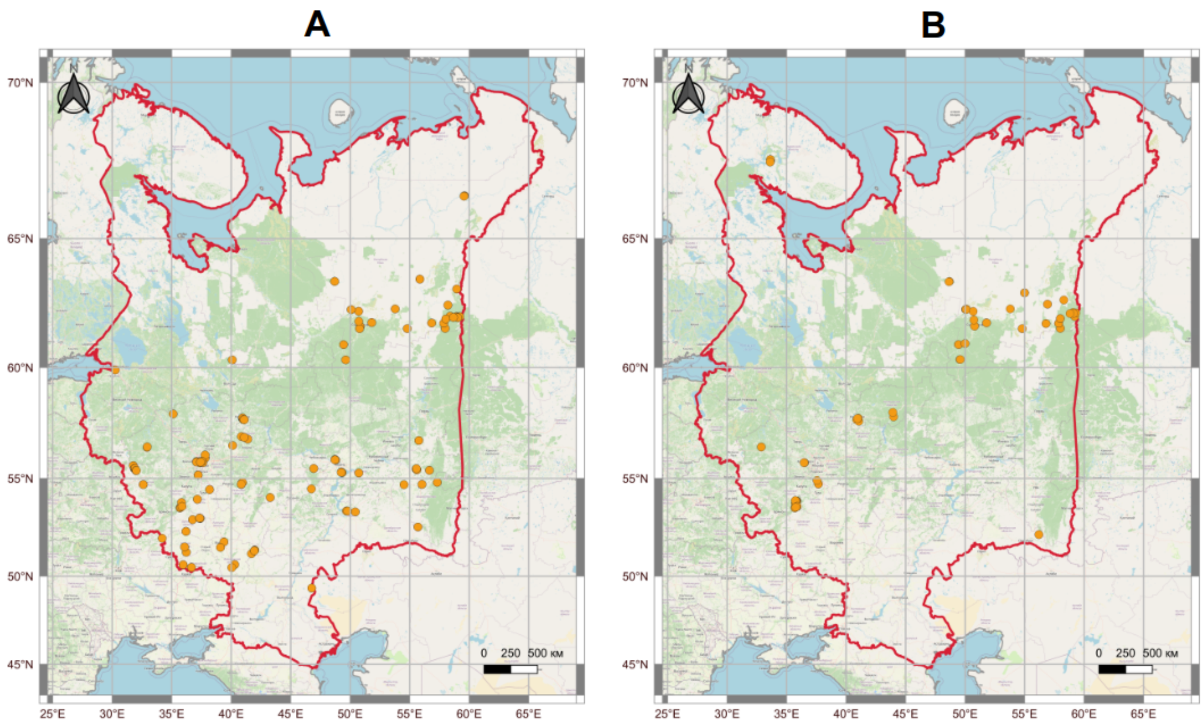

Fig. 1. A – locations of earthworm surveys according to literature data (Shashkov et al., 2023b), **B** – primary data for the European part of Russia (Phillips et al., 2020).

Table 1. Publications on the earthworm surveys in different habitat types (according to Phillips et al. (2019). * – not specified in this paper.

Habitat type	References
Evergreen coniferous forests	Akulova et al., 2017; Gavrilov, 1950; Geras'kina and Ermolov, 2022; Griuntal', 2010; Gordienko et al., 2016; Ivanova et al., 2018; Lychkovskaia, 2019; Perel', 1958; Sokolov, 1956; Valiakhmedov and Garipov, 2019
Deciduous coniferous forests (larch-dominated stands)*	Gavrilov, 1950; Geras'kina, 2016; Sokolov, 1956
Mixed forests	Akulova et al., 2017; Baluev, 1950; Chegodaeva, 2019; Gavrilov, 1950; Gavrilov and Perel', 1958; Geras'kina and Ermolov, 2022; Ivanova et al., 2018; Kutovaia et al., 2014; Lychkovskaia, 2019; Perel', 1958; Perel', 1979; Prizemin, 2012; Sharova, 1970; Sokolova, 2006; Sokolova, 2013
Hemiboreal forests	Geras'kina and Ermolov, 2022; Perel', 1979
Broad-leaved forests	Gavrilov, 1950; Gordienko et al., 2016; Penev et al., 1994; Perel', 1958; Perel' and Sokolov, 1964; Perel', 1979; Sharova, 1970; Sokolov, 1956; Valiakhmedov and Garipov, 2019; Vsevolodova-Perel' et al., 1997
Forest plantations	Tvornovich and Krasnikov, 2019; Vsevolodova-Perel' et al., 1997; Vsevolodova-Perel' et al., 2005
Meadows with shrubs and/or sparsely growing trees	Akulova et al., 2017; Lychkovskaia, 2019; Prizemin, 2012
Meadows	Akulova et al., 2017; Chegodaeva, 2019; Gavrilov and Perel', 1958; Geras'kina, 2016; Ivanova et al., 2018; Lychkovskaia, 2019; Matveeva, 1970; Perel', 1979; Prizemin, 2012; Tvornovich and Krasnikov, 2019; Valiakhmedov and Garipov, 2019
Agrocenoses	Akulova et al., 2017; Baluev, 1950; Chegodaeva, 2019; Geras'kina, 2009; Kutovaia et al., 2014; Malevich, 1955; Matveeva, 1970; Sokolova, 2006; Valiakhmedov and Garipov, 2019
Urban areas	Kutovaia et al., 2014; Lychkovskaia, 2019; Preobrazhenskaia, 2015

Results and discussion

According to the literature data, 24 earthworm species and 2 subspecies are reported in the European part of Russia: *Allolobophora chlorotica* (Savigny, 1826), *Aporrectodea caliginosa* (Savigny, 1826), *Aporrectodea icterica* (Savigny, 1826), *Aporrectodea longa* (Ude, 1885), *Aporrectodea rosea* (Savigny, 1826), *Aporrectodea trapezoides* (Dugés, 1828), *Bimastos rubidus* (Savigny, 1826), *Dendrobaena octaedra* (Savigny, 1826), *Dendrobaena tellermanica* Perel', 1966, *Eisenia atlavinyteae* Perel' & Graphodatsky, 1984, *Eisenia balatonica* (Pop, 1943), *Eisenia fetida* (Savigny, 1826), *Eisenia intermedia* (Michaelsen, 1901), *Eisenia nordenskioldi* (Eisen, 1879), *Eisenia uralensis* Malevič, 1950, *Eiseniella tetraedra tetraedra* (Savigny, 1826), *Eiseniella tetraedra hercynia* (Eisen, 1874), *Lumbricus baicalensis* Michaelsen, 1900, *Lumbricus castaneus* (Savigny, 1826), *Lumbricus rubellus* Hoffmeister, 1843, *Lumbricus terrestris* Linnaeus, 1758, *Octodrilus transpadanus* (Rosa, 1884), *Octolasion lacteum* (Örley, 1881), *Perelia tuberosa* (Svetlov, 1924), and *Riphaeodrilus diplotetratheca* (Perel', 1967).

The species, most commonly recorded in the surveys, are: epigeic *Dendrobaena octaedra* (51.7%), *Bimastos rubidus* (19.2%), and *Lumbricus castaneus* (12.5%); epi-endogeic *Lumbricus rubellus* (53.1% of surveys), and *Eisenia nordenskioldi* (32.0%); endogeic *Aporrectodea rosea* (45.4%), *Aporrectodea caliginosa* (37.6%), and *Octolasion lacteum* (35.8%); anecic *Lumbricus terrestris* (19.9%). Earthworms of other species were found sporadically and were reported in less than 10% of the surveys analyzed.

Dendrobaena octaedra was the most frequently found species in all types of forest habitats. It was recorded in 58.3% of surveys in evergreen coniferous forests, 55.4%, in mixed forests, 70.0%, in hemiboreal forests, and 75.5% in broad-leaved forests. In addition to this species, *Lumbricus rubellus* (55.0%) and *Eisenia nordenskioldi* (33.3%) were often found in evergreen coniferous forests; *Aporrectodea rosea* (35.7%), *Aporrectodea caliginosa* (30.4%), and *Eisenia nordenskioldi* (32.1%) in mixed forests; *Aporrectodea rosea* (63.3%), *Aporrectodea caliginosa* (59.2%), *Eisenia nordenskioldi* (44.9%), and *Octolasion lacteum* (57.1%) in broad-leaved forests. According to the available data on the abundance of species of various morpho-ecological groups, in evergreen coniferous forests, epi-endogeic species dominated most often, and endogeic and epigeic, less often; anecic species were not recorded in this biotope type. In the mixed forests, a high variability in the ratio of epigeic, epi-endogeic, and endogeic species was registered, while anecic worms were recorded sporadically. As a rule, earthworms of the endogeic morpho-ecological group prevailed in broad-leaved forests; anecic species were recorded in half of the surveys.

Lumbricus rubellus (68.6%) and *Aporrectodea rosea* (60%) were most common in meadow habitats, while *Aporrectodea rosea* (81.3%), *Lumbricus rubellus* (78.1%), and *Aporrectodea caliginosa* (71.9%), in agrocenoses. Endogeic or epi-endogeic species dominated in meadow habitats by abundance, but no anecic species were recorded there. Endogeic species dominated most often in agrocenoses. Anecic species were found in almost one-third of surveys taken in agrocenosis, in contrast to meadow habitats.

These results are generally consistent with the prevailing assumptions about the distribution and habitat preferences of earthworm species (Perel', 1979). At the same time, quantitative analysis of both species and community diversity of earthworms in different habitat types requires more data, including detailed information on the soil properties and vegetation.

A total of 1 to 9 species were recorded per survey. The highest species diversity was registered in the broad-leaved forests and urban areas, the lowest, in the larch forests (Table 2). High differences of the species richness were observed in all types of habitat, because the communities within each habitat type were heterogeneous in composition, age, duration of previous anthropogenic impacts, and other characteristics. The highest abundance of earthworms was recorded in broad-leaved forests, urbanized areas, and agrocenoses, the lowest, in larch forests and evergreen coniferous forests (Table 3). Higher abundance and diversity of earthworms in broad-leaved forests compared to mixed and coniferous ones is an expected result. A great amount of rapidly decomposable litter of broad-leaved tree and shrub species and a near-neutral pH of litter provide favourable conditions for the development of earthworm communities. In coniferous and mixed forests, there are slowly decomposable residues of coniferous trees and boreal shrubs in the litter layer, having acidic pH, which is unfavourable for earthworms (Geras'kina, 2020). High earthworm abundance in agrocenoses is apparently related to favourable soil properties in this habitat type. In our opinion, high abundance and diversity of earthworms in anthropogenic habitats is controversial. This habitat type covers a wide variety of urban areas, including unsuitable sites for earthworms. Only three surveys were assigned to this type, considering analyzed literature data. Obviously, this is not enough to cover the whole diversity of earthworms in urban areas. Generally, including this habitat type in modelling is a questionable issue due to its great heterogeneity.

Table 2. Species richness of the earthworm communities in different habitat types according to the literature data.

Habitat type	Number of surveys	Number of species, mean ± SD	Number of species (min—max)
Evergreen coniferous forests	60	3 ± 3	1–6
Deciduous coniferous forests (larch-dominated stands)	2	2 ± 0	2
Mixed forests	56	3 ± 2	1–8
Hemiboreal forests	10	3 ± 1	1–6
Broad-leaved forests	49	5 ± 2	3–8
Forest plantations	7	4 ± 1	3–6
Meadows with shrubs and/or sparsely growing trees	3	3 ± 2	2–5
Meadows	35	3 ± 2	1–7
Agrocenoses	32	4 ± 2	1–9
Urban areas	3	5 ± 2	3–7

The published data on the earthworm species diversity and abundance do not qualitatively contradict the model estimates by Phillips et al. (2019), according to which earthworm communities are predicted to be greater in broad-leaved forests and lower in coniferous forests in terms of both diversity and abundance.

Considerable disagreements are found when comparing the species diversity obtained in the field survey with model estimates (Fig. 2). According to the literature data, the average number of earthworm species found in surveys was 4 ± 2, while the values predicted by the model were 1 ± 1 species. According to literature data, the average abundance of earthworms in surveys from the European part of Russia is 77 ± 121 ind./m², but only 2 ± 1 ind./m² in the same geographical locations, according to model estimates.

According to the Phillips model, the species diversity of earthworms varies from 0 to 6 species, abundance, from 0 to 5 ind./m² throughout the European part of Russia (Fig. 3). At the same time, these estimates were 9 at the highest species and 720 ind./m² according to literature data (Tables 2, 3).

Therefore, the published estimates obtained from the literature data are considerably higher than those predicted by the model. This can be explained by the certain limitations applied for the primary data for modelling. In total, 176 surveys from the European part of Russia were used to build the model of Phillips et al. (2019), 115 of which were associated with the taiga zone of the Komi Republic (Fig. 1**B**). This area is characterized by low diversity of the earthworm communities due to climatic conditions (Krylova et al., 2011). Field surveys from other areas and natural zones of the European part of Russia (e.g., from broad-leaved forests of Kaluga Oblast) were represented sparsely and locally. Obviously, such undersampling data caused an underestimation of the earthworm community'es diversity in the model. In the present study, the literature data include the studies of hemiboreal and broad-leaved forests, forest steppes, and steppes, as well as the desert zone (Dzhanybek Station of the Institute of Forestry Science, Russian Academy of Sciences, Volgograd Oblast, oak introduction experiment), in addition to the surveys performed in the taiga zone.

At the same time, there are also gaps in the analyzed literature data. We have found no information on the earthworm distribution for the Pskov and Novgorod Oblasts, as well as for the Udmurt Republic. Sporadic data with missing geolocation were reported for the Republic of Karelia (Malevich, 1951; Rybalov and Kamaev, 2011), Ivanovo Oblast (Baluev, 1950), Vologda Oblast (Gavrilov and Perel', 1958; Perel', 1979), Kirov Oblast (Ustinov, 1962), and the taiga part of Arkhangelsk Oblast (Malevich, 1970;

Table 3. Earthworm abundance in different habitat types according to literature data.

Habitat type	Number of surveys	Abundance, ind./m^2 (mean ± SD)	Abundance, ind./m^2 (min–max)
Evergreen coniferous forests	52	20 ± 33	2–200
Deciduous coniferous forests (larch-dominated stands)	2	5 ± 0	–
Mixed forests	40	34 ± 56	1–258
Hemiboreal forests	1	20	–
Broad-leaved forests	30	217 ± 168	27–678
Forest plantations	0	–	–
Meadows with shrubs and/or sparsely growing trees	2	32 ± 36	6–58
Meadows	27	63 ± 87	2–390
Agrocenoses	25	108 ± 141	4–720
Urban areas	1	132	–

Perel', 1979). Surveys performed by I.V. Zenkova in the Murmansk Oblast, cited by Phillips et al. (2020), were not included in our dataset due to a lack of available papers in Russian (a methodology artefact of publication selection). Therefore, additional field research is required to obtain a more complete overview of earthworm distribution in the European part of Russia.

It should also be noted that the primary data for modelling were even more limited and represented by a few surveys for the territory of West Siberia. We assume that this data deficiency could also be the reason for the underestimation of earthworm community diversity within the eastern part of the studied area. The Middle Urals mountains are one of the centers of earthworm diversity (Perel', 1979), however, information on earthworm communities for this area is very limited. Nevertheless, primary data of long-term monitoring of earthworm communities in various habitat types in the Middle Urals are available through the GBIF global portal (Vorobeichik et al., 2021). Integration of these data into the input dataset for the model could probably improve the quality of predictions.

The protocol of input data selection for modelling, used by Phillips et al. (2019), followed certain criteria of data quality and completeness. For model experiments, only the studies were considered, where the material was collected in the field according to a standard sampling scheme, geographic coordinates of surveyed sites were specified or an accurate description of their location was given, at least one variable of soil chemical content was measured, and information on habitat type and the character of anthropogenic influences was provided. Most of the publications that we have analyzed within the present study did not meet at least one of these criteria, so it is unclear how it is technically possible to use them within the framework of the model proposed by Phillips et al. (2019).

The strict workflow of data selection, required by the model-building algorithm, limits considerably the volume of input data. The authors stated that 92.3% of sources were excluded during the filtering of the primary data (Phillips et al., 2021), which did not allow obtaining representative data for different geographical areas and habitat types. This led to an underestimation of the earthworm community's diversity, both in the European part of Russia and in other regions. In particular, the model underestimates the diversity of earthworm communities in tropical forests (James et al., 2021).

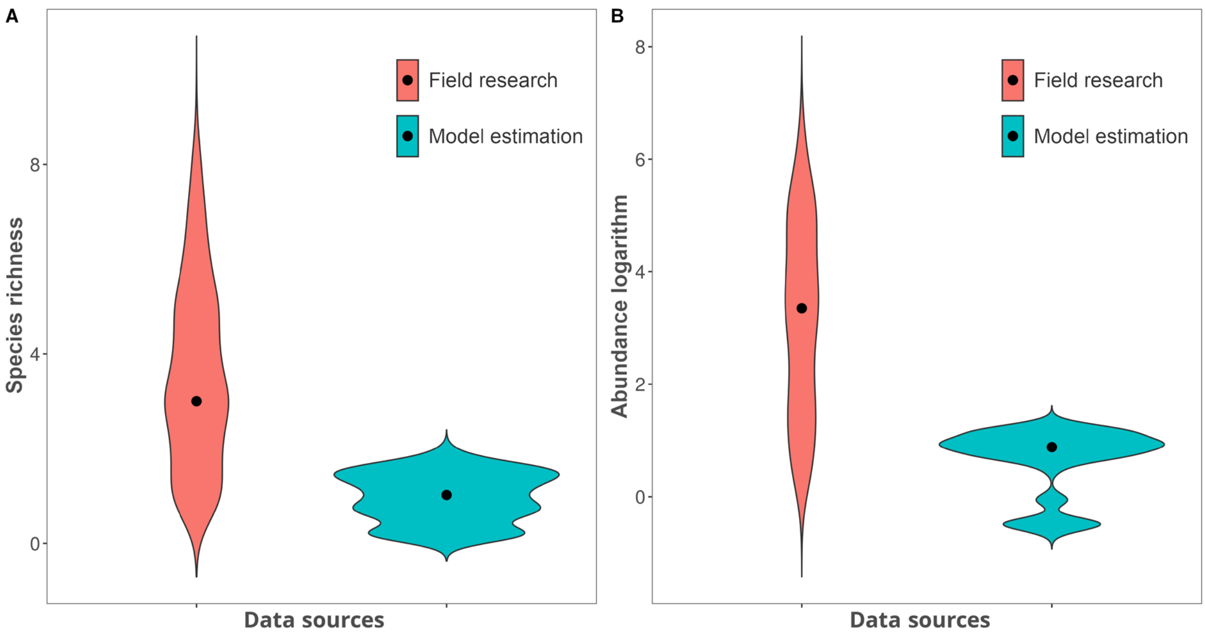

Fig. 2. Earthworm community diversity estimates according to field surveys (literature data) and predicted by the model (Phillips et al., 2019) for the same locations. Black dots within the diagrams are medians.

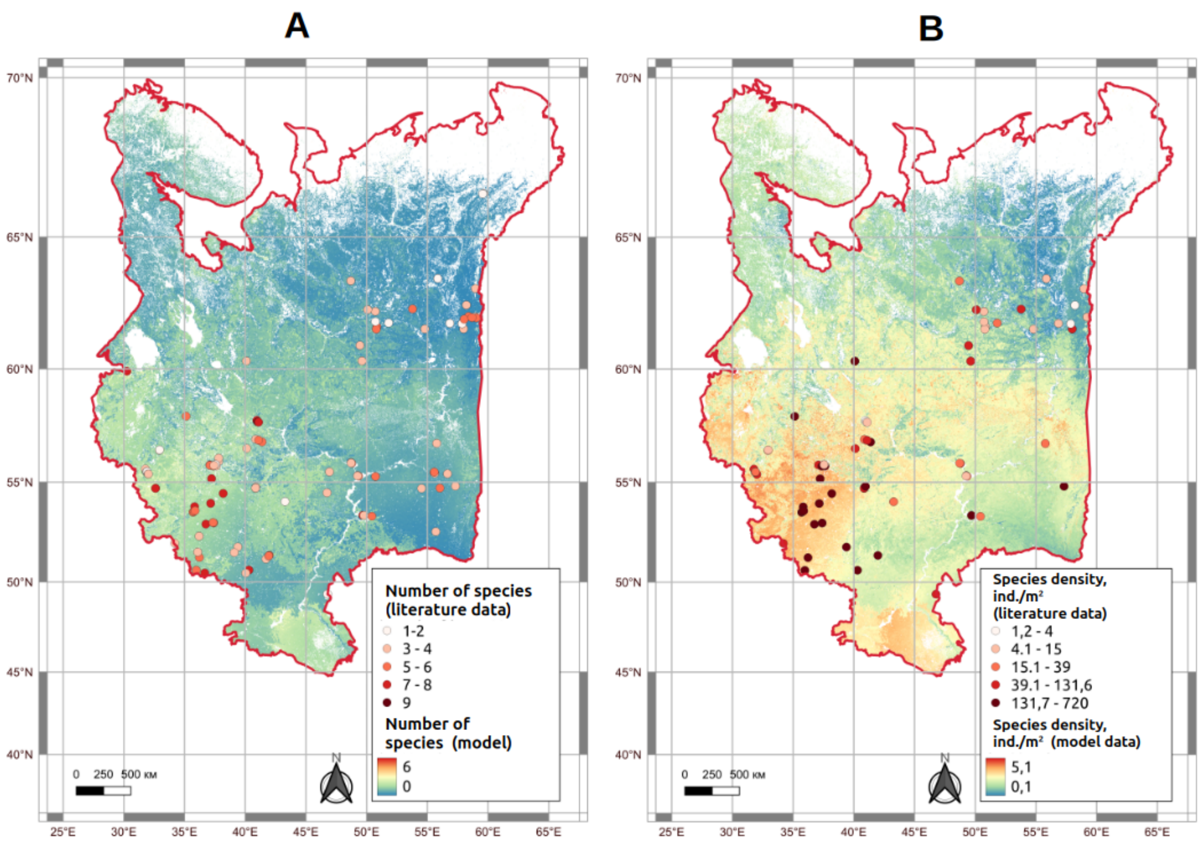

Fig. 3. Model estimates of species richness (**A**) and abundance (**B**) of earthworm communities according to Phillips et al. (2019). Dots show surveys from literature sources (Shashkov et al., 2023b).

It should be noted that in the present study the earthworm community diversity and abundance were estimated on the materials sampled in different years and seasons. The abundance of earthworms may vary considerably in the same locality from year to year depending on the amount of precipitation, snow cover thickness, the air temperature dynamic, and other climatic variables (Krylova et al., 2011). In addition, it was not always possible to identify unambiguously the habitat type based on the description provided by the authors, which could also bias the results. Therefore, we assume that our literature-based estimates could also be biased. Studies involving meta-analyses and additional data sources are required to clarify these results.

Conclusions

The study is the first attempt to compare the estimates of earthworm community diversity according to Helen R.P. Phillips's global diversity model with summarized literature data obtained during field surveys in the European part of Russia. Despite of the large amount of research conducted, earthworm diversity remains understudied in many areas of the region. Considerable inconsistencies are found when comparing model and estimates of species diversity and abundance of earthworms in various types of biotopes. The global model underestimates considerably both species diversity and abundance of earthworms in the European part of Russia. We suggest this is due to the insufficient amount of input data for modelling, which, in turn, is caused by the lack of available published data. Our findings demonstrate the need for method standardization and a thorough description of field data collection in scientific publications.

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