

Extent of Sampling Effort of the Romanian Centipedes (Myriapoda: Chilopoda): Issues and Advances

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Abstract: Over a century and a half of research, 112 valid species of centipedes have been recorded in Romania but data have resulted from studies on limited territories or specific habitats. We evaluated the currently known extent of the sampling effort for centipede species. A database with 2627 locations for every recorded species was generated and processed in geographic information system (GIS) using the 10 km EEA grid resolution with 2550 grid cells corresponding to Romanian territory. Only 451 of them had data, mostly (75.83%) with less than six species. The spatial statistical analysis validated the supposition of a strongly biased sampling for Romania and highlighted the hotspots of increased sampling efforts. Most hotspots were in the western half of the country and in Dobrogea, overlapping with the Romanian karst areas, while the greatest part of the eastern half was less studied. The grid cells with the highest Z scores, between 6.4 and 12.13, were all located in South-Western Romania corresponding to three ecoregions.

Key words: Chilopoda, sampling effort, hotspots, Romania.

Introduction

Studied for over a century and a half, the Romanian centipede fauna has 112 valid species and is one of the richest in Europe, with only Italy having a greater number of species (ION 2016). Approximately 26 species are considered endemic to the study area, most of them with very small distribution ranges. Despite this, centipedes, like most soil organisms, are still neglected in terms of conservation and have not been included in the Red List of Endangered Species in Romania, unlike in other European countries (e.g. Germany, VOIGTLÄNDER et al. 2011). Additionally, most of the faunistic and ecological records resulted from studies conducted on limited regions or specific habitats and often with a limited number of sampling methods. The aim of our study was to assess the currently known extent of the sampling effort for centipede species and to map the centipede diversity of Romania.

A suitable way to accumulate and present spatial information for a variety of organisms is by

mapping species distribution (COGĂLNICEANU et al. 2013). Some areas in Romania have been intensively studied and, therefore, centipede diversity is known to be higher there (e.g. MATIC 1963, 1971, NEGREA 1994, 2006, NEGREA et al. 1992, 1993, ILIE 2003 a,b, ILIE et al. 2003).

In Europe, similar distribution maps using grids to analyse centipede distribution were published by RAVNJAK & KOS (2015): their results showed that about a half of the Slovenian territory has been studied. DECKER (2011) also used the grid for Myriapoda of North Rhine – Westphalia. According to the European Atlas of Soil Biodiversity for Myriapoda, Romania is one of the top countries regarding species richness, estimated as being between 151 and 622 (JEFFREY et al. 2010).

The biogeographic, palaeogeographic and palaeoclimatic features of Romania are responsible for the high diversity of centipedes, with humidity and temperature being two of the most important envi-

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ronmental factors that influence centipede distribution (VOIGTLÄNDER 2011).

The tectonic processes on the Romanian territory affected the evolution of numerous species through impacting significantly on relief, geology and edaphic characteristics. The present-day fauna stems largely from some glacial refugia, in which animals retreated and survived during the Pleistocene glaciations (DRUGESCU 1994).

Romania is situated in the south-eastern part of Central Europe, between Eastern Europe and the Balkan Peninsula, and covers an area of 238,391 km². There is a wide range of habitat types in Romania: 357 habitats belonging to seven classes, as a consequence of climate conditions, diverse substrata (from acidic to alkaline), types of soils (from spodosol to chernozemic soil) and vegetation (DONIŢĂ et al. 2008). As the country is situated at the interface between various climates: temperate oceanic climate of Western Europe, temperate continental climate of Eastern Europe, Mediterranean climate specific to Southern Europe and also has some Pontic influences (FLOREA 2005), the climate conditions are geographically caused by the transition from Atlantic to continental climate. The Carpathian range (covering an area of 66,303 km², 27.8% of Romania's territory) has a strong influence on the climate according to altitude and on the distribution of the main types of soils with great impact on the vegetation (IELENICZ & PĂTRU 2004).

To better highlight some aspects regarding the centipede distribution and sampling efforts, we delineated each of the 21 ecological regions (ecoregions) on the map. Then the species number in the grid cells was tested for correlation with the typical characteristics of each ecoregion (climatic, topographical, lithological, pedological and land use), that allowed comparison and extraction of significant conclusions (FLOREA 2005).

Materials and Methods

Mapping the state of research on centipedes

We used occurrence records for centipedes sampled between the 1897 and 2016 on the entire Romanian territory from the following sources: the centipede collection of the Institute of Speleology "Emil Racoviță", published data (articles and conference papers), our own recently sampled species from the Leaota Mountains (GIURGINCA et al. 2015), Călugăreasă Forest (GIURGINCA & BABA 2016) and Bucharest urban parks (GIURGINCA et al. 2017). The specimens have been sampled systematically or randomly, most of them being preserved in the collec-

tion of microscopic slides and in ethanol at the Emil Racoviță Institute of Speleology.

We revised and corrected the species identification according to the latest species names of European centipedes and used only the species accepted in Europe's main zoological taxonomic index (Fauna Europaea), the electronic database of all known centipedes (ChiloBase2.0) and the latest revisions and catalogues (e.g. NEGREA 2006, BONATO & MINELLI 2014, ION 2016).

For some data records, the georeferencing using specific localities and toponyms was not possible, while other specimens were not identified to the species level; in both cases, we decided not to include them in our study. The occurrence database was managed in Microsoft Excel, georeferenced in Google Earth Pro, subsequently integrated in a GIS environment as geodatabase and associated with the 10×10 km² EEA (European Environment Agency) reference grid. This grid is considered an adequate tool to work with spatial data with inaccurate positions, as is often the case with old sampling points and for generalising data, statistical mapping and analytical processing and is also in line with the Pan-European standard (PEIFER 2011). Each grid cell has a unique identifier composed of cell size and cell coordinates. The Romanian territory is covered by 2550 quadrants, including those that partially cover the area.

The Romanian ecological units with characteristic conditions of climate, relief, lithology, hydrology, plant formations and soils were also delineated on one map (FLOREA 2005). The state of research on centipedes was represented by the number of species recorded within each grid cell. The result was a map of Romania, in which the number of species per grid cell had chromatic representation. For the grid colour bar, we used the following colour code: white for no data; dark green for 1 – 6 species; light green for 7 – 12 species; yellow for 13 – 18 species; orange for 19 – 24 species; red for 25 – 30 species; dark red for 31 – 35 species.

Spatial patterns analysis

We counted the number of centipedes records per grid cell, to highlight the potential bias in the sampling effort. Subsequently, we used Global Moran's I to estimate the general tendency of spatial autocorrelation in occurrences across the entire country. If the Moran's I test was statistically significant, the spatial pattern of centipedes records per grid cell could be spatially clustered ($Z > 0$), dispersed ($Z < 0$) or random ($Z = 0$).

To identify the statistically significant hot spots and cold spots of the sampling efforts from the ones

expected by random chance, we used Getis Ord G_i^* spatial statistic (ORD & GETIS 1995). Spatial relationships (for the grid cells that share a boundary, share a node, or overlap) might influence computations for the target grid cell and this determined inclusion of eight neighbours of a grid cell. All spatial analyses were performed in geographical information system software, with $\alpha = 0.05$ (ArcGIS ver. 10.1, ESRI).

Results

We generated a database with 2627 occurrences for the 112 centipede species. These belonged to the orders Scutigermorpha – 1 species, Lithobiomorpha – 61 species, Scolopendromorpha – 7 species and Geophilomorpha – 43 species recorded within 451 grid cells representing 17.68% of all cells corresponding to Romanian territory. Approximately 70% of all species from Romania have been preserved in the Centipede Collection of the Emil Racoviță Institute of Speleology, Bucharest (see Appendix 1).

The number of species represented on the 10 x 10 km² grid ranged from 0 to 35. The majority of grid cells with presence data (75.83%) comprised a low number of species: 342 grid cells with 1–6 species (Fig. 1). This resulted from the unsystematic way of sampling (mainly through punctual sampling repre-

sented by direct sampling using tweezers). Although this is the easiest and the oldest method, it is also less efficient compared to other methods like pitfall trapping and extraction of soil samples (TUF 2015).

The quadrant with the highest number of species (35) 10 km N532 E252 was located in South-Western Romania and covered mostly the Cloșani Karstic Region, situated in the North-East of the Mehedinți Mountains and characterised by a temperate climate with strong Mediterranean influence and beech woods with thermophilic characters (ILIE 2003). This area was extensively studied over a long period of time, as proved by numerous scientific papers published from 1957 to 1994 on Chilopoda from Cloșani Karstic Region (NEGREA 1963, 1964, 1965, 1966, MATIC 1957, 1966, 1972, DANCĂU & TABACARU 1964, DECOU & NEGREA 1969). Subsequently, ILIE (2003) sampled from the edaphic, mesovoid shallow substratum and cave environments using a wide spectrum of collecting methods. All these facts might be a possible explanation for the high numbers of species identified there. This grid cell was one of the fewest containing the endemic cave-dwelling centipede species *Lithobius decapolitus* Matic, Negrea & Prunescu, 1962 as well as *Harpolithobius banaticus* represented by the endemic subspecies *H. b. banaticus* Matic, 1961 (NITZU et al. 2016).

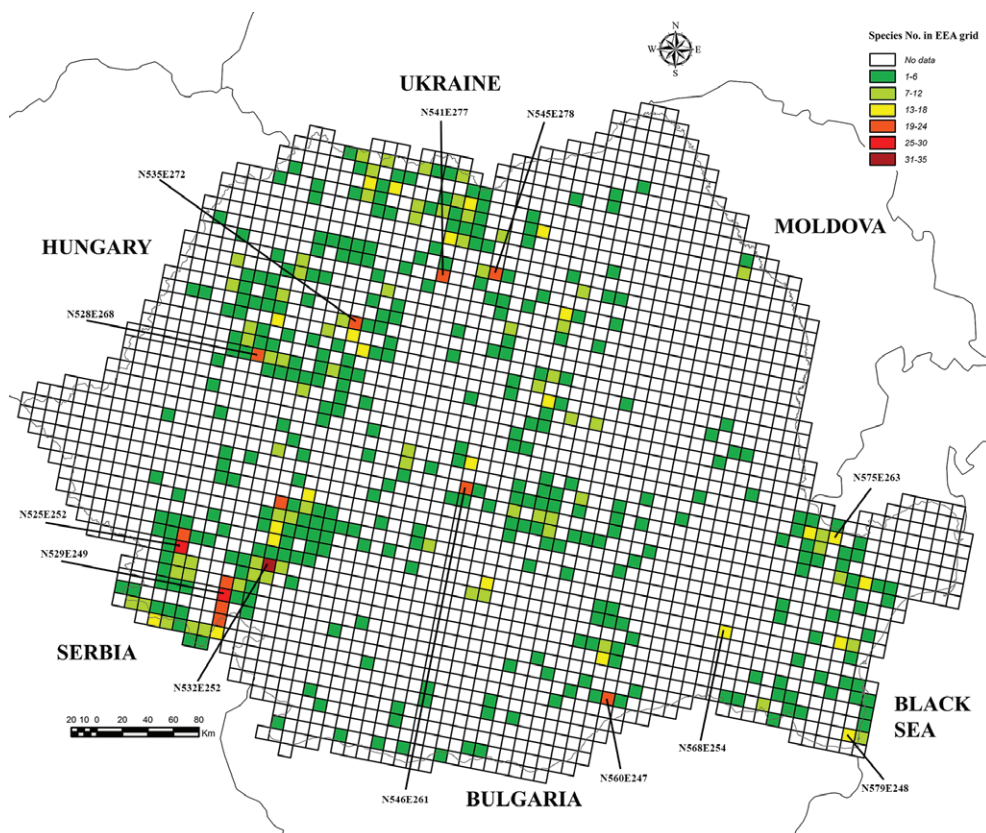


Fig. 1. Specific richness of the Romanian Chilopoda, EEA10×10 km grid resolution.

The next grid cells in terms of number of species contained were situated relatively close to the previous one: 10 km N525 E252 and 10 km N529 E249, both with 28 species, marked with red colour on the map (Fig. 1). The first quadrant covered the territory lying to the east of Caraşova. Caraş Gorges, along with the caves present there. It represented, over time, collecting points of high importance. The vegetation consisted mostly of deciduous forests, *Fagus sylvatica*, *Quercus cerris* and *Quercus petraea* being the dominant species (ILIE 2003b). The second quadrant comprised the territory situated to the south-east of Băile Herculane and intersected with Domogled – Valea Cernei National Park. The Orşova – Băile Herculane topoclimate type was characteristic to this intermontane depression with strong Mediterranean influence, Mediterranean plant species being common there (ILIE 2007).

Other grid cells with considerably high number of species were scattered mostly in the western half of the country. Grid cell 10 km N535 E272 (22 species) was an intersection area for the Transylvanian Plain, Someş Plateau and Apuseni Mountains; covering the city of Cluj and its south-eastern vicinity, including the Feleac Hill. Most of its sampling points were situated in the temperate deciduous forests dominated by oak species.

Grid cell 10 km N546 E261 quadrant (20 species) was the best represented grid cell from the East-Central Southern Carpathians, where MATIC (1964) had studied the vertical distribution of centi-

pedes from the Sâmbăta Valley (Făgăraş Mountains) from the beech forests, mixed forests, spruce forests up to the alpine zone.

Grid cell 10 km N560 E247 (20 species) corresponded completely to forest plains included in the Comana Natural Park, situated on the borderland between sylvosteppe (forest-steppe) and steppe.

The second best-studied site in the Romanian Plain, with 18 species, was the Călugărească Forest, part of the Ialomiţa Corridor (10 km N568 E254), one of the most arid regions in Romania. The collecting area included mixed Danubian–Pontic forests, as well as several areas with a strong anthropogenic impact, where the forests of white poplar, oak and elm were replaced by locust trees monoculture with a negative impact on the biodiversity (GIURGINCA & BABA 2016).

The quadrant with the highest number of species from the Eastern Carpathians was 10 km E545 N278; it covered a part of the largest volcanic complex of the Carpathian Mountains – Călimani Mountains. The flora there was less diversified in comparison with areas where dolomite and limestone rocks were dominant. Altitudinal distribution of centipedes had been studied there leading to the discovery of 19 species (MATIC & CSETERI 1983).

Grid cell 10 km N528 E268 (19 species) – the majority of species included there were collected from the caves and gorges of Sighiştel Valley, making it the best studied site from the Apuseni Mountains (DĂRĂBANŢU et al. 1969).

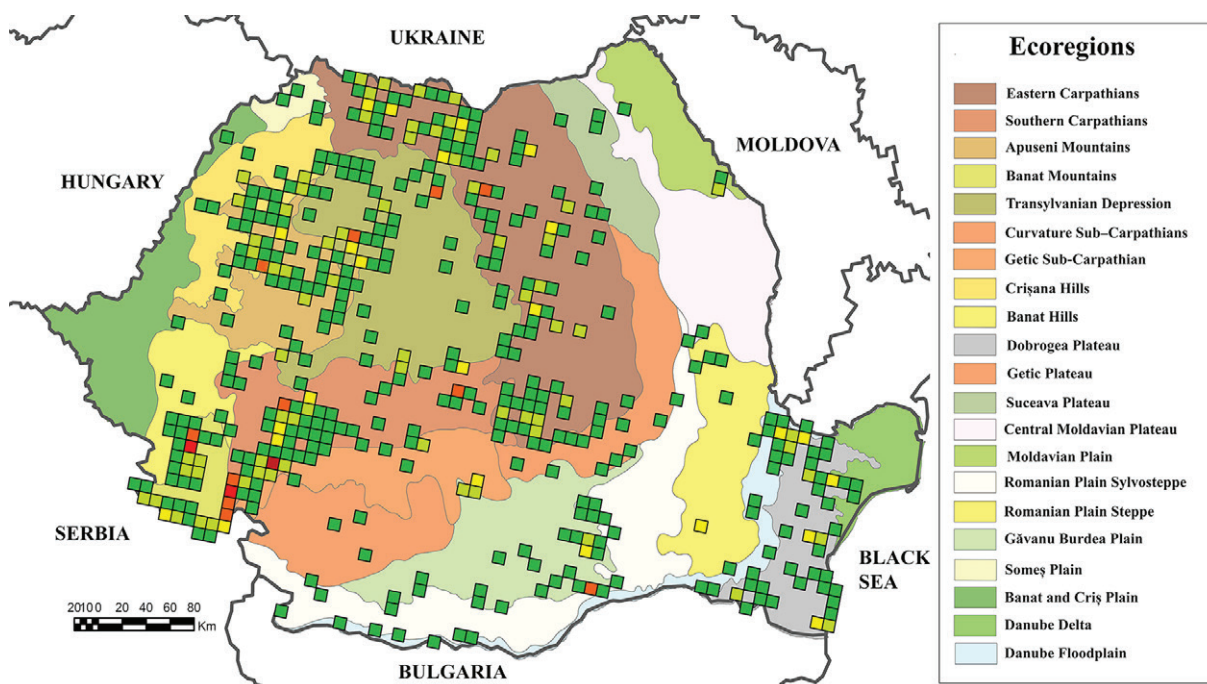


Fig. 2. Map of quadrants distribution according to the Romanian Ecoregions (colour code after DONIŢĂ et al. 2005).

Table 1. Number of quadrants within the Romanian Ecoregions.

ECOREGIONS	1–6 sp.	7–12 sp.	13–18 sp.	19–24 sp.	25–30 sp.	31–35 sp.
Eastern Carpathians	41	8	4	3		1
Southern Carpathians	68	26	7	1		
Apuseni Mountains	35	8	1	1		
Banat Mountains	16	9	2	3	2	
Transylvania Depression	38	3	2	2		
Curvature Sub-Carpathians	11					
Getic Sub-Carpathians	10	3	1			
Crişana Hills	14	4				
Banat Hills	11					
Dobrogea Plateau	27	6	5			
Getic Plateau	4					
Suceava Plateau	2					
Central Moldavian Plateau	2					
Moldavian Plain	1	1				
Romanian Plain Sylvosteppe	14					
Romanian Plain Steppe	6		1			
Găvanu Burdea Plain	20	3	1	1		
Someş Plain	3					
Banat and Criş Plain	1					
Danube Delta	3					
Danube Floodplain	15					
Total No.	342	71	24	11	2	1

In the south-eastern extremity of Romania, in Dobrogea, two grid cells were relevant: 10 km N575 E263 (16 species), corresponding to the Măcin Mountains, and 10 km N579 E248 (16 species), covering the area of the Movile Cave.

As most of the samples lacked data concerning the collecting habitats, we used the ecological regions of Romania and correlated them with the number of species recorded in each grid cell (Fig. 2, Table 1). There are 21 ecoregions with characteristic conditions (FLOREA 2005) that might be inhabited by specific centipede communities and the representation of the state of research in each one of them has been highlighted using the corresponding quadrants. If a cell covered more than one Ecoregions, it was assigned to the region that covered the most. The map clearly pinpointed the ecoregions with the minimum sampling efforts, with large gaps of information about centipede fauna: Banat and Criş Plains – one quadrant with one species, Suceava Plateau – two quadrants with one species each, the same case in for the Central Moldavian and Getic Plateaus – four quadrants with 1–3 species, the Danube Delta – three quadrants with an average of 3 species, Someş Plain also with three quadrants but with even fewer species.

The map highlighted a lower sampling effort in the vast agricultural areas like the plains listed above and large portions of the Romanian sylvosteppe (forest-steppe) and steppe, proving to be also least attractive for researches that often underestimated the

role played by the forest plains in supporting the biodiversity of soil-dwelling invertebrates (GIURGINCA & BABA 2016).

Other less studied ecoregions like Suceava, Central Moldavian and Getic Plateaus, large areas from the Getic Subcarpathians and the Eastern Carpathians had wide forest areas, offering suitable conditions for a high centipede diversity and deserve to be considered for further studies.

The spatial statistical analysis validated the supposition of a strongly biased sampling for Romania and highlighted the hotspots of increased sampling efforts (Fig. 3). Most of the hotspots were concentrated in the western half of the country and in Dobrogea, overlapping with the karst areas in Romania, while the majority of the eastern half was less explored. The grid cells with the highest Z scores, between 6.4 and 12.13 ($p < 0.05$ when Z scores took values between 2.01 and 12.13), were all located in South-Western Romania corresponding to three ecoregions: Banat Mountains, Banat Hills and south-western extremity of the Southern Carpathians. Other significant hotspots were situated in the northern extremity of the Eastern Carpathians, mainly due to recent efforts of DÁNYI (2006, 2008). The rest of the sampling efforts clustered in close proximity of the grid cells with considerably high number of species, described previously.

Among the 24 centipede species most frequently sampled in the grid cells, just three spe-

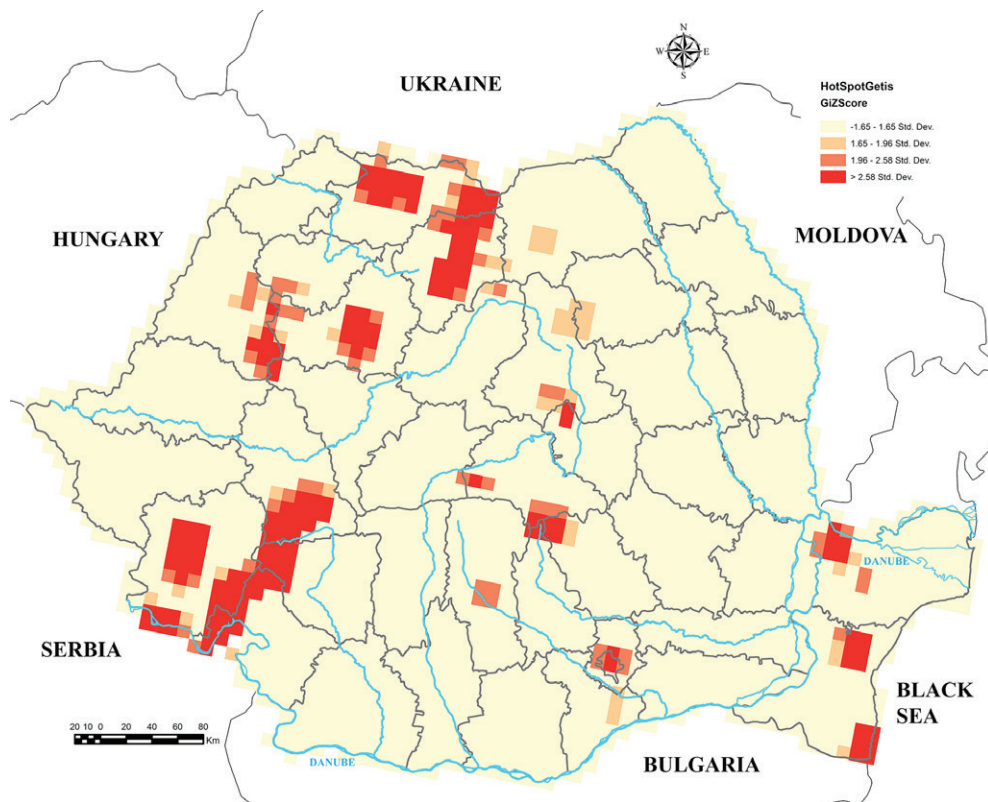


Fig. 3. Hotspots of sampling efforts within Romania. The p value is < 0.05 when Z scores take values between 2.01 and 12.13.

cies of Lithobiomorpha (*L. muticus*, *L. forficatus* and *L. burzenlandicus*) were recorded in more than 100 cells due to their surface- and leaf-litter habitats. *Cryptops parisi* was the most commonly sampled scolopendromorph in 92 grid cells, followed by *Cryptops hortensis* and *Cryptops anomalans* (68 and 43 grid cells, respectively). Being mainly soil dwellers (thus more difficult to collect), the geophilomorphs *Strigamia crassipes* and *Dicelloglyphus carniolensis* were recorded in 80 and 75 cells, respectively.

Discussion

This is the first cartographic representation describing the centipede sampling effort and spatial analysis in Romania, although similar maps exist for other taxa like amphibians and reptiles (COGĂLNICEANU et al. 2013 a, b). Other researchers also chose to represent the distribution in Romania according to the ecoregions, similarly to the species distribution of Orthoptera by IORGU et al. (2008).

According to the chorotypes proposed by NEGREA (2006) for Lithobiomorpha, Scutigermorpha and Scolopendromorpha species and ION (2016) for Geophilomorpha, a considerable number of species (26 species or 23.4%) are endem-

ics, most of them for the Romanian Carpathians, while four are cave-dwelling species (NITZU et al. 2016). Fifteen of the species found in Romania have European distribution, while nine have South-European and seven – Carpathian-Balkan.

The geospatial database and outputs, represented in our article, fill a gap in our knowledge about the centipede fauna of Romania. The lack of quality regarding biodiversity datasets made it difficult to analyse them from a biogeographical point of view but are enough for us to emphasise some aspects of the sampling efforts and to identify the state of research of the centipede fauna. Our results support the idea of a biased sampling within Romania, outlining clearly the hotspots of the sampling effort.

Based on the species number in the geographical grid system of 10 X 10 km², we have estimated that approximately 80% of the Romanian territory is poorly studied: although some of these areas have suitable conditions for high centipede diversity (Suceava, Central Moldavian and Getic Plateaus, large areas in the Getic Subcarpathians and the Eastern Carpathians), the number of currently recorded species seems to be underestimated.

All cartographic representations, and in particular the hotspot map, show that most of the sampling efforts have been concentrated in the western half

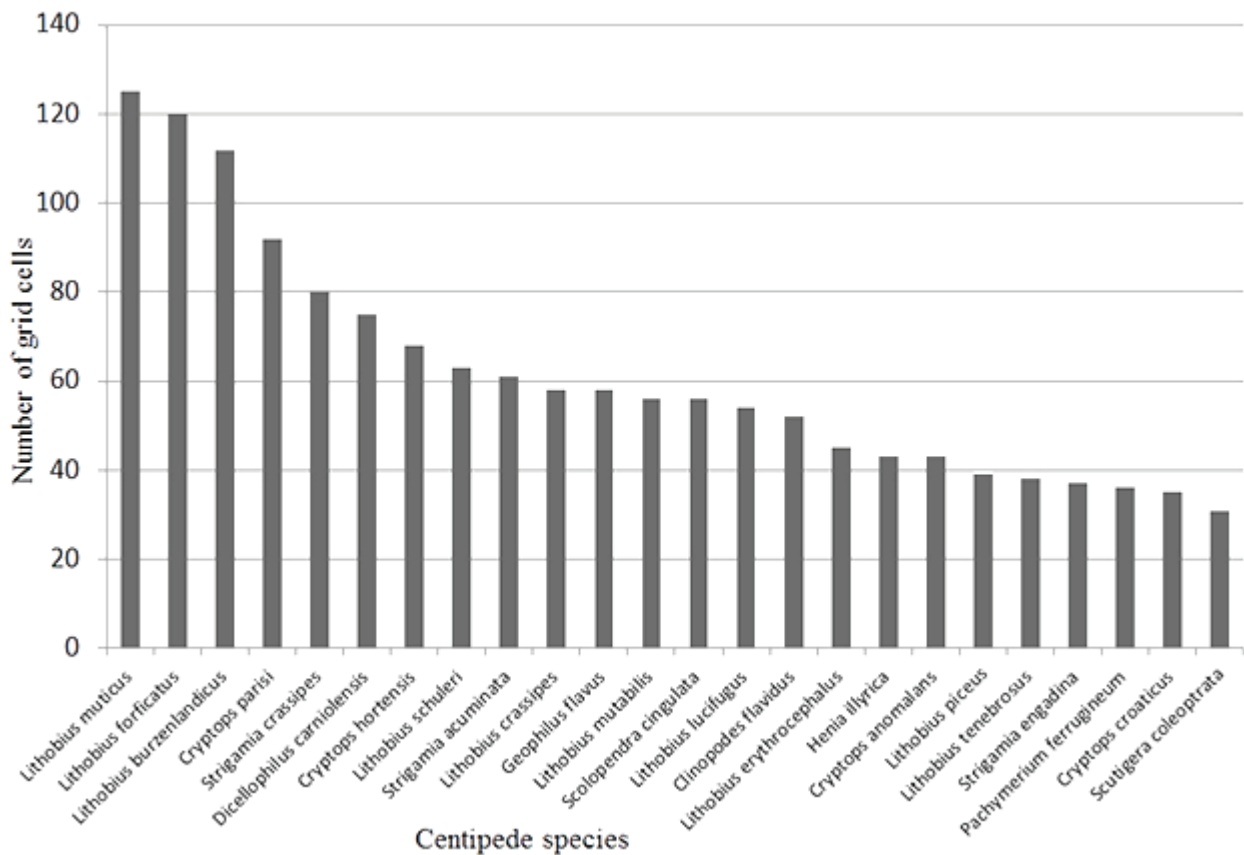


Fig. 4. The most frequently sampled species of Chilopoda in the grid cells.

of the country corresponding to three ecoregions: Banat Mountains, Banat Hills and south-western extremity of Southern Carpathians.

Our results are relevant for future projects like targeted studies aiming to generate distribution models or to assess the conservation status of some endangered centipede species.

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