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The Diversity of Subterranean Terrestrial Arthropods in Resava Cave (Eastern Serbia)

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Abstract: The Balkan region is rich in limestone deposits, which have created one of the largest hotspots of subterranean biodiversity. This paper gives an overview of the diversity of subterranean terrestrial arthropods in Resava Cave in eastern Serbia. This cave is protected and has the status of a natural monument. At the same time, it is one of the most visited caves in Serbia and its surroundings. Our study comprises the results of three years of biospeleological investigations of the famous Serbian cave in combination with data from the few available literature sources on the arthropod fauna of the cave. The arthropod samples were collected both manually and with pitfall traps. A total of 107 arthropod species from the four major subphyla were registered in the cave: 66 species of Hexapoda, 27 species of Chelicerata, 11 species of Myriapoda and three species of Crustacea. For four troglobitic, 16 troglophilic and 87 trogloxenic species recorded in the cave, descriptions of their microhabitats and information on their distribution in the cave are given. Considering the medium size of Resava Cave and the lack of permanent water flow in the two main levels on the one hand, and the large number of arthropod species recorded on the other, the cave is relatively rich in hypogean terrestrial arthropod fauna compared to other caves in Serbia that have been biospeleologically studied so far.

Keywords: Arthropoda; subterranean fauna; troglobite; troglophile; trogloxene; karst; limestone; biospeleology; Balkans

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1. Introduction

The subterranean terrestrial arthropods in Europe are generally the descendants of a tropical epigean fauna that lived in the area at the beginning of the Tertiary and later disappeared [1]. The process of karstification created a wide range of hypogean ecological niches, resulting in the formation of a large refugial zone for the original epigean fauna. For this reason, part of the fauna survived the dramatic climatic changes that followed the Tertiary in Europe [1]. The Serbian karst is inhabited by a large number of endemic cavernicolous animals belonging to the Palaeo-Mediterranean, Laurasian, Palaeo-Aegean and South- or North-Aegean phyletic series [2].

The main reasons for the extraordinary diversity of the Balkan troglobitic fauna include: (i) the diverse epigean fauna that populated the region in the distant past; (ii) the continuity of continental phases in different areas of the region; (iii) the presence of thick limestone layers and subsequent karstification; (iv) climatic conditions favoring the colonization of subterranean habitats; and (v) the divergent differentiation of various lower and higher taxa in numerous isolated hypogean niches [3]. Recent works on the unprecedented subterranean diversity in the Balkan region in Slovenia [4,5], Croatia [6] and Bosnia and Herzegovina [7] support these claims.

Similar phenomena of karstification and the development of a rich subterranean fauna also occurred on other continents, as recent studies on subterranean biodiversity in North America [8] and South America [9] confirm. Finally, the Asian limestone masses are the most impressive, with only the vast karst area in southern China, covering some 550,000 km^2 [10], having the greatest potential to be the world's largest hotspot of subterranean diversity with many specialized hypogean taxa [11,12]. Recently, numerous taxa from the karst of China have been described as new to science [13,14].

In Serbia, caves and pits can be found in carbonate rocks. These are mostly Mesozoic limestones that belong to many different geotectonic units [15]. Most of the caves and pits are located in the eastern (i.e., the Carpatho-Balkanides) and western parts of the country (Jadar Block and the Inner Dinarides) (Figure 1). The mountains in eastern Serbia represent a direct extension of the Southern Carpathians, which stretch from Romania, but they do not directly connect to the Balkanides [15].

The distribution of caves in the Serbian Carpatho-Balkanides coincides with the presence of two carbonate platforms in this area (Figure 1), both dating from the Upper Jurassic and Lower Cretaceous [15]. The larger one is known as the Kučaj-Tupižnica carbonate platform [16], while the much smaller is the Miroč carbonate platform [17]. The karst areas of the Carpatho-Balkanides in eastern Serbia are characterized by an extremely complex and variable relief (Figure 2). Cretaceous limestones are more common there, while Triassic limestones are rarer. However, Cenozoic formations are also widespread (mainly from the Oligocene and Neogene) [15]. The areas extending from the Beljanica, Kučajske Planine, Rtanj, Devica, Svrljiške Planine and Belava Mts. to Mt. Vlaška Planina belong to the central part of the Kučaj-Tupižnica carbonate platform [16], where Resava Cave is located (Figures 1 and 3).

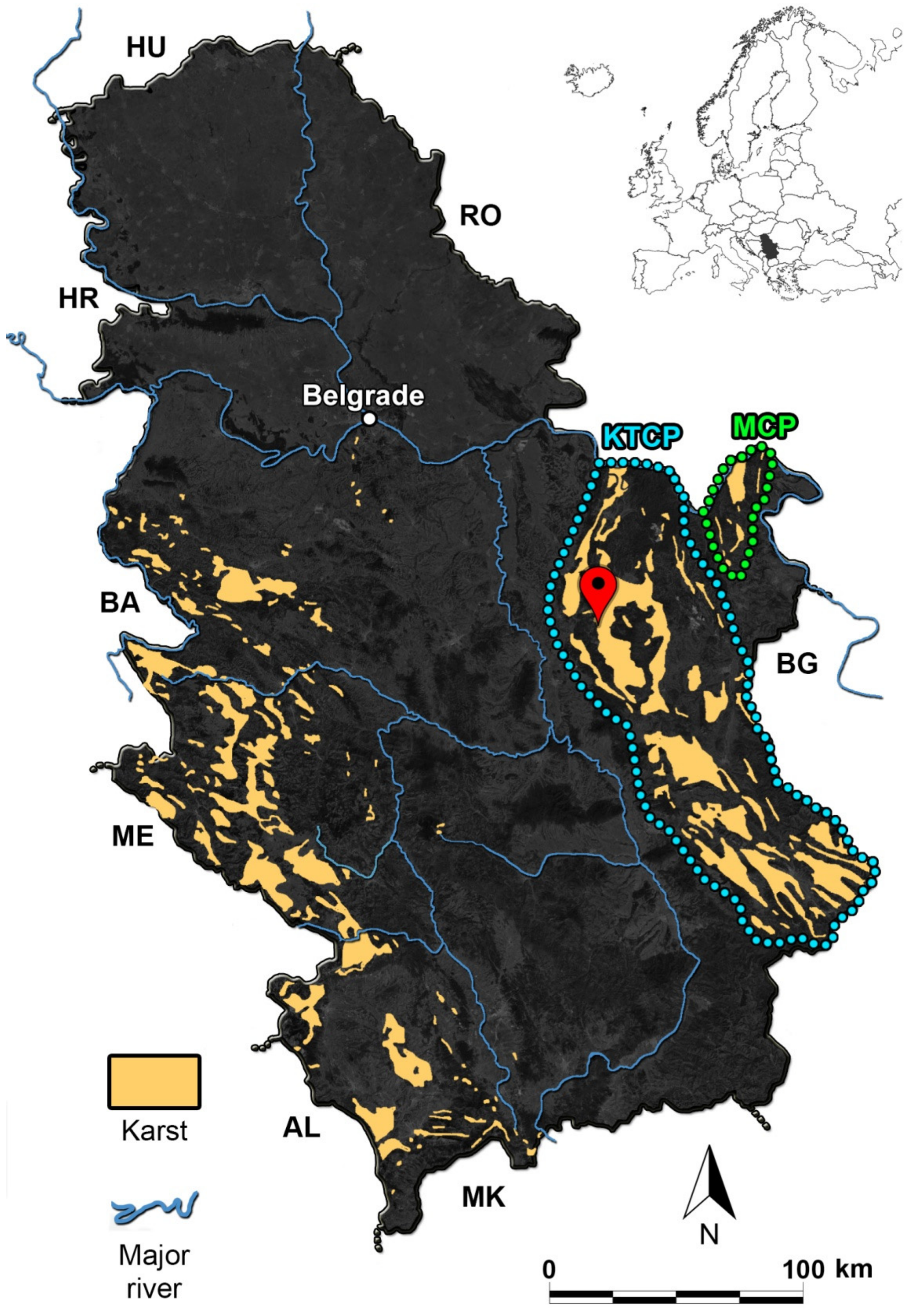

Figure 1. A map of Serbia with karst areas and the location of Resava Cave (red pin) (modified after [18]). The carbonate platforms of the Carpatho-Balkanides in eastern and southeastern Serbia are framed by the dotted lines. AL—Albania; BA—Bosnia and Herzegovina; BG—Bulgaria; HR—Croatia; HU—Hungary; KTCP—Kučaj-Tupižnica carbonate platform; MCP—Miroč carbonate platform; ME—Montenegro; MK—North Macedonia; RO—Romania.

Figure 2. Karst landscapes of the Carpatho-Balkanides in eastern Serbia. (**A**) Lazar's Canyon, Kučajske Planine Mts.; (**B**) Suva Prerast, Vratna Gates, Mt. Miroč; (**C**) one of the peaks of Mt. Stol; (**D**) the ridge of Mt. Veliki Krš. Photos: N. Vesović.

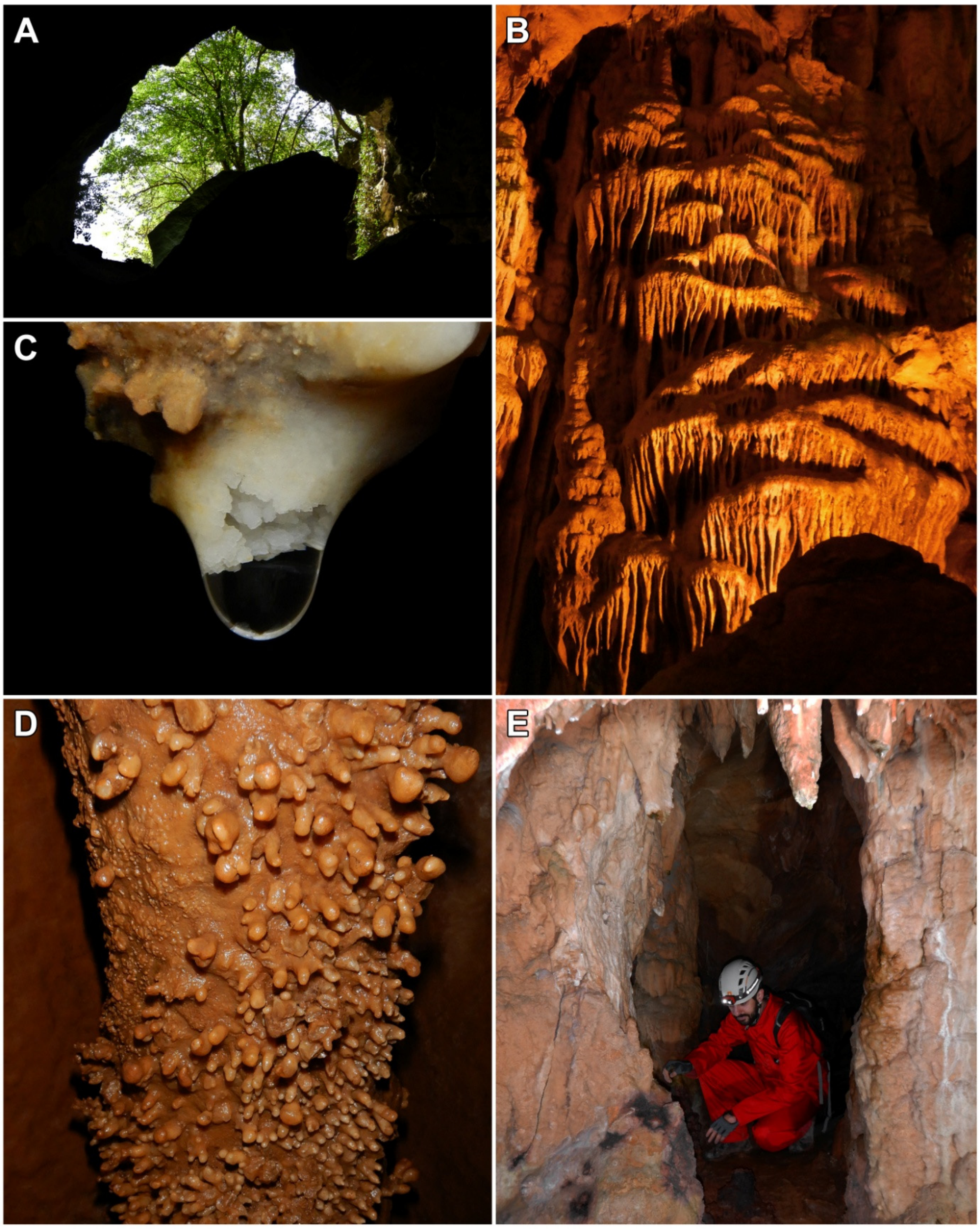

Figure 3. Resava Cave in eastern Serbia. (**A**) The cave entrance seen from the inside; (**B**) flowstone formation in the Menza Gallery; (**C**) formation of a new stalactite in the presence of trickling water; (**D**) corallite speleothems, a feature of the Coral Canals; (**E**) manual collection of hypogean terrestrial arthropods. Photos: N. Vesović and S. Ćurčić.

In contrast to a large number of comprehensive and detailed speleological studies, very few biospeleological studies have been conducted on the cave's living world, as evidenced by the small number of articles published to date on the fauna of Resava Cave [15,19–24].

Although the literature on the terrestrial arthropod fauna of Resava Cave is sparse, reporting only seven species [15,19–24], the existing references are of great importance as they contain descriptions of four new arthropod species to science from Resava Cave (a spider, a millipede, a dipluran and a ground beetle). All four species are blind, depigmented and have other morphological features typical of true cave dwellers (troglobites).

The spider *Centromerus serbicus* Deltshev, 2002 is endemic to several caves in the Kučajske Planine Mts., including Resava Cave [20,21]. It is a small, blind spider of yellowreddish color and with long legs. It was previously reported that Resava Cave is inhabited by another spider, *Porrhomma convexum* (Westring, 1851) (with Holarctic distribution), as well as the pseudoscorpion *Neobisium* cf. *carpaticum* Beier, 1935 (inhabits a wider Carpathian area in Europe), in addition to *C. serbicus* [15].

The millipede described from Resava Cave, *Serbosoma kucajense* (B. Ćurčić & Makarov, 1998), is endemic to Resava Cave (its type locality) and the nearby Vrtačelje (=Ledena Pećina) Pit [19,25]. It is completely blind and depigmented and has an elongated cylindrical body. This is one of the two diplopod species known from the cave according to the available literature data [19,24]. The report of another millipede from the cave (*Trachysphaera* sp.) was recently published [24]. *Trachysphaera* sp. is a very small, white millipede with a characteristic ribbed sculpture on the tergites. In case of danger it can curl up into a ball. It feeds on decaying organic matter of plant origin.

As far as hexapods are concerned, two species have been recorded so far [22,23]. The dipluran *Plusiocampa christiani* Condé & Bareth, 1996 is endemic to the subterranean habitats of eastern Serbia. In addition to Resava Cave, it also occurs in several other caves on the Kučajske Planine Mts. and Mt. Beljanica [23]. It is blind, completely depigmented and has long antennae and caudal filaments. The other hexapod species, the ground beetle *Duvalius petrovici* S. Ćurčić, Vrbica, Antić & B. Ćurčić, 2014, named in honor of Prof. Petrović, the first explorer of Resava Cave, is a stenoendemic of the cave [22]. It is a completely blind and almost depigmented beetle, with a large number of sensory hairs on the body.

The aim of our research in Resava Cave during the three-year period (2020–2022) was to determine the diversity of terrestrial arthropods in Resava Cave, which is the first detailed multi-year attempt of this kind for a cave on the territory of Serbia.

2. Materials and Methods

2.1. Sampling

As part of the research into the diversity of arthropods in Resava Cave, several expeditions have been carried out in recent years. The cave (Figure 4) has been studied biospeleologically in detail on six occasions. It was visited in 2020 (May and October), 2021 (May and September) and 2022 (September and November). The research was carried out on the basis of the authorization for research on strictly protected and protected wild species for scientific research and educational purposes granted by the Ministry of Environmental Protection of the Republic of Serbia for each of the three research years.

The expeditions were conducted by the team of the Institute of Zoology of the University of Belgrade—Faculty of Biology. The taxonomic identification was carried out mostly by experts from the same institution and to a lesser extent by experts from other institutions in Serbia and abroad (Bulgaria, China, Czech Republic, Poland, Romania and Slovakia). During the field trips, arthropods were collected manually in vials containing 70% ethanol. Empty pitfall traps (plastic cups with vaseline-coated walls) baited with rotten meat were also set up (Figure 4) during the visits to observe the arthropod fauna of the cave (they were checked after a few days). In addition to the traps set in search of terrestrial arthropods, all of the cave's halls and canals were thoroughly visually inspected during each research visit. For identification, we used available keys and original descriptions for different arthropod groups. For some species, the male genitalia were removed in order to identify them accurately. Most arthropod species were photographed in situ using a Nikon D5300 digital camera (Nikon Corp., Tokyo, Japan) equipped with a Tamron SP Di AF 90 mm F/2.8 macro lens (Tamron Co., Ltd., Saitama, Japan) and an EM-140 DG flash ring (Sigma Corp., Kawasaki, Japan) with a home-made light diffuser. Further identification and imaging using a Zeiss SteREO Discovery.V12 stereomicroscope (Carl Zeiss, Jena, Germany) equipped with a Flexacam C3 camera (Leica Microsystems, Wetzlar, Germany) was performed in the laboratory of the Institute of Zoology, University of Belgrade—Faculty of Biology. To obtain fully focused images, the frames were stacked using Zerene Stacker ver. 1.04. All figures were processed with Adobe Photoshop CS6 ver. 13.0.1.

All collected arthropod specimens were deposited in the collection of the Institute of Zoology, University of Belgrade—Faculty of Biology.

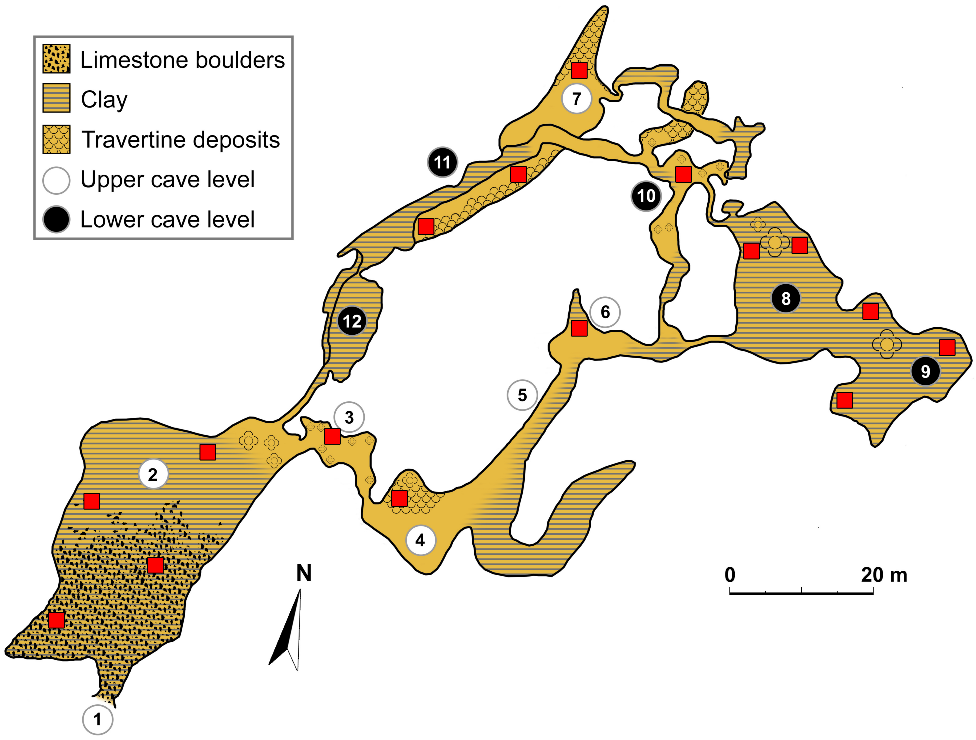

Figure 4. A plan of Resava Cave showing the sites where the arthropod fauna was sampled with pitfall traps (red squares) (modified after [15]). 1—entrance; 2—Entrance Hall; 3—Hall of Conjoined Columns; 4—Beehive Hall; 5—Canyon (=Dry) Canal; 6—Vestibule of History; 7—Crystal Hall; 8—Concert Hall (=Hall of Statues); 9—Boban's Hall; 10—Menza Gallery; 11—Coral Canals; 12—Kepa's (=Mud) Hall. Halls 6 and 7 are connected by an artificial tunnel.

2.2. Study Area

Resava Cave (=Resavska Pećina) is one of the best explored cave systems in Serbia. The original name was Divljakovac Cave (=Divljakovačka Pećina), named after the Divljakovac karst polje (=field), on the northern edge of which it is located. The cave is situated in the eastern part of the country, about 15 km southeast of the town of Despotovac (Figure 1) and about 4 km southeast of the village of Jelovac. The cave was formed in the limestones of the Babina Glava hill by the erosive activity of a sinking stream that flowed from the northwestern slopes of the Kučajske Planine Mts. [15].

The cave was discovered accidentally in 1962 by local shepherds and mountaineers, when they saw its entrance (44°04′22.1″ N, 21°37′47.7″ E), sitting on 485 m a.s.l. [15]. It was examined in detail by Serbian speleologists. Prof. Dr. Jovan Petrović and his colleagues were the first to carry out detailed speleological investigations in Resava Cave in the 1960s [26]. After these explorations, further speleological research was carried out by Prof. Dr. Radenko Lazarević [27] and Milorad Kličković [28]. Ten years after its discovery, on 22 April 1972, the cave was officially opened to visitors. It is visited by tens of thousands of tourists every year. The estimated age of the cave is 80 million years, while the oldest speleothems date back to 45 million years [26]. The total length of the cave halls, canals, galleries and a network of side passages is 4.5 km, of which 0.8 km have been made accessible to visitors. The depth of the cave is 80 m. Resava Cave has been protected since 1995, when it was declared a natural monument [29]. It has been a member of the International Show Caves Association (ISCA) since 2010. In 2017, LED lighting was installed to minimize the negative effects of light on the cave's microclimate and its wildlife.

The cave consists of two main levels, of which the upper level is on average drier and warmer, while the lower one is significantly wetter and colder. Limestone boulders are present in the Entrance Hall, while certain areas in the cave are covered with layers of clay and rich travertine deposits (Figures 3 and 4) [15].

2.3. Terminology

The classical Schiner-Racovitza terminology for subterranean terrestrial animals, which was widely used for a long time, comprised three ecological categories: troglobites, troglophiles and trogloxenes [30,31].

According to Sket [32], however, terrestrial cave dwellers should be divided into four ecological groups, depending on their degree of adaptation to the subterranean environment. Troglobites (=troglobionts) include species that inevitably complete their life cycle in caves. Their appearance and behavior are exclusively adapted to the subterranean way of life (e.g., loss of pigmentation and eyes, elongation of appendages). Eutroglophiles include species that can establish permanent subterranean populations, but are essentially epigean. Subtroglophiles include species that can only live in caves during a certain phase of their life cycle, but are dependent on the surface for some biological functions (e.g., feeding) and never establish permanent subterranean populations. Finally, trogloxenes include species that occur sporadically or accidentally in caves (they may be attracted to the cave by humidity, temperature or food) [32].

Although trogloxenes are not true cave dwellers (they are usually restricted to cave entrances) and their importance for the study of subterranean animals is low [32], their presence in caves should not be completely ignored, especially because they bring nutrients from epigean habitats into the caves. There is a possibility that some of them are actually subtroglophilic or even eutroglophilic when more is known about their ecology [33].

Similar to the terrestrial fauna, the aquatic subterranean fauna is also divided into corresponding ecological categories (stygobites, eustygophiles, substygophiles and stygoxenes).

In this paper, however, we have divided the subterranean terrestrial arthropods into three categories (troglobites, troglophiles and trogloxenes) according to the Schiner-Racovitza terminology, as it is difficult to distinguish between eutroglophiles and subtroglophiles and between subtroglophiles and trogloxenes in Resava Cave due to the paucity of data on the ecology of their populations in the explored cave. There is a possibility that some of the trogloxenic arthropods in Resava Cave are actually troglophilic, but there is no clear evidence for this.

3. Results

After three years of research, we found that Resava Cave provides permanent or temporary/occasional habitat for a total of 107 species of terrestrial arthropods. A total of four troglobitic species, 16 troglophilic species and 87 trogloxenic species were recorded in the cave.

3.1. Troglobitic Arthropods of Resava Cave

During the investigations, a total of four troglobitic species were registered (Table 1, Figure 5).

Table 1. A list of troglobitic arthropod species found in Resava Cave.

No.	Species	Family	Order	Class	Subphylum
1	*Centromerus serbicus* Deltshev, 2002	Linyphiidae	Araneae	Arachnida	Chelicerata
2	*Serbosoma kucajense* (B. Ćurčić & Makarov, 1998)	Anthroleucosomatidae	Chordeumatida	Diplopoda	Myriapoda
3	*Plusiocampa christiani* Condé & Bareth, 1996	Campodeidae	Diplura	Diplura	Hexapoda
4	*Duvalius petrovici* S. Ćurčić, Vrbica, Antić & B. Ćurčić, 2014	Carabidae	Coleoptera	Insecta	Hexapoda

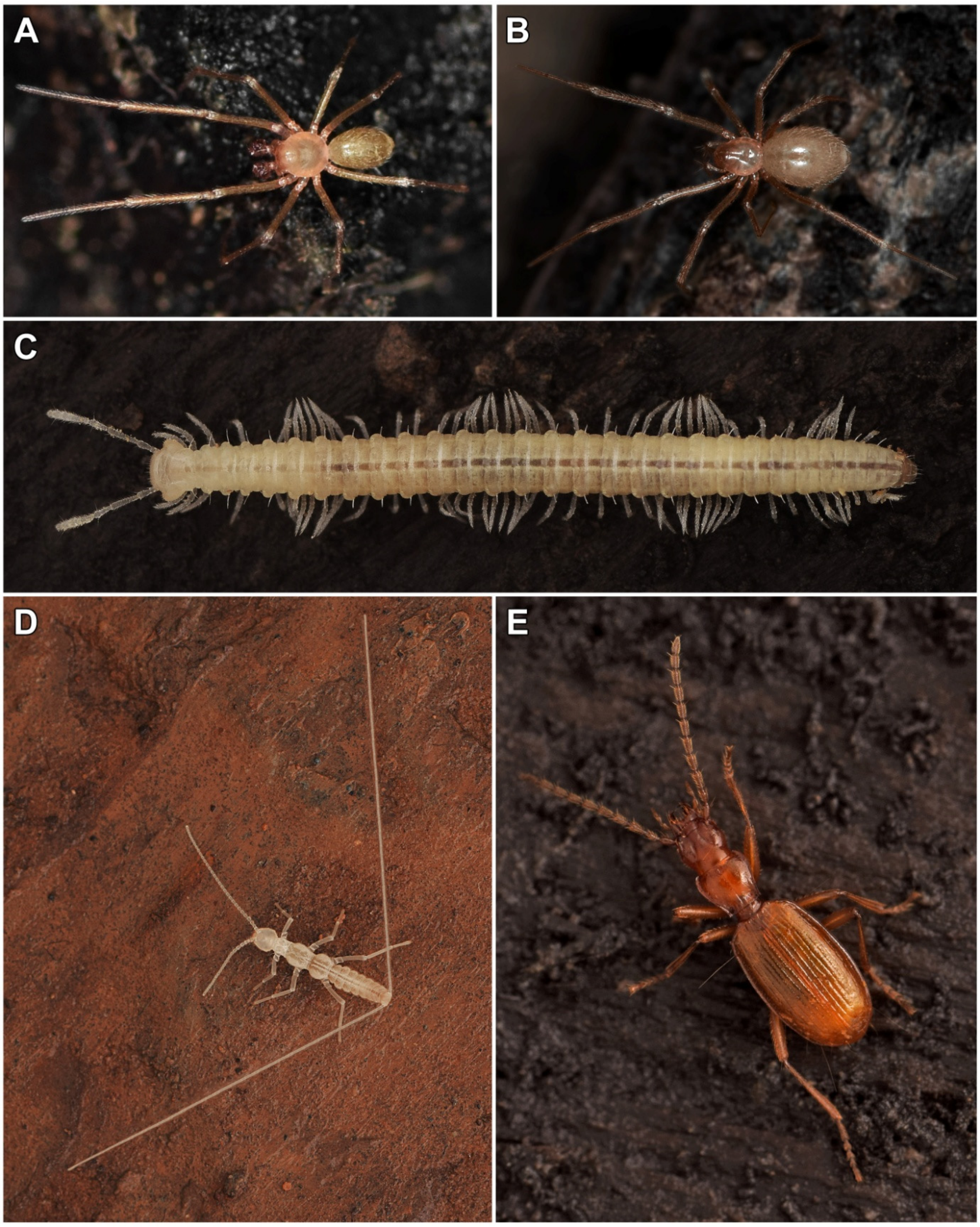

Figure 5. Troglobitic arthropods from Resava Cave. (**A**) A male of the spider *Centromerus serbicus*; (**B**) a female of *C. serbicus*; (**C**) the millipede *Serbosoma kucajense*; (**D**) the dipluran *Plusiocampa christiani*; (**E**) the ground beetle *Duvalius petrovici*. Photos: N. Vesović.

Of the troglobitic arachnids, only one species was recorded in Resava Cave—the spider *C. serbicus* (Figure 5A,B), which is endemic to caves in eastern Serbia [20,21]. Specimens of *C. serbicus* were observed in both levels of the cave (more frequently in the lower level), in complete darkness. The species was found in most of the halls of the cave with increased humidity both during visual inspection and in pitfall traps. We found its specimens most frequently under stones and decaying wood and in crevices in the walls.

Only one troglobitic myriapod has been recorded in Resava Cave, the millipede *S. kucajense* (Figure 5C), which is endemic to the former cave and Vrtačelje (=Ledena Pećina) Pit [19,25]. Live specimens of this species have been found in the cave in complete darkness during visual inspection and in pitfall traps (on the damp walls, on decaying wood and under stones).

As far as the troglobitic hexapods are concerned, two species live in Resava Cave. We have recorded the dipluran *P. christiani* (Figure 5D) and the ground beetle *D. petrovici* (Figure 5E), the former of which is endemic to caves in eastern Serbia [23], while the latter is a stenoendemic of Resava Cave [22]. Live specimens of the first species have been recorded during visual inspection and in pitfall traps in several halls of the cave (most frequently in the Concert Hall and the Boban's Hall). We found live specimens of the second species on the floor of the Menza Gallery, among decaying wood debris and in the damp clay. Specimens of this species were also found in pitfall traps set up on the damp walls and on the floor in the same gallery, but also in smaller numbers in the Coral Canals and the Concert Hall. Both troglobitic hexapod species were found in the lower level of the cave, in complete darkness and in similar microhabitats (on the damp floor and on the walls).

3.2. Troglophilic Arthropods of Resava Cave

During the investigations, a total of 16 troglophilic species were registered (Table 2, Figure 6).

Table 2. A list of troglophilic arthropod species found in Resava Cave.

No.	Species	Family	Order	Class	Subphylum
1	*Paranemastoma sillii* (Herman, 1871)	Nemastomatidae	Opiliones	Arachnida	Chelicerata
2	*Diplocephalus cristatus* (Blackwall, 1833)	Linyphiidae	Araneae	Arachnida	Chelicerata
3	*Porrhomma convexum* (Westring, 1851)	Linyphiidae	Araneae	Arachnida	Chelicerata
4	*Nesticus cellulanus* (Clerck, 1757)	Nesticidae	Araneae	Arachnida	Chelicerata
5	*Meta menardi* (Latreille, 1804)	Tetragnathidae	Araneae	Arachnida	Chelicerata
6	*Metellina merianae* (Scopoli, 1763)	Tetragnathidae	Araneae	Arachnida	Chelicerata
7	*Ixodes vespertilionis* Koch, 1844	Ixodidae	Ixodida	Arachnida	Chelicerata
8	*Hyloniscus* cf. *riparius* (C. Koch, 1838)	Trichoniscidae	Isopoda	Malacostraca	Crustacea
9	*Trachysphaera* sp.	Glomeridae	Glomerida	Diplopoda	Myriapoda
10	*Pygmarrhopalites pygmaeus* (Wankel, 1860)	Arrhopalitidae	Symphypleona	Collembola	Hexapoda
11	*Tomocerus vulgaris* (Tullberg, 1871)	Tomoceridae	Entomobryomorpha	Collembola	Hexapoda
12	*Troglophilus neglectus* Krauss, 1879	Rhaphidophoridae	Orthoptera	Insecta	Hexapoda
13	*Laemostenus punctatus* (Dejean, 1828)	Carabidae	Coleoptera	Insecta	Hexapoda
14	*Quedius mesomelinus* (Marsham, 1802)	Staphylinidae	Coleoptera	Insecta	Hexapoda
15	*Limonia nubeculosa* Meigen, 1804	Limoniidae	Diptera	Insecta	Hexapoda
16	*Speolepta leptogaster* (Winnertz, 1863)	Mycetophilidae	Diptera	Insecta	Hexapoda

Figure 6. Selected troglophilic arthropods of Resava Cave. (**A**) The harvestmen *Paranemastoma sillii*; (**B**) the spider *Meta menardi*; (**C**) the spider *Metellina merianae*; (**D**) the tick *Ixodes vespertilionis*; (**E**) the isopod *Hyloniscus* cf. *riparius*; (**F**) the millipede *Trachysphaera* sp.; (**G**) the springtail *Tomocerus vulgaris*; (**H**) the springtail *Pygmarrhopalites pygmaeus*; (**I**) the cricket *Troglophilus neglectus*; (**J**) the ground beetle *Laemostenus punctatus*; (**K**) the rove beetle *Quedius mesomelinus*; (**L**) the dipteran *Speolepta leptogaster*. Photos: N. Vesović.

A total of seven troglophilic arachnid species (one harvestmen, five spiders and one tick) are known from Resava Cave.

We found live specimens of the large troglophilic harvestmen *Paranemastoma sillii* (Hermann, 1871) (Figure 6A) in both levels of the cave, in complete darkness, mostly on the damp limestone surfaces (rocks, walls). We recorded a total of four troglophilic spider species in the cave: *Meta menardi* (Latreille, 1804) (Figure 6B), *Metellina merianae* (Scopoli, 1763) (Figure 6C), *Diplocephalus cristatus* (Blackwall, 1833) and *Nesticus cellulanus* (Clerck, 1757). The fifth troglophilic spider species, *P. convexum*, is only known from the literature [15] as an inhabitant of the cave, as we were unable to find it during our investigations. All the troglophilic spider species mentioned were observed mainly in the illuminated Entrance Hall (where there is the most food), and somewhat less in the inner parts of the cave, which belong to the upper level. The only tick species recorded in the cave, also a troglophile, was *Ixodes vespertilionis* Koch, 1844 (Figure 6D). We found live specimens of this species in both levels of the cave.

During our cave explorations, we found a single troglophilic crustacean—the isopod *Hyloniscus* cf. *riparius* (C. Koch, 1838) (Figure 6E). This is one of the most common species in the cave, occurring on very moist surfaces in both the upper and lower levels of the cave.

The only troglophilic millipede in the cave, *Trachysphaera* sp. (Figure 6F) was found in complete darkness in the lower level of the cave, but almost exclusively as single or few specimens on relatively dry, decaying wood.

A total of seven species of troglophilic hexapods (two taxa of the class Collembola and five taxa of the class Insecta) were recorded. These included two springtails, one orthopteran, two beetles and two dipterans. The springtail *Tomocerus vulgaris* (Tullberg, 1871) (Figure 6G) was found in both levels in almost all cave halls that are in complete darkness, but also on the floor of the illuminated Entrance Hall. It was observed in both humid and somewhat drier microhabitats. Another find was that of a springtail belonging to the genus *Pygmarrhopalites* Vargovitsh, 2009—*Pygmarrhopalites pygmaeus* (Wankel, 1860) (Figure 6H). We found it in small numbers only in pitfall traps set up in the upper level of the cave (the Beehive Hall), in complete darkness.

The troglophilic cave cricket *Troglophilus neglectus* Krauss, 1879 (Figure 6I) was found in the Entrance Hall of the cave. Both recorded troglophilic beetle species [the ground beetle *Laemostenus punctatus* (Dejean, 1828) (Figure 6J) and the rove beetle *Quedius mesomelinus* (Marsham, 1802) (Figure 6K)] were found in both the upper and lower levels of the cave. We observed them near the entrance, in the partially illuminated part of the cave, but also in complete darkness in the Canyon Canal, the Coral Canals and the Kepa's Hall in smaller numbers, on relatively dry surfaces. The short-palped cranefly (*Limonia nubeculosa* Meigen, 1804) was observed in complete darkness in the upper level of the cave, as well as in the Entrance Hall. The fungus gnat *Speolepta leptogaster* (Winnertz, 1863) (Figure 6L) is a small troglophilic dipteran, which we observed in complete darkness on the damp walls in the upper level of the cave, as well as in pitfall traps set up in the lower level of the cave.

3.3. Trogloxenic Arthropods of Resava Cave

During the investigations, a total of 87 trogloxenic species were registered (Table 3, Figure 7).

Table 3. A list of trogloxenic arthropod species found in Resava Cave.

No.	Species	Family	Order	Class	Subphylum
1	*Neobisium carpaticum* Beier, 1935	Neobisiidae	Pseudoscorpiones	Arachnida	Chelicerata
2	*Lacinius dentiger* (C. L. Koch, 1848)	Phalangiidae	Opiliones	Arachnida	Chelicerata
3	*Opilio ruzickai* Šilhavý, 1938	Phalangiidae	Opiliones	Arachnida	Chelicerata
4	*Phalangium opilio* Linnaeus, 1761	Phalangiidae	Opiliones	Arachnida	Chelicerata
5	*Harpactea* sp.	Dysderidae	Araneae	Arachnida	Chelicerata
6	*Stemonyphantes lineatus* (Linnaeus, 1758)	Linyphiidae	Araneae	Arachnida	Chelicerata
7	*Agroeca cuprea* Menge, 1873	Liocranidae	Araneae	Arachnida	Chelicerata
8	*Liocranum rupicola* (Walckenaer, 1830)	Liocranidae	Araneae	Arachnida	Chelicerata
9	*Alopecosa trabalis* (Clerck, 1757)	Lycosidae	Araneae	Arachnida	Chelicerata
10	*Pardosa alacris* (C. L. Koch, 1833)	Lycosidae	Araneae	Arachnida	Chelicerata
11	*Pirata latitans* (Blackwall, 1841)	Lycosidae	Araneae	Arachnida	Chelicerata
12	*Trochosa terricola* Thorell, 1856	Lycosidae	Araneae	Arachnida	Chelicerata

Table 3. *Cont.*

No.	Species	Family	Order	Class	Subphylum
13	*Philodromus margaritatus* (Clerck, 1757)	Philodromidae	Araneae	Arachnida	Chelicerata
14	*Philodromus* sp.	Philodromidae	Araneae	Arachnida	Chelicerata
15	*Pisaura mirabilis* (Clerck, 1757)	Pisauridae	Araneae	Arachnida	Chelicerata
16	*Metellina segmentata* (Clerck, 1757)	Tetragnathidae	Araneae	Arachnida	Chelicerata
17	*Tmarus* sp.	Thomisidae	Araneae	Arachnida	Chelicerata
18	*Xysticus lanio* C. L. Koch, 1835	Thomisidae	Araneae	Arachnida	Chelicerata
19	*Xysticus* sp.	Thomisidae	Araneae	Arachnida	Chelicerata
20	*Ligidium* cf. *hypnorum* (Cuvier, 1792)	Ligiidae	Isopoda	Malacostraca	Crustacea
21	*Trachelipus rathkii* (Brandt, 1833)	Trachelipodidae	Isopoda	Malacostraca	Crustacea
22	*Lithobius forficatus* (Linnaeus, 1758)	Lithobiidae	Lithobiomorpha	Chilopoda	Myriapoda
23	*Lithobius muticus* C. L. Koch, 1847	Lithobiidae	Lithobiomorpha	Chilopoda	Myriapoda
24	*Lithobius nigripalpis* L. Koch, 1867	Lithobiidae	Lithobiomorpha	Chilopoda	Myriapoda
25	*Cryptops anomalans* Newport, 1844	Cryptopidae	Scolopendromorpha	Chilopoda	Myriapoda
26	*Callipodella fasciata* (Latzel, 1882)	Callipodidae	Callipodida	Diplopoda	Myriapoda
27	*Craspedosoma raulinsii* Leach, 1814	Craspedosomatidae	Chordeumatida	Diplopoda	Myriapoda
28	*Glomeris hexasticha* Brandt, 1833	Glomeridae	Glomerida	Diplopoda	Myriapoda
29	*Megaphyllum bosniense* (Verhoeff, 1897)	Julidae	Julida	Diplopoda	Myriapoda
30	*Polydesmus subscabratus* Latzel, 1884	Polydesmidae	Polydesmida	Diplopoda	Myriapoda
31	*Lepismachilis* sp.	Machilidae	Microcoryphia	Insecta	Hexapoda
32	*Poecilimon schmidtii* (Fieber, 1853)	Phaneropteridae	Orthoptera	Insecta	Hexapoda
33	*Pachytrachis gracilis* (Brunner von Wattenwyl, 1861)	Tettigoniidae	Orthoptera	Insecta	Hexapoda
34	*Forficula auricularia* Linnaeus, 1758	Forficulidae	Dermaptera	Insecta	Hexapoda
35	*Ectobius erythronotus* Burr, 1898	Blattellidae	Blattodea	Insecta	Hexapoda
36	*Bertkauia lucifuga* (Rambur, 1842)	Epipsocidae	Psocodea	Insecta	Hexapoda
37	*Leptoglossus occidentalis* Heidemann, 1910	Coreidae	Hemiptera	Insecta	Hexapoda
38	*Lygaeus equestris* (Linnaeus, 1758)	Lygaeidae	Hemiptera	Insecta	Hexapoda
39	*Nemoura cinerea* (Retzius, 1783)	Nemouridae	Plecoptera	Insecta	Hexapoda
40	*Pedilophorus auratus* (Duftschmid, 1825)	Byrrhidae	Coleoptera	Insecta	Hexapoda
41	*Abax carinatus* (Duftschmid, 1812)	Carabidae	Coleoptera	Insecta	Hexapoda
42	*Anchomenus dorsalis* (Pontoppidan, 1763)	Carabidae	Coleoptera	Insecta	Hexapoda
43	*Calathus fuscipes* (Goeze, 1777)	Carabidae	Coleoptera	Insecta	Hexapoda
44	*Carabus convexus* Fabricius, 1775	Carabidae	Coleoptera	Insecta	Hexapoda
45	*Carabus coriaceus* Linnaeus, 1758	Carabidae	Coleoptera	Insecta	Hexapoda
46	*Carabus montivagus* Palliardi, 1825	Carabidae	Coleoptera	Insecta	Hexapoda
47	*Carabus ullrichii* Germar, 1824	Carabidae	Coleoptera	Insecta	Hexapoda
48	*Carabus violaceus* Linnaeus, 1758	Carabidae	Coleoptera	Insecta	Hexapoda
49	*Harpalus rufipes* (De Geer, 1774)	Carabidae	Coleoptera	Insecta	Hexapoda
50	*Leistus rufomarginatus* (Duftschmid, 1812)	Carabidae	Coleoptera	Insecta	Hexapoda
51	*Molops piceus* (Panzer, 1793)	Carabidae	Coleoptera	Insecta	Hexapoda
52	*Platynus scrobiculatus* (Fabricius, 1801)	Carabidae	Coleoptera	Insecta	Hexapoda

Table 3. *Cont.*

No.	Species	Family	Order	Class	Subphylum
53	*Trechus quadristriatus* (Schrank, 1781)	Carabidae	Coleoptera	Insecta	Hexapoda
54	*Mesosa curculionoides* (Linnaeus, 1761)	Cerambycidae	Coleoptera	Insecta	Hexapoda
55	*Otiorhynchus perdix* (Olivier, 1807)	Curculionidae	Coleoptera	Insecta	Hexapoda
56	*Otiorhynchus raucus* (Fabricius, 1777)	Curculionidae	Coleoptera	Insecta	Hexapoda
57	*Ruteria hypocrita* (Boheman, 1837)	Curculionidae	Coleoptera	Insecta	Hexapoda
58	*Lampyris noctiluca* (Linnaeus, 1767)	Lampyridae	Coleoptera	Insecta	Hexapoda
59	*Oedemera femoralis* Olivier, 1803	Oedemeridae	Coleoptera	Insecta	Hexapoda
60	*Valgus hemipterus* (Linnaeus, 1758)	Scarabaeidae	Coleoptera	Insecta	Hexapoda
61	*Ocypus nitens* (Schrank, 1781)	Staphylinidae	Coleoptera	Insecta	Hexapoda
62	*Ocypus olens* (Müller, 1764)	Staphylinidae	Coleoptera	Insecta	Hexapoda
63	*Eilema sororcula* (Hufnagel, 1766)	Erebidae	Lepidoptera	Insecta	Hexapoda
64	*Scoliopteryx libatrix* (Linnaeus, 1758)	Erebidae	Lepidoptera	Insecta	Hexapoda
65	*Asthena albulata* (Hufnagel, 1767)	Geometridae	Lepidoptera	Insecta	Hexapoda
66	*Camptogramma bilineata* (Linnaeus, 1758)	Geometridae	Lepidoptera	Insecta	Hexapoda
67	*Colotois pennaria* (Linnaeus, 1761)	Geometridae	Lepidoptera	Insecta	Hexapoda
68	*Epirrhoe* sp.	Geometridae	Lepidoptera	Insecta	Hexapoda
69	*Epirrita* sp.	Geometridae	Lepidoptera	Insecta	Hexapoda
70	*Hypomecis punctinalis* (Scopoli, 1763)	Geometridae	Lepidoptera	Insecta	Hexapoda
71	*Operophtera fagata* (Scharfenberg, 1805)	Geometridae	Lepidoptera	Insecta	Hexapoda
72	*Rheumaptera cervinalis* (Scopoli, 1763)	Geometridae	Lepidoptera	Insecta	Hexapoda
73	*Micropteryx* sp.	Micropterigidae	Lepidoptera	Insecta	Hexapoda
74	*Diloba caeruleocephala* (Linnaeus, 1758)	Noctuidae	Lepidoptera	Insecta	Hexapoda
75	*Hedya* sp.	Tortricidae	Lepidoptera	Insecta	Hexapoda
76	*Micropterna nycterobia* McLachlan, 1875	Limnephilidae	Trichoptera	Insecta	Hexapoda
77	*Micropterna sequax* McLachlan, 1875	Limnephilidae	Trichoptera	Insecta	Hexapoda
78	*Stenophylax permistus* McLachlan, 1895	Limnephilidae	Trichoptera	Insecta	Hexapoda
79	*Camponotus ionius* Emery, 1920	Formicidae	Hymenoptera	Insecta	Hexapoda
80	*Diphyus quadripunctorius* (Müller, 1776)	Ichneumonidae	Hymenoptera	Insecta	Hexapoda
81	*Lymantrichneumon disparis* (Poda, 1761)	Ichneumonidae	Hymenoptera	Insecta	Hexapoda
82	*Calliphora vomitoria* (Linnaeus, 1758)	Calliphoridae	Diptera	Insecta	Hexapoda
83	*Culex pipiens* Linnaeus, 1758	Culicidae	Diptera	Insecta	Hexapoda
84	*Heleomyza serrata* (Linnaeus, 1758)	Heleomyzidae	Diptera	Insecta	Hexapoda
85	*Heteromyza atricornis* Meigen, 1830	Heleomyzidae	Diptera	Insecta	Hexapoda
86	*Tarnania fenestralis* (Meigen, 1838)	Mycetophilidae	Diptera	Insecta	Hexapoda
87	*Chorisops nagatomii* Rozkošný, 1979	Stratiomyidae	Diptera	Insecta	Hexapoda

Figure 7. Selected trogloxenic arthropods from Resava Cave. (**A**) The pseudoscorpion *Neobisium carpaticum*; (**B**) the harvestmen *Lacinius dentiger*; (**C**) the harvestmen *Opilio ruzickai*; (**D**) the spider *Liocranum rupicola*; (**E**) the spider *Philodromus margaritatus*; (**F**) the centipede *Lithobius forficatus*; (**G**) the millipede *Megaphyllum bosniense*; (**H**) the millipede *Polydesmus subscabratus*; (**I**) the psocodean *Bertkauia lucifuga*; (**J**) the ground beetle *Molops piceus*; (**K**) the herald moth—*Scoliopteryx libatrix*; (**L**) the yellow shell moth—*Camptogramma bilineata*; (**M**) the caddisfly *Stenophylax permistus*; (**N**) the ichneumonid wasp *Lymantrichneumon disparis*; (**O**) the dipteran *Heleomyza serrata*. Photos: N. Vesović.

The largest number of arachnids found in Resava Cave represent trogloxenic species. During the investigations, a total of 19 such species were registered (Table 3, Figure 7A–E). The trogloxenic arachnids from the cave belong to the orders Pseudoscorpiones (one species) (Figure 7A), Opiliones (three species) (Figure 7B,C) and Araneae (15 species) (Figure 7D,E). The arachnid families richest in trogloxenes are Lycosidae (wolf spiders) (with four species), Thomisidae and Phalangiidae (with three species each). Most of the trogloxenic arachnids were found in the Entrance Hall of the cave.

Among the Crustacea, we found only two trogloxenic species (Table 3), both belonging to the order Isopoda, but to two different families (Ligiidae and Trachelipodidae). We found both trogloxenic isopods in the Entrance Hall of the cave (in the leaf litter, on the floor and on rocks).

Most of the myriapods found in Resava Cave are also trogloxenic taxa. We found a total of nine such species in the cave (Table 3, Figure 7F–H). They mostly belong to the class Diplopoda (five species), i.e., to the orders Callipodida, Chordeumatida, Glomerida, Julida and Polydesmida (with one species each). Slightly fewer species (four) belong to the class Chilopoda and the orders Lithobiomorpha (with three species) and Scolopendromorpha (with one species). The family and genus of myriapods richest in trogloxenes in Resava Cave are Lithobiidae and *Lithobius* Leach, 1814, with three species each, while all other families and genera of myriapods were represented by a single trogloxenic species each. In the Entrance Hall of Resava Cave we found all trogloxenic species of myriapods (in the leaf litter, on the ground, on rocks and under stones). *Callipodella fasciata* (Latzel, 1882) and *Lithobius forficatus* (Linnaeus, 1758) (Figure 7F) are the most common of the trogloxenic myriapod species recorded. The species *Glomeris hexasticha* Brandt, 1833, *Megaphyllum bosniense* (Verhoeff, 1897) (Figure 7G) and *Lithobius muticus* C. L. Koch, 1847 are somewhat less numerous, while the other trogloxenic myriapods are represented by far fewer individuals.

The largest number of hexapods in Resava Cave represent trogloxenic species. During our investigations, we found a total of 57 such species (Table 3, Figure 7I–O). The trogloxenic hexapods we detected all belong to the class Insecta, i.e., to the orders Coleoptera (23 species), Lepidoptera (13 species), Diptera (six species), Hymenoptera, Trichoptera (with three species each), Orthoptera, Hemiptera (with two species each), Dermaptera, Blattodea, Microcoryphia, Plecoptera and Psocodea (with one species each) (Table 3). The insect families richest in trogloxenes are Carabidae and Geometridae, with 13 and eight species, respectively.

We found most of the trogloxenic species of hexapods in the partially illuminated Entrance Hall of the cave (on the walls, on the floor, on rocks or under stones). The most common was the psocodean *Bertkauia lucifuga* (Rambur, 1842) (Figure 7I) (it was particularly common on large limestone boulders). Other trogloxenic insect species common in the Entrance Hall of the cave were the ground beetles *Carabus montivagus* Palliardi, 1825 and *Molops piceus* (Panzer, 1793) (Figure 7J), the European earwig—*Forficula auricularia* Linnaeus, 1758, the herald moth—*Scoliopteryx libatrix* (Linnaeus, 1758) (Figure 7K), the yellow shell moth—*Camptogramma bilineata* (Linnaeus, 1758) (Figure 7L), the rove beetle *Ocypus nitens* (Schrank, 1781), the caddisfly *Stenophylax permistus* McLachlan, 1895 (Figure 7M), the common house mosquito—*Culex pipiens* Linnaeus, 1758 and the dipteran *Heteromyza atricornis* Meigen, 1830. The remaining trogloxenic insect taxa were less common in the cave (Figure 7N).

4. Discussion

As a result of strong geotectonic movements (e.g., folding and faulting) of the limestone masses in Serbia, numerous fissures and canals were formed, which penetrate deep into the limestone layers and enable both free circulation of groundwater and intensification of the karst process in the superficial and deep parts of the limestone masses [15].

Study of the hypogean inhabitants of the Serbian karst has provided further evidence of their great age and diverse origins [3]. Apart from this, it is apparent that specific aspects of the geomorphological and climatic events in the Balkans, together with the peculiarities of historical development of the fauna there, have led to the area becoming the main center of dispersal and colonization of species and species groups, i.e., the main source for the revival and emergence of biodiversity in the Mediterranean and Southeast Europe [3].

Summarizing the results of our investigations carried out in recent years, a total of 107 arthropod species (66 hexapods, 27 arachnids, 11 myriapods and three crustaceans) were found in Resava Cave. Four species (3.74%) are troglobites (Table 1, Figure 5), 16 species (14.95%) are troglophiles (Table 2, Figure 6), while the remaining 87 species (81.31%) are trogloxenes (Table 3, Figure 7).

As there is neither an underground stream nor stagnant water in Resava Cave, no aquatic subterranean organisms (stygobites, stygophiles or stygoxenes) were found there.

The following caves and pits in the surroundings of Resava Cave were also biospeleologically examined in the past (Table 4): Lazar's (=Zlot) Cave (with 26 species of terrestrial arthropods, of which nine troglobites) [34], Vernjikica Cave (with 15 species of terrestrial arthropods, of which six troglobites) [34], Golema Porica Pit (with 10 species of terrestrial arthropods, of which three troglobites) [35,36], Sesalac Cave (with six species of terrestrial arthropods, of which two troglobites) [24,37,38], Devojačka (=Gaura Fećilor) Cave (with five species of terrestrial arthropods, of which four troglobites) [39,40], Vrtačelje (=Ledena Pećina) Pit (with four species of terrestrial arthropods, of which two troglobites) [25] and Tupižnička Ledenica Pit (with four species of terrestrial arthropods, of which one troglobite) [41]. In addition to Resava Cave, Lazar's Cave, Vernjikica Cave and Sesalac Cave are also adapted for tourist visits. The terrestrial arthropod fauna of certain caves in other parts of Serbia, which are adapted for tourist visits, was also studied. According to the available literature data, 15 species of terrestrial arthropods live in Hadži-Prodan's Cave in southwestern Serbia, three of which are troglobitic [42], Stopića Cave in western Serbia is inhabited by eight taxa of terrestrial arthropods, one of which is troglobitic [43], while Ceremošnja Cave in eastern Serbia is home to five species of terrestrial arthropods, three of which are troglobitic [44,45]. Only in two of the caves mentioned (Lazar's Cave and Vernjikica Cave) a greater number of troglobitic terrestrial arthropod species was found than in Resava Cave, but the latter cave is characterized by the highest overall diversity of terrestrial arthropods (with 107 species) compared to all others in Serbia. One of the reasons for this assertion lies in the particular morphology of Resava Cave (it has a large Entrance Hall), which allows many trogloxenes to reside in it. It should also be noted that the biospeleological investigations in most of the caves mentioned lasted a year or even less, and they mainly focused not on the entire cave fauna, but only on troglobites.

Table 4. List of biospeleologically surveyed caves/pits in Serbia (with four or more arthropod species detected) with the number of troglobitic and total terrestrial arthropod species recorded.

No.	Cave/Pit Name	Troglobitic Arthropods	Total Terrestrial Arthropods
1	Lazar's (=Zlot) Cave	9	26
2	Vernjikica Cave	6	15
3	Resava Cave	4	107
4	Devojačka (=Gaura Fećilor) Cave	4	5
5	Golema Porica Pit	3	10
6	Hadži-Prodan's Cave	3	15
7	Ceremošnja Cave	3	5
8	Sesalac Cave	2	6
9	Vrtačelje (=Ledena Pećina) Pit	2	4
10	Stopića Cave	1	8
11	Tupižnička Ledenica Pit	1	4

Considering the medium size of Resava Cave and the lack of permanent water flow in the two main levels on the one hand, and the large number of arthropod species recorded on the other, the cave is relatively rich in hypogean terrestrial arthropod fauna compared to other caves in Serbia that have been biospeleologically studied so far. The terrestrial arthropod fauna of Resava Cave appears to be well preserved, and populations of endemic and protected arthropod species are constantly present despite the fact that it is a site visited by tourists, which speaks for its responsible management.

4.1. Arachnida of Resava Cave

The arachnid fauna of Resava Cave comprises 27 species (one troglobite, seven troglophiles and 19 trogloxenes). According to the literature [15,20,21], only three species (*C. serbicus*, *N.* cf. *carpaticum* and *P. convexum*) have been reported so far in Resava Cave, of which we were able to confirm two (*C. serbicus* and *N. carpaticum*), while the remaining 24 species we found were not yet known for Resava Cave. Representatives of four arachnid orders (Araneae, Ixodida, Opiliones and Pseudoscorpiones) were recorded. Most of the species we found belong to spiders (21) and harvestmen (four), while pseudoscorpions and ticks were represented by one species each. The families with the most species in Resava Cave are Linyphiidae and Lycosidae (with four species each), followed by Tetragnathidae, Thomisidae, Phalangiidae (with three species each), Liocranidae and Philodromidae (with two species each). Two species each were recorded within the genera *Metellina* Chamberlin & Ivie, 1941, *Philodromus* Walckenaer, 1826 and *Xysticus* C. L. Koch, 1835, while the other genera include one species each. During our investigations, we observed a large number of individuals of certain species of spiders (*C. serbicus*, *M. menardi* and *M. merianae*) and harvestmen (*O. ruzickai* and *P. sillii*), which indicates the presence of their stable populations in the cave. The presence of the pseudoscorpion *N. carpaticum* was confirmed in the Entrance Hall of the cave [15], where there are deposits of leaf litter that favor the development of this species.

Interestingly, despite several visits by our research team to Resava Cave in recent years, the spider *P. convexum* has not been recorded there since its discovery in 1998 [15]. On the contrary, the spider *C. serbicus* was found in large numbers, which confirms that the population of this specialized troglobitic species is quite stable in Resava Cave. This finding is very valuable as it is the only troglobitic arachnid in the cave. It is endemic to several caves in eastern Serbia (Vernjikica Cave, Resava Cave, Lazar's Cave, Izviđačka Cave and Manda's Cave) [20,21]. Considering the troglophiles, we found a stable population of the harvestmen *P. sillii*, an inhabitant of beech forests and caves, which is widely distributed in the Balkans and Southern Europe [46]. The troglophilic spiders *M. menardi* and *M. merianae* are common in Resava Cave and form stable populations there. They prefer somewhat drier habitats and we have often seen them on the walls, where they weave their webs. The troglophilic tick *I. vespertilionis* is a rather large species, which parasitizes bats and is usually found in caves with bat colonies [47].

4.2. Crustacea of Resava Cave

The crustacean fauna of Resava Cave includes three isopod species (one troglophile and two trogloxenes) that we found during our investigations, but which were not previously known to live in the cave. During our research, we observed a large number of the troglophilic species *H.* cf. *riparius*, suggesting its stable population in the cave. It is native to Central and Eastern Europe and can endure long periods under water [48]. Other species are trogloxenic and were observed sporadically.

The expected number of isopod species in Resava Cave is probably somewhat higher than we have indicated.

4.3. Myriapoda of Resava Cave

A total of 11 species of myriapods were recorded, which are divided into two classes: Diplopoda (with seven species) and Chilopoda (with four species). We found a significantly higher number of myriapod species in Resava Cave than indicated in the literature [19,24], where only two species of millipedes were reported to inhabit the cave (*S. kucajense* and *Trachysphaera* sp.). During our investigations, we found the two species of diplopods mentioned above and nine others that can be considered new to the fauna of Resava Cave. So far, no representatives of the class Chilopoda have been recorded in Resava Cave, but we found four centipede species there [*Cryptops anomalans* Newport, 1844, *Lithobius forficatus* (Linnaeus, 1758), *L. muticus* and *L. nigripalpis* L. Koch, 1867]. During our expeditions, representatives of seven orders and eight families of Myriapoda (five orders and six families of Diplopoda and two orders and two families of Chilopoda) were recorded in Resava Cave. Within the class Diplopoda, species of the orders Callipodida, Chordeumatida, Glomerida, Julida and Polydesmida and of the families Anthroleucosomatidae, Callipodidae, Craspedosomatidae, Glomeridae, Julidae and Polydesmidae were recorded. Within the class Chilopoda, taxa of the orders Lithobiomorpha and Scolopendromorpha and of the families Cryptopidae and Lithobiidae were found. Most of the recorded myriapod species belong to the order Lithobiomorpha (with three species), followed by the orders Chordeumatida and Glomerida (with two species each), while all other orders are represented by only one species each. The families with the most species are Lithobiidae (with three species) and Glomeridae (with two species), while all other families have only one species each. Of the eight genera of myriapods, *Lithobius* (with three species) is the most species-rich, while the other genera contained only one species each. Most species of Diplopoda and Chilopoda have stable populations in Resava Cave, as evidenced by the large number of specimens found during our research and their presence during all our visits.

The presence of the most important myriapod species, the troglobitic diplopod *S. kucajense*, was confirmed in Resava Cave mainly in its lower level (only one specimen was observed in the upper level), which is wetter and colder, favoring the development of this species. This finding is very valuable as it is the only troglobitic myriapod from Resava Cave. The increased humidity on the walls and on the floor of the cave (the presence of trickling water) and the presence of decaying wood as a food source are essential for the survival of this species. The population of this species in Resava Cave, although vulnerable and not so numerous, is stable, as evidenced by the presence of live specimens that we have observed during most of our visits. This information is very important for the monitoring and conservation of this species in its natural microhabitats in Resava Cave.

In addition, we confirmed the presence of *Trachysphaera* sp. in Resava Cave. We were unable to identify the specimens to species level as we only collected females and juveniles, whereas *Trachysphaera* species can only be accurately identified from the males. The taxon from Resava Cave most closely resembles the species *Trachysphaera costata* (Waga, 1857), *T. corcyraea* (Verhoeff, 1900) and *T. similicostata* (Radu & Ceuca, 1951), which were found in some other caves of the Carpatho-Balkanides of Serbia [24]. It is the only troglophilic myriapod from Resava Cave.

The findings of the millipede species *C. fasciata* and *Polydesmus subscabratus* Latzel, 1884 (Figure 7H), which are endemic to the Balkans, are also of great importance. Our record of *P. subscabratus* is significant as the species is very rare in Serbia and its previous findings in the country date back to the 1980s. Our discovery of the centipede species *L. nigripalpis* in Resava Cave is the first precise finding of this species in Serbia, which confirms its occurrence in this country. This species is distributed in the Balkans and the Middle East [49]. Other centipede species from Resava Cave are more widespread, some of which are subcosmopolitan (*L. forficatus*). The four species of centipedes mentioned were observed in the Entrance Hall of the cave (under stones and in the leaf litter).

The definite number of myriapod species in Resava Cave is probably somewhat higher than we have indicated.

4.4. Hexapoda of Resava Cave

We identified a total of 66 species of hexapods (two troglobites, seven troglophiles and 57 trogloxenes), which were assigned to the classes Collembola, Diplura and Insecta. Since only one species was previously known from Resava Cave [22], 65 species are new to the fauna of the cave. Representatives of 15 orders (three orders of Entognatha and 12 orders of Insecta) were recorded. Within the Entognatha, species of the classes Collembola and Diplura were recorded, while within the class Insecta, taxa of the orders Blattodea, Coleoptera, Diptera, Dermaptera, Hemiptera, Hymenoptera, Lepidoptera, Microcoryphia, Orthoptera, Plecoptera, Psocoptera and Trichoptera were found. Most of the hexapod species recorded belong to beetles (26), moths (13), dipterans (eight), caddisflies, hymenopterans and orthopterans (three species each). The families with the most hexapod species in Resava Cave are Carabidae (with 15 species), Geometridae (with eight species), Curculionidae, Staphylinidae and Limnephilidae (with three species each). The most species-rich hexapod genera were *Carabus* Linnaeus, 1758 (with five species), *Micropterna* Stein, 1873, *Ocypus* Leach, 1819 and *Otiorhynchus* Germar, 1822 (with two species each), while the other recorded genera contained only one species each. Certain species of spingtails, rove beetles and psocodeans are very numerous in Resava Cave. These are *T. vulgaris*, *Q. mesomelinus* and *B. lucifuga*, respectively.

Apart from Resava Cave, the troglobitic dipluran *P. christiani* has been recorded in several other caves in the area, i.e., it is an endemic of the Kučajske Planine Mts. and Mt. Beljanica in eastern Serbia [23]. The carabid species *D. petrovici* is a stenoendemic of Resava Cave [22]. It is obvious that the increased humidity on the walls (the presence of trickling water) and on the floor of the cave, as well as a sufficient food supply are essential for the survival of these species.

The population of the troglophilic springtail *T. vulgaris* in Resava Cave is very large, as the species was very common in the cave. As far as its distribution is concerned, it is a widespread species in the Holarctic, often found in Europe and North America [50]. Another troglophilic species, the tiny collembolan *P. pygmaeus*, is actually the smallest arthropod in Resava Cave, but also one of the smallest in Serbia. Compared to *T. vulgaris*, we observed a much lower occurrence of *P. pygmaeus* in the cave, but it is also questionable whether it can be easily overlooked due to its small size. The number of Collembola species potentially inhabiting this cave is probably higher (possibly not less than 10), but they are difficult to find *in situ*. In contrast to most other Orthoptera, which feed on plants and live outside caves, the troglophilic *T. neglectus* is carnivorous and very common in European caves, especially in the Balkans [51].

Both troglophilic beetle species from Resava Cave are predators and are considered common in European caves, where they are found in bat guano [52]. The carabid *L. punctatus* is common in Serbian caves [52] and is also found outside caves. The rove beetle *Q. mesomelinus* is often found on a substrate consisting of bat guano and decaying wood [52]. Its population in Resava Cave is much larger than that of *L. punctatus*.

The troglophilic cranefly *L. nubeculosa* is widespread in European caves and is also found in forests, where its larvae feed on rotting wood [53]. The other troglophilic dipteran in the cave, *S. leptogaster*, lives in subterranean habitats of the Palaearctic and its larvae spin slimy hanging threads [54].

Interestingly, among the trogloxenes, the findings of the psocodean *B. lucifuga* and the dipteran *Heleomyza serrata* (Linnaeus, 1758) (Figure 7O) in Resava Cave are the first records of these two species on the territory of Serbia.

The actual number of hexapods in Resava Cave is probably much higher, especially among the trogloxenes, as their presence in the cave may also be accidental.

4.5. Distribution of Ecological Groups of Terrestrial Arthropods in Resava Cave

As far as the distribution of troglobites is concerned, they inhabit completely dark parts of Resava Cave, especially in the lower level of the cave (less often in the upper level), where the presence of moisture in the substrate (especially with trickling water) and air has been noted. We observed them mainly in the lower level of the cave on the walls, on decaying pieces of wood, on the floor, on rocks and speleothems and under stones, while they were much less present in the upper level of the cave. Most troglophiles were observed inside the cave on less moist substrate than that inhabited by troglobites (under stones, on the limestone walls, in guano). *Troglophilus neglectus* was only found in the illuminated Entrance Hall, where part of the populations of *T. vulgaris* and *L. punctatus* were also detected. Trogloxenes are mainly found in the Entrance Hall (under stones, in the rubble and leaf litter, on the walls), the driest part of Resava Cave, but with the greatest food supply.

The large number of arthropod species recorded indicates that this cave is a very important refuge for fauna. The greatest biological richness of Resava Cave is the occurrence of endemic troglobitic species, two of which (*C. serbicus* and *S. kucajense*) are strictly protected in Serbia [55]. The populations of troglobites in the cave, although vulnerable, are present and stable throughout the year, which is confirmed by the fact that we found live individuals of all four troglobitic species during all six visits, which is particularly important for the monitoring and conservation of these species in their natural microhabitats in the cave. The occurrence of *C. serbicus* is significantly high in the cave, similar to that of the dipluran *P. christiani* and the millipede *S. kucajense*. The occurrence of *D. petrovici* is significantly lower than that of the other three troglobites in the cave, which is not unusual as the former species is a relatively large subterranean predator.

It is certain that the actual number of terrestrial arthropod species living in Resava Cave is higher than currently known, as some species are easier to overlook. These are rare species, those with smaller populations, species with shorter activity periods and those from isolated microhabitats. Therefore, it is necessary to continue the biospeleological studies in Resava Cave in the future to record such taxa. It is desirable to conduct surveys using other collection methods to determine the actual state of arthropod diversity in the cave (including the status and abundance of their populations).

As far as sampling is concerned, possible biases that may have affected the results (representativeness of the arthropod samples collected) could certainly be reduced by spatial and temporal improvements. Therefore, as many different microhabitats as possible should be investigated in the cave, which would probably lead to the collection of additional taxa, especially from the class Collembola. On the other hand, sampling in each month of the year, repeated several times in the following years, would certainly provide new information on the terrestrial fauna of the cave. In temperate caves, flooding and cold air infiltration in winter and early spring can disrupt the relatively constant physical conditions of the cave environment [56].

Like other habitats, caves also have their own trophic webs, but in caves they are simpler and functionally less complex than in epigean ecosystems due to the lower species richness [57]. The arthropod species found in Resava Cave are detritivores or predators. Detritivores such as springtails and millipedes play a very important role among the arthropods. They feed on bat droppings and decompose other organic matter that can enter the cave from surface habitats in various ways (from the soil, with plant roots, through sinking streams, with trogloxenic animals) [56]. The detritivores are eaten by predators such as spiders, harvestmen and pseudoscorpions. Centipedes and beetles are often the main predators in subterranean habitats.

In addition, it is necessary to focus future studies on other groups of invertebrates (roundworms, snails, annelids, etc.), which are also very important in the trophic webs of the cave and surrounding habitats.

4.6. Human Influence on Subterranean Biodiversity

As far as the impact of human activities on subterranean biodiversity is concerned, each cave is unique due to its morphological characteristics, its gate system and its management measures. The relative humidity, temperature, CO_2 concentration, artificial light, noise, etc. can be affected by tourist traffic. To assess the risks, a multi-year study of the terrestrial fauna of a cave should be carried out, focusing on the troglobites. The results from a cave in France show that tourism does not necessarily have a negative impact on the biodiversity of the cave [58]. The authors demonstrated that neither the number of specimens observed nor the species richness at the sampling sites had decreased as a result of tourist visits to the cave [58]. If human influence does not cause significant microclimatic changes and does not disturb the microhabitats of arthropods (suitable spaces such as rock crevices), the survival of cave-dwelling invertebrates is not at risk [58]. Despite the high vulnerability of cave-dwelling organisms, disturbance of cave habitats does not necessarily lead to a decline in species diversity if the disturbance is limited in terms of duration, intensity and spatial extent in relation to the size of the cave [58]. In a case study of four Romanian caves, some of them were found to maintain normal levels of relative humidity despite visits by tourists [59]. In the unventilated caves, however, the temperature and CO_2 concentration showed large fluctuations during the peak tourist season [59].

In the same study, the authors proposed several management measures for the sustainable use of show caves [59]. First, control of lighting is required through a combination of early removal of lampenflora and adjustment of lighting levels (both light intensity and duration). Another measure is continuous monitoring of CO_2 levels and occasional ventilation through the airlocks during the peak season in caves without a natural entrance. In caves where the hazard varies seasonally, seasonal changes in visitor management can be made, benefiting both the cave environment and the visitor health [59]. Finally, microbiological monitoring of surfaces should be routinely carried out to control pathogens introduced by visitors [59].

It is difficult to discuss the impact of adaptation to tourism on the biodiversity of Resava Cave, as there is no comparable data before the cave was commercially opened to visitors. However, we can state that the wildlife we encountered in the cave seems to survive relatively undisturbed despite the introduction of stairs and LED lights in the cave. It seems like a good idea to bring rotting pieces of wood into the cave and place them on the floor of the damp halls in the lower level of the cave to give the millipedes a better chance of survival (it should be ensured that the wood provided does not contain any animals). This potential conservation measure would be particularly important for the troglophilic *Trachysphaera* sp., which is always present in the cave, albeit in small numbers. The provision of additional wood as a food source would certainly strengthen its population in the cave. Another advantage of this measure would be the possibility to collect male specimens for the final identification of the species.

If there are no new anthropogenic changes, the current management does not seem to jeopardize the survival of the fauna in Resava Cave, which has already been demonstrated for other show caves in situ [58]. Of course, further studies on ecological impacts would provide much more information on the status and prospects of terrestrial arthropod populations in the cave. Certainly, conservation efforts should focus on the obligate cave dwellers—the troglobites.

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