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An updated checklist of Italian cave springtails (Collembola), with new records, species descriptions and DNA barcodes

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SUMMARY

Springtails (Collembola) are among the most abundant subterranean invertebrates, yet knowledge of their diversity in Italian caves remains incomplete. This study serves to update the Italian cave springtail checklist, which has been previously documented as containing 106 species. The updated checklist, which incorporates data from literature up to the year 2025, as well as the results of new field surveys conducted in northern Italy and DNA barcoding analyses, now lists 134 species. Among the recorded taxa, 38 are obligate cave-dwellers and 28 are endemic, with Onychiuridae being the most represented family. The following three new species are described: *Onychiuroides alpinus* n. sp., *Deuteraphorura venetiana* n. sp., and *Protaphorura baldanii* n. sp. These species are from Veneto and Lombardy. The analysis of data from ice caves has led to the conclusion that these environments serve as refugia for cold-adapted species. Furthermore, the data suggest the presence of a previously unrecognized shared Alpine–Pyrenean lineage. These findings underscore the rich and understudied subterranean biodiversity in Italy and highlight the importance of continued taxonomic and ecological research to inform conservation strategies for vulnerable cave ecosystems.

INTRODUCTION

Springtails are among the most abundant and widespread animals on Earth, occurring from Antarctica to the tropics (Rosenberg et al. 2023; Potapov et al. 2023). A considerable proportion of this group has adapted to hypogean environments-subterranean habitats such as

caves-where springtails are among the most diverse and abundant invertebrates (Juberthie 2000). It is noteworthy that, within the Hexapoda, springtails exhibit one of the highest proportions of troglobitic species, with 6.15% of described species considered obligate cave dwellers. These organisms often dominate terrestrial oligotrophic caves in terms of abundance (Deharveng and Bedos 2018). A significant number of species have been observed to be closely associated with guano deposits, where they constitute the dominant group after mites (Deharveng and Bedos 2012).

Hypogean springtails are typically distinguished by a lack of pigmentation and an absence of eyes. However, these traits alone are insufficient to reliably distinguish obligate cave-dwellers from other hypogean species inhabiting surface habitats (Dallai and Malatesta 1982; Deharveng and Bedos 2018; Lunghi et al. 2022). The presence of troglomorphic adaptations - such as elongated appendages, hypertrophy and multiplication of antennal sensilla, and modifications of the foot complex - or verified ecological preferences can be used to confidently indicate an obligate cave-dweller (Thibaud and Deharveng 1994; Kováč et al. 2016, 2023). However, troglomorphy is closely associated with the specific microhabitat conditions occupied by each subterranean species (Parimuchová et al. 2020), and thus not all troglobionts necessarily exhibit troglomorphic characteristics.

The first and, to date, only checklist of Italian cave springtails was compiled by Dallai and Malatesta (1982), reporting 106 species. Despite Italy being one of the most intensively explored karst regions in Europe, knowledge of its subterranean Collembola fauna remains fragmentary and outdated.

The aim of this study is to provide an updated checklist and database of cave-dwelling springtails in Italy, incorporating new records and describing three species new to science.

MATERIALS AND METHODS

Literature data and dataset organization

This update is based on data published up to February 2025. The nomenclature was updated according to the work of Bellinger et al. (2025), while the original nomenclature from Dallai and Malatesta (1982) is also reported where applicable. The inclusion of records was contingent upon their identification at the species or subspecies level; those identified solely at higher taxonomic levels were excluded. Distribution information was obtained from the original publications or group synopses, with references provided in the database. The available data on obligate cave dwellers was extrapolated from Fiera et al. (2021). For newly discovered species for which distribution and ecological information is lacking, those found exclusively in caves are considered obligate cave dwellers.

Specimen preparation and morphological analysis

This checklist also includes some new data from Northern Italy (Table 1).

Following the sorting process, the specimens were preserved in 96% ethanol and stored at 4°C. For slide preparation, individuals were immersed in a 10% KOH solution for clearing, then transferred to chloralphenol and permanently mounted in Swann medium, following the protocol described by Rusek (1975). Voucher specimens preserved in ethanol from the Sieson, Taccole and Valon caves are currently housed at the Museo Civico di Storia Naturale di Verona, Italy. Specimens from the Bergamo caves are housed at the Museo Civico di Scienze Naturali “Enrico Caffi” in Bergamo, Italy. Finally, specimens from the Scorluzzo cave are housed at the MUSE – Science Museum of Trento, Italy. The holotypes and paratypes of new species, as well as material examined for known species are lodged in the Senckenberg Museum of Natural Sciences in Görlitz – Germany (SMNG). Other specimens mounted

on slides from Siesone, Taccole and Valon cave are currently preserved at the Museo Civico di Storia Naturale di Verona in Italy. Other specimens mounted on slides from Bergamo caves are preserved in the Museo Civico di Scienze Naturali "Enrico Caffi" in Bergamo.

Morphological analyses were conducted using a Leica (Wetzlar, Germany) light microscope and species description and imaging were facilitated using a Nikon Eclipse Ci microscope equipped with phase contrast optics and a drawing tube. The species were identified by the author using keys reported in Gisin (1960), Bretfeld (1999), Potapov (2001), Thibaud et al. (2004), Pomorski (2006), Fiera and Weiner (2013), Parimuchová and Kováč (2016), Fanciulli (2018), and Skarżyński (2019).

Table 1. Italian caves for which new data are presented in this study along with collection data. Additionally, the existence of permanent ice within the cave has been documented, along with observations concerning the presence of additional organisms. The column "Ice" indicate the presence of permanent ice.

Cave name	Site	Province	Leg.	Det.	Sampling date	Sampling method	Coordinates (WGS84)	Ice	Notes
First World War artificial cave	Lombardy, Mount Scorluzzo, Stelvio Pass	Sondrio	Mauro Gobbi, Leonardo Latella	Barbara Valle	27.VII.2020	Subterranean Sampling Devices (SSD)	46°31'19.0"N 10°26'33.7"E	-	During the First World War it was inhabited by soldiers, then ice filled it. After 2020, ice was melted for studying the shelter.
Buso del Valon (438 V VR)	Veneto, Bosco Chiesanuova (site described by Petri et al, (2022)	Verona	Leonardo Latella	Barbara Valle	6.VII.2022, 16.IX.2022	Superficial Pitfall traps (in Petri et al. (2022), corresponding to traps ST1-ST3-ST5)	45°41'32.1"N 11°06'11.1"E	yes	In the same cave, the a study on seasonal abundance and spatio-temporal distribution of the troglophylic harvestman *Ischyropsalis ravasinii* (Petri et al. 2022)
1331LoBG Laga	Lombardy, Bergamo Prealps, Colli Ranica, Ponteranica	Bergamo	Gianni Comotti	Barbara Valle	23.V.2023	Pitfall traps	45°44'10.4"N 9°41'34.8"E	no	Associated fauna: *Boldoriella carminatii, Laemostenus insubricus, Troglohyphantes comottii*
Gallerie Mount Plagna, Presolana	Lombardy, Bergamo Prealps, Presolana	Bergamo	Gianni Comotti, Alda Baldan	Barbara Valle	29.III.2023	Pitfall traps	45°55'57.2"N 10°05'45.4"E	no	Associated fauna: *Allegrettia pedersolii, Boldoriella trezzii, Laemostenus insubricus, Ubychia leonardi,* Pselaphidae
Coren Bus Casazza (1489LoBG),	Lombardy, Bergamo Prealps,	Bergamo	Gianni Comotti	Barbara Valle	07.VI.2023	Pitfall traps	45°44'31.3"N 9°52'51.3"E	no	Associated fauna: *Allegrettia pavani rossii*, *Viallia mismae, Pavaniola comottii,* Araneae.
Pietre Coti ("sharpening stones") artificial cave	Lombardy, Bergamo Prealps, Berzo Grone	Bergamo	Gianni Comotti, Alda Baldan	Barbara Valle	19.IV.2023	Pitfall traps	45°43'25.5"N 9°54'39.4"E	no	Associated fauna: *Allegrettia pavani, Laemostenus insubricus. Troglophilus cavicola*

DNA barcoding

DNA barcoding was used as a complementary tool to morphology, when suitable material was available. In instances where feasible, DNA barcoding was conducted on specimens from the Veneto and Bergamo caves (Table 1). However, for certain species, suboptimal preservation conditions or the limited availability of specimens precluded this method. Whole genomic DNA was extracted from the whole individuals using the Wizard® SV Genomic DNA Purification System (Promega, Madison, WI, USA). The amplification of the cytochrome c oxidase subunit 1 (COI-5P fragment, cox1) was performed using the primers LCO1490 (5′ GGTCAACAAATCATAAAGATATTGG 3′; forward) and HCO2198 (5′ AAACTTCAGGGTGACCAAAAAATCA 3′; reverse) (Folmer et al. 1994). The mitochondrial ribosomal large subunit RNA (16S) was amplified using the primers LR-J-12887M (5′ CCGGTCTGAACTCAAATCATGT 3′; forward) and LR-N-13398M (5′ CGACTGTTTAACAAAAACAT 3′, reverse)

(Simon et al. 1994, modified after Zhang et al. 2015). The PCR reactions were carried out using AmpliTaq Gold™ 360 Master Mix in a total volume of 10 µL, including 2 µL of genomic DNA and 0.5 µL of each primer (10 µM). The thermal cycling profile comprised of an initial denaturation at 95°C for 5 minutes, followed by 35 cycles of denaturation at 95°C for 1 minute, annealing at 50°C for 1 minute, and extension at 72°C for 90 seconds, with a final extension at 72°C for 7 minutes (Valle et al. 2025). The purification of PCR products were accomplished through the utilization of the Wizard® SV Gel and PCR Clean-Up System (Promega, Madison, WI, USA). Subsequent to this purification step, bidirectional sequencing was performed using a 3730xl DNA Analyzer (Applied Biosystems™) at BMR Genomics (Padova, Italy). The assembly and editing of the sequence were conducted using the Benchling platform (2024). The final curated sequences were submitted to BOLD (Ratnasingham and Hebert 2007) as part of the "ITCAV" project ("ITCAV Checklist of the Italian Cave Collembola"). The sample identification codes are reported in Table S1 of the Supplementary Material.

Dataset organization and information

The dataset is available as a Supplementary file of this paper (Table S1).

The initial column presents the taxon name (species), with and asterisk indicating new records for Italian Fauna (with respect to the last update reported in Dallai et al. 1995), accompanied by the authorship. The ensuing two columns presen the family and the genus of each species, respectively. The fourth column reports nomenclatural reference to the first checklist of Italian cave springtails by Dallai and Malatesta (1982), if present. The fifth column indicates the troglobiont status of a species (*), while the sixth column reports endemic (e) and subendemic (se) species. The seventh column delineates the distribution range, while the eighth column provides references related to distribution. The ninth column indicates whether the data are novel and have not been previously published, and it provides the sampling site. The subsequent column delineates the sample ID of barcoded specimens, which have been uploaded within the "ITCAV" project on the BOLD System. The final column presents references to reports from Italian caves exclusively for species with a European or more limited distribution).

The dataset is entitled: Checklist_of_the_Italian_Cave_Collembola.

Dataset citation: the citation of this paper.

Nomenclatural Acts

The new names contained in this article are available under the International Code of Zoological Nomenclature. This work and the nomenclatural acts it contains have been registered in ZooBank. Zoobank Life Science Identifier (LSID) for this publication is: urn:lsid:zoobank.org:pub:7C5FF94B-EA73-4F0F-8A49-5501BA3535AE. The LSID registration and any associated information can be viewed in a web browser by adding the LSID to the prefix 'https://zoobank.org/'.

RESULTS

Several taxa reported in this study represent different levels of taxonomic and faunistic novelty. Three species are described here as new to science, namely *Onychiuroides alpinus* n. sp., *Deuteraphorura venetiana* n. sp. and *Protaphorura baldanii* n. sp.

In Italy, 134 species have been documented within caves (Table 2; Supplementary Table S1). Among these, 38 (28 %) could be identified as obligate cave dwellers, 28 (21 %) as endemic and 5 (4 %) as subendemic. The family with the most species found in caves is Onychiuridae (39 species, 21 of which are obligate cave dwellers), followed by Hypogastruridae (22 species, three of which are obligate cave dwellers) and Isotomidae (20 species, one of which is an obligate cave dwellers). The dominant genus is

Deuteraphorura (16 species), followed by *Pseudosinella* (8 species) and *Ceratophysella* (7 species).

In addition, a number of species are reported with detailed morphological notes, as they show relevant differences from their nominal taxa and require further taxonomic investigation (Table 1). The following taxa are particularly noteworthy: *Folsomia* cf. *nigrimaculata* Najt, 1981 and *Orchesella* cf. *semitaeniata* Latzel, 1917 from Veneto, Bus delle Taccole, Verona Province; *Desoria* cf. *fjellbergi* (Najt, 1981) from Veneto, Caverna del Sieson, Vicenza Province; *Ceratophysella macrocantha* Stach, 1946, *Desoria duodecimoculata* Denis, 1927, *Deutheraphorura* cf. *imperfecta* and *Orchesella* cf. *alticola* Stach, 1960 from Veneto, Buso del Valon, Verona Province; *Onychiuroides granulosus* (Stach, 1930) from Lombardy, Bergamo Province, Coren Bus Casazza, 1489LoBG. For other species found, remarks are provided about the specimens analyzed.

For several species, molecular data (cox1 and/or 16S) were obtained, when suitable material and DNA quality were available, providing complementary support to morphological identification and implementing online libraries of cave fauna. Barcode data were generated in particular for taxa collected from Veneto and Bergamo caves (Table 1). In particular, 12 species were barcoded (cox1 was provided for nine species, 16S for 11 species).

Table 2. Number of Italian cave springtails species within each Family and totally, with absolute and relative frequency of troglobiont and endemic and subendemic species in each family (the percentages are calculated considering only Italian cave springtail species)

Family	N° of species	N° of troglobiont species	% of troglobionts in the family	% of troglobiont with respect to other families	N° of endemic-subendemic species	% of endemics-subdendemics in the family	% of endemic with respect to other families
Poduridae	1	0	0	0	0	0	0
Hypogastruridae	22	3	14	8	3	14	9
Onychiuridae	39	21	54	55	18	46	55
Neanuridae	6	0	0	0	0	0	0
Odontellidae	1	0	0	0	0	0	0
Isotomidae	20	1	5	3	1	5	3
Entomobrydae	1	0	0	0	0	0	0
Orchesellidae	7	2	29	5	2	29	6
Paronellidae	17	6	35	16	5	29	15
Tomoceridae	5	1	20	3	1	20	3
Oncopoduridae	1	0	0	0	0	0	0
Neelidae	2	0	0	0	0	0	0
Arrhopalitidae	6	3	50	8	2	33	6
Sminthuridae	5	1	20	3	1	20	3
Dicyrtomidae	1	0	0	0	0	0	0
Total	134	38			33		

Description of three new species and morphological notes on other taxa

Nomenclatural abbreviations: Abd = abdominal segment; Ant = antennal segment; ms-setae = micro s-setae; PAO = postantennal organ; Th = thoracic segment; sens = sensilla; Tita = tibiotarsus; VT = ventral tube.

Onychiuroides alpinus n. sp. - Figures 1a-d-g-k-m

Synonyms: "*Onychiuroides* sp. n." in Latella and Brighenti (2024).

Material examined: ITALY, "Caverna del Sieson" (Sieson cave), Vicenza province, Northern Italy (45°53'39.7" N, 11°23'19.3" E); 4.VI-13.XI.2022, pitfall traps, leg. Latella L, det. Valle B. Type material from the same locality: female holotype on slide; 9 paratypes on slides. Types are preserved in the collection of Senckenberg Museum of Natural Sciences, Görlitz (SMNG; holotype code SMNG-APT-AA04673; paratype codes SMNG-APT-AA04674 to SMNG-APT-AA04682), and other material is at the Natural History Museum of Verona (Italy). BOLD sample IDs: OSI2, OSI3, and OSI4 (cox1 and 16S).

Diagnosis: *O. alpinus* n. sp. exhibits feature typical of the genus, such as three pseudocelli arranged in a triangle pattern on the posterior side of the cephalic region, the presence of the ms-sens on Ant. IV at approximately half the length, and the presence of morel-like sensilla on Ant. III organ (according to Pomorski 2006). It differs from all *Onychiuroides* species in that it has 2 + 2 (rather than 1+1) pseudocelli on the Th. II (Pomorski 2006). It is also characterized by the presence of 2,2,1,2, ventral pseudocelli on the abdomen.

Description: Body length: 2.8–3-6 mm (including antennae). Color in alcohol white. Abd. V-VI fused dorsally. Anal spines are absent. Granulation is uniform, and the antennal base is not marked by granulation. The subapical organite is typical, and is not guarded by integumentary papillae. The antennal III sense organ consists of 5 papillae, 2 sensory rods, 2 morel-like sensory clubs, 5 guard setae (Fig. 1k), and one ms in a ventro-lateral position at its base. The ms-sens on Ant. IV is about half the length of the antennomerous. The PAO has 11-13 finely granulated vesicles, that are 0.6 times as long as the nearest pseudocellus (Fig. 1d). The bases of the vesicles do not touch each other. The basomedial field of the labium has 4 + 4 setae, and the basolateral field has 6 setae, 5-6 + 5-6 postlabial setae along the ventral groove. The maxillary outer lobe lacks a basal seta. The labial palp is of type 0 according to Fjellberg (1999) with 6 proximal setae. The mandibles has a strong molar plate and four apical teeth. The head of the maxilla has two elongated lamellae (about 1.2 times as long as the length of the maxillary head). The dorsal chaetotaxy is differentiated into gradually tapered and apically pointed mesosetae and microsetae. The dorsal macrosetae are weakly differentiated and are mainly visible on Abd. V-VI. The M/s ratio is approximately 2 on Abd. V. On Abd. I seta m1 is a micrososeta.

The dorsal chatotaxy is as shown in Fig. 1a. The thoracic sternites are without setae. The tibiotarsi has 11 apical setae (Fig. 1g). The VT has 21-23 + 21-23 lateral/basal setae. The claw has no distinct tooth (Fig. 1g). The empodial appendage is usually shorter than the claw, though sometimes it is almost as long. It lacks a basal lamella. The male ventral organ is absent. The pseudocellar formula dorsally: 3,3/2,4,4/4,4,4,3,3 (Fig. 1a); ventrally: 2/0,0,0/2,2,1,2. The formula of the pseudocelli on subcoxa 1: 2/2/2. The dorsal cephalic pseudocelli are arranged in a triangle (according to Pomorski, 2006). The ventral chaetotaxy of the furcal area is as shown in Fig. 1m.

Etymology: The new species was named for its geographical distribution, it was first described in an Alpine cave.

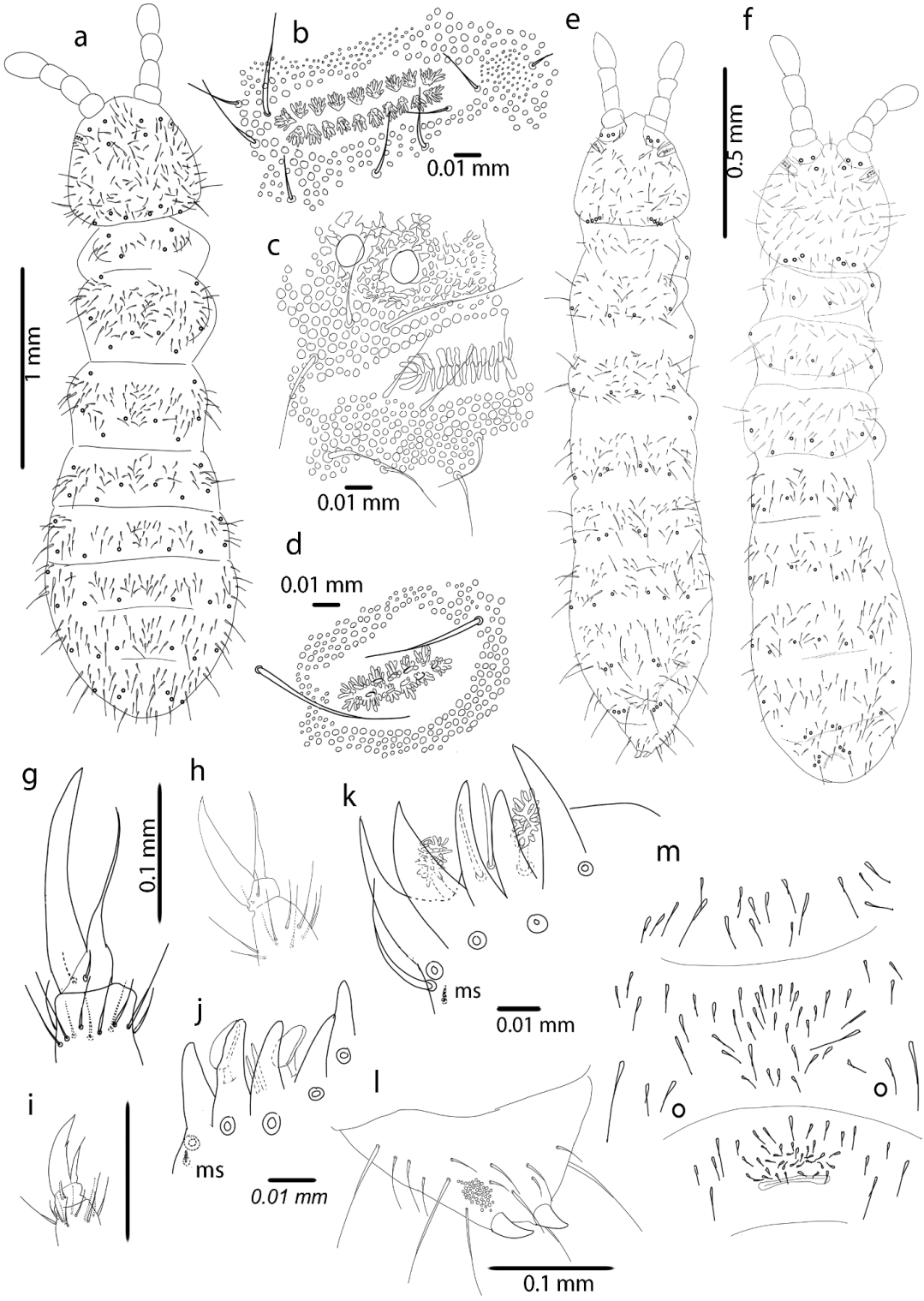

Figure 1. Diagnostic characteristic of the three new species described, *Onychiuroides alpinus* n. sp., *Deutheraphorura venetiana* n. sp., *Protaphorura baldanii* n. sp.: a) *Onychiuroides alpinus* n. sp. dorsal chaetotaxy and pseudocelli (Holotype); b) *Deutheraphorura venetiana* n. sp. postantennal organ; c) *Protaphorura baldanii* n. sp. postantennal organ; d) *O. alpinus* n. sp. postantennal organ; e) *P. baldanii* n. sp. dorsal chaetotaxy and pseudocelli; f) *D. venetiana* n. sp. dorsal chaetotaxy and pseudocelli; g) *O. alpinus* n. sp claw; h) *D. venetiana* n. sp. claw; i) *P. baldanii* n. sp. claw; j) *D. venetiana* n. sp. Ant. III Organ; k) *O. alpinus* n. sp. Ant. III Organ; l) *P. baldanii* n. sp. anal spines and Abd. VI chaetotaxy; m) *O. alpinus* n. sp. ventral chaetotaxy of furcal area and genital opening.

Distribution and ecology: The species is known from the Sieson cave in Italy's European Alps (Vicenza Province; Latella and Brighenti 2024), and is therefore considered a troglobiont. It was found in an ice cave (see Latella and Brighenti 2024 for more information).

Morphological remarks: the new species belong to *Onychiuroides* Bagnall, 1948 for the absence of anal spines, head and terga with typical 3-4 pseudocelli, body feebly plurichaetotic, tibiotarsi with 11 distal pointed setae, the three pseudocelli arranged in a triangle pattern on the posterior side of the cephalic region, the ms-sens on Ant. IV at approximately half the length, and the presence of morel-like sensilla on Ant. III organ (according to Pomorski 2006). It differs from all *Onychiuroides* species in that it has 2 + 2 (rather than 1+1) pseudocelli on the Th. II (Pomorski 2006). It is also characterized by the presence of 2,2,1,2, ventral pseudocelli on the abdomen.

***Deuteraphorura venetiana* n. sp. - Figures 1b-f-j-h**

Synonyms: "*Deuteraphorura* sp. n." in Latella and Brighenti (2024).

Material examined: ITALY, Veneto, Verona province, "Bus delle Taccole"/Taccole cave (45°42'38.2" N, 10°39'31.7" E, 1,820 m a.s.l); 12.VII - 4.IX.2020, pitfall traps; leg. Latella L, det. Valle B (Latella and Brighenti 2024). The type material from the same locality includes a female holotype and 7 paratypes on slides. The types are preserved in the collection of the Senckenberg Museum of Natural Sciences in Görlitz (SMNG; holotype code SMNG-APT-AA04683; paratype codes SMNG-APT-AA04684 to SMNG-APT-AA04690), and other material is at the Museo Civico di Storia Naturale di Verona in Italy. BOLD sample IDs: DTA5 and DTA6 (16S).

Diagnosis: Taking into account the geographic distribution and the pseudocellar formula, the closest species is *D. eduardi* (following Fanciulli et al. 2018), which differs in that it has only 2+2 posterior pseudocelli on the head (rather than 3+3, as in in *D. venetiana* n. sp.) and 3+3 on the Abd. V (rather than 4+4), and by the presence of the male organ on the abdomen.

Description: The average length is 2.2-2.6 mm The body is cylindrical with fine, non-uniform cuticle granulation (coarser near the pseudocelli). Anal spines are absent. Colour in alcohol white. The area antennalis is clearly marked. Ant. IV has an apical organite and one ms at its base in a ventro-lateral position. Sensilla on Ant. IV are not clearly distinguishable from ordinary setae. Ant. III organ consists of two sensory organs, two sensory rods, five papillae and five guard setae and a lateral ms (below the level of the last guard seta of Ant. III Organ (Fig. 1j). The PAO consists of approximately 18 compound vesicles arranged in two parallel rows (Fig. 1b), that are about as long as the nearest pseudocellus. The basomedial field of the labium has 4 + 4 setae; the basolateral field has five setae, and there are 4+4 postlabial setae along the ventral groove. The maxillary outer lobe has one basal seta. The labial palp is of the AB type, according to Fjellberg (1999) with six proximal sete. The mandibles have a strong molar plate and four apical teeth. The VT has 6 + 6 abdominal lateral setae, and lacks a basal chaeta. The body setae are weakly differentiated into micro-, meso- and macrosetae. The M/s ratio is approximately 2 on Abd. V. Dorsal cephalic chaeta d0 is present. Abd. IV has p0 chaeta between the posterior, medial pseudocelli. The thoracic sterna lack ventral setae. The tibiotarsi have nine apical setae (Fig. 1h). The claw is without an inner tooth (Fig. 1h) and the slender empodial appendage is without an inner basal lamella and reaches 9/10 of the inner edge of the claw. The pseudocelli formula dorsally: 3,3/1,3,3/3,3,3,4,4; ventrally: 2/0,0,0/1,2,1,2 (Fig. 1f); Subcoxae have one pseudocellus each.

Etymology: The new species' name is derived from its geographical distribution. It was first described in a cave from the Veneto region.

Distribution and ecology: The species is known from the Taccole Cave in the Italian Alps (Verona Province), thus it is considered a troglobiont (Latella and Brighenti 2024). It was found in an ice cave (see Latella and Brighenti (2024) for more information).

Morphological remarks: the new species belongs to *Deuteraphorura* Absolon, 1901 for the absence of anal spines, Ant. III Organ with 5 papilla and bent sensory clubs, numerous (>8) compound vescicles of PAO, the presence of nine apical setae on tibiotarsi, the furca reduced to finely granulated area and for the presence of seta d0 on the head. The closest species is *D. eduardi* (following Fanciulli et al. 2018), according to the geographic distribution and the pseudocellar formula (in particular by having 1 +1 dorsal pseudocelli on Th. I) but differs in that it has only 2+2 posterior pseudocelli on the head (rather than 3+3, as in in *D. venetiana* n. sp.) and 3+3 on the Abd. V (rather than 4+4), and by the presence of the male organ on the abdomen. Among the species reported for Italy, other species characterized by having 1+1 dorsal pseudocelli on Th. I differ from *D. venetiana* n. sp. for other important characteristics (following Fanciulli et al. 2018), like the ventral sensillar formula (*D. silvaria* and *D. pseudoinsubraria*), or the number of dorsal pseudocelli on Abd. V (*D. bergamaria*, *D. defensaria*, *D. cebennaria*, *D. imperfecta*, *D. dunaria*).

***Protaphorura baldanii* n. sp. - Figures 1c-e-i-l**

Material examined: ITALY, Lombardy, Bergamo Prealps, Presolana, Gallerie Mount Plagna (45°55'57.2"N, 10°05'45.4"E), 29.III.2023. Pitfall traps yielded only one specimen, which was mounted on a slide, leg. Comotti G. Baldan A., det. Valle B.. Type material from the same locality: subadult female holotype on a slide; preserved in the collection of the Senckenberg Museum of Natural Sciences in Görlitz (SMNG; holotype code SMNG-APT-AA04691).

Diagnosis: *P. baldanii* n. sp. is characterized by having 4+4 pseudocelli dorsally at the posterior side of the head, which is not a common feature among the known *Protaphorura* species reported in Parimuchová and Kováč (2016). The same dorsal pseudocellar formula is reported in the *P. pseudoglebata* Arbea and Jordana, 1989, described for Spain, which, unlike *P. baldanii* has ventral pseudocelli on the head.

Description: Body length: 2.1 mm (females). The body shape is typical for the genus and has anal spines on distinct papillae. Colour white in alcohol. The granulation is distinct and coarse, especially on the head. There are up to 18 granules between the p1 chaetae on the hind margin of the head. The antennae are almost as long as the head, and the area antennalis is clearly marked. Ant. I has 9-16 setae. Ant. III Organ has 5 guard setae, 5 papillae, 2 smooth sensory rods that are shorter than the papillae and 2 morel-like sensory clubs.The ms is in a ventro-lateral position at level of the last guard chaeta. The subapical organite of Ant. IV is placed in an unprotected cavity. Ms on Ant. IV is in a lateral positionat approximately 1/3 of the segment length measured from the base. The PAO has 32 simple vesicles (Fig. 1c). The basomedian field of the labium has 4+4 chaetae, 5+5 postlabial setae in a symmetrical arrangement. The maxillary outer lobe has a simple palp with 1 basal seta. Pseudocellar formula dorsally: 3,4/0,2,2/3,3,3,3,3 (Fig. 1e); ventrally: 0/0,0,0/0,0,0,0. Subcoxae I–III have 1 pseudocellus each. The ventral parapseudocelli are not visible, subcoxae have 1 parapseudocellus each. Th. I-II-III ventrally have 1-2-2 setae, respectively on each side of the medial part. Dorsal chaetotaxy is plurichaetotic. Seta d0 on the head is absent. Th. I is variable, with 9-10 setae per half side of the tergum The dorsal chaetotaxy is as shown in Fig. 1e. The ratio of setae M./s on Abd. V is 3/1. The anal spines and prespinal setae are as shown in Fig. 1l. The furca remnant has a distinct arched cuticular fold with two rows of chaetae (one row placed on the fold and one row posterior to the fold). The VT has 9-10 + 9-10 distal and 1+1

basal chaetae on each side. The tibia of all legs has 11 chaetae in the distal circle. The claw has no lateral teeth and has an inner tooth midway along its length (Fig. 1i).

Etymology: The new species name is derived from the name of one of the speleologist who discovered it: Alda Baldan.

Distribution and ecology: The species is known from the Gallerie Mount Plagna – Presolana, caves in Italy's, European Alps, specifically in Bergamo Province, and is therefore considered a troglobiont.

Morphological remarks: the new species found belongs to *Protaphorura* Absolon, 1901 for the presence of anal spines, of posterior cephalic pseudocelli and of lateral pseudocelli on the body, a vestigial furca, for the presence of numerous, simple vescicles of PAO and for the absence of seta d0 on the head. P. baldanii n. sp. is characterized by having 4+4 pseudocelli dorsally at the posterior side of the head, which is not a common feature among the known Protaphorura species reported in Parimuchová and Kováč (2016). *Protaphorura baldanii* n. sp. is morphologically close to *P. pseudoglebata* Arbea and Jordana, 1989, described for Spain, for having the same dorsal sensillar formula, but *P. pseudoglebata* has ventral pseudocelli on the head. Following the key reported in Parimuchová and Kováč (2016), species similar to *P. baldanii* are *P. edentata* (Kos, 1939) and *P. zlatiborensis* Lucić, Čurcić, Pavković-Lučić & Tomić, 2008, respectively from Julian Alps and Serbia, since they also lack ventral pseudocelli on the head. However, *P. edentata* differs for having Ant. III Organ with only four papillae and a different sensillar formula (33/022/23343), while *P. zlatiborensis* differs for claws distinctly elongated and dorsal pso according to the followin formula: 32/022/22223.

Ceratophysella gibbosa (Bagnall, 1940)

Material examined: ITALY, Lombardy, Bergamo Province, Bergamo Prealps, Colli Ranica, Ponteranica, 1331LoBG Laga (45°44'10.4" N, 9°41'34.8" E), 23.V.2023, pitfall traps, many individuals collected (leg. Comotti G, det. Valle B). BOLD sample IDs: CPO1, CPO2, and CPO3 (cox1). The alcohol and slide specimens are preserved at the Museo Civico di Scienze Naturali "Enrico Caffi" in Bergamo, Italy.

Both morphology and genetics were compared with sequences available online. The comparison was done using DNA alignment on BLASTIN. This confirmed the identification.

Ceratophysella macrocantha Stach, 1946

Synonyms: "*Ceratophysella* cf. *macrocantha*" in Latella and Brighenti (2024).

Material examined: ITALY, Veneto, Verona province, "Buso del Valon"/Valon cave (438 V VR; 45° 41' 32.26" N, 11° 06' 11.10" E); 6.VII.2022, pitfall traps (leg. Latella L., det. Valle B.); only one specimen. – ITALY, Veneto, Verona province, "Bus delle Taccole"/Taccole cave, (45° 42' 38.2" N, 10° 39' 31.7" E, 1820 m a.s.l), 12.VII - 4.IX.2020, pitfall trap, many specimens (leg. Latella L., det. Valle B. (Latella and Brighenti 2024). BOLD sample IDs (specimens from Taccole): CMA5 and CMA6 (16S) from Taccole cave. The alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

Ceratophysella macrocantha belongs to the *armata*-group and can be easily distinguishable for its empodium, which is as long as the claw and does not split into branches, as well as by its mucro, which has a small lamella (not spoon-like). Other notable characteristics are the apical vescicles on Antennomerous IV, which is tripartite. The chaetotaxy of examined samples also reflects the redescription of *C. macrocantha* by Skarzynski (2019). The seta p3 is absent on the abdominal tergum IV. The thoracic tergum II has setae m3 and m4. Seta a2 is similar to a3. Seta p1 on the abdominal tergum IV is developed as macrosetae. Seta p2 is developed as microsetae. Setae p3 is absent. Additional seta m2 is present.

The abdominal tergum V has long a-setae. Setae p2 are present. Morphologically, the PAO is particularly large (almost 3 times the length of the nearest OMMA), and the pigmentation is not uniform, but rather speckled with white spots, suggesting populations adapted to a cave habitat. The larger PAO and the shorter Anal spines with respect to *C. macrocantha* (see Skarzynski, (2019)) could suggest it is a separate species.

***Cribrochiurus subcribrosus* (Gisin, 1957)**

Material examined: ITALY, Lombardy, Bergamo Province, Bergamo Prealps, Presolana, Gallerie Mount Plagna (45°55'57.2"N, 10°05'45.4"E), 29.III.2023, pitfall traps, eight individuals collected (leg. Comotti G. Baldan A.; det Valle B.). BOLD sample IDs: OPL2 and OPL4 (cox1 and 16s). The head of OPL4 is mounted on a slide. The alcohol and slide specimens are preserved at the Museo Civico di Scienze Naturali "Enrico Caffi" in Bergamo (Italy).

Samples of *Cribrochiurus subcribrosus* are characterized by the absence of PAO and the presence of numerous pseudocelli on the tergites (including those on the posterior part of the head and in lateral position on the body).

***Deutheraphorura* cf. *imperfecta* (Denis, 1938)**

Material examined: ITALY, Veneto, Verona Province, "Buso del Valon"/Valon cave (438 V VR; 45° 41' 32.26" N, 11° 06' 11.10"E); 16.IX.2022, pitfall traps, leg. Latella L., det. Valle B. Only 5 specimens were found. They were mounted on slides and preserved at the Museo Civico di Storia Naturale di Verona (Italy).

The italian specimens analyzed from the "Buso del Valon" exhibit 2+2 ventral pseudocelli on the head, rather than 3+3 reported by Fanciulli et al. (2018) and Parimuchová and Kováč (2016). This corroborates Denis' (1938) observations on Italian specimens from the Veneto region, contrasting with those from Switzerland, which present 3+3), as documented by Gisin (1960). The dorsal pseudocellar formula observed is: 3,2/1,3,3/3,3,3(4),5,4; the ventral pseudocellar formula was observed as: 2/0(1?),1,1/2,2,1,2.

***Desoria* cf. *fjellbergi* (Najt, 1981)**

Synonyms: "*Desoria* n. sp." in Latella and Brighenti (2024).

Material examined: ITALY, Veneto, Vicenza Province, "Caverna del Sieson"/Sieson cave (45° 53' 39.7" N, 11° 23' 19.3"E); 4.VI-13.XI.2022, pitfall traps, leg. Latella L., det. Valle B. (Latella and Brighenti 2024). BOLD sample IDs: DFJ1, DFJ2, and DFJ3 (cox1 and 16S). The alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

The Italian specimens from "Caverna del Sieson", already reported in Latella and Brighenti (2024) and identified by the author, presents some differences from the nominal species described in the Pyrenees. These differences include: length (2 mm versus 0.9-1.3 mm reportedby Najt (1981)), the number of posterior setae on dens (17-23 versus 11 reported by Najt (1981)), and the number of setae on VT (4+4 anterior, 4+4 lateral, and 8 posterior). Additionally, Abd. V-VI are clearly separated whereas they are partly fused according to Najt (1981). A peculiar feature of *Desoria fjellberg*i is the elongated lamellae of the maxilla, which are visible in the Sieson samples. The Italian specimens are likely a differentiated population or a new species related to *D. fjellbergi* (Najt, 1981), and warrant further analysis.

***Desoria duodecimoculata* Denis, 1927 - Fig. 2d**

Material examined: ITALY, Veneto, Verona Province, "Buso del Valon"/Valon Cave (438 V VR; 45° 41' 32.26" N, 11° 06' 11.10"E); 6.VII.2022 and 16.IX.2022 (leg. Latella L., det. Valle B.). BOLD sample IDs: DVA1ITCAV, DVA2ITCAV, and DVA3ITCAV (16S).

Alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

The analysed specimens exhibit uniform dark pigmentation and white appendages. They have a quadridentate mucro without seta and the apical tooth is very small and difficult to see.The apical seta on the dens is 2-2.5 times the length of the mucro. The VT has 7 posterior, 1+1 anterior and 4+4 laterodistal setae. Tita has pointed tenent hairs. The mouth has a bifurcated maxillary palp and 4 proximal and 4 basomedian setae. Considering OMMA, G and H, if present, are not visible. On Ant. IV, there is a bifurcated pin-like seta and a medium-sized, globular, subapical, depressed sens. The specimens correspond to *D. duodecimoculata*, which belongs to the *D. nivalis* complex, for each analyzed characteristic. However, they do not correspond to the number of posterior setae on dens, which were originally described as 8 (Potapov, 2001) and range from 10 to 14 in specimens analysed for this work.

Folsomia cf. *nigrimaculata* Najt, 1981

Synonyms: "*Folsomia nigrimaculata* Najt, 1981" in Latella and Brighenti (2024).

Material examined: ITALY, Veneto, Verona Province, "Bus delle Taccole"/Taccole Cave (45° 42' 38.2" N, 10° 39' 31.7" E, 1820 m a.s.l); 12.VII - 4.IX.2020, pitfall traps, leg. Latella L., det. Valle B. (reported in Latella and Brighenti, 2024). Only one specimen was found and mounted on a slide, and preserved at the Museo Civico di Storia Naturale di Verona (Italy).

According to the species description in Potapov (2001), the single Italian sample from "Bus delle Taccole" has a mucro with two dens, 1+1 anterior and 16+16 posterior setae on Man, 2+2 OMMA, one spherical sens on Abd V, 3 posterior setae (not clearly visible) and 6 anterior setae on the dens. It differs from the nominal species in that it has only 3 posterior setae on dens, whereas *F. nigromaculata* should have 5. Further analysis of the Italian population is warranted.

Isotomurus alticolus (Carl, 1899) - Fig. 2c

Material examined: ITALY, Veneto, Verona province, "Buso del Valon"/Valon Cave (438 V VR; 45° 41' 32.26" N, 11° 06' 11.10" E); 6.VII.2022 and 16.IX.2022 (leg. Latella L., det. Valle B.). BOLD sample IDs: IVA2, and IVA3 (cox1 and 16S). Alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

Identification was performed according to Potapov (2001). The claws are very long and slender, ratio with a length/width ratio of 8:2. The mucro is straight with a seta. and the pigment correspond to the description of *I. alticolus* in caves by Deharveng (2008).

Kalaphorura paradoxa (Schäffer, 1900)

Material examined: ITALY, Veneto, Verona Province, "Buso del Valon"/Valon cave (438 V VR; 45° 41' 32.26" N, 11° 06' 11.10"); 6.VII.2022 and 16.IX.2022, pitfall traps, two individuals mounted on slide (leg. Latella L., det. Valle B.). ITALY, Veneto, Verona Province, "Bus delle Taccole"/Taccole cave (45° 42' 38.2" N, 10° 39' 31.7" E, 1820 m a.s.l), 12.VII - 4.IX.2020, pitfall traps, twenty specimens collected (leg. Latella L., det. Valle B. Samples from "Buso delle Taccole" belong to those reported in Latella and Brighenti (2024), but were likely not reported due to an error. The specimens in alcohol and mounted on slides are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

Some important characteristics are reported here. Pseudocellar dorsal formula: 2,0/0,1,1/1,1,1,2,2. The third abdominal tergum has submedial pseudocelli. The furca is reduced to knobs with some setae. The anterior cephalic pseudocelli are located inside the antennal area. There are two medial setae on Abd VI. According to Fiera and Weiner (2013), it corresponds to *K. paradoxa* for the position of the a0 seta on Abd VI.

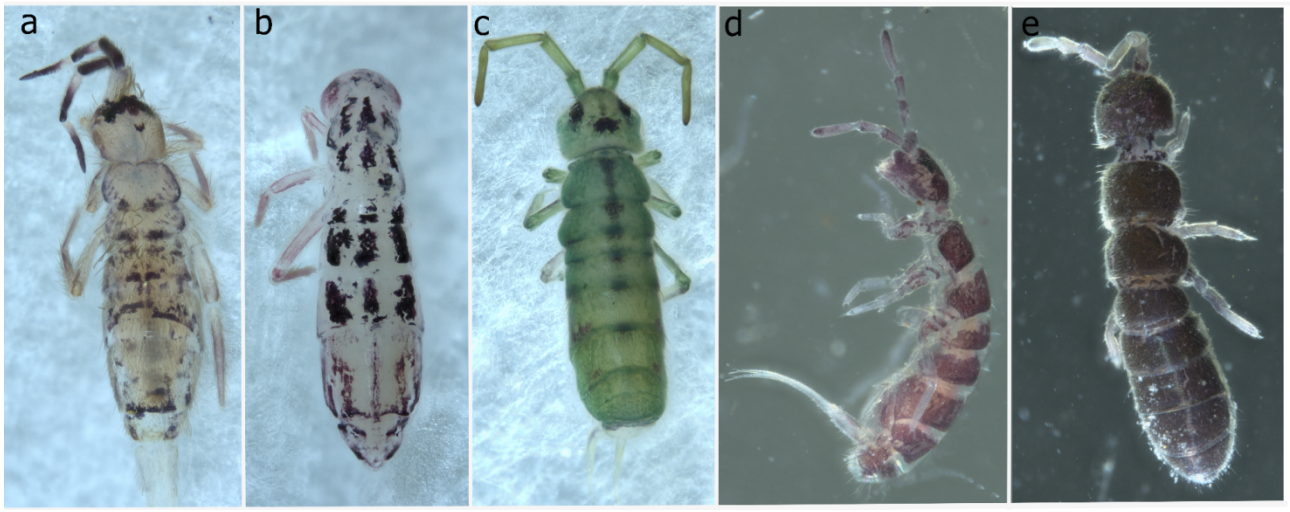

Figure 2. Pigmentation patterns of a) *Orchesella* cf. *alticola*, b) *Orchesella* cf. *semitaeniata*, c) *Isotomurus alticolus*, d) *Desoria duodecimoculata* and e) *Desoria* cf. *fjellbergi*, analysed in this work. Since the specimens were collected using pitfall traps, the pigmentation is damaged, particularly in the *Orchesella* spp. and *D. duodecimoculata*.

***Onychiuroides granulosus* (Stach, 1930)**

Material examined: ITALY, Lombardy, Bergamo Province, Coren Bus Casazza (1489LoBG; 45° 44' 31.3" N, 9° 52' 51.3" E). 7.VI.2023, pitfall trap, leg. G. Comotti. ITALY, Lombardy, Bergamo Province, Berzo Grone, Pietre Coti ("sharpening stones") artificial cave (Pietre Coti ("sharpening stones") artificial cave (45°43'25.5"N 9°54'39.4"E), 19.IV.2023, Pitfall traps, Leg. Comotti G., Baldan A., det. Valle B. BOLD sample IDs: OCO2 and 3 (cox1 and 16S) (From Berzo Grone) and CAS2ITCAV (16S) (from Coren Bus Casazza).

Our samples from Coren Bus Casazza have 5 setae on each side of the Th I. Those from Berzo Grone have 4. In Pomorski (2006), 6-7 setae are reported for the Polish samples. Both populations investigated have 1+12 setae per side on the VT, not 1+8 as reported in Pomorski (2006). Additionally, our samples from Coren Bus Casazza have 9 compound vesicles on PAO, not 10-11 as reported in Pomorski (2006). Other characteristics match those reported in Pomorski (2006): the dorsal pseudocellar formula (33/133/3333), head ventrally with 1+1 pseudocelli, the tita with 11 apical setae, the body plurichaetotic, and the presence of seta d0 on the head.Ant. III Organ with five papillae and ms on Ant. IV is in the first half of the antennomerous.

***Orchesella* cf. *alticola* Stach, 1960 and *Orchesella* cf. *semitaeniata* Latzel, 1917 - Figs. 2a,b**

Material examined: for *Orchesella* cf. *alticola* – ITALY: Veneto, Verona province, "Buso del Valon"/Valon cave (438 V VR; 45°41'32.26" N, 11°06'11.10"E); 6.VII.2022, pitfall traps (leg. Latella L., det. Valle B.). Only one specimen was foundand used for genetic analysis. Bold sample IDs: OVA1 (cox1 and 16S). For *Orchesella* cf. *semitaeniata* – ITALY, Veneto, Verona Province, "Bus delle Taccole"/Taccole Cave (45°42'38.2" N, 10°39'31.7" E, 1820 m a.s.l); 12.VII - 4.IX.2020, MSS traps, leg. Latella L., det. Valle B. (linked to Latella and Brighenti (2024) sampling, but not reported there, due to an error). BOLD sample IDs: OTA1 and OTA2 (cox1 and 16S). 20 specimens were found in poor conditions. The alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

The few samples collected were in poor condition, so identification is only indicative and based on pigmentation and keys reported in

Gisin (1960). The pigmentation pattern of *O.* cf. *semitaeniata* seems especially characteristic (like the nominal species, but with pigmentation on Abd IV, whereas in *O. semitaeniata* it is unpigmented). A picture of the pigmentation pattern is provided for both species (Fig. 2). Although *O. semitaeniata* was collected with other species reported in Latella and Brighenti (2024), this species was not mentioned in that publication, likely due to a typo.

***Protaphorura fimata* (Gisin, 1952) *sensu* Pomorski (1998)**

Material examined: ITALY, Italy: Lombardy, Bergamo Province, Bergamo Prealps, Berzo Grone, Pietre Coti Cave ("Sharpening Stones") 45°43'25.5"N, 9°54'39.4"E, 19.IV.2023, pitfall traps (Leg. Comotti G., Baldan A., Det. Valle B.). BOLD sample IDs: PCO1ITCAV, PCO2ITCAV, and PCO3 (cox1 and 16S) Alcohol and slide specimens are preserved at the Museo Civico di Scienze Naturali "Enrico Caffi" of Bergamo (Italy).

According to the taxonomic key reported by Parimuchová and Kováč (2016), our samples belong to this species (pseudocellar formula: 3,3/0,2,2/3,3,3,3,3, with one ventral pseudocellus on the head, PAO with 25 vescicles, and Ant. III Organ with 5 papillae and rods shorter than the papillae, and anal spines that converge However, the pseudocelli on Th II do not correspond: there should be one on each side, but there are two.

***Pseudosinella concii* Gisin, 1950**

Synonyms: *Pseudosinella concii* Gising, 1950 in Latella and Brighenti (2024).

Material examined: ITALY, Veneto, Verona Province, "Buso del Valon"/Valon Cave (438 V VR; 45° 41'32.26" N, 11°06'11.10"E); 6.VII.2022 and 16.IX.2022 (leg. Latella L., det. Valle B.), many specimens. ITALY, Veneto, Vicenza Province "Caverna del Sieson"/Sieson Cave, (45°53'39.7"N, 11°23'19.3"E); 4.VI-13.XI.2022, pitfall traps, leg. Latella L., det. Valle B. (for Sieson, only two poorly preserved specimens were available; thus, the identification is *P.* cf. *concii*). The alcohol and slide specimens are preserved at the Museo Civico di Storia Naturale di Verona (Italy).

The specimens are characterized by the presence of pigment and the absence of OMMA. and unguis' wing tooth. The unguiculus is basally swollen with a minute tooth. The M1 labial macrocheta is smooth, and Ant. III apical organ is paddle-shaped. The length is approximately 2.8-3 mm. The taxonomic keys followed are: Gisin (1960) and the updated world species taxonomic keys presented in Bellinger et al. (1996-2022).

DISCUSSION

Cave springtail diversity

The number of cave-dwelling Collembola recorded from Italy has increased from 106 to 134 species since the last published checklist (Dallai and Malatesta 1982). Notably, only 10 additional studies on this topic have been published in the four decades since that publication (excluding the present work; Fanciulli 1999; Fanciulli et al. 2003, 2005, 2006, 2010, 2018; Dallai and Fanciulli, 2009; Iacovone, 2006; Latella and Brighenti 2024; Petri et al. 2025). This substantial rise in species richness — including endemics and obligate cave species — is remarkable given the limited research effort during this period. Almost every newly explored cave in areas of known endemism has yielded at least one new species (e.g., Fanciulli 1999; Fanciulli et al. 2005, 2006, 2010, 2018; Dallai and Fanciulli, 2009; Latella and Brighenti 2024), as confirmed also by the new findings reported here. Collectively, these patterns strongly suggest that our current knowledge of the subterranean Collembola fauna in Italy is far from complete, and many species likely remain undescribed. Noteworthy, 19 of the 28 species newly reported from the Italian caves are also new to the Italian fauna (the

last Italian checklist is reported in Dallai et al. (1995)). This reinforces the need for continued systematic exploration and taxonomic work, a trend similarly observed in other habitats in Italy (Valle et al. 2021, 2024, 2025) and worldwide (Shveenkova 2011; Porco et al. 2012; Thibaud 2013; Ferreira et al. 2018; Skarżyński et al. 2025).

In temperate-region caves, the most abundant families are Onychiuridae, Hypogastruridae (Deharveng and Bedos, 2018). Onychiuridae is the richest family in Italian cave habitats and exhibits the highest level of adaptation to subterranean life. It also shows the greatest increase in new records compared to previous checklists (Dallai and Malatesta 1982), with 13 additional species. The dominant cave genus within this family, *Deuteraphorura* Absolon, 1901, includes 18 species in Italy — occurring in both caves and surface habitats — most of them endemic to the Italian peninsula (Fanciulli et al., 2018, updated with new data from this work, including description of *Deutheraphorura venetiana* sp. n.).

Hypogastruridae includes 22 cave species in Italy but only three unpigmented obligate cave-dwellers with very restricted distribution: *Acherontiella cavernicola* (Brescia Lombardy), *Acherontiella carusoi* (Siracusa, Sicily), and *Bonetogastrura subterranea* (Varese, Lombardy and Switzerland). The record from the Scorluzzo artificial cave (Lombardy, Stelvio Pass) of *Schaefferia sexoculata* — a mainly cave-dwelling species, although not strictly a troglobiont — presented in this study represents the first record for Italy.

Among the Isotomidae (20 species reported from Italian caves), the only species showing strongly developed troglomorphic features in *Isotomurus subterraneus*, an obligate cave-dweller from the karst area near Trento.

In Italy, the most pronounced troglomorphic adaptations occur in the genus *Pseudosinella* (family Paronellidae), including elongated legs, claws and antennae, as well as enhanced sensory structures. However, this family has a wide ecological spectrum, and only three Italian species are obligate cave-dwellers: *Pseudosinella insubrica* (Bergamo, Lombardy and Switzerland), *P. concii* (different caves in Italy and Switzerland), *P. feneriensis* (Borgosesia, Piedmont). *Troglopedetes ruffoi* (Abisso Cave, Apulia) is the only Italian representative of this genus, which is primarily composed of tropical Paronellidae adapted to Asian caves (Fanciulli et al. 2003). It likely represents a relict tropical lineage that survived in subterranean refugia during the Quaternary glaciations (Fanciulli et al. 2003).

Within Tomoceridae the only Italian obligate cave-dweller of note is *Tritomurus scutellatus* Frauenfeld, 1854, one of the earliest described cave-adapted springtail species from the former Yugoslav karst.

Among Symphypleona and Neelipleona, only a few species have been recorded from Italian caves. Cave Sympypleona are mainly represented by Arrhopalitidae and Sminthurididae. In Italian caves, Arrhopalitidae are dominated by *Pygmarrhopalites* Vargovitsh, 2009 with *P. giovannensis* endemic to San Giovanni Cave (Sardinia), known only from females. Sminthuridae is highly heterogeneous, with, some taxa inhabiting canopy layers, but includes two notable cave species: *Disparrhopalites patrizii*, with an European distribution (Dallai 1970; Dallai and Malatesta 1982), and *D. tergestinus*, a fully blind species described for a cave near Trieste (Fanciulli et al. 2005).

Considering that only about 20% of the estimated global springtail diversity has been described (Potapov et al. 2020), habitats with a high incidence of endemism — such as Italian caves — clearly warrant much further intensive exploration.

Ice caves

In the context of current climate change, ice-cave fauna deserves particular attention, both because of the conservation issues associated

with ice-dependent habitats — now severely threatened by global warming — and because of the potential role of these habitats, when persisting, as climatic refugia for cryophilic species at direct risk of extinction. The presence of permanent ice inside caves increases local habitat heterogeneity and supports higher biodiversity, while also enabling the persistence of cryophilic and endemic relict species (e.g., Raschmanová et al. 2013, 2018; Petrovová et al. 2024). Yet, the springtail fauna of Italian cold caves remains largely unexplored. The samples from Veneto ice caves analyzed in this study — representing the only available data on springtails from Italian ice caves (partially reported in Latella and Brighenti 2024) — highlight the occurrence of endemism and underscore both the rarity of these habitats and the urgent need for further research and conservation.

Desoria cf. *fjellbergi* from Sieson ice Cave is of particular interest, as it appears to represent a new species morphologically related to *Desoria fjellbergi*, a cryophilic taxon originally described from the Pyrenees. Notably, its pigmentation pattern — dark body and pale antennae — is typical of proglacial cryophilic species (Eisenbeis et al. 1999; Valle et al. 2025). Two individuals genetically similar to *D.* cf. *fjellbergi* from Sieson Cave were found by the author on an Alpine glacier (Forni Glacier, Sondrio Province, Italy, 17.VII.2024, sample IDs "GFO11, GFO14"), possibly providing the first evidence for caves acting as refugia for cryophilic glacial springtail species (Valle et al. in preparation), although further studies are required.

Some cave-dwelling entities identified in this study appear closely related to cryophilic species previously described from the Pyrenees, but never recorded in the Alps (i.e. *Folsomia* cf. *nigrimaculata* Najt, 1981, *Desoria* cf. *fjellbergi* (Najt, 1981)). Together with the glacial species *Gnathisotoma bicolor* (Valle et al. 2025), these findings suggest the possibility of a shared Alpine–Pyrenean cryophilic springtail lineage that has so far remained undetected. This may point to ancient biogeographical connections and/or potentially common glacial-refugial histories across southern European mountain ranges. Such a lineage clearly warrants further morphological and molecular investigation to clarify its taxonomic status and evolutionary relationships.

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