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Preface to the Proceedings of the 31th European Congress of Arachnology, Vác, Hungary, 2018 July 8-13

The Congress, covering the whole breadth of arachnology, was organised over four days with scientific sessions and an additional mid-congress excursion day. Hungarian arachnologists, a well forged community of professionals and amateurs, organised the event in co-operation with the Hungarian Ecological Society and the Centre for Agricultural Research of the Hungarian Academy of Sciences.

The host town for the Congress was Vác, which is a small historic town located on the left bank of the Danube, 30 km north of Budapest, making transportation quite convenient. Because of its intact main square and surrounding historic quarter of zig-zagging small streets the town is rightfully called a "baroque treasure box". Vác is a religious centre and seat for one of the catholic archbishops. In fact, the stairs of the main church, the Cathedral, gave the best opportunity for the congress photo. With its promenade, water sports life and ferry to the Szentendrei Island, town-life is strongly connected to the Danube. Vác is also the gate for the famous Danube Bend, where the river takes a 180° turn to break through between the Pilis and Börzsöny Mountains. The angle shaped Danube Bend inspired the Congress logo, which reminded its designer, Éva Szita, of the fractional orb web of Hyptiotes paradoxus. On the logo this triangular-shaped web is framed by the Danube - the threads meeting at Vác - with the uloborid spider perching on the signal thread.

The Congress venue was provided by the Apor Vilmos Catholic College, a teacher training college, located centrally in the old town of Vác. The College had modest but very welcoming facilities, all on-site, from auditoria to student housing, a canteen and a lovely shaded inner yard for relaxation and coffee breaks. The organization needed quite a team. Core organizers (Ferenc Samu chair, Csaba Szinetár cochair, Tamás Szűts scientific organizer, Éva Szita and László Mezőfi logistics, Zsolt Szabó secretary) were helped by some 20 volunteers, who did everything from IT, to making coffee, getting fresh fruit and pastries from the local market and bakery, guided tours, documenting events and administration.

We had 133 participants from all over the world (27 countries). With the help of sponsors and mutual agreements between societies we could give free registration and various discounts to over 20 student attendants. The scientific program (to our judgement) nicely matched the available time. There were no parallel sessions, but no unnecessary gaps either. We had 58 oral and 53 poster presentations, of which nearly half was given by students. The opening ceremony, following a tradition that started in Nottingham, eased the audience to the more serious program by a brief introduction to the natural values of the Danube Bend, followed by showing "arachnologists in their natural habitats" through the lively social photos of Christian Komposch.

We managed to invite excellent plenary speakers, whose themes gave the main topical anchor points to the scientific sessions. The first day, Monday, was largely a "molecular day", marked by the keynote lecture of Rosa Fernandez. She summarised the largest invertebrate phylogenomic analyses to



date, done in her lab, which synergistically with comparative transcriptomics and lineage diversification analyses aspires to build a robust backbone for the Spider Tree of Life. A session on spider silk joined the day's molecular theme, spiced by a talk on webs and soft robotics by Fritz Vollrath. A special symposium on spider distributions, organised by Yuri Marusik, closed Monday. Tuesday was more distinguished by spider behaviour, introduced by the plenary talk of Jutta Schneider, who reported on an impressive line of experiments concerning sex specific life-history and mating strategies in Nephila. Further themes of the day were spider feeding both at the behavioural and at the food-web level. Spider have tales to tell, well, actually about the tail of one of their ancestors. This ancient peculiar spider proved to be a link between true siders and the extinct Uraraneida. This intriguing story was told in Thursday's plenary talk by Paul Selden, followed up by sessions on arachnid evolutionary tricks and environmental issues. On the closing day Christian Wirkner delivered a keynote speech on the evolutionary morphology of chelicerates, not just to show the diversity of research areas arachnology encompasses, but also to demonstrate the utility of astonishing technical revolutions allowing virtual three-dimensional analyses of the internal anatomy of animals, especially if they join together with the use of rigorous, theoretically based dictionaries. Further morphological talks were followed by ecological sessions that included research in both above ground and below ground habitats.

The Congress was also rich in extracurricular activities. In fact, so rich, that we had three early morning programs, including a walk on the Danube river bank flood-forest path, dragon boating and an early visit to the thriving local market of Vác. The evening programs were more in line with arachnology congress traditions. We had a sightseeing tour followed





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by pub-crawling (to give a different perspective), a memorable Russian party that was nearly washed away by a thunderstorm – but luckily a basement student club provided shelter to the event. Unfortunately the rain stuck to our social programs, which made the mid-congress tour quite tricky. Eventually all three tours, the one to the Börzsöny Mountains, another to the Szentendrei Island and the third to the Visegrád castle coped with the weather in good spirits and joined together in the evening in the dark forests of Börzsöny for a goulash cooked on an open fire. Luckily the Congress dinner was not only delightful, but also free from weather extremities, allowing for a late evening fierce folk dancing in the yard of the restaurant.

At the end of the meeting, as part of the closing ceremony, the audience could watch a short video about the most memorable events of the Congress. After that we celebrated the best student presentations and posters during an award ceremony. Jens Runge (Germany, first prize for best talk), Ondřej Michálek (Czech Republic, second best talk), Filippo Milano (Italy, third best talk), Pavla Dudová (Czech Republic, first prize for best poster), Yun-Yun Tsai (Czech Republic, second best poster) and Rebecca Heidbrink (Germany, third best poster) were the winners this year. Réka Ágota Szabó (Romania) was the winner of the Special Prize of the National Geographic Hungary. Congratulations!

We thank everyone who took part in the meeting and we hope to meet many colleagues at next years' congresses!

Ferenc SAMU

Three-dimensional modelling in arachnology as exemplified using *Porrhomma*-species (Araneae: Linyphiidae)

Vlastimil Růžička & Adam Růžička



doi: 10.30963/aramit5801 Abstract. Three-dimensional modelling has shown its importance in many fields, including zoological systematics. It is difficult to distinguish females of *Porrhomma egeria* Simon, 1884 and *P. campbelli* F. O. Pickard-Cambridge, 1894 according to only dorsal and ventral views of the vulva. The same is true for the pair *P. microps* (Roewer, 1931) and *P. profundum* Dahl, 1939. A caudal view is necessary to distinguish the vulvae of these species pairs. A 3D model combines all important views of the female genitalia (ventral, dorsal, lateral and caudal) into a single unit.

Keywords: 3D modelling, female genitalia, Porrhomma egeria, Porrhomma campbelli, Porrhomma microps, Porrhomma profundum, spiders

Zusammenfassung. Dreidimensionale Modelle in der Arachnologie am Beispiel von *Porrhomma***-Arten (Araneae: Linyphiidae).** Dreidimensionale Modelle haben in vielen Bereichen eine Bedeutung, einschließlich der zoologischen Systematik. Die Weibchen von *Porrhomma egeria* Simon, 1884 und *P. campbelli* F. O. Pickard-Cambridge, 1894 sind lediglich nach der dorsalen und ventralen Ansicht der Vulva schwierig zu unterscheiden. Gleiches gilt für das Artenpaar *P. microps* (Roewer, 1931) und *P. profundum* Dahl, 1939. Die caudale Ansicht ist zur Unterscheidung der Vulven dieser Artenpaare notwendig. Ein 3D-Modell vereint alle wichtigen Ansichten des weiblichen Genitals (ventral, dorsal, lateral und caudal).

The spider genus Porrhomma Simon, 1884 is one of the most unpopular among arachnologists, because of the difficulty of species identification. Differentiating species represents a problem, particularly among females with similar genitalia. Usually, dorsal and ventral views of the vulva are provided (Thaler 1991); this is, however, insufficient in some cases. Růžička (2018) added lateral and caudal views to understand the spatial structure of the copulatory ducts and spermathecae in Porrhomma. To comprehend the complicated structure of copulatory ducts in Hahnia C. L. Koch, 1841, Kovblyuk et al. (2017) used a schematic illustration of the copulatory ducts consisting of one line, which followed the spatial course of the ducts. We were inspired by Qing et al. (2015), who recommended 3D models and 3D prints to visualize important morphological characters in nematodes. Here, we (1) recommend the use of 3D models to describe and distinguish female genitalia in spiders and (2) document the advantage of 3D models in distinguishing two pairs of similar species belonging to the genus Porrhomma.

Material and methods

Specimen preparation and study

Spiders were examined with an Olympus SZX-12 stereomicroscope in 80 % ethanol. The vulva was separated from the opisthosoma using a scalpel and passed through 40 %, 20 % ethanol and distilled water to 10 % sodium hydroxide, which digests soft structures at room temperature. Subsequently, it was coloured in an ethanol solution of chlorazol black (for details see Růžička 2018).

Further details were studied with an Olympus BX-40 compound microscope, and photographs were taken with an Olympus C-5060 wide zoom digital camera mounted on the

This contribution was presented at the 31st European Congress of Arachnology, Vác, Hungary, 2018 July 8–13

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microscope. The photos were montaged using CombineZP image stacking software. The photo was used as a background layer in the Inkscape Vector Drawing Program, the line drawing was prepared and the printed image was detailed by hand. A 3D model was created in Blender 3D, based on the combination of photos and line drawings. Spermathecae are brown, copulatory ducts are blue (cf. Figs 1 and 2 with Fig. 4 in Růžička 2018). The final model can be rotated and observed in the program from any angle.

Female genitalia

The female genitalia usually consist of sclerotized plates, copulatory ducts, spermathecae and fertilisation ducts. In *Porrhomma*, copulatory ducts start with a copulatory opening in the aperture. Behind a side loop, they continue by an ascending (in ventral view) part above the aperture wall to the median plane, closely under the integument. The spermatheca is formed at the end of the copulatory duct. It consists of a broader main sack with a slender appendix.

Results

Porrhomma egeria Simon, 1884 versus

Porrhomma campbelli F. O. Pickard-Cambridge, 1894

In these two species, the spermathecae are formed immediately behind the side loop under the ventral body wall, starting at the midway of the ascending part of the copulatory ducts. Appendices of *P. egeria* are oriented usually to the side (see Fig. 633.3 in Thaler 1991), appendices of *P. campbelli* are oriented usually to the median line (see Fig. 634.3 in Thaler 1991), but not in all cases; cf. Figs 8a and 9a in Thaler (1968). The main sacks of these two species are hardly distinguishable in ventral and dorsal views (Figs 1c, d; cf. also Figs 8a, b and 9a, b in Thaler 1968, and Figs 21D, F and 15D, F in Růžička 2018).

The principal difference between the form of the main sacks of these two species is visible in caudal view. In *P. egeria*, the main sacks end at the base of the appendices and the axes of their end part are convergent; i.e. they are directed towards the centre of the opisthosoma (Fig. 1a). In *P. campbelli*, the main sacks reach deeper inside the opisthosoma, they are cur-



Fig. 1: A model of the caudal (a,b) and dorsal (c,d) views of the vulvae. **a**, **c**. Porrhomma egeria; **b**, **d**. Porrhomma campbelli. Abbreviations: A, appendix; MS, main sack; SL, side loop; example axes of the end part of the main sacks

ved around the appendices, and the axes of their end part are divergent; i.e. they are directed oblique laterally (Fig. 1b). In the 3D model, all these differences are clearly visible.

Porrhomma microps (Roewer, 1931) versus Porrhomma profundum Dahl, 1939

In these two microphthalmic species, the copulatory ducts have a broad side loop and ascending part, and the spermathecae are situated deeper in the opisthosoma. All species of the *microphthalmum*-group are characterised by a conspicuous fold, which is formed in the uppermost part of the vulva (Růžička 2018). Vulvae are hardly distinguishable in ventral and dorsal views (e.g., Miller & Kratochvíl 1940).

The main difference is visible in caudal view. The fold is very conspicuous in *P. microps* (Fig. 2a), but it is not as tight in *P. profundum* (Fig. 2b). Moreover, the inner branch



Fig. 2: A model of the caudal (a, b) and dorsal (c, d) views of vulvae. **a**, **c**. *Porrhomma microps*; **b**, **d**. *Porrhomma profundum*. Abbreviations as in Fig. 1. F, fold of the copulatory duct; access of the end part of the main sacks; access of the inner part of the fold

of the fold goes directly towards the median plane in *P. microps* (Fig. 2c), whereas it goes obliquely in *P. profundum* (Fig. 2d). The whole main sacks are oriented to the sides in *P. microps* (Fig. 2c), whereas they are oriented obliquely upwards in *P. profundum* (Fig. 2d). In the 3D model, all differences are clearly visible.

Models are freely available to view on: http://adamruzicka.cz/porrhomma/

Discussion

A 3D model combines ventral, dorsal, lateral and caudal views and represents a good approach to understand the spatial structure of the vulva. The accuracy of the final reconstruction is not comparable to that using micro-computed-tomography and serial sectioning and visualization using 3D-reconstruction software (e.g. Runge & Wirkner 2016). 3D modelling is not meant to provide a completely realistic image, rather to present morphological aspects in a more comprehensible way.

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Catalogue of the pseudoscorpions (Pseudoscorpiones) in František Miller's collection (Department of Zoology, National Museum, Prague)

František Šťáhlavský & Petr Dolejš



doi: 10.30963/aramit5807

Abstract. The present catalogue lists data for a total of 176 specimens belonging to 18 species in the pseudoscorpion collection of the Czech arachnologist František Miller (1902–1983), housed in the National Museum in Prague. The material was collected during 1940–1976 in the modern-day Czech Republic and Slovakia. For these two countries, especially noteworthy items are species such as *Mesochelifer ressli, Rhacochelifer euboicus, Neobisium brevidigitatum* and *Neobisium* cf. *jugorum*.

Keywords: Arachnological collection, Bohemia, faunistics, historical records, Moravia, Slovakia

Zusammenfassung. Katalog der Pseudoskorpione (Pseudoscorpiones) in František Millers Sammlung (Abteilung für Zoologie, Nationalmuseum Prag). Im vorliegenden Katalog werden Daten von 176 Exemplaren aus 18 Arten aus der Pseudoskorpion-Sammlung des tschechischen Arachnologen František Miller (1902–1983) aus dem Nationalmuseum in Prag aufgelistet. Das Material wurde im Zeitraum 1940–1976 in den heutigen Ländern Tschechische Republik und Slowakei gesammelt. Für diese beiden Länder sind die Nachweise folgender Arten besonders bemerkenswert: *Mesochelifer ressli, Rhacochelifer euboicus, Neobisium brevidigitatum* und *Neobisium* cf. *jugorum*.



Fig. 1: Prof. RNDr. František Miller, DrSc. (1902–1983) (personal archive of Jan Buchar)

ondary school in the small Czech town of Soběslav during the Second World War. In 1947, he obtained his habilitation at the University of Agriculture in Brno and worked there until his death on 14 January 1983 (Buchar 1997).

During his fruitful life (65 published papers), Miller primarily studied spiders of the family Linyphiidae (Buchar 1997). As formalin pitfall traps and sieving belong to the most important collecting methods in arachnology, Miller's material also contains other soil or epigean invertebrates, including pseudoscorpions. The majority of the material was collected in the surroundings of Miller's places of work. His large private collection was purchased by the National Muse-

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Professor RNDr. František Miller. DrSc. (Fig. 1) was born in Kročehlavy near Kladno on 27 January 1902. After graduating at the Faculty of Science of the Charles University in Prague, he started to teach at secondary schools in the Slovak towns of Štubnianske Turčianske) (today Teplice (1929) and Žilina (1939), and in the Czech town of Jindřichův Hradec (1939). He became director of the secum in Prague, Czech Republic, from Miller's widow, Jarmila Millerová, in 1983 and deposited in the Department of Zoology of this Museum under accession numbers 100/83 and 103/83 (e.g., Kůrka 1994, Dolejš & Kůrka 2013, Kocourek & Dolejš 2016, Dolejš & Tuf in press). Beside spiders, the collection also contained unsorted material of other invertebrates obtained together with spiders: harvestmen, pseudoscorpions, mites, centipedes, millipedes, isopods, etc. In this paper, we present a review of the pseudoscorpions (Pseudoscorpiones) found in the Miller's collection. It contains 176 specimens, representing 18 species in five families. The collection contains historical records of particular value for faunistic purposes (Krajčovičová et al. 2017).

The pseudoscorpion collection of the National Museum contains specimens preserved in ethanol, as well as some dry specimens. Most of the spirit material was collected by the former curator, Dr. Antonín Kůrka, from the Czech Republic and during inventory research in the newly established Brdy Protected Landscape Area (Just et al. 2018). Further recent material was collected during expeditions of the Department of Entomology to the Dominican Republic, New Zealand, Puerto Rico and South Africa. The historical material (dry specimens and a few spirit specimens) comes from various destinations: besides the former Czechoslovakia (including the southwestern part of modern Ukraine), these include the Balkan Peninsula, Brazil, Italy and Mexico. Miller's collection is thus an important part of the pseudoscorpion collection of the National Museum.

Material and methods

All pseudoscorpion specimens are maintained in 80% ethanol. Almost all of them (with the exceptions of *Rhacochelifer euboicus*) were sexed and identified by the first author, using Christophoryová at al. (2011). Families are sorted systematically; genera and species are sorted alphabetically according to nomenclature used in Harvey (2013).

The data are arranged as follows: locality – (number of mapping grid square) – date of collection – number and sex of specimens – (inventory number).

The present administrative divisions of Europe are used. Within the Czech Republic, the historical regions of Bohe-



Fig. 2: Map of localities where Miller collected pseudoscorpions

mia and Moravia are recognized following Kment (2009). The geographic position of localities (Fig. 2) is given by grid squares after Buchar (1982) and, in the case of Czech settlements, after Pruner & Míka (1996).

Images of selected specimens were made using an Olympus SZX12 stereomicroscope equipped with an Olympus E-510 or DP70 camera, and processed using the Quick-PHOTO MICRO 2.3 (Promicra) software including the module Deep Focus 3.2.

Abbreviations:

D = deutonymph, P = protonymph, T = tritonymph.

Systematic list Chthoniidae Daday, 1889 *Chthonius heterodactylus* Tömösváry, 1883 No collecting data: 1 ♀ (P6d-342/2006). *Ephippiochthonius tetrachelatus* (Preyssler, 1790) (Fig. 3) SLOVAKIA: Štúrovo (8278), 10. Jun. 1956, 1 ¢ (P6A 6816).

Neobisiidae Chamberlin, 1930

Neobisium brevidigitatum (Beier, 1928) (Fig. 4) SLOVAKIA: Vysoké Tatry Mts., Aug., 2 &, 1 & (P6A 6817).

Neobisium carcinoides (Hermann, 1804)

CZECH REPUBLIC: **Bohemia**: Kvilda, at base of *Betula* sp. (6947), 6. Oct. 1960, 3 & 2 & (P6A 6818); **Moravia**: Pálava (7165–7266), 10. May 1956, 1 & (P6A 6819); Pavlov (7165–7166), Aug. 1948, 1 & (P6A 6820); Rejvíz (5769), 1 & 1 & 4 TT (P6A 6846); Skřítek Peatbog (6068), 2 & (P6A 6847). SLOVAKIA: Bratislava (7868), 1 & 1 T (P6A 6821); Vysoké Tatry Mts., Aug., 14 & (P6A 6822). **No collecting data:** 1 & 5 & (P6A 6822)(P6A-342/2006).





0.5 mm

Fig. 3: Ephippiochthonius tetrachelatus, female (P6A 6816)

Fig. 4: Neobisium brevidigitatum, female (P6A 6817)

Neobisium carpaticum Beier, 1935

SLOVAKIA: Malá Fatra Mts. (7868), Aug. 1948, 2 &, 2 \, 2 \, (P6A 6823).

Neobisium crassifemoratum (Beier, 1928) No collecting data: 1 ♂, 2 ♀♀ (P6d-342/2006).

Neobisium erythrodactylum (L. Koch, 1873)

CZECH REPUBLIC: **Moravia**: Jeseník (5769), Jun., 1 &, 1 & (P6A 6824); Jinošovice Rock, in grass at forest margin (6862), 13. Sep. 1940, 2 & 1, 1 D (P6A 6825); Pálava (7165–7266), 5. May 1956, 1 & (P6A 6826), 10. May 1956, 1 & (P6A 6827); Rejvíz (5769), 11 & 3, 8 &, 3 TT (P6A 6848). SLOVAKIA: Banská Štiavnica, on *Abies* sp. (7579), Jun. 1956, 1 & (P6A 6828); Beluj (7679), 25. Mar. 1955, 1 T, leg. Patočka (P6A 6829); Turie (6878), Aug., 1 & (P6A 6830).

Neobisium fuscimanum (C. L. Koch, 1843)

CZECH REPUBLIC: **Bohemia**: Pernek (7249), 30. Jul. 1956, 1 & 2 & (P6A 6831); **Moravia**: Pavlov (7165–7166), Aug. 1948, 1 & (P6A 6832); Skřítek (6068), 1 & (P6A 6849). **No collecting data**: 1 & (P6d-342/2006).

Neobisium cf. jugorum (L. Koch, 1873) (Figs 5-10)

SLOVAKIA: Modré pleso Lake, 2200 m a.s.l. (6887), 12. Apr. 1948, 3 &ð, 1 & (P6A 6833); unknown, 4 & (P6d-342/2006).



Fig. 5: Neobisium cf. jugorum, female (P6A 6833)



Fig. 6: Neobisium cf. jugorum, male (P6A 6833)



Figs 7-10: Epistomes of *Neobisium* cf. *jugorum* (P6A 6833), female (7) and males (8-10)

Neobisium sylvaticum (C. L. Koch, 1835)

CZECH REPUBLIC: **Bohemia**: Blata, 3. Apr. 1948, 1 \Re (P6A 6834); Jindřichův Hradec (6855–6856), 1 \Re (P6A 6835); Říčky (6764), Oct., 1 \eth (P6A 6836); **Moravia**: Bobrava Valley (6865), 30. Sep., 1 \circlearrowright (P6A 6837); Jeseníky Mts., Jul. 1956, 1 \circlearrowright , 1 \Re (P6A 6838); Pouzdřany (7065), 15. Oct. 1966, 13 \Re (P6A 6839); Skřítek Peatbog (6068), 1 T (P6A 6840); **Unknown**: Račice, Nov., 6 \eth , 2 \Re (P6A 6841). SLOVAKIA: Vrútky (6879), IX, 1 \S (P6A 6842). **No collecting data:** 5 \eth , 6 \Re , 3 TT (P6d-342/2006).

Cheliferidae Risso, 1827

Chelifer cancroides (Linnaeus, 1758)

CZECH REPUBLIC: **Moravia**: Brno, in house, 19. Dec. 1964, 1 ¢ (P6A 6843); Mohelno (6863), Jun. 1940, 1 ¢ (P6A 6803); Šerák Mt. (5868), 5. Aug. 1946, 1 ¢ (P6A 6804). **Unknown:** locality H-138/65, 1 T (P6A 6805). **No collecting data:** 3 &, 2 \$\$ (P6d-342/2006).

Dactylochelifer latreillii (Leach, 1817)

CZECH REPUBLIC: Moravia: Lednice (7266), 10. Jul. 1958, 1 9 (P6A 6806).

SLOVAKIA: Bratislava, nest of *Turdus merula* (7868), 11. May 1961, 1 & 1 D (P6A 6807), 1 & (P6A 6808); Domica (7588), 10. May, 1 & (P6A 6809). **Unknown:** locality H-173/65, 2 dd (P6A 6810). **No collecting data:** 1 \, (P6d-342/2006).

Mesochelifer ressli Mahnert, 1981 (Fig. 11)

CZECH REPUBLIC: Moravia: Mohelno (6863), 10. Jul. 1958, 1 9 (P6A 6844).

Chernetidae Menge, 1855

Chernes hahnii (C. L. Koch, 1839)

CZECH REPUBLIC: **Moravia**: Bílovice, on *Platanus* sp., 20. May , 4 &, 1 & (P6A 6812); Bobrava Valley (6865), 4. May , 1 & (P6A 6845); Lednice (7266), 1. Jun., 3 &, 1 &, 1 T (P6A 6813).

Chernes similis (Beier, 1932) (Fig. 12)

SLOVAKIA: Domica (7588), 10. May, 1 & (P6A 6811).

Lamprochernes nodosus (Schrank, 1803)

CZECH REPUBLIC: **Bohemia**: Nový Bydžov, in a flat (5758), 4. Oct. 1976, 1 ^Q (P6A 6814); Soběslav (6754), Apr. 1946, 3 ^{QQ} (P6A 6815).

Atemnidae Kishida, 1929

Atemnus politus (E. Simon, 1878) (Fig. 13) SLOVAKIA: Štúrovo (8278), 10. Jun. 1956, 1 ^Q (P6A 6802).

Discussion

The material of pseudoscorpions from the collection of Prof. Miller forms a significant part of this order housed in the National Museum in Prague. Given that the main collecting methods used were formalin pitfall traps and sieving, it is not surprising that half of Miller's samples contain representatives of the family Neobisiidae, which are closely associated with the soil. This material includes the species Neobisium carcinoides, which is one of the most widespread European species (Harvey 2013) and one of the most abundant pseudoscorpions inhabiting leaf litter in Central Europe (e.g. Christophoryová et al. 2007, Šťáhlavský & Chytil 2013, Muster & Blick 2015). Among the other neobisiid species in Miller's collection are Neobisium erythrodactylum, Neobisium fuscimanum and Neobisium sylvaticum, from several localities. These species have been mentioned in many faunistic papers on the Czech Republic and Slovakia (see Christophoryová et al. 2012) and they seem to be typical for the leaf litter in Central Europe. The most interesting material of the genus Neobisium in the collection is that of the species N. brevidigitatum and N. cf. jugorum. Neobisium brevidigitatum was described from Romania (Beier 1928) and later recorded from Georgia, Poland and Slovakia (see Harvey 2013). Although detailed collecting information is lacking for the material from the High Tatra Mountains, it confirms the presence of this species in the Western Carpathians, which was previously mentioned only from Great Fatra (Krumpál 1980) and, with doubt,



Fig. 11: Mesochelifer ressli, female (P6A 6844)



Fig. 12: Chernes similis, male (P6A 6811)



Fig. 13: Atemnus politus, female (P6A 6802)

from the Pienin Mountains (Rafalski 1967). The specimens of *N*. cf. *jugorum* from Modré pleso Lake in the High Tatra Mountains provide an additional record of this species from the Carpathians that was already recorded by Verner (1960) from these mountains. However, Miller's specimens from one locality show variability in the shape and size of the epistome from none in the female to sharp pronounced in some males (see Figs 7-10). All other characteristics correspond to the features typical to *N. jugorum* (e.g. Beier 1963). The fauna of the family Neobisiidae is still not well known from the Carpathian region and preliminary cytogenetic results indicate existence of additional taxa in this region (e.g. Šťáhlavský et al. 2012). The pronounced difference in the epistomes between males and females is not mentioned in this species and we cannot exclude the possibility that Miller's material represents in fact a new species with distinct sexual dimorphism.

Miller collected several pseudoscorpion species a long time before the final published records for the Czech or Slovak Republics. For example, his collection of Atemnus politus (Atemnidae) in 1956, close to Štúrovo, predates that of the female collected in 1974 in the same area that served to establish the presence of this species in Slovakia (Krumpálová & Krumpál 1993). Miller's specimens of Rhacochelifer euboicus (Cheliferidae) were also the first to be collected in Slovakia and his abundant material enabled the description of the variability of morphological characteristics (Krajčovičová et al. 2017) from populations situated at the northern limit of its distribution (Hernández-Corral et al. 2018). Among the rare species (in the Czech Republic and Slovakia) in the Miller's collection belongs also Mesochelifer ressli, a species usually found under the bark of the trees (e.g. Šťáhlavský & Chytil 2013).

It is evident that Miller's collection includes valuable material and provides important historical records for pseudoscorpions in the Czech Republic and Slovakia.

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Comparing pitfall trapping and suction sampling data collection for ground-dwelling spiders in artificial forest gaps

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doi: 10.30963/aramit5808 Abstract. This study focuses on the comparison of two frequent ground-dwelling spider collecting methods, pitfall trapping and D-Vac suction sampling, in relation to artificial gap openings of a forest stand in West-Hungary. With pitfall traps, we collected 928 specimens, representing 34 species. With suction sampling, we collected 1254 specimens, belonging to 41 species. Examining the distribution of the communities, both sampling methods showed higher spider densities in forest gaps than in the forest stand. On average, the pitfall trapping accessed larger-sized spider species. The hunting and nocturnal spiders were also represented in the pitfall samples, while the D-Vac method detected more web builders. The ordination analysis showed that the two methods accessed different communities. Thus, we suggest their combined use.

Keywords: Araneae, Carpathian Basin, D-Vac, gap, pitfall trapping, turkey oak

Zusammenfassung. Vergleich von Bodenfallen und Saugfängen bodenlebender Spinnen auf künstlichen Waldlichtungen. Es werden zwei häufig angewendete Sammelmethoden verglichen, Bodenfallen und D-Vac Saugfänge, und zwar auf künstlichen Lichtungen in einem Waldbestand in Westungarn. Mit Bodenfallen wurden 928 Individualen aus 34 Arten gefangen. Mithilfe der Saugfänge wurden 1254 Individuen aus 41 Arten gesammelt. Bei beiden Methoden sind die Individuenzhalen auf den Lichtungen größer als im Wald. Mit Bodenfallen wurden im Durchschnitt größere Spinnenarten gefangen. Laufjäger nachtaktive Arten waren in den Bodenfallen stärker vertreten, während mit dem Saugfängen mehr netzbauende Arten gefangen wurden. Eine Ordination zeigt, dass beide Methoden unterschiedliche Gemeinschaften erfassten. Daher schlagen wir ihre kombinierte Anwendung vor.

Formation of gaps is a part of the natural regeneration process in temperate forests (Brokaw & Busing 2000, Vepakomma et al. 2008, Fledmann et al 2018, Senécal et al. 2018, Keram et al. 2019). In response to this, the popularity of 'gap-cutting' techniques is rising, and they may become essential in modern, close-to-natural forest management practices. The employment of these techniques is still relatively new however, therefore our information and understanding regarding their mechanics is lacking (Elek et al. 2018, Keram et al. 2019). In order to assess the effects of artificial gap openings on forest ecosystems and on forest floor arthropods, ground-dwelling spiders are suitable study objects (Wise 1993, Horváth et al. 2009, Elek et al. 2016, 2018). Two of the most commonly used methods for studying this taxon are pitfall trapping and suction sampling (Samu & Sárospataki 1995, Mommertz et al. 1996, Samu et al. 1997, Woodcock 2005, Kádár & Samu 2006).

Because of their relatively cheap maintenance and low labour requirements, pitfall traps have been used to collect epigeic arthropods since the early 1900s in many habitat types (e.g., Lang 2000, Zhao et al. 2013, McCravy 2018), including forests and forest gaps. Pitfall trapping is a passive sampling technique, as is suction sampling, in that they do not use any attractant (e.g., Zou et al. 2012, McCravy 2018). This method is considered to provide data on the degree of activity rather than actual population densities of the captured species, and tend to over-represent large-bodied species and slightly under-represent diurnal species. Furthermore, this trapping technique is sensitive to several external disturbance effects

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(e.g., Merrett & Snazell 1983, Topping & Sunderland 1992, Sunderland et al. 1995, Hancock & Lang 2011, Zou et al. 2011, McCravy 2018). Nevertheless, pitfall trapping tends to represent the highest percentage of the surveyed taxa, including rare species when compared to other sampling methods, making it almost essential for inventory studies (e.g., Churchill & Arthur 1999, Cardoso et al. 2008, Sabu & Shiju 2010).

In contrast to pitfall trapping, D-Vac suction sampling is considered to have relatively high cost and labour requirements, but it is far less sensitive to species activity and can provide a measure of arthropod density (McCravy 2018). On the other hand, it often under-represents large and heavy species, and species that frequently occur under the soil surface, vegetation or debris (Lang 2000, Elliott et al. 2006, McCravy 2018). This sampling process causes more disturbances (Sunderland et al. 1995). Finally, both methods are sensitive to undergrowth cover (Sunderland et al. 1995, Zou et al. 2012, McCravy 2018). Because of the reasons listed above, D-Vac suction is not as popular as pitfall trapping, but it is still widely used in entomological researches (Samu et al. 1997, Elliott et al. 2006).

While there have been numerous studies dedicated to the comparison of pitfall trapping and D-Vac suction sampling regarding various habitats, there have been none – to the best of our knowledge – that compared the two methods regarding artificial gaps in forest ecosystems. Therefore, our main goal was to conduct such a survey, focusing on the following questions:

- 1. Is there any difference between the communities accessed by the two sampling techniques, especially regarding species and specimen numbers, family compositions, similarity- and diversity indices and body sizes?
- 2. Do the communities accessed by the two different methods show differentiations between the two habitats (forest stand and gaps)?
- 3. Considering our findings and field experiences, is one of the sampling methods more suitable than the other to survey such study sites, or can they be used in a complementary manner?

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Materials and methods Study sites and methods

Our data collection was carried out in West Hungary, near the town of Vép in the Gyöngyös-plain (47.22750°N, 16.78917°E, 190 m a.s.l.). The mosaic-like landscape structure of this region consists mainly of agricultural fields, permanent grasslands with anthropogenic influence (mowing) with natural vegetation, and forest patches. The studied subcompartment was a homogenous turkey oak (Quercus cerris L. 1735) stand, aged 70 years (in 2014), containing 12 artificial gaps (#1-#12) opened in 2010 (approximately 15 × 30 m) (Kollár 2017). Only the gaps had understory, which was densely populated by turkey oak saplings and Rubus patches. Everywhere else, the forest floor was covered with threads of Poa species and thin leaf litter. The forestry climate category of the subcompartment is hornbeam-oak. The elevation of the terroir is 200 m, with plain geomorphology. Topsoil is deep, consisting of brown forest soil with pise texture and has no excess water.

We surveyed two artificial gaps (#7 and #9) of the subcompartment, and the stand around them, with double-cupped Barber-type pitfall traps (PT) (Barber 1931, Woodcock 2005, Kádár & Samu 2016). They had a diameter of 90 mm at the top, and were filled with 10% acetic acid solution as a preservative. In each gap, the traps were positioned in 70 m long transects along the longitudinal axis of the gaps, with 15 traps in each transect, 5 m apart from each other. Traps N°-5 and N°-11 were at the approximate edges of the gaps (Fig. 1). Emptying of these traps took place once, after two weeks of field use, on 24. Jun. 2014.

The D-Vac suction sampling (DV) (Dietrick 1961) was carried out on 24. Jun. 2015. We surveyed six additional gaps (#1, #2, #4, #6, #10 and #11). At each gap, we sampled five, 0.1 m² areas, starting from the centres of the gaps, 5 m apart from each other, with double repetition (Fig. 1.). We chose this sampling layout of the suction sampling for the following reasons. We intended to have the same sample size (30), as the pitfall trapping (we consider the 'A' and 'B' transects repetitions of each other). We also believed that surveying the gaps and transects of the original pitfall trapping would be suboptimal, since the samplings we conducted there in previous years were quite extensive, which could have influenced a new sampling. Finally, since the D-Vac sampling took place during only a single day, we intended to survey as many addi-



Fig. 1: Arrangement of the pitfall traps (top) and D-Vac suction samplings (bottom) at each gap (top view). Gaps represented as dark rectangles

Tab. 1: Changes in community attributes along the sampling transects. Samples located at the same relative positions in the transects are summarized. Species (S) and specimen (n) numbers represented as percentages of the total catch results (PT – pitfall trapping; DV – suction sampling, d – the distance of the sample from the centre of a gap [m]; H' – Shannon diversity; [mm] – body size; samples located inside gaps are **bold**)

Sample	d	S	n	H'	[mm]
PT.1	35	11.76	5.28	0.89	4.85
PT.2	30	14.71	2.16	1.20	5.62
PT.3	25	11.76	3.02	1.15	5.77
PT.4	20	23.53	2.05	1.89	5.34
PT.5	15	26.47	4.85	1.73	5.12
РТ.6	10	38.24	7.11	2.03	5.03
PT.7	5	47.06	14.87	2.21	5.08
PT.8	0	35.29	5.28	2.24	5.55
РТ.9	5	47.06	9.16	2.47	4.92
PT.10	10	26.47	6.25	1.38	5.15
PT.11	15	23.53	14.22	1.50	5.80
PT.12	20	44.12	9.81	2.08	5.71
PT.13	25	38.24	7.00	2.08	4.80
PT.14	30	20.59	5.28	1.33	4.90
PT.15	35	29.41	3.66	1.85	5.58
DV.1	45	41.46	14.99	2.66	2.66
DV.2	30	36.59	16.67	2.46	3.56
DV.3	15	34.15	18.66	2.34	2.41
DV.4	7,5	58.54	23.84	3.01	2.01
DV.5	0	43.90	25.84	2.68	1.86

tional gaps as possible, to mitigate the unforeseeable negative effects that may occur during samplings (e.g. anthills, fallen dead wood, big game activity, etc.). The specifications of the used suction device (Stihl SH86) are as follows: a 0.8 kW (or 1.1 hp) 27.2 cm³ petrol engine with 7200 rpm speed, 770 m³/h suction capacity. A 2 litre, densely woven textile bag was used for sample collections. This device is similar in principle to the one used by Samu & Sárospataki (1995).

In common field practice, pitfall traps are generally used for weeklong intervals, while an individual vaccum sampling only lasts for minutes. We choose to follow these practices in our survey. Since our present study is part of a larger, complex survey of the sub-compartment (Kollár 2017), we decided to keep and include the original designations of the gaps.

Data analysis

Given that we did not have the same number of samples in the different habitats, we will not make direct comparisons between their explored communities. Instead, our aim was to compare either individual samples (usually every sample, with every other sample), or the total data of both methods. We analysed the following data: numbers of species (S) and specimens (n), family and guild composition, and average body sizes [mm], which were identified by using literature data for every species (Nentwig et al. 2018). We also calculated the Shannon (H') diversity (based on natural logarithms), which is known to be sensitive to undersampling (May 1975, Beck & Schwanghart 2010), but we consider the surveyed communities well explored. To calculate this index, only data from mature specimens were used. 13.5

S





105

n

p: 0.003

Fig. 2: Violin plots representing: **S.** the distribution and probability density of species numbers; **n.** specimen numbers; **H**'. Shannon diversities; **[mm].** average body sizes [mm] of the ground-dwelling spider communities accessed by the different sampling methods; p values show the results of t-tests comparing the datasets; PT – pitfall trapping; DV – suction sampling

In order to visualise and compare the distribution of our four main data (s, n, H', [mm]) and their probability density, we used violin plots, which are basically box plots that also show the probability density of the data at different values, usually smoothed by a kernel density estimator (Hinze & Nelson 1998). We included every individual sample (30-30) for both sampling methods (Fig. 2.). During this analysis, we also used Student's t-test to compare the datasets of the two sampling methods. We considered differences to be significant at p<0.05 values.

To observe potential changes in the spider communities through the survey transect (i.e. between the gaps and forest stand) we organised the data by summarizing the samples located at the same relative positions in the transects for both methods. To make the results more comparable, we represented S and n as percentages of the total catch results (Tab. 1.).

We compared the family compositions of the two methods by species and specimen numbers, which were also represented as percentages of the total catch results (Tab. 2.). All these values were calculated by summarising the data from each sample in the same relative position. To classify the spider families into the two basic guild categories (web makers and hunters), we used the work of Cardoso et al. (2011), and we represented the data in pie charts (Fig. 3.).

Two different analyses were conducted to compare the similarities between the samples for the two methods. First, we computed the Renkonen similarity indices between the DV and PT samples (Tab. 3.). In addition, we also conducted an ordination analysis (Fig. 4.), where we applied non-metric multidimensional scaling (N-MDS). The similarity matrices were based on Bray-Curtis distance measures (Bray & Curtis 1975, Anderson & Willis 2003). The corresponding ST value

was 0.13, which is within the preferred acceptance interval (Podani 1997). The data were analysed by collecting methods and by sampling position, and only mature specimens were included. Both analyses were computed using the PAST 3.2 program (Hammer et al. 2001).

Finally, we used linear regression analysis to model the relationships between the distance from the centre of the gaps (d) and our measured data (n, S, [mm] and H'). We considered relationship to be significant at p<0.05 values (Tab. 4.).

Results

The pitfall traps collected 928 (463 juvenile) specimens, representing 34 species. The suction sampling gathered 1254 (1087 juvenile) specimens, belonging to 41 species. This means an average of 2 specimens/day/trap for pitfall trapping and an average of 21 specimens/sampling (equal to 0.1 m²) for D-Vac sampling. Eleven species occurred only in pitfall traps, while nineteen species occurred only in D-Vac samples.

The violin plots show that the mean and maximum values are higher in the pitfall samples in all four cases (S, n, H', [mm]). The graph representing the distributions of the body sizes shows that data from the D-Vac samples are multimodal. The two peaks are in the ~4.5 and ~1.5 mm body ranges. This may indicate that the D-Vac sample collection method has assessed two different sized groups from the same community. However, the samples of from pitfall trapping seem to be mostly be the ~4.5 mm body range, with many outlier data points in both the minimal and the maximal ranges. Additionally, the datasets of the two methods show significant differences in the case of all four variables (Fig. 1.).

Both the S and n values are highest in the inner part of the transects (i.e. in the gaps) in the case of both methods. Addi-

Tab. 2: Family compositions. Values represented as percentages of the total catch results (PT – pitfall trapping; DV – suction sampling; highest differences in **bold**).

т	Specim	en number	Species number		
Taxa	РТ	DV	РТ	DV	
Agelenidae	0.97	0.19	2.94	2.13	
Atypidae	2.70	0.19	2.94	2.13	
Clubionidae	0.11	0.10	2.94	2.13	
Dictynidae	0.11	0.00	2.94	0.00	
Dysderidae	0.22	0.10	2.94	2.13	
Gnaphosidae	9.06	1.46	11.76	2.13	
Hahniidae	0.00	0.19	0.00	2.13	
Linyphiidae	4.31	50.58	20.59	40.43	
Lycosidae	74.43	37.04	8.82	6.38	
Mimetidae	0.00	0.19	0.00	2.13	
Miturgidae	2.70	1.95	5.88	4.26	
Mysmenidae	0.00	0.78	0.00	2.13	
Philodromidae	0.54	0.39	2.94	2.13	
Phrurolithidae	0.32	0.19	2.94	2.13	
Pisauridae	0.11	0.00	2.94	0.00	
Salticidae	0.97	2.14	8.82	6.38	
Tetragnathidae	0.00	0.19	0.00	4.26	
Theridiidae	0.86	1.66	11.76	10.64	
Thomisidae	0.76	2.63	5.88	6.38	
Zodariidae	1.83	0.00	2.94	0.00	

tionally, the D-Vac data shows that the highest [mm] values are in the stands, while the lowest are in the gaps (Tab. 1.).

Examining the family-structures of the samples considering the two sampling method, it can be stated that the share of the family Linyphiidae regarding both the total species and specimen numbers were higher in the D-Vac samples.



Fig. 3: Guild structure of the communities accessed by the two sampling methods (PT – pitfall trapping; DV – suction sampling; S – species number; n – specimen number)

Tab. 3: Renkonen similarity index values between the samples of the two methods. Samples located at the same relative positions in the transects are summarized (PT – pitfall trapping; DV – suction samplings; numbers in brackets represent the distance [m] of the sample site from the centre of the gaps; highest values in **bold**)

	DV.1(0)	DV.2(7.5)	DV.3(15)	DV.4(30)	DV.5(45)
PT.1(35)	0.21	0.26	0.32	0.15	0.09
PT.2(30)	0.21	0.29	0.29	0.23	0.17
PT.3(25)	0.18	0.26	0.29	0.12	0.09
PT.4(20)	0.39	0.46	0.48	0.24	0.25
PT.5(15)	0.25	0.26	0.40	0.20	0.13
PT.6(10)	0.32	0.43	0.58	0.33	0.23
PT.7(5)	0.33	0.50	0.49	0.35	0.29
PT.8(0)	0.37	0.53	0.46	0.34	0.28
PT.9(5)	0.34	0.45	0.54	0.37	0.34
PT.10(10)	0.29	0.42	0.41	0.25	0.25
PT.11(15)	0.30	0.37	0.40	0.28	0.17
PT.12(20)	0.21	0.26	0.40	0.20	0.09
PT.13(25)	0.25	0.32	0.45	0.20	0.18
PT.14(30)	0.25	0.26	0.32	0.15	0.09
PT.15(35)	0.25	0.29	0.29	0.24	0.16

We got the same results for the family Gnaphosidae in the pitfall samples. Furthermore, the share of the family Lycosidae in the total specimen numbers was higher in the pitfall samples (Tab. 2.). Additionally, the guild analysis showed that the majority of the spiders (considering both S and n) were hunters in the pitfall traps, and web builders in the D-Vac samples (Fig. 3.).

The Renkonen similarity values showed that four of the D-Vac samples show the highest similarities to those pitfall samples which are located in the gaps (Tab. 3.).

In the ordination analysis, the samples of the two methods are organised into two distinct groups. Both the largest similarities and largest dissimilarities can be seen in case of the pitfall traps. The superimposed minimum spanning tree indicate fairly good 2D solutions (Fig. 4.).

According to the regression analysis, the distance of the sampling sites shows significant relationships with specimen number, species number and diversity in case of the pitfall traps; and only with specimen number in case of suction samplings. All these values show negative connection. The R² values are generally low, the highest being 0.38 (Tab. 4.).

Discussion

The total sample size of the pitfall traps may be considered lower than expected. The specific reason for this is unknown, but some factors may be partially responsible: the dry microclimate of the investigated forest, the big game activity in the area and the carabid attractive properties of the acetic acid.

Both the total and the relative catching numbers were higher using the suction sampling method. The formation of two distinct groups can be interpreted in the ordination analysis as the two methods accessed somewhat different communities, which is in line with the findings of Samu & Sárospataki (1995), Green (1999) and Cardoso et al. (2008). The reason the D-Vac samples were mostly similar to the gap located pitfall samples (according to the Renkonen indices), might be that the gap located pitfall traps caught more small 0.225

0.150

0.075

0 0 0 0 0

-0.075



10

PT.9

Ì 0V.3

DV

7 PT.11

PT.13

PТ

т.2

PT.

based on Bray-Curtis dissimilarity. Dots represent the sampling sites in the transects, with minimum spanning tree. Samples located at the same relative positions in the transects are summarized (PT - pitfall trapping; DV suction sampling; circles - forest located samples; squares - edge located samples; triangles - gap located samples)

and/or web-building specimens. Examining the family structures, Linyphiidae was more represented in the D-Vac samples, while Lycosidae and Gnaphosidae were more represented in the pitfall samples. Underrepresentation of Lycosidae in D-Vac samples has been reported in multiple studies (Merrett & Snazell 1983, Dinter 1995). The distribution of body size data showed that the pitfall traps could catch larger species on average, as has been shown in several previous papers (Sunderland et al. 1995, McCravy 2018). The changes in community characteristics along the transects, and the results of the regression analysis show that the effects of the gap openings were more prominent regarding species numbers, specimen numbers and diversity indices, especially using pitfall traps.

Multiple reasons may have caused the differences observed between the sampling methods. One of the more obvious is the duration of each sampling. While pitfall traps were active for 14 days (and nights), the suction sampling took place during one day (in daytime). This means that less abundant and/or nocturnal species (i.e. Gnaphosidae) are more likely to be caught by pitfall traps. The disturbance (vibrations) caused by the suction device may also be responsible for the underrepresentation of hunting spiders (i.e. wolf spiders) in these samples. In addition, smaller and lighter species (Linyphiidae) may be easier to catch using suction sampling, which is in line with the findings of Mommertz et al. (1996). In addition, the D-Vac suction may unable to access those specimens that are under debris (leaf litter, dead wood, stone), or in the topsoil at the time of the samplings (Sunderland et al. 1987).

In summary, we suggest that for ground-dwelling spiders in forest ecosystems - partly because of its habitat's higher structural complexity - the D-Vac suction sampling is more suitable for short-term examinations, while pitfall traps can more effectively conduct the research requiring longer durations. Overall, both methods seem to be adequate to explore the effects of gap openings, but they access somewhat different attributes of the spider community. Pitfall trapping was more sensitive towards larger and/or active hunting species, while suction sampling resulted a higher abundance of web building and/or smaller species. Therefore, in order to gain a more detailed picture on the ground-dwelling spider community of a given area, we suggest their combined use, perhaps with a pitfall focus due to this cheap maintenance and low labour requirements.

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Tab. 4: Linear regression analysis. We considered relationships to be significant at P < 0.05 values (D - distance from the centre of the gaps; independent variable; I – intercept; n – specimen number; S – species number; [mm] – average body size; H' – Shannon diversity; PT – pitfall trapping; DV – suction sampling)

	РТ					DV			
	\mathbb{R}^2	Р	Ι	D		R ²	Р	Ι	D
n	0.1466	0.0367	45.7368	-0.7930	n	0.1376	0.0436	51.6882	-0.5071
S	0.3480	0.0006	9.3421	-0.1576	S	0.0361	0.3147	4.7902	-0.0303
[mm]	0.0010	0.8708	5.2534	0.0015	[mm]	0.1152	0.0665	1.6619	0.0216
H'	0.3843	0.0003	2.0101	-0.0250	H'	0.0460	0.2549	1.3711	-0.0072

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Is cooperation in prey capture flexible in the Indian social spider Stegodyphus sarasinorum?

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Abstract. Among social spiders, cooperation is a key characteristic behaviour. Cooperation in prey capture increases the probability of successful prey capture and to some extent reduces the individual costs associated with foraging. We assessed spider cooperation in prey capture under natural conditions in relation to the number of spiders in the colony and the type and size of the prey captured by the social spider *Stegodyphus sarasinorum* Karsch, 1892 (Araneae: Eresidae). First, we determined natural prey in the spider webs and found that beetles (Coleoptera) were the most frequent prey followed by grasshoppers (Orthoptera). These two prey types were then used to study the cooperative hunting behaviour of this spider. We investigated prey capture frequency, recruitment and immobilization time when spiders are more active in the mornings and less active around midday. The study revealed that the immobilization time and recruitment time were shorter when hunting beetles, the smaller sized prey, while larger numbers of spiders were recruited in response to grasshoppers, the larger prey. The study concluded that cooperative behaviour in *S. sarasinorum* depends on the size of prey present.

Keywords: cooperative behaviour, immobilization, predatory efficiency, recruitment time

Zusammenfassung. Gibt es flexible Kooperation beim Beutefang der indischen sozial lebenden Spinnenart Stegodyphus sarasinorum? Unter sozialen Spinnen gehört Kooperation zum charakteristischen Verhaltensinventar. Kooperation erhöht die Chancen auf erfolgreichen Beutefang und reduziert den individuellen Aufwand, der damit verbunden ist. Wir untersuchten die Kooperation beim Beutefang von Stegodyphus sarasinorum Karsch, 1892 (Araneae: Eresidae) unter natürlichen Bedingungen. Zuerst bestimmten wir die Beute in den Netzen und fanden am zahlreichsten Käfer (Coleoptera) vor Heuschrecken (Orthoptera). Diese beiden Beutetypen dienten dann für genauere Studien des Beutefangverhaltens der Art. Die Häufigkeit und die Dauer des Verhaltens (Beuteerwerb und -fixierung) ist am Morgen höher als in der Mittagszeit. Die Dauer war bei den Käfern, der kleineren Beute, kürzer als bei den Heuschrecken, der größeren Beute. Das Kooperationsverhalten von S. sarasinorum hängt von der Größe der verfügbaren Beute ab.

Among invertebrates, social life has evolved in two taxa: spiders and insects. In spiders, cooperation is considered a characteristic of a social species (Brach 1975, Jackson 1979, Krafft 1970, Riechert et al. 1986). Among the permanently social spiders, there are approximately twenty species of cooperative spiders distributed across seven families and most of them show remarkable convergent evolution of a suite of traits associated with their social way of life (Lubin & Bilde 2007, Bilde & Lubin 2011). The genera *Anelosimus* and *Stegodyphus* contain both social and subsocial species with multiple independent origins of permanent sociality (Agnarsson 2006, Johannesen et al. 2007). In permanent associations, the individuals share the same web and co-operate in different activities: web construction, prey capture, brood care and web maintenance (Lubin & Bilde 2007).

Organisms foraging in groups experience increased foraging efficiency in comparison to solitary foragers by capturing large or greater numbers of prey, reducing the likelihood of prey escape, hunting risk and lower variability in prey capture (Rypstra 1989). Therefore it decreases the individual consumption rate, which buffers the group against starvation (Caraco et al. 1995) and enables an increase in dietary niche (Guevara & Aviles 2007). Also, resource distribution is a key ecological factor influencing group dynamics (Packer & Ruttan 1988). Hence group living increases the competition for resources with group size (Krause & Ruxton 2002, Majer et al. 2018). Because of this, most species of social spiders live in tropical regions of the world and lowland rain forest where

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insect size and density is highest, but several sub-social species reach into the Eastern United States and other temperate areas (Powers & Aviles 2007, Guevara & Aviles 2007). New world *Anelosimus* occur in the most productive continental biome i.e., tropical rain forests while the Old World *Stegodyphus* inhabit drier savannah habitats. Low precipitation seasonality supports abundance in social spiders (Majer et al. 2015). *Stegodyphus* species are restricted to areas with relatively high vegetation productivity and insect biomass (Majer et al. 2013).

Social spider nests can contain hundreds or thousands of individuals, who build communal webs to capture insect prey. The communal two or three-dimensional webs that social spiders build function ecologically as single units that intercept prey through their surface (Aviles 1997). Thus the surface area of this webbing exposed to the environment should determine the frequency with which prey items enter the webs (Majer et al. 2018). It is observed that the mean available web surface per individual decreases from solitary to social species (Jackson 1978, Majer et al. 2018). So it can be assumed that in order to increase their rate of energy removal per individual and per web surface unit social spiders must have developed several strategies. For these purposes social spiders could (a) increase the capture ratio of available prey, (b) enlarge their prey size range and capture very large prey that is not available to solitary spiders or increase their prey size range in relation to dietary niche, or (c) reduce capture web production in relation to colony size (Majer et al. 2018).

Cooperation is expected to be of mutual benefit (Downes 1995), either by direct or indirect (kin-selected) benefits like altruism, mutualism, strong reciprocity and group selection (Lehmann & Keller 2006, West et al. 2007). According to the risk-sensitive foraging theory, group hunting occurs in two situations where average prey availability exceeds the minimum necessary for survival (Uetz & Hieber 1997), or where a single prey item is too large to be consumed by a single

This contribution was presented at the 31st European Congress of Arachnology, Vác, Hungary, 2018 July 8–13

predator. Previous studies described the influence of cooperation on the predatory efficiency of social spiders (Jackson 1979, Krafft 1970, Pasquet & Krafft 1992, Guevara & Avilés 2011, Majer et al. 2018). In Anelosimus, there is a tendency for social species to capture larger prey (Nentwig 1985, Avilés et al. 2007, Guevara et al. 2011). For Stegodyphus the effects are less strong and with increasing group size, per capita foraging rate decreases (Majer et al. 2018). However, more information is needed on cooperation, predatory efficiency and the nature and size of the prey captured in other species in the genus Stegodyphus (Eresidae). In the present study, characteristics of spider cooperation were studied in the Indian cooperative spider Stegodyphus sarasinorum (Karsch, 1892), which is one of three permanently cooperative species in the genus Stegodyphus (Kraus & Kraus 1988). Individuals live in large cooperatively built colonies with a nest or retreat and a sheet web for prey capture (Jackson & Josephs 1973). The aim of this study was to analyse the efficiency and prey immobilizing characteristics of cooperative prey capture under natural conditions in relation to the type and size of the captured prey.

Material and methods Study organism and site

Stegodyphus sarasinorum Karsch, 1892 (Eresidae), is a permanent social spider found in India, Sri Lanka, Nepal and Myanmar (Kraus & Kraus 1988, WSC 2019). It makes large complex silk nest of variable sizes on bushes, shrubs, rocky areas and open fields, where flying insects are abundant (Bradoo 1972). The nest is placed in trees and shrubs or sometimes fences, and made by incorporating the structure, leaves,







Fig. 1: a. Map of the study area at Christ College, Irinjalakuda (red spots = social spider web colonies); **b.** distribution of colony in Eugenia uniflora; c. an individual colony of S. sarasinorum; d. immobilization of the prey

branches, prey remnants and also their own exuviae into the silk nest. The site identified for the study was on the Christ College campus (10.350°N, 76.200°E, 12 m a.s.l., Fig.1a), located in the town of Irinjalakuda in the Thrissur district in Kerala. The study was undertaken during the period of June-September 2017. The observations were made in the field (Fig. 1b-d).

Methods

Natural prey of S. sarasinorum. The natural prey was identified by examining prey remnants (wings, cuticle, mouthparts, etc.) from the nest. We sampled 30 nests for the identification of the natural prey types. Observations were repeated 3 times

in relation to a total number of prey sumplea							
	Coleoptera	Orthoptera	Hymenoptera	Hemiptera	Isoptera	Total	
Remnants of the prey	48 (40%)	26 (22%)	22 (18%)	18 (15%)	6 (5%)	120	
Fresh prey	12 (63%)	5 (26%)	2 (11%)	0	0	19	

Tab. 1: Number of prey sampled from the webs of *S. sarasinorum* (prey remnants sampled and fresh prey captured); in brackets: percentage of each order in relation to a total number of prey sampled

in one month. The type (order) and size of the prey remnants were noted and identified to the order level with the help of taxonomic keys. We selected two natural types of prey based on their size; a beetle (Coleoptera) and grasshopper (Orthoptera).

Time of activity of spiders. The test periods were chosen by observing and recording the activity of spiders in the field at different times of the day (8 am to 5 pm at each hour). Observations were made during 5 days chosen randomly at the beginning of the test. We noted the different activity of spiders including web weaving, prey capture, feeding, etc. Close observation of the spiders in the field revealed increased weaving and prey capturing/feeding activity at 8.00–8.30 am, while a decrease in these activities was found at around 11.00–11.30 am. From these observations, two periods were chosen: active (8.00–8.30 am) and passive (11.00–11.30 am).

Size of the colony. At the end of the experimental period, all spiders were collected and carefully counted. The average numbers of individuals were 85 per colony (range 20 to 130). Efficiency, predation and cooperation of S. sarasinorum. Grasshoppers were captured with a sweep net (Mean Length = 30 mm, SD = 0.366, n = 72), and beetles with a light trap (Mean Length = 20 mm, SD = 0.311, n = 72). Of the 144 tests, 72 tests were carried out during the inactive period and the remaining 72 tests were conducted during the active period. The test was conducted in 9 colonies over 8 days either with an equal amount of grasshoppers or beetles. We placed larger prey (grasshoppers) and smaller prey (beetles) 15 cm away from the nest entrance and observed the spider-hunting behaviour. The main events of prey capture, the number of spiders recruited, recruitment time and prey immobilization time were recorded.

Statistical analysis. A Wilcoxon rank sum test ('W' is the test statistic) was performed to compare the frequencies of capture for the two prey types (grasshoppers and beetles) in the nine colonies, and also for analyzing immobilization time and recruitment time of two prey types during two different periods. The Spearman's rank correlation coefficient was computed to access the relationship between immobilization time and numbers of recruited spiders for subduing the two different prey types. A significance level of 95% was used to indicate the level of significance in the results. Statistical tests were done using the software R (R Core Team 2018).

Results

Natural prey of *S. sarasinorum*. From the nests of all colonies sampled, remnants of 120 insects were collected, identified (to insect order) and measured (Tab. 1). The median size of the prey was 10 mm and the largest prey item reached 50 mm in length. Coleoptera (40%) and Orthoptera (22%) were the most common prey types, followed by Hymenoptera (18%), Hemiptera (15%) and Isoptera (5%). We collected 19 prey in the process of being eaten (median size = 20 mm; the largest

size = 40 mm in length). Coleoptera was the most numerous (63% of total captures). The data show that *S. sarasinorum* catches prey ranging from 10 to 50 mm and a large proportion are Coleoptera and Orthoptera (Tab. 1).

Efficiency, predation and cooperation of *S. sarasinorum*. During the active period (8.00–8.30 am) most of the spiders were occupied outside the nest and some of them fed on prey. But in the passive period (11.00–11.30 am) the number of spiders present outside the nest was less. Whenever prey was placed in the web it created vibrations in the silky threads. These vibrations allow the spider to localize the prey and move asynchronously from the nest towards the prey and entangle the prey by biting different parts of its body. After immobilization, some spiders fed on the prey and some stayed in different parts of the web while others moved into the nest.

It was found that the frequency of reaction to prey did not differ in the 9 cases considered (W = 43.5, p-value = 0.821). Throughout our experiment, we found that the spiders' consumption of a prey item was influenced by vibrations made by the prey and not solely by the differences in the size of grasshoppers and beetles. The immobilization time was higher for grasshoppers than for beetles both in the active (W = 1296, p-value = 2.652 e⁻¹³) and passive (W = 1296, p-value = 2.716 e⁻¹³) periods (Tab. 2 & Fig. 2). Similarly, recruitment time was longer for grasshoppers than for beetles both in active (W = 1296, p-value = 1.58 e⁻¹⁴) and passive (W = 1296, p-value =1.619 e¹⁴) periods (Tab. 2). The spiders always reacted faster to beetles than to grasshoppers (Fig. 2). In the passive periods, there was a tendency towards a positive correlation between the immobilization time and a number of recruited spiders to subdue grasshoppers (Spearman's rank correlation, r = 0.288, p-value = 0.087). In the case of beetles, the correlation between immobilization time and the number of recruited spiders, although numerically negative, did not significantly differ from no-correlation ($r_s = -0.119$, p-value = 0.487). Similarly, in the active periods, both in the case of grasshoppers and beetles immobilization time and number of recruited spiders was not significantly correlated (r = -0.160, p-value = 0.3499; r = -0.064, p-value = 0.706) (Tab. 2).

Tab. 2: Medians of the three different parameters used to explain spider cooperation in prey capture; data presented in relation to spider activity periods and prey types; in bracket: superior and inferior quartiles of the data

	Period Inactive	Active	Prey types Grasshopper	Beetle
Immobilization time	20	10	30	6
(minutes)	(4–60)	(2–30)	(12–60)	(2–15)
No. of spiders	8	9	12	7
recruited	(3–18)	(6–30)	(6–30)	(3–16)
Recruitment time	8.5	3.5	21.5	1
(minutes)	(1–40)	(1–30)	(5–40)	(1–3)



Fig. 2: Immobilization time (minutes) and recruitment time (minutes) of grasshoppers and beetles during the two periods

Discussion

Cooperative social spiders share a communal web and nest where the colonies can extend to group sizes from a few to thousands of individuals (Whitehouse & Lubin 2005). In the case of S. sarasinorum, even those who did not participate in the actual prey capture activities may join in the feeding and feed communally (Bradoo 1980). Among the 30 nests analyzed on the Christ College campus, we found that the most abundant prey of S. sarasinorum was the order Coleoptera (beetles). The second most abundant prey is Orthoptera, which includes grasshoppers. This finding is similar to Majer et al. (2018), where this social Stegodyphus mostly captured the prey from the taxa Coleoptera, Diptera and Hymenoptera and the less abundant prey taxa included Isoptera, Lepidoptera and Orthoptera. Our results confirms that social Stegodyphus species forage in relation to available prey rather than on specific prey types. Pasquet & Krafft (1992) studied the cooperative behaviour in another social spider Anelosimus eximius. This spider captured a large proportion of Orthoptera and Lepidoptera.

Cooperative prey capture behaviour may function to capture prey that is much larger than the body size of the spider predator (Nentwig 1985, Yip et al. 2008), with several individuals within a group feeding on the prey item simultaneously. *Anelosimus eximius* captures larger prey than spiders of similar size but with a less complex organization (Nentwig & Christenson 1986), and also other social *Stegodyphus* increase dietary niche through cooperative prey capture (Majer et al. 2018). This is also confirmed by our result that *S. sarasinorum* can capture larger sized prey (up to 50 mm) than its own body size (7.5 \pm 0.07 mm). Group living and cooperative foraging are hypothesized to expand dietary niche to meet the increasing resource demand of the group and reduce competition, and risk of conflict over the distribution of resources (Ulbrich & Henschel 1999, Majer et al. 2018).

The cribellate web sheets formed by *S. sarasinorum* act as an excellent trap for large insects like locusts, grasshoppers, wasps, beetles, dragonflies, moths and many other kinds of Coleoptera and Hymenoptera, etc. (Bradoo 1972). Once these insects become ensnared in the web, they cannot escape. The struggle of the prey in the web causes web vibrations. The source of vibrations is detected by the vibration receptors located in the legs of the spiders (Walcott & van der Kloot 1959). We did not detect differences in the reaction to prey, suggesting that spiders do not differentiate prey type based on web vibrations.

Pasquet & Krafft (1992) reported that cooperation depends on prey types in *A. eximus.* In *S. sarasinorum* immobilization time and the number of spiders recruited differed between the two prey items in the active and passive periods. The spiders took a longer time to immobilize grasshoppers, as compared to beetles, indicating that larger prey (grasshoppers) requires more effort to subdue. Optimal foraging theory suggests that spiders should invest in the prey that provides the highest energy return. However, social spiders are dependent on the prey that arrives in their webs, and they cannot freely choose a preferred prey type. Our data shows that beetles were more frequent than grasshoppers, and spiders rapidly captured beetles.

Stegodyphus sarasinorum may exhibit two responses to increasing energy needs: it may widen its range of prey by aiming for large-sized insects, and optimize capture efficiency by reducing the time needed to immobilize its prey, which increases its chance of making additional captures. Our study suggests that *S. sarasinorum* uses a different strategy in response to larger prey size, as more spiders were recruited to subdue grasshoppers than beetles during prey capture and prey immobilization. This reflects the fact that grasshoppers are larger and provide more food, and therefore it pays for the spiders to invest more in their capture.

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