Comparison of the species composition of Gamasina mite communities (Acari: Mesostigmata) in selected caves of the Kraków-Częstochowa Upland (southern Poland) and their immediate surroundings

Gabriela Barczyk* and Grażyna Madej

Department of Ecology, University of Silesia, Katowice, Poland

(Received 16 April 2013; accepted 7 October 2014; first published online 1 December 2014)

This paper presents the results of a study performed in eight caves located in the area of the Kraków-Częstochowa Upland. In total, 586 samples (400 cm³ each) were taken from the caves and sites located up to one metre from the main entrances of the caves. Of 109 species belonging to 13 families that were identified, four were species new for Polish fauna. In this study, cluster analysis and correspondence analysis were used to compare the species composition of mite communities living in the caves and their immediate surroundings. We also examined the possibility of isolating troglophilic species based on IndVal analysis. Those results showed distinct differences between Gamasina mites living in two distinct habitats. We also established indicator species for the examined caves.

Keywords: Gamasina mites; Polish caves; statistical analysis; troglophilic species

Introduction

Research on caves is an important element of wider research on the factors contributing to species diversity. Caves are unique yet weakly researched habitats, in particular concerning their fauna, which is dominated by arthropods, including mites. Acarological research in caves has been scarce as a result of taxonomic and methodological difficulties associated with sampling (Ducarme et al. 2003). Mite fauna in European caves has been researched in several studies: Leruth (1939), Lundqvist et al. (1999), Fend‘a and Košel (2000), Ducarme et al. (2003), Ducarme, André, et al. (2004), Mašán and Madej (2011) and Skubała et al. (2013).

To date, mite fauna in Polish caves has not been thoroughly researched with only a few studies on cave mites: Pax and Maschke (1935), Willmann (1936, 1939, 1951), Maschke (1936), Skalski (1967), Dylewska and Błoszyk (2006) and Maślak and Barczyk (2011). The shortage of information about Gamasina mites in subterranean environments was the inspiration for this research.

The aim of this research was to determine the species composition of Gamasina mites inhabiting selected caves and determine if the mites had formed distinct communities and how they differed from communities outside the caves. We also attempted to establish troglophilic species.

*Corresponding author. Email: gabriela.barczyk@us.edu.pl

© 2014 Taylor & Francis
Materials and methods
The material for this study was collected between 2007 and 2009. Eight caves of various sizes were selected: Lodowa Cave (Jaskinia Lodowa), which has upper and lower floors, Schronisko near Lodowa Cave (Schronisko koło Jaskini Lodowej), ‘Under the Lodowa’ Cave (Jaskinia Poniżej Lodowej), Błotna Cave (Jaskinia Błotna), ‘Pod Porzeczką’ Cave (Jaskinia Pod Porzeczką), Studnisko Cave (Jaskinia Studnisko), ‘Under the Sokola Mountain’ Cave (Jaskinia pod Sokolą Górą) and Jasna Cave (Jaskinia Jasna) (Table 1). All the caves were situated in beech-dominated forests. Data were obtained from 586 samples: 316 samples were taken from caves and 270 from sampling sites 1 m from the main entrance to each cave. Mites were extracted a week later using a Tullgren funnel. Species were identified using keys by Michałdzieński (1969), Błaszak (1974), Gilyarov and Bregetova (1977), Hyatt (1980), Hirschmann and Wiśniewski (1982a, 1982b), Dielmann (1991), Karg (1993), Mašán and Fend’a (2004), Mašán (2007), Gwiazdowicz (2007), Mašán and Halliday (2010) and Castihilo et al. (2012). The genus name Paragamasus is used instead of Lysiogamasus, according to Juvara-Bals (2002). Similarity relationships between the species composition of Gamasina fauna at the study sites is demonstrated in a cluster analysis of the Bray–Curtis formula using CAP 4.0 (Community Analysis Package 4) (Seaby and Henderson 2007). In order to determine indicator species for the caves and external sites, the Indicator Value (IndVal) method was used. This method has been described by Dufrêne and Legendre (1997).

IndVal is the result of multiplying the relative abundance (specificity) and relative frequency (fidelity) by 100. The index has a maximum value of 100% when all the individuals of a given species can be found in one group of samples and where the species is present in all samples of this group. IndVal was calculated for the two groups of sampling sites (cave and cave surroundings).

In order to determine the main levels of divisions into groups, a hierarchical classification based on Ward (1963) was used. IndVal was calculated using INDVAL 2.0 software. Randomization was performed for 1000 replicates. Multivariate analysis was carried out to explore relationships between the different habitats and the mite communities inhabiting them. The ordination algorithm used was correspondence analysis (CA) using the CANOCO community ordination program (TerBraak and Šmilauer 2002). The analysis took into account species with more than 100 specimens. The abundance of Gamasina mites was transformed (log[x + 1]) for the ordination analyses.

Results
At the examined sites, 109 mite species were identified, from 13 families (Table 2). In the taxonomic spectrum the most represented families were: Ascidae, Ameroseiidae, Veigaiidae and Ologamaside in the caves, and Zerconidae and Veigaiidae in sites located up to 1 m from the main entrances of the caves. Cluster analysis showed distinct differences in species composition between the communities of mites inhabiting caves and those living outside caves (Figure 1), which was confirmed by the results of CA. The first canonical axis greatly diversified the sites and explained 16.5% of the variability of mite assemblages, dividing them into two groups: those inhabiting caves and those outside. The second canonical axis showed internal differences within the groups. The distribution of species
Table 1. Characteristics of sampling sites.

| Location above sea level of main hole(s) | Lodowa Cave | Schronisko near Lodowa Cave | ‘Under the Lodowa’ Cave | Błotna Cave | ‘Pod Porzeczką’ Cave | Studnisko Cave | ‘Under the Sokola Mountain’ Cave | Jasna Cave |
|-----------------------------------------|-------------|-----------------------------|-------------------------|-------------|---------------------|----------------|---------------------------------|-----------|
| Length (m)                              | 30.5        | 30.6                        | 22.0                    | 140.0       | 67.0                | 337.0          | 70.0                           | 85.0      |
| Depth (m)                               | 5.4         | 4.2                         | 4.3                     | 42.0        | 15.0                | 77.5           | 26.0                           | 0         |
| Denivelation (m)                        | 12.5        | 6.0                         | 7.8                     | 42.0        | 15.0                | 77.5           | 26.0                           | 0         |
| Coordinates                             | 50°20′44.82″ N, 19°35′44.00″ E | 50°20′44.93″ N, 19°35′44.15″ E | 50°20′40.86″ N, 19°35′39.98″ E | 50°20′53.36″ N, 19°35′56.12″ E | 50°43′43.55″ N, 19°16′04.78″ E | 50°43′44.69″ N, 19°16′14.99″ E | 50°24′55.14″ N, 19°41′29.28″ E |
| Exposure of the entrance hole           | NW          | NE                          | W                       | E           | NE, SW              | W              | S                              | NW        |
| Microclimate                            | Static cold* | Mixed Rock shelter          | Static Talus            | Mixed Talus | Static Solution     | Static Solution | Dynamic Solution                 | Dynamic   |
| Types of cave                           | Talus       | Horizontal                 | Vertical                | Vertical    | Horizontal          | Vertical        | Horizontal                     | Easy      |
| Passage growth                          | Horizontal  | Easy                        | Difficult               | Very difficult | Easy              | Very difficult | Very easy                      | Very easy |
| Difficulty level                        | Easy        | Difficult                   |                         |             |                     |                 |                                 |           |
| Frequency of visit                      | Several times a year | Once a few year | Once a few year | Several times a year | Once a year | Several times a month | Once a month | Once a month |
| Abbreviation (cave/surface site)        | LC/bLC      | SC/bSC                      | PLC/bPLC                | BC/bBC      | PC/bPC              | StC/bStC       | SGC/bSGC                       | JC/bJC    |

Note: * applies only to the lower level.
Table 2. The list of Gamasina mite species and the number of specimens at the sampling sites (for abbreviations see Table 1).

| No. | Family/species       | LC | SC | PLC | BC | PC | StC | SGC | JC | bLC | bSC | bPLC | bBC | bPC | bStC | bSGC | bJC |
|-----|----------------------|----|----|-----|----|----|-----|-----|----|-----|-----|------|-----|-----|------|------|-----|
| 1   | Parazercon radiatus  |    |    | 3   |    |    |     |     |    |     |     |      |     |     |      |     |     |
| 2   | Prozercon fimbriatus |    |    | 5   | 7  | 16 | 1   | 1   | 36 | 35  |      |      |     |     |      |     |     |
| 3   | Prozercon kochi      |    |    | 2   | 7  | 2  | 5   | 59  | 14 | 16  | 1   | 1   |     |     |      |     |     |
| 4   | Prozercon selnicki   |    |    | 1   | 2  | 6  | 1   | 1   |     |     |     |     |     |     |      |     |     |
| 5   | Prozercon traegardhi |    |    | 13  | 38 | 3  | 8   | 2   | 3  | 5   | 1   | 1   |     |     |      |     |     |
| 6   | Zercon curiosus      |    |    | 13  | 38 | 3  | 8   | 2   | 3  | 5   |     |     |     |     |      |     |     |
| 7   | Zercon peltatus      |    |    | 15  | 78 | 45 | 3   | 1   | 19 | 6   | 34  | 2    | 2   | 29  | 29   |     |     |
| 8   | Zercon triangularis  |    |    | 2   | 28 | 33 | 6   | 1   | 54 | 25  | 51   | 33   | 33  | 49  | 62   | 56   |     |
| 9   | Zercon jageticola    |    |    | 2   | 2  | 2  | 4   | 2   | 34 | 2   | 49  | 52   |     |     |      |     |     |
| 10  | Zercon vacuus        |    |    | 1   |    | 7  | 8   |     |     |     |     |      |     |     |      |     |     |
| 11  | Zercon arcuatus      |    |    | 1   |    | 1   |     |     |     |     |     |      |     |     |      |     |     |
| 12  | Zercon baloghi       |    |    | 1   | 15 | 6   |     |     |     |     |     |      |     |     |      |     |     |
| 13  | Zercon berlesei      |    |    |     |    |     |     |     |     |     | 5   | 12   |     |     |      |     | 9   |
| 14  | Zercon peltatus      |    |    | 3   | 39 | 29 | 2   | 5   | 4  | 4   | 3   | 3    | 8   |     |      |     |     |
| 15  | Zercon storkani      |    |    | 2   |    | 5   | 12  | 1   | 5   |     |     |      |     |     |      |     |     |

**Parasitidae**

| No. | Family/species       | LC | SC | PLC | BC | PC | StC | SGC | JC | bLC | bSC | bPLC | bBC | bPC | bStC | bSGC | bJC |
|-----|----------------------|----|----|-----|----|----|-----|-----|----|-----|-----|------|-----|-----|------|------|-----|
| 16  | Gamasodes spiniger   |    |    |     |    |    |     |     |    |     |     |      |     |     |      |     |     |
| 17  | Eugamasus cavernicola|    |    |     |    |    |     |     |    |     |     |      |     |     |      |     |     |
| 18  | Eugamasus furcatus   |    |    | 2   |    | 9  | 4   | 4   |     |     |     |      |     |     |      |     |     |
| 19  | Parasitus hortivagus |    |    |     |    |    |     |     | 1  |     |     |      |     |     |      |     |     |
| 20  | Parasitus loricatus  |    |    | 13  | 3  | 5  | 9   | 17  | 117| 2   |     |      |     |     |      |     |     |
| 21  | Poecilochirus carabi |    |    | 2   |    | 4   |     |     |     |     |     |      |     |     |      |     |     |
| 22  | Porrhostaspis lunulata|    |    |     |    |    |     |     |     |     |     |      |     |     |      |     | 18 |
| 23  | Vulgarogamasus kraepelini | 5 | 3 | 9 | 8 | 1 | 5 | 3 | 4 | 11 | 9 | 9 |

(Continued)
| No. | Species                          | Count 1 | Count 2 | Count 3 | Count 4 | Count 5 | Count 6 | Count 7 | Count 8 | Count 9 | Count 10 | Count 11 | Count 12 | Count 13 | Count 14 | Count 15 | Count 16 | Count 17 | Count 18 | Count 19 | Count 20 |
|-----|---------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 25  | Vulgarogamasus maschkeae        | 1       | 1       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 26  | Vulgarogamasus remberti         | 1       | 1       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 27  | Vulgarogamasus niedneri         | 2       | 2       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 28  | Vulgarogamasus cedermanii       | 7       | 4       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 29  | Holoparasitus intermedius       | 11      | 6       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 30  | Holoparasitus cebaii             | 2       | 2       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 31  | Holoparasitus remberti          | 11      | 6       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 32  | Leptogamasus oblongus           | 2       | 2       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 33  | Leptogamasus rectangulatus      | 9       | 18      | 28      |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 34  | Leptogamasus parvulus           | 7       | 2       | 7       |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |         |
| 35  | Leptogamasus (Aclerogamasus) alpestris | 5 | 2 | 7 | | | | | | | | | | | | | | | | | | |
| 36  | Leptogamasus (Aclerogamasus) simillimus | 5 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 37  | Paragamasus (Aclerogamasus) brevicornis | 1 | 1 | 5 | 2 | 2 | 9 | 1 | 1 | | | | | | | | | | | | |
| 38  | Paragamasus (Aclerogamasus) digitatus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 39  | Paragamasus (Androgamasus) brevicornis | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 40  | Paragamasus (Androgamasus) circumfusus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 41  | Paragamasus (Androgamasus) homopodoides | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 42  | Paragamasus (Aclerogamasus) sanguineus | 10 | 3 | 2 | 9 | 8 | 6 | 2 | 2 | 1 | | | | | | | | | | | | |
| 43  | Paragamasus (Aclerogamasus) isoscelus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 44  | Paragamasus (Aclerogamasus) gracilis | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 45  | Paragamasus (Pergamasus) vagabundus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 46  | Paragamasus (Pergamasus) brevicornis | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 47  | Paragamasus (Pergamasus) transversus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 48  | Pergamasus (Pergamasus) mediorudis | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 49  | Pergamasus (Pergamasus) barbatus | 1 | 1 | 5 | | | | | | | | | | | | | | | | | | |
| 50  | Veigaiidae                       | 24      | 1       | 34      | 34      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      | 16      |
| 51  | Veigaiidae cervus                 | 22      | 8       | 16      | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       |
| 52  | Veigaiidae exigua                 | 22      | 8       | 16      | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       | 4       |
Table 2. (Continued).

| No. | Family/species                        | LC | SC | PLC | BC | PC | StC | SGC | JC | bLC | bSC | bPLC | bBC | bPC | bStC | bSGC | bJC |
|-----|---------------------------------------|----|----|-----|----|----|-----|-----|----|-----|-----|------|-----|-----|------|------|-----|
| 53  | Veigaia kochi                         |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 54  | Veigaia nemorensis                    | 77 | 256| 54  | 6  | 81 | 25  | 77  | 27 | 194 | 135 | 274  | 131 | 18  | 253  | 251  | 171 |
| 55  | Veigaia planicola                     | 26 |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 56  | Veigaia transisalae                   |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
|     | **Digamasellidae**                    |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 57  | *Dendrolaelaps* (Punctodendrolaelaps* arvicolus | 17 | 3  | 35  | 3  | 41 | 7   | 46  | 23 | 9   | 1   | 18   | 17  | 13  |      |      |     |
| 58  | *Dendrolaelaps* (Punctodendrolaelaps* rotundus | 1  |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
|     | **Ologamasidae**                      |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 59  | *Cyrtolaelaps chiropterae*            | 1  |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 60  | *Cyrtolaelaps mucronatus*             | 3  | 17 | 4  | 629 | 7  |     |     |    |     |     |      |     |     |      |      |     |
| 61  | *Euryparasitus emarginatus*           | 5  | 2  | 4  | 31  |     |     |     |    |     |     |      |     |     |      |      |     |
| 62  | *Gamasellus montanus*                 |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 63  | *Gamasellus spiricornis*              |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
|     | **Rhodacaridae**                      |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 64  | *Rhodacarus calcarulatus*             |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 65  | *Rhodacarus coronatus*                |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 66  | *Rhodacarus mandibularis*            |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 67  | *Rhodacarellus apophyseus*           |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 68  | *Rhodacarellus silesiacus*           |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
|     | **Macrochelidae**                     |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 69  | *Geholaspis* (Geholaspis* longispinosus |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 70  | *Geholaspis* (Longicheles* mandibularis |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 71  | *Macrocheles* carinatus*              |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |
| 72  | *Macrocheles* montanus*               |    |    |     |    |    |     |     |    |     |     |      |     |     |      |      |     |

(Continued)
|   | Scientific Name                                      |   |
|---|-----------------------------------------------------|---|
| 73| Macrocheles (Macrocheles) tardus                    | 3 |
| 74| Macrocheles (Macrholaspis) dentatus                 | 5 |
| 75| Macrocheles (Macrholaspis) recki                    | 4 |

### Pachylaelapidae

|   | Scientific Name                                      |   |
|---|-----------------------------------------------------|---|
| 76| Pachyseius humeralis                                | 28 |
| 77| Olopachys sucellus                                  | 18 |
| 78| Pachyseius (Longipachyseius) cf. longisetis          | 5  |
| 79| Pachyseius (Longipachyseius) sublongisetis           | 2  |
| 80| Pachyseius (Pachyseius) imitans                     | 5  |
| 81| Pachyseius (Pachyseius) littoralis                  | 2  |
| 82| Pachyseius (Pachyseius) trogophilus                 | 14 |
| 83| Pachyseius (Pachyseius) pectinifer                  | 5  |

### Ameroseiidae

|   | Scientific Name                                      |   |
|---|-----------------------------------------------------|---|
| 88| Ameroseius furcatus                                  | 411|
| 89| Ameroseius plumea                                    | 1  |
| 90| Ameroseius pluminerus                                | 2  |

### Ascidae

|   | Scientific Name                                      |   |
|---|-----------------------------------------------------|---|
| 91| Antennoseius bacatus                                  | 4  |
| 92| Asca aphidioides                                     | 1  |
| 93| Gamasellodes bicolor                                 | 1  |
| 94| Lasioseius lawrencei                                 | 2  |
| 95| Lasioseius muricatus                                 | 2  |

(Continued)
| No. | Family/species                        | sites |
|-----|--------------------------------------|-------|
|     |                                      | LC    | SC | PLC | BC | PC | StC | SGC | JC | bLC | bSC | bPLC | bBC | bPC | bStC | bSGC | bJC |
| 96  | *Arctoseius brevichelis*              |       |    |     |    |    |     |     |    |     |     |      |     |     |      |     |     |
| 97  | *Arctoseius cetratus*                 | 24    | 37 | 71  |    |    | 63  | 34  | 19 | 4   | 1   |     | 1   | 1   |     | 17  |     |
| 98  | *Arctoseius magnanalis*               | 8     | 11 |     |    |    | 8   | 34  | 63 | 19  | 4   |     | 1   | 1   |     |     |     |
| 99  | *Arctoseius venustulus*               | 2     | 5  |     |    |    | 8   | 34  | 63 | 19  | 4   |     | 1   | 1   |     |     |     |
| 100 | *Zerconopsis remiger*                 | 7     | 3  | 1   |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 101 | *Melicheridae*                       |       |    |     |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 102 | *Proctolaelaps pygmaeus*              | 39    | 96 | 74  | 162| 9  | 2   | 12  | 1  |     |     |     |     |     | 4   |     |     |
| 103 | *Eviphididae*                        |       |    |     |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 104 | *Eviphis ostrinus*                    | 2     | 8  | 1   | 3  |    | 7   | 1   | 2  | 2   | 1   | 28  |     |     |     |     |     |
| 105 | *Laelapidae*                         |       |    |     |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 106 | *Gaeolaelaps aculeifer*               | 3     | 15 | 5   | 26 | 3  | 31  | 5   | 2  | 16  | 26  | 7   | 5   | 25  |     |     |
| 107 | *Gaeolaelaps brevipilis*              |       |    |     |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 108 | *Gaeolaelaps nolli*                   | 1     |    |     |    |    | 13  | 9   | 2  | 4   | 5   |     |     |     |     |     |
| 109 | *Haemogamasus nidi*                   | 1     |    |     |    |    |     |     |    |     |     |     |     |     |     |     |     |
| 110 | *Hypoaspis (Alloparasitus) oblonga*   |       |    |     |    |    |     |     |    |     |     |     |     |     | 8   | 7   |     |
| 111 | *Hypoaspis (Alloparasitus) sardoa*    | 4     |    |     |    |    |     |     |    |     |     |     |     | 1   |     |     |
| 112 | *Ololaelaps placentula*               |       |    |     |    |    |     |     |    |     |     |     |     |     | 5   |     |     |
in the ordination space (Figure 2) showed on the right side of the axis species found only in caves, and on the left side those only in external sites. This distribution of species indicates a strong environmental gradient represented by the first canonical axis, which has a significant impact on the observed differences in the species composition between the communities in the examined habitats. The analysis of data made it possible to distinguish indicator species for the two groups of sites, established on the basis of Ward’s method (Figure 1). In group 1, the highest IndVal was observed for two species: *Proctolaelaps pygmaeus* (96.28%) and *Parasitus loricatus* (85.71%), with a statistically confirmed significance (Table 3). These results confirm the results of previous analyses, indicating significant differences in species composition of mite communities found in the studied caves and their immediate surroundings.

Discussion

The spatial variability of the land area covered in this study is key for the understanding of the structure of local mite communities. The presence of caves has a significant effect on the biodiversity, but only detailed research may explain how they influence soil mesofauna and whether it was possible to determine species specific to these habitats. The species found in the examined spaces did not reveal morphological changes characteristic for arthropods of deep caves (Howarth 1983).

Among the species recorded in the Polish underground habitats, we recorded species well known from caves in other countries, some considered as cavernicolous or even troglobite. The indicator species of the examined caves was *Proctolaelaps pygmaeus*. This species has also been discovered in caves in Slovakia (Fend’a and Košel 2000) and Australia (Halliday 2001), and in old mines (Solarz et al. 2002). A high IndVal (96.28%) indicates that in the studied area this species preferred cave
habitats. Despite this, it needs to be remembered that this is a ubiquitous species, present in various types of habitats and substrates.

Among the species which preferred caves, the most abundant was *Cyrtolaelaps mucronatus*. *Cyrtolaelaps* species are mostly nidicolous and common inhabitants of the nests of Micromammalia. *C. mucronatus* is commonly reported in caves (Lundqvist et al. 1999; Fend’a and Košel 2000; Papáč et al. 2006). That species was accompanied by *Cyrtolaelaps chiropterae*, rather scarce in this study. In this research, *Parasitus loricatus* was another species strongly associated with the examined caves. *P. loricatus* is a widespread European species, occurring in compost, dung heaps, rotting vegetation, mushroom beds, small mammal nests, birds’ nests in burrows, holes in trees, mixed forests and caves (Hyatt 1980). The species is broadly distributed in European caves (Leruth 1939; Schmölzer 1995; Lundqvist et al. 1999; Fend’a and Košel 2000; Papáč et al. 2006). In Poland, this species has been previously known in only several caves (Micherdziński 1969) and old mine tunnels (Skubała et al. 2005). A high IndVal (85.71%) confirmed its troglobilic nature. Another indicator species of the studied caves, also with a high IndVal (71.43%), was *Vulgarogamasus kraepelini*, in line with the results of Schmölzer (1995).

---

Figure 2. Diagram of the correspondence analysis (CA) for the sampling sites. The diagram shows only the most important species (for abbreviations see Table 1).
Table 3. Indicator species at two groups of sampling sites.

| Species                        | IndVal | Mean | SD  | t       | Rank | p   |
|-------------------------------|--------|------|-----|---------|------|-----|
| **First group (caves)**       |        |      |     |         |      |     |
| 2 Proctolaelaps pygmaeus      | 96.28  | 51.60| 13.20| 3.386   | 2    | **  |
| 3 Parasitus loricatus         | 85.71  | 36.91| 12.54| 3.893   | 1    | **  |
| 4 Arctoseius cetratus         | 74.79  | 51.55| 11.24| 2.067   | 44   | **  |
| 5 Vulgarogamasus kraepelini   | 71.43  | 29.77| 11.20| 3.719   | 7    | **  |
| 6 Macrocheles montanus        | 68.21  | 31.88| 11.23| 3.237   | 12   | **  |
| 7 Ameroseius furcatus         | 59.66  | 45.03| 12.70| 1.152   | 149  | NS  |
| 8 Euryparasitus enarginatus   | 57.14  | 27.03| 10.72| 2.809   | 23   | NS  |
| 9 Vulgarogamasus oudemansi    | 57.14  | 26.31| 11.09| 2.780   | 31   | **  |
| 10 Cyrtolaelaps mcroronatus   | 56.67  | 35.24| 11.17| 1.918   | 52   | *   |
| 11 Geholaspis longispinosus   | 56.65  | 54.63| 10.95| 0.185   | 368  | NS  |
| 12 Zercon romagniolus         | 54.22  | 53.77| 9.89 | 0.045   | 424  | NS  |
| 13 Prozercon traegardhi       | 51.43  | 47.77| 12.16| 0.301   | 384  | NS  |
| 14 Paragamasus similis        | 49.45  | 32.19| 10.85| 1.591   | 119  | NS  |
| 15 Pachyseius humeralis       | 46.79  | 47.52| 12.33| -0.059  | 475  | NS  |
| 16 Dendrolaelaps arviculus    | 45.53  | 53.69| 7.72 | -1.058  | 871  | NS  |
| 17 Cyrtolaelaps chiropterae   | 42.86  | 21.32| 9.37 | 2.298   | 59   | *   |
| 18 Zercon baleghi             | 42.86  | 21.29| 9.29 | 2.321   | 53   | *   |
| 19 Zerconops remiger          | 42.86  | 21.60| 9.94 | 2.139   | 83   | *   |
| 20 Zerconopsis peltatoides    | 41.62  | 49.83| 12.28| -0.668  | 702  | NS  |
| 21 Veigaia transisale         | 40.06  | 30.35| 11.83| 0.821   | 264  | NS  |
| **Second group (surface sites)** |     |      |     |         |      |     |
| 2 Paragamasus misellus        | 93.28  | 47.40| 12.78| 3.590   | 1    | **  |
| 3 Zercon triangularis         | 86.91  | 56.83| 10.57| 2.847   | 2    | **  |
| 4 Antennoseius bacatus        | 77.78  | 34.81| 10.42| 4.124   | 6    | **  |
| 5 Geholaspis mandibularis     | 75.88  | 47.50| 10.73| 2.646   | 24   | **  |
| 6 Zercon peltatus peltatus    | 75.37  | 51.61| 11.55| 2.058   | 46   | **  |

(Continued)
Table 3. (Continued).

| Species                        | IndVal | Mean  | SD   | t      | Rank | p   |
|--------------------------------|--------|-------|------|--------|------|-----|
| 7 Gaeolaelaps aculeifer        | 68.87  | 53.81 | 7.92 | 1.901  | 56   | *   |
| 8 Asca aphidioides             | 66.71  | 43.65 | 10.45| 2.206  | 38   | **  |
| 9 Vulgarogamasus kraepelini    | 66.67  | 31.64 | 10.93| 3.205  | 19   | **  |
| 11 Veigaia exigua              | 65.92  | 56.03 | 9.14 | 1.082  | 159  | NS  |
| 12 Veigaia nemorensis          | 62.63  | 56.07 | 4.45 | 1.472  | 98   | NS  |
| 13 Eviphis ostrinus            | 58.86  | 49.06 | 12.78| 0.767  | 188  | NS  |
| 14 Prozercon kochi             | 58.11  | 47.00 | 13.89| 0.880  | 231  | NS  |
| 15 Rhodacarus mandibularis     | 55.56  | 29.38 | 11.05| 2.368  | 55   | *   |
| 16 Gaeolaelaps nolli           | 53.47  | 33.26 | 11.67| 1.732  | 55   | *   |
| 17 Rhodacarellus silesiacus    | 52.84  | 37.41 | 12.20| 1.264  | 107  | NS  |
| 18 Olophys suecicus            | 52.42  | 51.12 | 8.45 | 0.154  | 361  | NS  |
| 19 Zercon curiosus             | 52.30  | 32.29 | 11.73| 1.706  | 118  | *   |
| 20 Parazercon radiatus         | 49.23  | 33.07 | 12.09| 1.336  | 143  | NS  |
| 21 Pergamasus barbarus         | 48.85  | 50.36 | 10.36| –0.145 | 474  | NS  |
| 22 Holoparasitus calcaratus    | 44.44  | 25.79 | 10.84| 1.720  | 87   | *   |
| 24 Pachydellus furcifer        | 43.75  | 45.27 | 11.59| –0.131 | 491  | NS  |
| 25 Pergamasus mediocris        | 42.18  | 44.99 | 12.38| –0.227 | 582  | NS  |

Note: IndVal – the IndVal index, t – the result of a $t$-test computing the weighted distance between randomized values and the observed values, Rank – the rank of the observed value among the decreasingly ordered randomized value distribution. **The results of both tests were statistically significant, *the results of one test was statistically significant, NS – not statistically significant, means denote mean IndVal from random permutations. The table shows only the most important species, with IndVal > 40%.
Among the species recorded in the examined caves, we recorded well-known cave species from other countries, some considered as cavernicolous or even troglobite. The species found only in the studied caves are: Zercon baloghi (Mašán and Fend’a 2004), Eugamasus cavernicola (Gilyarov and Bregetova 1977; Hyatt 1980), Parasitus hortivagus (Karg 1993), Vulgarogamasus maschkeae (Micherdziński 1969), Vulgarogamasus remberti (Micherdziński 1969), Vulgarogamasus oudemansi (Maschke 1936; Willmann 1951; Lundqvist et al. 1999; Fend’a and Košel 2000), Euryparasitus emarginatus (Lundqvist et al. 1999) and Haemogamasus nidii (Baggini and Pavan 1955). The species found both in the studied caves and in their surroundings are Eugamasus furcatus (Micherdziński 1969), Pergamasus crassipes (Baggini and Pavan 1955, Micherdziński 1969), Veigaia kochi, Veigaia transisalae (Schmölzer 1995) and Gaeolaelaps aculeifer (Schmölzer 1995; Papáč et al. 2006). Porrhostaspis lunulata was usually found in caves (Leruth 1939; Micherdziński 1969; Hyatt 1980; Skubala et al. 2013), although in our study it was present only in sampling sites outside the caves. Based on the lists of previously identified species of Mesostigmata in Poland (Blaszk and Madej 1997; Skorupski 2008), in the collected material four new species for Polish fauna were found: Paragamasus arcuatus – a species found only at the site directly in front of Schronisko near Lodowa Cave, Parasitus hortivagus – a species found only at the ‘Under the Lodowa’ Cave, Pachylaelaps sublongisetis – found at four sites (‘Under the Lodowa’ Cave and in front of the following caves: Lodowa Cave, Studnisko Cave, and ‘Under the Sokola Mountain’ Cave) and Pachyglobolaelaps hallidayi – a species exclusive to the immediate vicinity of the Jasna Cave.

Comparative analysis of mite communities in the caves and their immediate surroundings showed differences in the species composition between these sites. A greater diversity of mites occurred near the caves, similar to a study by Culver and Sket (2000). Classification analysis and canonical analysis (CA) indicated large differences in the species composition between the mite communities living in caves, even though some of the caves were connected or existed in the same rock mass. Cave communities showed greater specificity than communities outside caves.

The use of IndVal helped to distinguish indicator species for the examined sites. The IndVal method has been used before in the analysis of Mesostigmata mites communities, by Ducarme, Wauthy, et al. (2004) and Salmane and Brumelis (2008). Based on the obtained results one cannot unambiguously indicate troglophilic species. In fact, IndVal indicated those species with a high level of ecological plasticity and adaptability that were well tolerant to the specific abiotic factors in the caves. Species found in the studied caves have often been found in non-subterranean habitats. The exception is Parasitus loricatus, the only species which could be classified as troglophilic. That is why IndVal may be more helpful in the determination of ecological preferences of a given species but does not give ground for global conclusions.

Analysis of available literature and obtained results also showed difficulties with the classification of Gamasina mites as troglobionts or troglophiles. Many mite species originally described as troglobionts or troglophilic species were later found outside the cave environment. The reason may be the still insufficient body of acarological research in caves. Especially in Poland, mite fauna inhabiting these specific habitats has been weakly researched. However, these habitats are essential for understanding the ecology of mites.
Acknowledgements

The authors would like to thank Prof. C. Blaszk for suggestions regarding the article. This paper is part of the first author’s PhD thesis and was supported by research grant [No: N N304 319236] from Polish Ministry of Science and Higher Education.

References

Baggini A, Pavan M. 1955. Studi sugli Scorpioni. Ital J Zool. 22:329–340.
Blaszk C. 1974. Zerconidae (Acari, Mesostigmata) Polski. Monografie Fauny Polski. Tom.3. Warszawa, Kraków: Polska Akademia Nauk, Zakład Zoologii Systematycznej i Doświadczalnej, PWN.
Blaszk C, Madej G. 1997. Gamasida: Antennophorina, Microgyniina, Sejina, Gamasina. In: Razowski J, editor. Checklist of animals of Poland. Vol. IV, Part I–XXXI Porifera – Symphyla. Kraków: Wydawnictwo Instytutu Systematyki i Ewolucji Zwierząt PAN; p. 190–202.
Castilhlo RC, De Moraes GJ, Halliday RB. 2012. Catalogue of the mite family Rhodacaridae Oudemans, with notes on the classification of the Rhodacaroidea (Acari: Mesostigmata). Zootaxa. 3471:1–69.
Culver DC, Sket B. 2000. Hotspots of subterranean biodiversity in caves and wells. J Cave Karst Stud. 62:11–17.
Dielmann M. 1991. Zur Taxonomie der Raubmilben (Acari: Gamasina) unter besonderer Berücksichtigung der Gattung Pergamasus Berlese, 1904 [dissertation]. Karlsruhe: Universität Karlsruhe.
Ducarme X, André H, Wauthy G, Lebrun, P. 2004. Comparison of endogeic and cave communities: microarthropod density and mite species richness. Eur J Soil Biol. 40:129–138. doi:10.1016/j.ejsobi.2004.10.003
Ducarme X, Michel G, Lebrun P. 2003. Mites from Belgian Caves: an extensive study. Subterranean Biol. 1:13–23.
Ducarme X, Wauthy G, André HM, Lebrun P. 2004. Survey of mites in caves and deep soil and evolution of mites in these habitats. Can J Zool. 82:841–850. doi:10.1139/z04-053
Dufrêne M, Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monograph. 67:345–366.
Dylewska M, Błaszynski J. 2000. Roztoče (Acarina: Mesostigmatida) jaskyň Slovenského raja. In: Mockovský M, Kovač L, Fulín M, editors. Fauna jaskýň [Fauna of the caves]. Zborník referátov. Košice: Východoslovenské múzeum; p. 21–30.
Gilyarov MS, Bregetova NG. 1977. Key to the soil inhabiting mites. Mesostigmata Leningrad: Nauka. Russian.
Gwiazdowicz DJ. 2007. Ascid mites (Acari, Mesostigmata) from selected forest ecosystems and microhabitats in Poland. Poznań: Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego.
Halliday RB. 2001. Mesostigmatid mite fauna of Jenolan Caves, New South Wales (Acari: Mesostigmata). Aust J Entomol. 40:299–311. doi:10.1046/j.1440-6055.2001.00247.x
Hirschmann W, Wiśniewski J. 1982a. Weltweite Revision der Gattungen Dendrolaelaps Halbert 1915 und Longoseius Chant 1961 (Parasitiformes). Beschreibung der Untergattungen und Arten, Bestimmungstabellen, Chaetotaxie, Porotaxie. Acarologie, Nürnberg, 29–1
Hirschmann W, Wiśniewski J. 1982b. Weltweite Revision der Gattungen *Dendrolaelaps* Halbert 1915 und *Longoseius* Chant 1961 (Parasitiformes). Artenverzeichnisse, Krankheiten, Missbildungen, Inseminationsapparate, Abbildungen. Acarologie, Nürnberg, 29-II, (94 tabl).

Howarth FG. 1983. Ecology of cave arthropods. Annu Rev Entomol. 28:365–389. doi:10.1146/annurev.en.28.010183.002053

Hyatt KH. 1980. Mites of the subfamily Parasitinae (Mesostigmata: Parasitidae) in the British Isles. Bull Br Museum Nat Hist. 38:1–378.

Juvara-Bals I. 2002. A revision of the genus *Heteroparasitus* new status, with the description of *Heteroparasitus (medio parasititus) athiasae* subgen. sp. n. from Spain and with a key to the genera of Pergamasinae (Acari, Gamasida, Parasitidae). Rev Suisse Zool. 109:23–46.

Karg W. 1993. Acari (Acarina), Milben Parasitiformes (Anactinochaeta) Cohors Gamasina Leach Raußmilben. Fischer, Jena, Germany: Die TierweltDeutschlands 59.

Leruth R. 1939. La biologie du domainesouterrain et la faunecavernicole de la Belgique. Mémoire du Musée royal d’Histoire naturelle de Belgique. 87:396–418.

Lundqvist L, Hippan H, Koponen S. 1999. Invertebrates of Scandinavian caves. IX. Acari: Mesostigmata (Gamasina), with a complete list of mites. Acarologia. 40:357–365.

Mašán P. 2007. A review of the family Pachylaelapidae in Slovakia, with systematic and ecology of European species (Acari: Mesostigmata: Eviphidoidea). Bratislava: Institute of Zoology Slovak Academy of Sciences.

Maschke K. 1936. Höhlenfauna des Glatzer Schneeberges. 5. Die Metazoenaufauna der Bergwerke bei Mährisch-Alstadt. Beiträge zur Biologie des Glatzer Schneeberges. 2:175–191.

Mašák M, Barczyk G. 2011. Oribatid mites (Acari, Oribatida) in selected caves of the Kraków-Wieluń Upland (southern Poland). Biol Lett. 48:107–116. doi:10.1098/rsbl.2010.0111

Micherdziński W. 1969. Die Familie Parasitidae Oudemans 1901 (Acarina, Mesostigmata). Kraków: Zakład Zoologii Systematycznej PAN. Państwowe Wydawnictwo Naukowe.

Papáč V, Kováč L, Mock A, Košíel V, Fend’a P. 2006. Terestrické článkonožce (Arthropoda) vybraných jaskýň SliečkejPlániny.Výskum, využívania ochrana jaskýň 5, zborník referátov, SJJ, Demänovská dolina 2005, Liptovský Mikuláš p. 187–199.

Pax F, Maschke K. 1935. Die Höhlenfauna des Glatzer Schneeberges. I. Die rezente Metazoenaufauna. Beiträge zur Biologie des Glatzer Schneeberges, Breslau. 1:4–72.

Salmane I, Brumelis G. 2008. The importance of the moss layer insustaining biological diversity of Gamasina mites in coniferous forest soil. Pedobiologia. 52:69–76. doi:10.1016/j.pedobi.2008.03.002

Schmolzer K. 1995. Catalogus faunae Austriae. Einsystematisches Verzeichnisaller auf österreichischem Gebiet festgestellten Tierarten. Teil IX f: U.- Ordn.: Anactinochaeta (Parasitiformes). Wien: Verlag der Österreichischen Akademie der Wissenschaften.

Seaby RMH, Henderson PA. 2007. CAP ver.4 (Community Analysis Package 4), Version 4.0; Pisces Conservation Ltd.

Skalski AW. 1967. Charakterystyka współczesnej fauny Szczeliny Choczołowskiej w Tatrach. Prace Muzeum Ziemi. 11:281–287.

Skorupski M. 2008. Wykaz gatunków Acari: Mesostigmata. In: Bogdanowicz W, Chudzicka E, Pilipuk I, Skibińska E, editors. Fauna Polski- charakterystyka i wykaz gatunków. 3. Warszawa: Muzeum i Instytut Zoologii PAN; p. 64–76.
Skubała P, Dethier M, Madej G, Solarz K, Mąkol J., Kaźmierski, A. 2013. How many mite species dwell in subterranean habitats? A survey of Acari in Belgium. Zoologischer Anzeiger – A Journal of Comparative Zoology. 252:307–318. doi:10.1016/j.jcz.2012.09.001

Skubała P, Madej G, Solarz K, Kłyś G. 2005. Old mine underground galleries as the habitat for mites (Acari). In: Tajovský K, Schlaghamerský J, Pižl V, editors. Contributions to Soil Zoology in Central Europe I. Proceedings of the 7th Central European Workshop on Soil Zoology, České Budějovice; 2003 Apr 14–16. České Budějovice: Institute of Soil Biology, Academy of Sciences of the Czech Republic; p. 141–147. ISBN 80-86525-04-X.

Solarz K, Madej G, Żbikowska-Zdun K, Dudziak G. 2002. Mites of orders Acaridida, Gamasida and Oribatida in coal mines of upper Silesian region (Poland). In: Ignatowicz S, editor. Postępy polskiej akarologii. Warszawa: SGGW; p. 179–191.

Ter Braak CJF, Šmilauer P. 2002. CANOCO Reference Manual and User’s Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5). Ithaca (NY): Microcomputer Power.

Ward JH. 1963. Hierarchical grouping to optimize an objective function. J Am Stat Assoc. 58:236–244. doi:10.1080/01621459.1963.10500845

Willmann C. 1936. Die Milben der Reyersdorfer Höhle. Mitten für Höhlen- und Karstforschung. 3:123–124.

Willmann C. 1939. Die Moorfaune des Glatzer Schneeberges. 3. Die Milben der Schneebergmoore. Beiträge zur Biologie des Glatzer Schneeberges, Breslau. 5:427–458.

Willmann C. 1951. Die hochalpine Milbenfauna der mittleren Hohen Tauren insbesondere des Grossglockner-Gebietes (Acari). Bonner Zoologische Beiträge. 2:141–176.