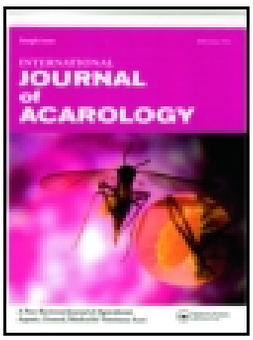

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Mites *Trichouropoda* and *Uroobovella* spp. (Uropodoidea) phoretic on bark beetles (Scolytinae): a comparison from a declining mountain spruce forest in Central Europe

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ABSTRACT

Mites of the genera *Trichouropoda* and *Uroobovella* are characteristic associates of bark beetles which act as agents of their dispersal in many types of forest ecosystems worldwide. We compared the phoretic assemblages of *Trichouropoda* and *Uroobovella* mites on six species of bark beetle associated with Norway spruce (*Picea abies* (L.) Karsten), namely: *Dryocoetes autographus* Ratzeburg, *Hylastes cunicularius* Erichson, *Hylurgops palliatus* (Gyllenhal), *Ips typographus* (Linnaeus), *Pityogenes chalcographus* (Linnaeus) and *Polygraphus poligraphus* (Linnaeus). Bark beetles were caught at random in non-baited flight-interception traps set in the shrub layer of a declining mountain spruce forest in the Tatra Mountains, West Carpathians, Central Europe. Over four years of a bark beetle outbreak, a total of six species of mites and 12 phoretic associations between mites and beetles were recorded. A newly documented host association includes that of *Trichouropoda pecinai* Hirschmann & Wiśniewski with *H. palliatus*. The most frequently recorded mite-beetle associations were: *T. pecinai* with *H. cunicularius, Trichouropoda obscura* (Koch) with *H. palliatus, Trichouropoda polytricha* (Vitzthum) with *P. chalcographus* and *I. typographus* and *Uroobovella vinicolora* (Vitzthum) with *D. autographus*. The results suggest that most of the recorded mite species have distinct bark beetle dispersants and that niche partitioning in these dispersants may be reflected by the observed mite–host associations.

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Introduction

Mites of the superfamily Uropodoidea (Acari: Mesostigmata: Uropodina) occur in the litter and soil (Wiśniewski and Hirschmann 1993; Mašán 2001; Gwiazdowicz et al. 2015), ephemeral patchy habitats like decaying and rotten wood, bird and mammal nests (Mašán 2001; Błoszyk et al. 2006) or flower heads (Roets et al. 2007). They are among the most frequently collected mite associates of bark beetles (Coleoptera: Curculionidae: Scolytinae) (Knee et al. 2012) found in beetle galleries (Kaczmarek et al. 1992; Kaczmarek and Michalski 1994; Gwiazdowicz 2008) or directly on beetles (Hirschmann 1971; Kofler and Schmölzer 2000) which provide means of dispersal for deutonymphs.

Trichouropoda (Trematuridae) and *Uroobovella* species (Urodinychidae) are typical representatives of uropodoids phoretic on bark beetles. A wide distribution (Moser, Perry et al. 1989; Mašán 2001), development in various tree species (Hirschmann 1971; Wiśniewski and Hirschmann 1993) and phoretic ties to more than one species of bark beetle (Hirschmann 1971; Kiełczewski et al. 1983; Knee et al. 2012) enable the study of ecological plasticity of these mites in various environments and habitats.

Investigations of *Trichouropoda* and *Uroobovella* mites on bark beetles provide valuable data not only about the host utilization by mite species (cf. Kršiak, Zach, Kulfan 2009; Knee et al. 2012; Gwiazdowicz et al. 2015). Detailed knowledge of ecology and, in particular, habitat/microhabitat requirements of bark beetles, available for most species in Europe and especially for pests (Pfeffer 1955; Jakuš 1995, 1998; Wermelinger 2004; Lieutier et al. 2007), may be used to determine less well-known microhabitats of mite species, provided phoretic ties between the representatives of the two groups are known.

Herein, we focus on the *Trichouropoda* and *Uroobovella* mite species associated with bark beetles infesting Norway spruce. In spruce forests within Europe, these and many other mesostigmatid mites are mostly studied on *Ips typographus* (Linnaeus) obtained through pheromone trapping (Moser and Bogenschütz 1984; Moser, Eidmann et al. 1989; Feketeová 2011a, 2011b; Gwiazdowicz et al. 2011, 2012, 2015; Čejka and Holuša 2014a) and less frequently on beetles other than *I. typographus* (Hirschmann 1971; Kaczmarek et al. 1992; Kofler and Schmölzer 2000; Kršiak and Zach 2007; Kršiak, Zach, Jakuš 2009; Kršiak, Zach, Kulfan 2009). *Trichouropoda* and *Uroobovella* mites have not yet been compared between species of bark beetle developing in Norway spruce, and their host records (e.g. Hirschmann 1971; Kiełczewski et al. 1983; Wiśniewski and Hirschmann 1993; Kofler and Schmölzer 2000; Gwiazdowicz and Gutowski 2012; Gwiazdowicz et al. 2015) are hardly comparable as they come from different areas and habitats or were obtained by different methods and with unequal efforts.

Trichouropoda and *Uroobovella* mite species may be transported by several bark beetle associates of Norway spruce. The widely spread mite *Trichouropoda polytricha* (Wiśniewski and Hirschmann 1993; Moser et al. 1997), for example, has been collected from *I. typographus, Ips amitinus* (Eichhoff), *Ips duplicatus* (Sahlberg), *P. chalcographus, H. palliatus* and *D. autographus* (Moser, Eidmann et al. 1989; Gwiazdowicz et al. 2011, 2015; Knee et al. 2012; Čejka and Holuša 2014b). Some of these beetles, however, could transport *T. polytricha* more frequently and more abudantly or they could transport other mite species.

Using quantitative data from a declining mountain spruce forest in Central Europe, collected during a bark beetle outbreak, we addressed the question of whether or not the phoretic assemblages of mites within the genera *Trichouropoda* and *Uroobovella* differ between *D. autographus, H. cunicularius, H. palliatus, I.*

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typographus, P. chalcographus and *P. poligraphus* – six species of bark beetle occupying specific niches and exploiting specific resources in spruce trees (Pfeffer 1955; Schlyter and Anderbrant 1993; Jakuš 1995, 1998; Peltonen and Heliövaara 1999; Hedgren 2004). Most of the beetles examined are widely distributed pests of Norway spruce, and *I. typographus* and *P. chalcographus* are among the top 10 most important pests within the bark and wood boring insects in living trees in Europe (Grégoire and Evans 2007). Two mite associates of *I. typographus* within the genera *Trichouropoda* and *Uroobovella, T. polytricha* and *U. ipidis*, are known to transmit spruce-pathogenic fungi (Moser, Perry et al. 1989; Moser et al. 1997).

It is hypothesized that niche partitioning of the given six species of bark beetle will be reflected by the composition of their phoretic assemblages of *Trichouropoda* and *Uroobovella* mites.

Material and methods

Study area

The study was carried out in the Tatra Mountains, West Carpathians, Central Europe. The mountain area (Tichá, Bielovodská, Velická and Tomanova dolina valley, approximately 170 km^2, 1100–1360 m a.s.l.) is represented by mature Norway spruce-dominated (about 95% dominance) semi-natural and natural mountain forests (Eu-Vaccinio-Picenion Oberd. 1957). The forest structure is modified by forestry practices in lower altitudes, and by wind, avalanches and bark beetles within the entire area. The local bark beetle outbreaks in the study area in 2004 and 2005 were followed by a large-scale outbreak of *I. typographus* between 2006 and 2007. This outbreak resulted from highly excessive wind disturbance on 19th November 2004 (Zach et al. 2010).

Sampling of bark beetles and uropodoid mites

Flying bark beetles were collected between 15 May and 30 September 2004–2007 during the progradation and culmination phase of bark beetle outbreak. Every year, they were caught in non-baited flight interception traps set in stands (situations) with all trees, 30–40% of trees and no trees felled by the wind (seven traps in each situation, $n = 21$). The traps consisted of the cover, two transparent acrylic panes (40 by 60 cm) crossed at right angles, a circular dark green funnel (diameter 40 cm) placed below the panes, and a white collector with water and a small amount of coarse salt as conservant. They were attached to poles or barkless trees at heights of 1.3–1.6 m (measured from the ground to the lower margin of panes) and were emptied monthly.

In the laboratory, bark beetles were separated from other trapped invertebrates and organic detritus (needles, fragments of bark, twigs and lichens) deposited in the traps. Beetles with and without mites were separated, counted and identified according to Pfeffer (1995). Beetles with mites were placed individually into vials containing 70% ethanol. Mites (deutonymhs) were extracted from beetles manually using forceps, slide mounted using Liquido de Swann mounting medium, examined using Leica DM 1000 and PZO SK 14 microscopes and identified according to Mašán (2001).

Data analysis

To characterize the associations of *Trichouropoda* and *Uroobovella* mite species and their bark beetle dispersants during a bark beetle outbreak, abundance data from the 4 years (numbers of beetles and mites) were analysed as one data set. The proportion of beetles carrying mites was expressed as a percentage of all beetles of a certain species sampled. The frequency of occurrence and the relative dominance of mite species documented on bark beetles were calculated for each species of the beetle.

A bipartite graph (Dormann et al. 2008) was constructed to illustrate the ties between mite and bark beetle species. Cluster analysis (algorithm average linkage) was employed to measure the dispersion of phoretic mites on particular bark beetle dispersants using Morisita's overlap index (Morisita 1959). Drawing the graph and the clustering were performed in R (R Development Core Team 2014) with the use of the community ecology package vegan (Oksanen et al. 2013).

Results

A total of 1746 uropodoid mites of six species, *Trichouropoda pecinai, Trichouropoda obscura, Trichouropoda polytricha, Trichouropoda tuberosa, Uroobovella vinicolora* and *Uroobovella ipidis*, were found attached to 941 (10%) individuals of the 9403 *H. cunicularius, H. palliatus, P. chalcographus, I. typographus, D. autographus* and *P. poligraphus* examined.

The proportion of bark beetle dispersants (%), the frequency of occurrence (F%) and the relative dominance (D%) of mite species on particular hosts (ordered by transfer efficacy for mites: highest – lowest) was as follows:

Hylastes cunicularius

A total of 567 *H. cunicularius* (16%, $n = 3542$) transported a total of 1110 mites of four species. *Trichouropoda pecinai* was most frequent (F = 96.5%, n = 567) and most abundant (D = 94.2 %, n = 1110) on infested beetles, followed by *T. obscura* (F = 8.5%, D = 5.2%), *U. vinicolora* (F = 1.1%, D = 0.5%) and *U. ipidis* (F = 0.2%, D = 0.1%).

Hylurgops palliatus

A total of 244 *H. palliatus* (13.4%, n = 1818) carried a total of 429 mites, of which *T. obscura* was most frequent (F = 99.6%, n = 244) and most abundant (D = 99.5%, n = 429), followed by *T. pecinai* (F = 0.4%, D = 0.5%).

Pityogenes chalcographus

A total of 60 *P. chalcographus* (4.7%, n = 1270) transferred a total of 97 mites. All of them were a single species *T. polytricha*.

Ips typographus

A total of 45 *I. typographus* (3.8%, n = 1189) carried a total of 70 mites of two species, of which *T. polytricha* was most frequent (F = 91.1%, n = 45) and most abundant (D = 85.7%, n = 70), followed by *U. vinicolora* (F = 20%, D = 14.3%).

Dryocoetes autographus

A total of 19 *D. autographus* (2.8%, n = 670) held a total of 28 mites of two species. The mite *U. vinicolora* was most frequent (F = 84.2%, n = 19) and most abundant on the beetle (D = 75%, n = 28), followed by *U. ipidis* (F = 15.8%, D = 25%).

Polygraphus poligraphus

A total of 6 *P. poligraphus* (0.7%, n = 914) transported a total of 12 mites, all representing the species *T. tuberosa*.

In summary, a total of 12 associations of *Trichouropoda* and *Uroobovella* mite species and their bark beetle dispersants have been documented (Figure 1). The associations differed between species of bark beetle; however, two species, *I. typographus* and *P. chalcographus*, shared a similar mite fauna dominated by *T. polytricha* (Figure 2).

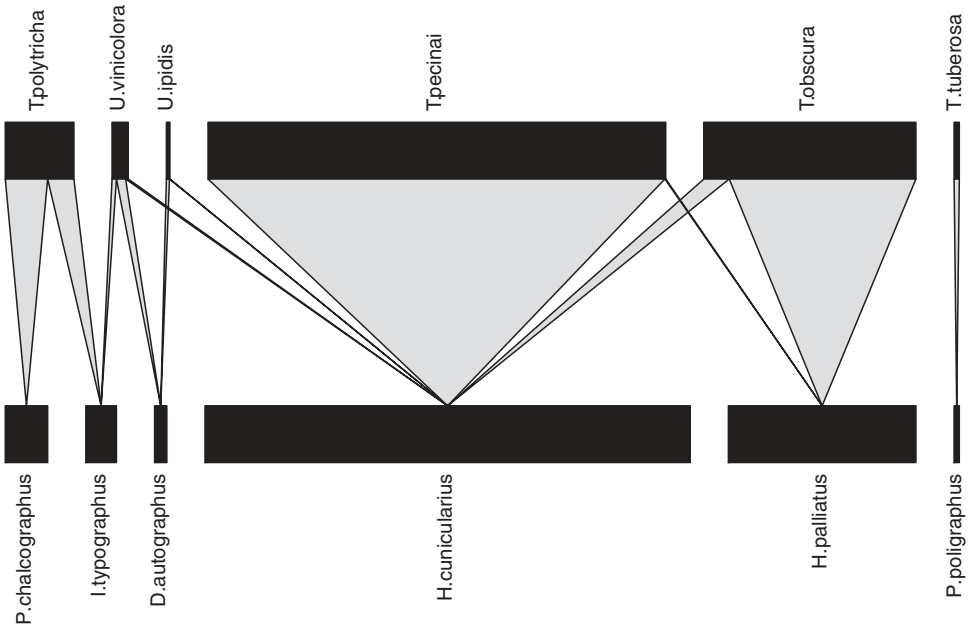

Figure 1. A bipartite graph illustrating the 12 phoretic associations between mite and bark beetle species (6 × 6 species matrix) in a mountain spruce forest during a bark beetle outbreak. Rectangles represent species, and the width is proportional to the sum of interactions involving particular species. Interacting species are linked by triangles with the size proportional to the number of interactions. Tatra Mountains, Central Europe, 2004–2007.

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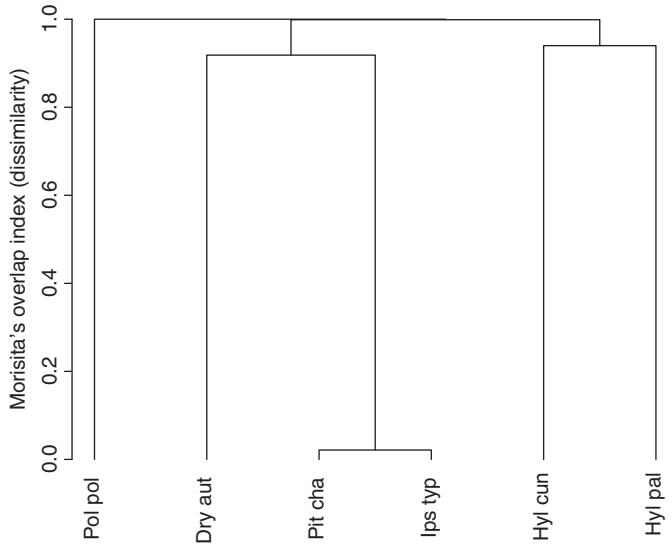

Figure 2. Clustering six species of bark beetle by six *Trichouropoda* and *Uroobovella* species phoretic on them. Cluster analysis, average linkage, Morisita's overlap index. Pol pol – *Polygraphus poligraphus*, Dry aut – *Dryocoetes autographus*, Ips typ – *Ips typographus*, Pit cha – *Pityogenes chalcographus*, Hyl pal – *Hylurgops palliatus*, Hyl cun – *Hylastes cunicularius*. Tatra Mountains, Central Europe, 2004–2007.

The frequent mite–beetle associations were the following: *T. pecinai* with *H. cunicularius, T. obscura* with *H. palliatus, T. polytricha* with *P. chalcographus* and *I. typographus, U. vinicolora* with *D. autographus*. Other associations were infrequent, and some of them relatively rare (e.g. *T. pecinai* with *H. palliatus, T. tuberosa* with *P. poligraphus*).

Discussion

Most mite–bark beetle associations in this study are already known from spruce forests within Europe (Hirschmann 1971; Kiełczewski et al. 1983; Moser and Bogenschütz 1984; Moser, Eidmann et al. 1989; Kaczmarek et al. 1992; Wiśniewski and Hirschmann 1993; Kaczmarek and Michalski 1994; Kofler and Schmölzer 2000; Mašán 2001; Kršiak and Zach 2007; Kršiak, Zach, Jakuš 2009; Kršiak, Zach, Kulfan 2009; Gwiazdowicz et al. 2011, 2012, 2015; Feketeová 2011a, 2011b; Gwiazdowicz and Gutowski 2012; Knee et al. 2012). A newly documented association includes the infrequent relationship of *T. pecinai* with *H. palliatus*. Of the beetles examined, *H. cunicularius* had highest transfer efficacy (highest proportion of phoronts) for the *Trichouropoda* and *Uroobovella* mites in the shrub layer of mountain forest in decline, whereas the efficacy of *P. poligraphus* was lowest.

Microhabitats of bark beetles have no sharp boundaries, and the degree of overlap in resource use varies among species of bark beetle that co-occur within brood trees (Økland et al. 2009). The occurrence of *T. polytricha* on both *I. typographus* and *P. chalcographus* separates these two scolytines with well-documented niche overlap (Hedgren 2004; Byers 2007; Økland et al. 2009) from the other four species of bark beetle in this study. In mountain areas of Central Europe, *I. typographus* and *P. chalcographus* prefer open-canopy, often wind-disturbed spruce forests, colonizing standing and/or lying trees exposed to solar radiation (Zumr 1984). The association of *U. vinicolora* with *I. typographus/ D. autographus* may reflect spatial proximity and certain overlap of microhabitats of these two scolytine species in spruce trunks (P. Zach, personal observation). *Polygraphus poligraphus*, an infrequent dispersant of *T. tuberosa* in the study area, typically, is associated with shaded standing spruce trees in close-canopy forests (Pfeffer 1955) and does not occur together with *I. typographus* under the bark of infested trees (Kula and Zabecki 2010). The scolytine *H. palliatus*, frequently dispersing *T. obscura*, also requires shade (Peltonen and Heliövaara 1999), preferring moist trunks or logs on the forest floor (Zach et al. 1997; Kula and Zabecki 2010). The forest floor area supports *H. cunicularius* which inhabits spruce stumps, roots and lying trunks or logs having contact with soil (Pfeffer 1955). Markedly different proportions of *T. pecinai* on *H. cunicularius* and *H. palliatus*, highly likely, indicate much greater affinity to the forest soil in the case of *H. cunicularius*. According to Mašán (2001), *T. pecinai* is a soil detricol-subcorticol, which might explain the frequent recording of this less well-known mite on *H. cunicularius*. Based on pheromone trapping, *U. ipidis* is predominant on *I. typographus* in the lower altitudes of West Carpathians (Feketeová 2011a, 2011b). We did not record *U. ipidis* on *I. typographus* in the study area at all but documented it on *D. autographus* and, rarely, on *H. cunicularius*. This shows that *I. typographus* do not always and not everywhere

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carry *U. ipidis* frequently. The mite *U. ipidis*, for example, was less abundant on *I. typographus* than *T. polytricha* in the Białowieża National Park and Izery Mountains, north-eastern and south-western Poland, respectively (Gwiazdowicz et al. 2012). As species interactions may vary due to variation in expression of traits in individuals and population structure (Økland et al. 2009), and geographic variations in environments (Thompson and Cunningham 2002), we recommend their further study here.

The results suggest a close relationship between *T. pecinai* and *H. cunicularius, T. obscura* and *H. palliatus, T. polytricha* and *P. chalcographus/I. typographus*. In some cases, phoretic relationships are very strong (Błoszyk et al. 2013; Gwiazdowicz et al. 2013; Napierała et al. 2015). However, many mite species associated with forest insects are specific in terms of habitats rather than in terms of hosts (Lindquist 1970). Beside the bark beetle associates of Norway spruce (see introduction), the mite *T. polytricha* is known to be dispersed by *Ips cembrae* (Heer) infesting European larch (*Larix decidua* Mill.) (Knee et al. 2012) and/or *Ips sexdentatus* Böerner inhabiting *Pinus halepensis* Mill. (Moraza et al. 2013). Although developing in different species of conifers, all of the known hosts of *T. polytricha* within the genus *Ips* (Moser, Eidmann et al. 1989; Moser et al. 1997; Gwiazdowicz et al. 2011; Knee et al. 2012; Moraza et al. 2013; Čejka and Holuša 2014a) require microhabitats under the sunlit or partly sunlit bark (Pfeffer 1955; Zumr 1984; Jakuš 1998), and judging from known brood trees (Pfeffer 1995), their niches are much narrower than that of the mite. In the Białowieża forest in Poland, Gwiazdowicz and Gutowski (2012) recorded the mite *T. obscura* on *Hylastes angustatus* (Herbst) and *Hylastes ater* (Paykull), the two scolytines having similar microhabitat requirements as the related species *H. cunicularius* which transports *T. obscura* in the Tatra Mountains. Interestingly, present knowledge of uropodoid mites infesting Norway spruce within Europe suggests low similarity with the phoretic associations of uropodoids on the representatives of the genus *Pityokteines* which develop in Silver fir (*Abies alba* Mill.) (cf. Pernek et al. 2008, 2012).

Bark beetle trapping in non-baited traps can only be effective in an epidemic situation (bark beetle outbreak). Each beetle specimen sampled can be considered as an independent random sample of a certain species from a certain microhabitat. Theoretically, there might be as many microhabitats as beetles caught. We realize that larger sample sizes of bark beetle dispersants, especially in *P. poligraphus*, could reveal few other mite–bark beetle associations (cf. Hirschmann 1971; Gwiazdowicz et al. 2015). Also, we are aware that some of the deutonymphal uropodoids could fall off bark beetles during the trapping process. The proportion of mites that fell off the bark beetles could not be determined as the bark beetle trapping, as described, was not selective. Bark beetles and other wood boring insects transporting *Trichouropoda* and *Uroobovella* mites (Wiśniewski and Hirschmann 1993; Gwiazdowicz and Gutowski 2012) were also caught, providing possible sources for released mites in the traps. Considering much tighter attachment of deutonymphs to bark beetle dispersants (by means of the anal pedicel) than in the representatives of other mite groups attaching to hosts, for example, by claws (Moser et al. 2005), we do not expect this to be excessive, at least not with regard to detection of predominant mite species on certain species of bark beetle or determination of prominent bark beetle dispersants of recorded mite species.

It may be concluded that the ties between *Trichouropoda* and *Uroobovella* species and their bark beetle dispersants in mountain spruce forests may be more intimate than judged from the literature (cf. Hirschmann 1971; Wiśniewski and Hirschmann 1993; Kofler and Schmölzer 2000; Knee et al. 2012). The six *Trichouropoda* and *Uroobovella* species in the study, as hypothesized, have their prominent bark beetle dispersants (in most cases different species) and, highly likely, ecological optima in the gallery systems of these dispersants. Testing is required, however, to prove whether or not these mite species have greater affinity to certain species of bark beetle. Despite much effort made, there are still little data to support these conclusions, and considerable research is needed to even remotely answer many types of questions that arise.

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