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Alpha diversity of mesostigmatid mites associated with the bark beetle *Ips typographus* (L.) in Poland

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Abstract. 1. The major aim of this study was to establish the role and importance of the spruce bark beetle *Ips typographus* (L.) in increasing species biodiversity in spruce forests through phoresy of mesostigmatid mites. The study is a close examination of 26 041 specimens of *I. typographus*, which were carriers of 7210 individuals of mites, classified into 24 species. The most numerous species were *Dendrolaelaps quadrisetus*, *Trichouropoda polytricha*, and *Urobovella obovata*. It is noteworthy that the last two species have not been found so far in other types of microhabitat. Moreover, the analysed material also contained a few extremely rare species such as *Amblyseius rademacheri* and *Uroseius acuminatus*.

2. The spruce bark beetle is regarded by forestry experts as one of the most common pest beetles inhabiting spruce forests of Eurasia. Although this species sometimes causes serious economic damage in some regions, it is also one of those organisms which create favourable conditions for many species of fungi and invertebrates; also, it often serves as a carrier for many other organisms. The results of the study show that both presence and abundance of *I. typographus* determine occurrence of many species, and for this reason forest management evaluations of the function of this beetle in forest ecosystems should also take into account the importance of the species in increasing biodiversity of forests.

Key words. Acari, Gamasina, Uropodina, phoresy, spruce forest.

Introduction

The Norway spruce *Picea abies* (L.) Karsten is a very important species in many forest ecosystems of Central and Eastern Europe. The geographic range of occurrence of the species is not continuous (i.e. the range is non-linear), as the species occurs mainly in two separate areas. One of them is the lowland area in north-east and the other is the highlands in central parts of Europe. These two regions are separated by areas without the Norway spruce *Picea abies* (L.) (Skrøppa, 2003).

Spruce tree stands, especially those planted by humans, are frequently infested by pest insects, including the spruce bark beetle *Ips typographus* (L.), which is thought to be one of the most common pest beetles in spruce forests of Eurasia (Schroeder, 2001). The abundance of the species is usually low in all spruce forests, but population fluctuations (high population density) can result in huge economic losses (Feicht, 2004). The economic losses, usually in the form of dead trees, have occurred so far, for example, in Central Europe, in the Scandinavian countries, and in Russia (Faccoli & Buffo, 2004). Moreover, two outbreaks of this pest beetle in 1981 and 1987 in Western Sudetes in Poland resulted in extensive damage of roughly 15 000 ha of the spruce stands (Grodzki, 2004).

Due to the fact that *I. typographus* (L.) often causes serious damage in spruce forests, most studies usually focus on the negative impact of the species on forest ecosystems. In some cases, they also discuss the role of its natural enemies, which can occur on the spruce beetle

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itself or on feeding grounds that it inhabits. This is quite evident especially in the case of those species of mites which feed on eggs and larvae of *I. typographus* (Kiełczewski & Michalski, 1962).

In European forests about 140 species (besides Coleoptera, Diptera, Hymenoptera, and other insect orders) have been found in infested trees (Hedgren & Schroeder, 2004). Thus far, almost 60 species of mesostigmatid mites have been found in bark beetle galleries of *I. typographus* (Gwiazdowicz, 2008). Moreover, feeding areas of the species are usually located under spruce bark, which is also inhabited by many species of fungi (Bałazy *et al.*, 1977, 1987; Bałazy & Wiśniewski, 1984; Bałazy, 1993; Wiśniewski & Hirschmann, 1993). Some bark beetles and their fungal and mite associates often form complex symbiotic relationships, whereas other have virulent fungal associates (Klepzig *et al.*, 2001; Six & Wingfield, 2011; Penttinen *et al.*, 2013). This suggests that biological activity of the beetle, which is negatively perceived by those interested solely in forest management, can be also shown as something positive, especially when it is presented in the light of species biodiversity protection.

Mesostigmatid mites are arachnids inhabiting both litter and soil of all types of forest ecosystems, as well as unstable microhabitats such as dead rotten wood, feeding areas of different species of insects, anthills, and nests of birds and mammals (Lindquist *et al.*, 2009; Salmane & Brumelis, 2010). In forests of Central Europe over 1000 species of mesostigmatid mites have been found so far, most of which were predatory species, but there were also specimens of parasite, mycetophagous, and saprophagous species (Karg, 1993; Wiśniewski & Hirschmann, 1993; Błoszyk, 1999). Due to the small size of the body (0.3–1.5 mm) and physical limitations to move from one habitat to another, they usually disperse by means of very specific zoochory also called phoresy, which can have different forms of relationship, including both unspecific euryxenous and stenoxenous (Binns, 1982; Athias-Binche, 1990). Mesostigmatid mites attach to the body of the host (an insect or myriapod) and they are often carried long distances from one microhabitat to another (Schwarz & Müller, 1992; Gwiazdowicz, 2000; Błoszyk *et al.*, 2006, 2013; Gwiazdowicz *et al.*, 2013). This phenomenon has been also observed on the spruce beetle *I. typographus* (L.), which can be a carrier for mesostigmatid mites (Gwiazdowicz *et al.*, 2011, 2012; Čejka & Holuša, 2014).

The major aim of this study was to ascertain species composition and abundance of mesostigmatid mites carried by the spruce beetle *I. typographus* (L.) in three different locations. The data obtained from the observations were used in the analysis intended to measure the scale of phoresy and to explain the mechanisms of this phenomenon, especially to establish the criteria which determine the choice of a particular part of the beetle's body to which mites attach most frequently. The last goal of the study was to evaluate the role and importance of *I. typographus* for species biodiversity of mesostigmatid mites inhabiting spruce stands.

Materials and methods

The observations were carried out in three different study sites located in economic forests. The first study site was in Antonin Forest District (51°23′–51°35′N; 17°30′–17°58′E), in a lowland area of spruce-tree belt. The second study site was in Suwałki Forest District (53°55′–54°25′N; 22°45′–23°15′E), in the lowland in the northern part of the natural range of the Norway spruce *Picea abies* (L.). The third study site was located in the Forest Promotional Complex Lasy Bieszczadzkie in the Bieszczady Mountains (49°03′–49°21′N; 22°12′–22°55′E; 500–800 m a.s.l.), in the southern part of the natural range of the Norway spruce (Fig. 1).

The material for analysis was collected with using 75 Boregard traps (3 study sites × 25 traps), which were emptied for 3 weeks (between the 2nd and 23rd of August 2010). The traps were placed in the forest areas close to the border zone and exposed to direct sunlight. A Boregard trap is a pipe (height = 135 cm, Ø = 15 cm) containing a commercial attractant Ipsodor W (Chemipan, Poland). The construction of this type of trap prevents mite migration/escape and ensures that all mite individuals are brought into the trap phoretically. The collected mites were preserved in 70% ethanol, mounted on permanent (using Hoyer's medium) and semi-permanent (using lactic acid) slides, counted, and identified with the latest taxonomical descriptions.

Moreover, diversity (Shannon's diversity index, H') and evenness (Evenness index, E = H'/ln [Richness]) indices were estimated for each location. The species abundance was established by counting the number of species in each collected sample. One-way ANOVA and Tukey's tests were also conducted to check the statistical significance of the differences between Shannon's diversity index and evenness for each location. The level of significance for all statistical tests was $\alpha = 0.05$. Principal component analysis (PCA) was also used to explore compositional variation between the samples. All statistical analyses were conducted in R 3.0.1 (R Core Development Team 2012). PCA was conducted with *vegan* library (Oksanen, 2013).

Results

Species composition and community structure

In this study, 26 041 specimens of spruce bark beetles were examined (Antonin – 6865 specimens, Suwałki – 4282, Bieszczady – 14 894). The number of bark beetles collected from a sample ranges from 12 to 1421 with the median of 218 insects. The mean number of bark beetles in each sample was statistically considerably higher ($P < 0.001$) in Bieszczady (595.76 ± 69.62) than in Antonin (274.60 ± 58.80) and Suwałki (171.28 ± 27.28). The mean number of mites on each caught beetle was statistically considerably higher ($P < 0.05$) in Antonin (0.50 ± 0.11) than in Suwałki (0.26 ± 0.04) and Bieszczady (0.24 ± 0.03). The total number of all caught mites

Fig. 1. Area covered by Norway spruce stands in Poland (Skrøppa, 2003). Study sites are marked as follows: 1 – Antonin Forest District, 2 – Suwałki Forest District, 3 – Bieszczady Mountains.

was 7210 specimens out of which 24 species were identified, and depending on the location the number of the species was from 10 to 17 (Table 1). Furthermore, the number of mite specimens collected from one sample in Antonin was 10-535, in Suwałki 0-130, and in Bieszczady 22-845. The mean abundance of mites in one sample was statistically significantly higher ($P < 0.05$) in Bieszczady (154.44 ± 36.31) than in Suwałki (41.88 ± 8.35). The mean number of mites on 100 bark beetles in a sample was 33.29 ± 4.12 individuals. The Shannon's diversity index was statistically higher ($P < 0.001$) in Bieszczady than in Antonin (0.76 ± 0.07) and Suwałki (0.62 ± 0.06). Finally, the Evenness index was not significantly different for each of the examined study sites.

The Sørensens similarity coefficient for Antonin-Bieszczady was 62.50%, for Suwałki-Bieszczady 51.85%, and for Antonin-Suwałki 48.00%. (Table 1).

The results of the PCA show diversity of the examined mite communities (Fig. 2). The first axis of ordination (PCA1) explains 66.25% of variance and the second axis of ordination (PCA2) explains 30.25%. The points in the PCA diagram representing samples were close. The samples from the Bieszczady Mountains, however, had a higher number of Uropodina deutonymphs. It explains their occurrence near *Trichoruopoda polytricha* and *Uroobovella obovata*. The outstanding observations are the results of species composition which significantly differ from the other samples, for example, by the higher number of *Dendrolaelaps quadrisetus*. The diversity between the study sites is lower than that between samples from individual study sites.

Whereas the species composition and structure of the analysed mite communities were different for each study site, only five species occurred in all locations. The most numerous species were *Dendrolaelaps quadrisetus*, *Trichouropoda polytricha*, *Urobovella obovata*, *Proctolaelaps fisheri*, and *Vulgarogamasus oudemansi* (Table 2; Fig. 3). In the lowlands (i.e. in Antonin and Suwałki), the most

Table 1. Diversity of mesostigmatid mites in *Ips typographus* pipe traps.

	Antonin	Suwałki	Bieszczady	*F*	*P*
Total number of mite species	15	10	17	–	–
Mean number of mite species	3.92 ± 0.33[b]	3.29 ± 0.27[b]	5.16 ± 0.30[a]	9.99	<0.001
Total abundance	2364	1015	3831	–	–
Mean abundance	96.68 ± 24.29[ab]	41.88 ± 8.35[b]	154.44 ± 36.31[a]	4.81	0.011
Mean number of bark beetles	274.60 ± 58.80[b]	171.28 ± 27.28[b]	595.76 ± 69.62[a]	16.25	<0.001
Mean mite per one beetle	0.50 ± 0.11[a]	0.26 ± 0.04[b]	0.24 ± 0.03[b]	4.31	0.017
Shannon (*H*)	0.76 ± 0.07[b]	0.62 ± 0.06[b]	1.09 ± 0.04[a]	17.02	<0.001
Eveness (*E*)	0.60 ± 0.05	0.58 ± 0.03	0.69 ± 0.02	2.70	0.074

ns, not significant.
The values are mean ± SE.

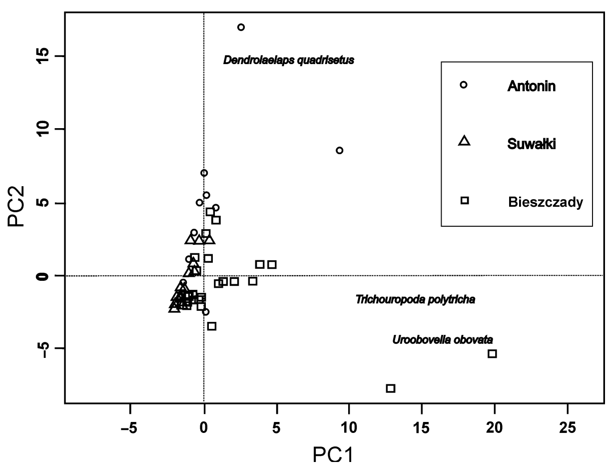

Fig. 2. Principal component analysis (PCA) of species diversity in examined areas.

numerous species was *D. quadrisetus*, but in the Bieszczady Mountains it was *T. polytricha*.

Place of attachment preferences of mites

Uropodina deutonymphs attach firmly to insect bodies by means of the anal pedicel (Fig. 4), whereas species from the suborder Gamasina, including deutonymphs from the genus *Dendrolaelaps*, attach to the carrier's body by means of their legs or chelicerae (Błoszyk *et al*., 2002), and for this reason they often fall off. These species have neither morphological nor physiological adaptation capabilities to disperse through phoresy. For this reason, it was very hard to estimate exactly how many of those species were present on each caught beetle and which part of the body they were attached to while being carried. Most of the found Gamasina specimens (84.5%) were attached to the carrier with their legs and they fell off when the specimen had been preserved in ethanol. The mites found on the bodies of the caught beetles belonged to 10 different species, with high abundance of *T. polytricha*. Those mite specimens which did not fall off from the bodies of *I. typographus* show that they probably were usually attached to the carrier on the elytra and thorax of the beetle (Fig. 5).

Discussion

Although ecology of many phoretic species is an object of intensive research, it is still one of the fields that require further investigations (Pernek *et al*., 2008, 2012; Penttinen *et al*., 2013). The phenomenon of phoresy occurs frequently among Gamasid mites from such families as Macrochelidae, Parasitidae, Laelapidae, Ascidae, Eviphididae, as well as Uropodid mites and in some families of Actinedida, e.g. Scutacaridae and Anoetidae (Bajerlein & Błoszyk, 2004; Wayne *et al*., 2013). Some species of mites, similar to Uropodina deutonymphs, use insects only as vehicles to disperse (Kršiak *et al*., 2010), but some of them, for example *D. quadrisetus*, increase mortality of bark beetles (Penttinen *et al*., 2013). Almost all species found in the examined areas occurred in the bark beetle galleries (Gwiazdowicz, 2008). For example, *D. quadrisetus* was also found in the feeding areas of many species of Scolytinae in Europe, but also in North America (i.e. Canada, Guatemala, USA) and in northern Africa (Hirschmann & Wiśniewski, 1982). A slightly smaller range of occurrence has been observed for *P. fisheri*, found in feeding grounds of many insects in Central Europe (Karg, 1993; Gwiazdowicz, 2007). On the other hand, *T. polytricha* has been found so far in Europe and Central Asia (Wiśniewski & Hirschmann, 1993). Interestingly, despite intensive investigations conducted by the research team of J. Błoszyk, no specimen of this species has been found in other types of microhabitats (the team has analysed so far roughly 20 000 litter and soil samples from all types of forests, including several types of open environments and merocenoses). Although *U. obovata* was found in other types of microhabitat (e.g. forest litter, rotting trunks, and meadows), it did not occur in high abundance in these microhabitats (J. Błoszyk, unpublished data).

The other species of mites were also found in Europe, northern Africa, and USA (Wiśniewski & Hirschmann, 1993; Gwiazdowicz, 2007, 2010). The exception in this respect is the European species *U. obovata*, which can

Table 2. Diversity of mesostigmatid mites found in *Ips typographus* pipe traps in examined sites: F – frequency, A – abundance, D – dominance.

Species	Antonin Forest District			Suwałki Forest District			Bieszczady Mountains			Total (ind.)
	F (%)	A (ind.)	D (%)	F (%)	A (ind.)	D (%)	F (%)	A (ind.)	D (%)	
Amblyseius rademacheri	–	–	–	4.17	1	0.10	–	–	–	1
Antennoseius sp.	–	–	–	–	–	–	4.00	1	0.03	1
Cornigamasus lunaris	–	–	–	–	–	–	4.00	1	0.03	1
Cyrtolaelaps mucronatus	4.00	1	0.04	–	–	–	–	–	–	1
Dendrolaelaps quadrisetus	100.00	1604	67.85	100.00	725	71.43	100.00	1154	30.12	3483
Dendrolaelaps zwoelferi	4.00	2	0.08	–	–	–	–	–	–	2
Gamasolaelaps excisus	–	–	–	–	–	–	4.00	1	0.03	1
Halolaelaps sp.	–	–	–	–	–	–	4.00	4	0.10	4
Hirstionyssus isabellinus	4.00	2	0.08	4.17	1	0.10	–	–	–	3
Macrocheles glaber	–	–	–	4.17	1	0.10	4.00	5	0.13	6
Parasitus consanguineus	–	–	–	4.17	1	0.10	–	–	–	1
Pleuronectocelaeno austriaca	8.00	4	0.17	–	–	–	20.00	8	0.21	12
Poecilochirus carabi	32.00	24	1.02	–	–	–	12.00	7	0.18	31
Poecilochirus davydovae	4.00	2	0.08	–	–	–	4.00	1	0.03	3
Proctolaelaps fisheri	16.00	9	0.38	25.00	26	2.56	84.00	146	3.81	181
Trichouropoda ovalis	–	–	–	4.17	1	0.10	16.00	6	0.16	7
Trichouropoda polonica	4.00	1	0.04	–	–	–	16.00	7	0.18	8
Trichouropoda polytricha	100.00	479	20.26	83.33	194	19.11	100.00	1415	36.94	2088
Uroobovella nova	16.00	6	0.25	–	–	–	–	–	–	6
Uroobovella obovata	76.00	217	9.18	58.33	52	5.12	96.00	1043	27.23	1312
Uroobovella sp.	12.00	9	0.38	–	–	–	36.00	29	0.76	38
Uroobovella vinicolora	4.00	2	0.08	–	–	–	–	–	–	2
Uroseius acuminatus	–	–	–	–	–	–	8.00	2	0.05	2
Vulgarogamasus oudemansi	8.00	2	0.08	41.67	13	1.28	4.00	1	0.03	16
Total	–	2364	100.00	–	1015	100.00	–	3831	100.00	7210

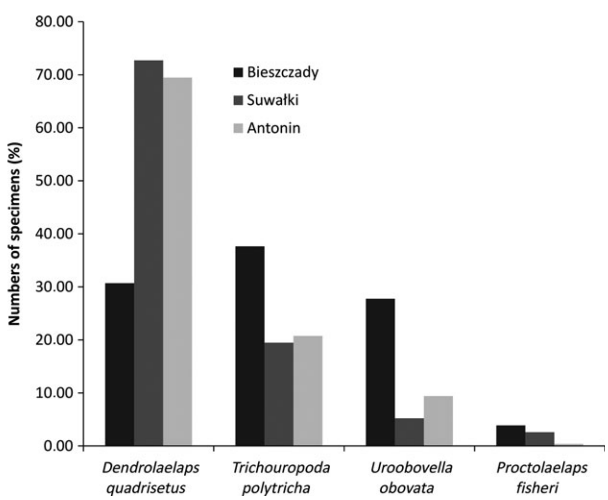

Fig. 3. Percentage of dominant mite species in each study site.

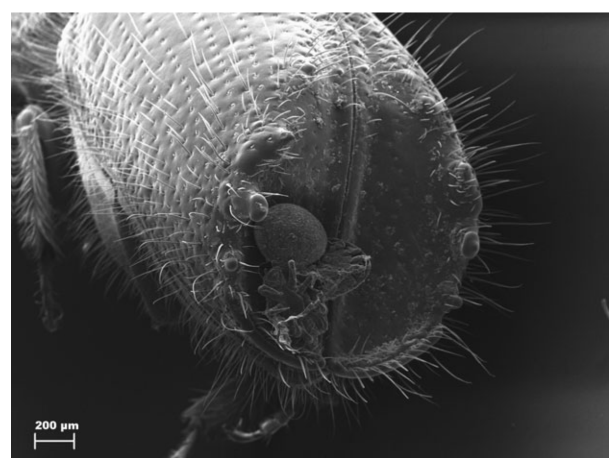

Fig. 4. Phoretic mites attached to abdomen part of a spruce bark beetle.

occur in a wide spectrum of habitats, with evident preference for forest habitats. This species can be also found on peatlands, nests of small mammals, turfs growing on limestone rocks, in rotten stumps and tree hollows, and on meadows (Błoszyk, 1999; Napierała & Błoszyk, 2013). The species definitely prefers habitats located in the areas of the European Plain, whereas in mountains it occurs sporadically up to 900 m above the sea level. Wiśniewski and Hirschmann (1993) showed that *U. obovata* occurs more often in anthills than in the galleries of bark beetles.

Besides species which usually occur under tree bark, there were also fairly rare species, which prefer totally different microhabitats. One of them is *Hirstionyssus isabellinus*, which is an obligatory blood feeder (Korallo-Vinarskaya *et al.*, 2009). This species is quite common in the Palearctic

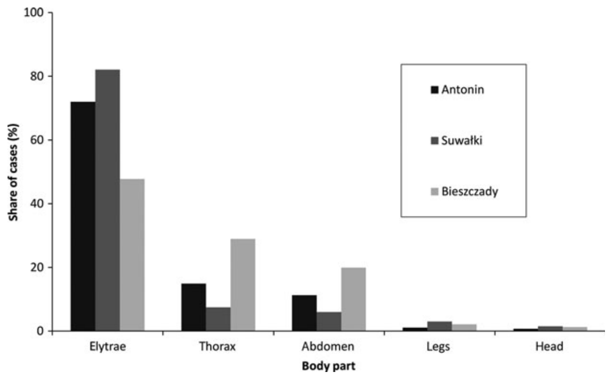

Fig. 5. Place of attachment of found mites on the body of *Ips typographus* (L.).

zone. It is usually found on small rodents from two genera, i.e. *Microtus* and *Clethrionomys*, and also in their nests. The species is less common on those from the genus *Mus musculus* (Çicek *et al*., 2008) and mustelids from the genus *Mustela* (Evans & Till, 1966; Mašán & Fenda, 2010).

Poland is one of the very few countries whose fauna of Mesostigmata mites has been thoroughly described (i.e. roughly 1000 species have been described so far). For this reason, it is quite surprising that the analysed material contained new phoretic species from this genus carried by the spruce bark beetle. The analysed material also contained *Amblyseius rademacheri* (Dosse, 1958), which usually occurs on leaves of many tree species, including *Acer*, *Alnus*, and *Betula* (Salmane & Petrova, 2002), but also on leaves of many herbs (Karg, 1993). Moreover, the collected samples also contained specimens of *Uroseius acuminatus* (C.L. Koch, 1847), which is usually described as a species occurring mainly in soil and humus, and a phoretic species carried by beetles from the Phoridae family (Wiśniewski & Hirschmann, 1993). *Urosejus acuminatus*, however, cannot be regarded as a typical soil mites because no specimen of this species has been found yet by Błoszyk in 17 000 samples from different types of forest environment collected in Central Europe (J. Błoszyk, unpublished data). This species is extremely rare.

Depending on the species, phoretic mite specimens represented various developmental stages. Similar to previous studies (e.g. Gwiazdowicz *et al*., 2011), the most dominant species such as *D. quadrisetus*, *T. polytricha*, and *U. obovata* were represented only by deutonymphs, whereas in the case of *Pleuronectocelaeno austriaca*, *Proctolaelaps fisheri*, and *Uroseius acuminatus* only adult specimens were found (both males and females). This confirms that in the case of Uropodina mites, mainly deutonymphs are able to disperse through phoresy. Uropodina mites at this stage of their development are highly scleroticised forms, much smaller and lighter than adult forms, and thus they are capable of dispersing by means of other arthropods (Błoszyk & Bajaczyk, 1999; Mašán, 2001; Bajerlein *et al*., 2006; Błoszyk *et al*., 2006; Gwiazdowicz *et al*., 2006). Furthermore, they are also much more resistant to the impact of unfavourable environmental conditions (e.g. they tolerate considerable amplitudes of moisture and temperature) than larvae and protonymphs. Phoresy is one of the phenomena characteristic of Uropodina species inhabiting unstable microhabitats (Napierała & Błoszyk, 2013). This phenomenon has not been observed for common species inhabiting litter and soil.

One of the peculiarities of phoresy is that particular species of insects are the only carriers for specific species of mites, e.g. coprophilous and necrophilous insects are carriers only for those mite species which have the same habitat preferences (Haitlinger, 1991, 2004; Gwiazdowicz, 2000). In some cases, the phoretic relationship is very strong, especially when one species of insect or closely related species of insects are carriers for one mite species, for example *Plagionotus detritus* is carried only by *Trichouropoda sociata* and *Tetropium* sp. beetles are carriers only for *Trichouropoda shcherbakae* (Błoszyk *et al*., 2013; Gwiazdowicz *et al*., 2013). A similar phoretic relationship can be observed for the spruce bark beetle, which is a carrier only for one group of mite species. Thus, the most dominant mite species found on the body of the spruce bark beetle do not occur on bodies of insect species from other groups.

Many previous studies also show that mites have specific preferences for attaching only to some parts of the carrier's body. Those who in their studies touch upon this phenomenon usually state that mites quite often attach to the elytra and legs of the beetle (Costa, 1963; Bajerlein & Błoszyk, 2004; Błoszyk *et al*., 2013; Gwiazdowicz *et al*., 2013; Penttinen *et al*., 2013). In these studies, similar to those published by Mašán (2001) and Feketeová (2011), the found mites were frequently attached to the elytra and thorax, but fairly seldom to the legs. The results presented in this study are different from those published by Kršiak *et al*. (2010), who found many specimens of Uropodina mites on legs of the beetle. As has been already said, it is hard to estimate exactly how many mites were attached to one spruce bark beetle because some of them probably detached from the caught beetles soon after they had been taken out of the traps, which can be also observed in earlier studies (Pernek *et al*., 2012; Penttinen *et al*., 2013). Unfortunately, this methodological problem has not been solved yet. Be it noted that among the specimens that detached from the caught beetles *D. quadrisetus* was more numerous than *T. polytricha* and *U. obovata*, which probably stems from the fact that these species attach to the carrier's body in different ways. Moreover, nothing is known about the stimulus which tells mites that they should attach to the beetle. Regarding the fact that Uropodina mites move very slowly, they need much time to get on the body of the carrier. The process of attaching to the body of the carrier by means of the pedicle is rather very fast (observations – unpublished data). The results of previous studies on acarofauna of feeding grounds of beetles (Kiełczewski & Wiśniewski, 1983; Gwiazdowicz, 2008) suggest that the process of attaching to the carrier's body takes place under tree bark, just before the imago leaves the host tree.

Conclusions

Although from the economic point of view, the spruce bark beetle *I. typographus* (L.) is regarded as a pest insect, the species considerably increases biodiversity not only by creating favourable environmental conditions for many species of fungi and invertebrates but also by dispersing many wingless species. The large scale of this phenomenon presented in many studies proves that many species of mites change their habitats mainly through phoresy. The high species diversity of mite communities inhabiting bark beetle galleries and the occurrence of rare species on bodies of beetles prove the great importance of *I. typographus* (L.) in increasing biodiversity in forest areas of the Northern Hemisphere. Phoretic relationships between mites and insects can be extremely helpful in establishing the current distribution of the former, as well as in finding the places of origin and migration routes after the last glacial period. As can be seen *I. typographus* is extremely important in the biology of *T. polytricha*, which occurs only in galleries of the beetle, and in the biology of *U. obovata*, whose abundance on the body of beetle species was much higher than in other types of habitat. Both presence and abundance of *I. typographus* determine occurrence of many species in the environment and for this reason forest managers should take into account the great importance of the spruce bark beetle as an insect increasing biodiversity of forests.

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