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Mites Associated with the European Spruce Bark Beetle *Ips typographus* (Linnaeus, 1758) in Europe, with New Evidence for the Fauna of Serbia

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Abstract: Various biotic and abiotic factors are the cause of the decline of coniferous forests throughout Europe. Trees weakened by unfavorable weather conditions create an ideal environment for a possible outbreak of bark beetles. The damage caused by bark beetles costs billions of dollars worldwide every year. Extreme climate events are responsible for the enormous forest losses in Tara National Park in the last ten years, leading to a massive bark beetle infestation. The understanding of the diversity and role of mites as biological control agents is still insufficient. In this study, we summarize the current knowledge on the diversity of mites associated with *Ips typographus* L. in Europe and provide information on the diversity of these mites in Serbia. *Paraleius leontonychus*, *Uroobovella ipidis*, *Dendrolaelaps quadrisetus*, *Histiostoma piceae*, and *Trichouropoda polytricha* were detected for the first time in Serbia. Moreover, the occurrence of *Paraleius leontonychus* represents the southernmost occurrence of this species.

Keywords: Acari; Coleoptera; Curculionidae; Scolytinae; biodiversity; Tara National Park

1. Introduction

Biotic and abiotic disturbances associated with climate change currently pose the greatest threat to coniferous forests in Europe [1–4]. In Serbia, a sharp decline in coniferous forests has been observed since 2012 [5–10]. The main reason for this decline was droughts that occurred during growing seasons and caused damage of 116,290 m^3 with a percentage of 89% dead spruces and fir [11].

Tara National Park is located in the western part of Serbia, part of the Dinaric Alps. With an area of 19,175 ha and about 1013 plant species, Tara National Park is the third most diverse area in Serbia [12,13]. Forest ecosystems cover almost 80% of the total land area. The most common forest community is mixed forests of beech, fir, and spruce (*Piceo-Fago-Abietetum* Čolić, 1965), which are also known for the occurrence of the endemic and endangered Serbian spruce *Picea omorika* (Pančić) Purk. [14]. Tara National Park Enterprise data estimate the loss of about 6.4% (112,879.3 m^3 of wood) of the forest area in the last 10 years due to extreme climatic events and subsequent pest calamities

[15].

Bark beetles are a major threat to physiologically weakened coniferous forests [16]. The most abundant is the European spruce bark beetle, *Ips typographus* Linnaeus, 1758 (Coleoptera, Curculionidae, Scolytinae). Research on natural enemies and potential control agents for this species in Serbia has so far been limited to hymenopteran parasitoids and entomopathogenic fungal associations [17–19]. However, interactions between mites and bark beetles have been overlooked. Previously, more than 250 mite species associated with bark beetles have been described worldwide [20]. Their interactions fall into three main categories: predatory, mite-fungus symbiosis, and phoretic [21]. The most common type of interaction between mites and bark beetles is phoresis. Phoresis may also be considered harmful to bark beetles by limiting their movement and potential dispersal [22]. In addition, previous studies have shown that mites are able to transmit fungal spores in beetle galleries, e.g., *Proctolaelaps scolyti* (Evans, 1958) and *Tarsonemus crassus* (Schaarschmidt, 1959), which contribute to the transmission of *O. novo-ulmi* Brasier, 1991 to elms [23] or spores of *Ophiostoma* sp. by mites of the genus *Histiostoma* Kramer, 1876 [24]. In addition, phoretic mites are potential vectors of entomopathogenic fungi such as *Beauveria bassiana* (Bals.-Criv.) Vuill. (1912) [25]. Studies on the diversity of phoretic mites associated with *I. typographus* have already been conducted in several European countries (see Table S1).

The main objective of this study was to summarize the knowledge about the mites associated with *I. typographus* reported so far from Europe and to provide a view of the diversity of these mites in Serbia.

2. Materials and Methods

2.1. Study Area

Our research was conducted at six selected sites in the Tara National Park in Serbia (Figure 1). Site No. 1 is located in the southwestern part of the National Park (43°53′25.22″ N, 19°30′43.87″ E) at an altitude of 1143 m.a.s.l. It is covered with mixed stands of spruce, fir, and beech (*Piceo-Abieti-Fagetum drymetosum* association). Site No. 2 was located near site No. 1 (43°53′24.63″ N 19°30′34.21″ E), at an altitude of 1155 m.a.s.l., with the same forest stands. Site No. 3 (43°53′49.49″ N 19°29′46.08″ E) was located in the western part, at an altitude of 1196 m.a.s.l. It is covered with mixed stands of spruce, fir, and beech (*Piceo-Abieti-Fagetum typicum*). Site No. 4 (43°55′33.85″ N 19°25′16.60″ E) is located near No. 3, with the same forest stands and at a similar altitude (1158 m.a.s.l.). Sites No. 5 (43°55′22.09″ N 19°27′13.90″ E) and No. 6 (43°56′15.19″ N 19°28′19.66″ E) are adjacent to each other and belong to the same forest stands as No. 3 and 4, with an average altitude of 1000 m.a.s.l.

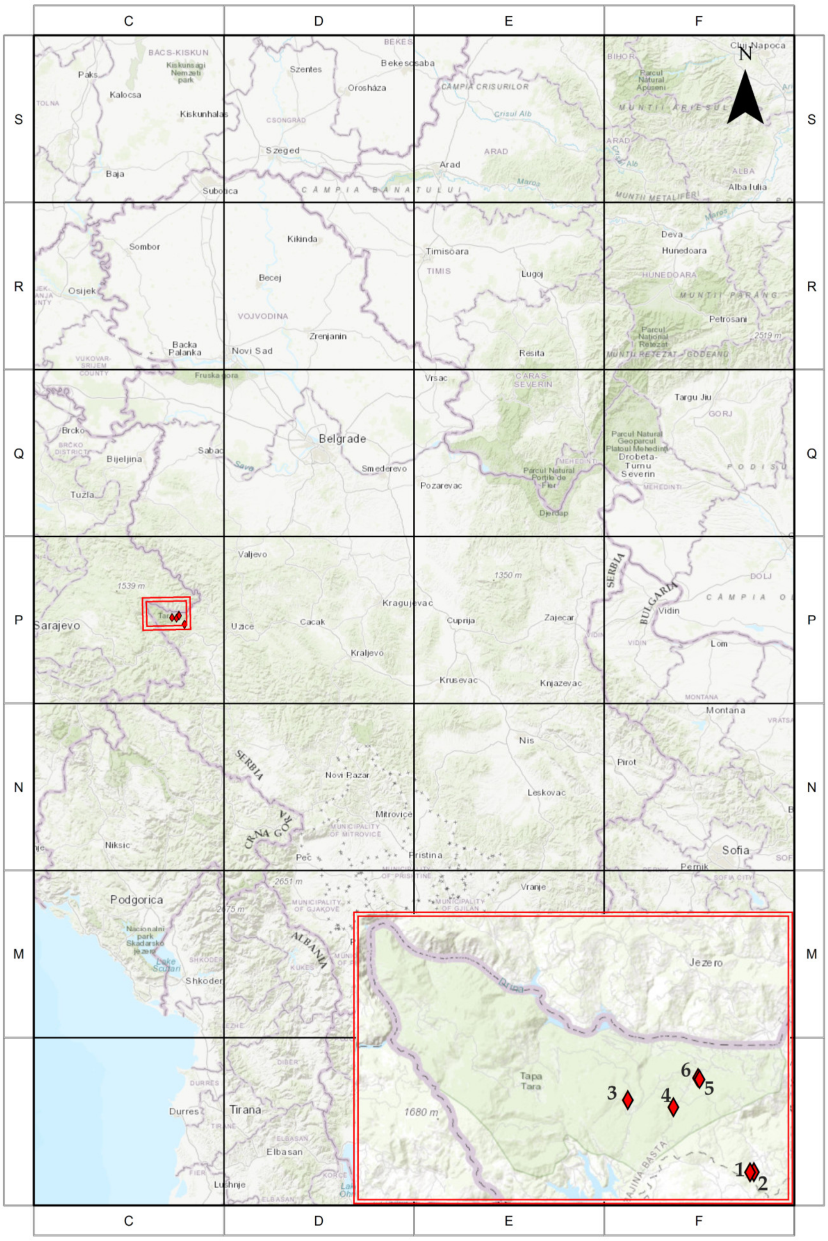

Figure 1. Location of the study areas in Tara National Park, Serbia.

2.2. Sampling Methods

In Tara National Park, cross-barrier pheromone traps (THEYSOHN®) have been used to monitor bark beetle populations since 2014 [26]. For our research, we used the same pheromone traps equipped with IT Ecolure pheromones. We collected the captured adults of *I. typopgraphus* during the first flight in April 2016. The collected adults were packed in plastic boxes and brought to the laboratory of the Institute of Forestry in Belgrade. We examined the bark beetles under a stereomicroscope, counted the mites, and placed them in Eppendorf tubes containing ethanol and lactic acid before preparation [27]. The mites were sorted into morphospecies using the key published by Moser and Bogenschütz [28] and identified by Milan Pernek. For the assessment of species dominance and frequency of occurrence in the bark beetle samples, we followed the statistical method used by other authors [29–33] (Table 1). The dominance parameters were eudominant (>30%), dominant (15.01%–30%), subdominant (7.01%–15%), recedent (3.01%–7%), and subrecedent (<3%); the frequency parameters were euconstant (>50%), constant

(30.01%–50%), subconstant (15.01%–30%), accessory species (5.01%–15%) and accidental occurrence (<5%).

Table 1. The mite species found on the captured adults of *I. typographus*, their total number, dominance, frequency in the samples, and location on the body of the bark beetles.

Species	Number	Dominance (%)	Frequency (%)	Location
Paraleius leontonychus (Berlese, 1910)	267	Dominant (18.98)	Eucostant (66.66)	Thorax, Elytral declivity, Head
Uroobovella ipidis (Vitzthum,1923)	191	Subdominant (13.57)	Eucostant (66.66)	Thorax, Elytral declivity, Head
Dendrolaelaps quadrisetus (Berlese 1920)	374	Eudominant (26.58)	Eucostant (83.33)	Under elytra, Elytral declivity
Histiostoma piceae Scheucher, 1957	10	Subrecedent (0.71)	Accidental (16.67)	Elytral declivity
Trichouropoda polytricha (Vitzthum, 1923)	565	Eudominant (40.16)	Eucostant (100.00)	Thorax, Elytral declivity, Head

2.3. Photographing Methods

Before photographing, we made permanent preparations for the identified mites according to the protocol of Saito et al. [34]. Photographing was performed with the Olympus BX63 fluorescence microscope and cellScens Dimension software. For photographing the adults of *I. typographus* with the mites, we used Olympus SZX16 with Olympus SDF Plapo 1XPF lens and PROMICRA 3-5CP camera together with QuickPHOTO MICRO 3.2 software.

3. Results

The data on species used to summarise current knowledge on mites associated with *I. typographus* in Europe were obtained from various literature sources (see Table S1). We found data about 97 species from 12 countries (Bulgaria, Croatia, the Czech Republic, Finland, Georgia, Germany, Poland, Romania, Russia, Slovakia, Sweden, and Turkey). The countries with the highest reported diversity of mites were Russia (53 species), Germany (25 species), and Finland (22 species). The lowest number of mite species was reported from Croatia (3 species). The most common mite species in Europe were *Dendrolaelaps quadrisetus* (Berlese, 1920), detected in 11 countries, *Trichouropoda polytricha* (Vitzthum, 1923)—found in 10 countries, *Uroobovella ipidis* (von Vitzthum, 1923)—documented in 9 countries, *Proctolaelaps fiseri* (Samsinak, 1960)—found in 8 countries, and *Histiostoma piceae* (Scheucher, 1957), detected in 5 countries.

We also examined 4093 adults of *I. typographus* collected in Tara National Park, from which we obtained 1407 mites (Table 1). All five species were found for the first time in Serbia (Figure 2).

3.1. List of the Species Newly Recorded in Serbia

1. Order: Oribatida

   Family: Scheloribatidae Jacot, 1935
   Genus: *Paraleius* Travé, 1960
   Species: *P. leontonychus* (Berlese, 1910)
   Figure 2a
   Distribution: Holarctic
   Note: The species is often also listed in the literature as *Siculobata leontonycha* (Berlese, 1910). *P. leontonychus* is a fungivorous (or detritivorous) species of oribatid mite with strong hooked claws helping it to reach the bark beetle galleries [35]. This phoretic species was previously found on various European bark beetle species, such as *Cryphalus abietis*, *Dryocoetes autographus*, *Hylurgops palliatus*, *Ips amitinus*/*I. sexdentatus*/*I. typographus*, *Pityogenes chalcographus*, *Pityokteines*

curvidens/*P. spinidens*/*P. vorontzowi*, *Scolytus multistriatus*, and *Tomicus minor*/*T. piniperda* [36–39].

2. Order: Mesostigmata

Family: Urodinychidae Berlese, 1917
Genus: *Uroobovella* Berlese, 1903
Species: *U. ipidis* (Vitzthum, 1923)
Figure 2b
Distribution: Europe and western Asia
Note: The deutonymphs of *U. ipidis* are phoretic and were previously found on various European bark beetle species, such as *I. typographus*/*I. sexdentatus*, *Hylastes cunicularius*, *Pityokteines curvidens*/*P. spinidens*/*P. vorontzowi*, and *Pityogenes chalcographus* [28,32,37–46].

3. Order Mesostigmata

Family: Digamasellidae Evans, 1957
Genus: *Dendrolaelaps* Halbert, 1915
Species: *D. quadrisetus* (Berlese, 1920)
Figure 2c
Distribution: Holarctic and Neotropical region
Note: Deutonymphs of *D. quadrisetus* are phoretic and positioned mainly under the elytra of bark beetles. However, Khaustov et al. [47] observed that deutonymphs of this species increase their size by feeding on the eggs of *I. typographus*.
D. quadrisetus was previously found on many European bark beetle species, e.g., *Crypturgus cinereus*, *Dryocoetes autographus*, *Hylastes opacus*, *Hylesinus varius*, *Hylurgops glabratus*/*H. palliatus*, *Ips acuminatus*/*I. amitinus*/*I. cembrae*/*I. sexdentatus*/*I. typographus*, *Pityogenes chalcographus*, *Pityokteines curvidens*/*P. spinidens*/*P. vorontzowi*, *Polygraphus poligraphus*, *Scolytus intricatus*/*S. ratzeburgii*, *Tomicus minor*/*T. piniperda*, and *Xyleborus cryptographus* [24,28,37,38,41,44,48–52].

4. Order: Sarcoptiformes

Family: Histiostomatidae Berlese, 1897
Genus: *Histiostoma* Kramer, 1876
Species: *H. piceae* Scheucher, 1957
Figure 2d
Distribution: Palearctic region
Note: The deutonymphs of this species are phoretic and can also carry hyperphoretic plant pathogenic fungi (e.g., *Ophiostoma* spp.). *H. piceae* has previously been found mainly in the subelytral spaces of *I. typographus*. However, they have also previously been found in other bark beetle species, such as *Dryocoetes hectographus*, *Ips cembrae*, *Pityogenes chalcographus*, and *Pityokteines curvidens*/*P. spinidens*/*P. vorontzowi* [24,28,37,38,40,41,45,53–55].

5. Order: Mesostigmata

Family: Trematuridae Berlese, 1917
Genus: *Trichouropoda* Berlese, 1916
Species: *T. polytricha* Vitzthum, 1923
Figure 2e
Distribution: Holarctic region
Note: The deutonymphs of *T. polytricha* are phoretic to various European bark beetle species, such as *Dryocoetes autographus*, *Hylastes cunicularius*, *Hylurgops palliatus*, *Ips amitinus*/*I. cembrae*/*I. sexdentatus*/*I. typographus*, and *Pityogenes chalcographus* [28,39–44].

Figure 2. Five newly recorded mite species of *I. typographus* in Serbia and their position on the body of the bark beetle. (**a**) *Paraleius leontonychus*, (**b**) *Uroobovella ipidis*, (**c**) *Dendrolaelaps quadrisetus*, (**d**) *Histiostoma piceae*, (**e**) *Trichouropoda polytricha*. (**f**) Mites on the elytra declivity of *I. typographus*, (**g**) mites under the elytra of *I. typographus*, (**h**) mites on the thorax of *I. typographus*.

3.2. Abundance of Newly Found Mite Species at the Sites Studied in National Par Tara

At site No. 1, we collected 1099 adults of *I. typographus*, from which we obtained 322 mites (*P. leontonychus*—78 indv.; *U. ipidis*—2 indv.; *D. quadrisetus*—128 indv.; *H. piceae*—10 indv.; *T. polytricha*—104 indv. indv.). At site No. 2, we collected 412 adults of *I. typographus* and obtained 347 mites (*P. leontonychus*—102 indv.; *U. ipidis*—28 indv.; *D. quadrisetus*—102 indv.; *T. polytricha*—115 indv.). At site No. 3, we collected 442 adults of *I. typographus* with 180 mites (*D. quadrisetus*—78 indv.; *T. polytricha*—102 indv.), At site No. 4, we collected 148 adults of *I. typographus*, of which we found only 12 mites (*T. polytricha*—12 indv.). At site No. 5, we collected 1717 adults of *I. typographus* and obtained 354 mites (*P. leontonychus*—54 indv.; *D. quadrisetus*—12 indv.; *U. ipidis*—83 indv.; *T. polytricha*—205 indv.). At site No. 6, we collected 275 adults of *I. typographus*, from which we obtained 192 mites (*P. leontonychus*—33 indv.; *U. ipidis*—78 indv.; *D. quadrisetus*—54 indv.; *T. polytricha*—27 indv.).

4. Discussion

Our study provides an overview of the current knowledge on mites associated with *I. typographus* in Europe and, for the first time, provides information on their diversity in Serbia and fills the gap in their known distribution. Based on their occurrence in other European countries, all recorded species were expected to be present in Serbia as well. The most frequently found mite species were *T. polytricha* (565 individuals) and *D. quadrisetus* (374 individuals). This result agrees with the results from other European countries, where these two species were considered the most common (see Table S1). However, *P. leontonychus* was also found relatively frequently at sites No. 2, 5, and 6, and *U. ipidis* was also among the most frequently found species at sites No. 4 and 5. The first detection of the fungivorous (or detritivorous) *P. leontonychus* and its higher abundance at three studied sites can be considered very interesting, as this morphologically unique species has so far only been found in northern parts of Europe (see Table S1) [50,56]. The most frequent locations on the body of the bark beetle were elytral declivity and the head. This also corroborates previous observations [45]. Similar to previous studies [28,40,43], our methods for detecting mites on European spruce bark beetles most likely did not cover the full diversity of mites associated with them, so more sensitive methods (e.g., examining mites from tree bark and bark beetle galleries) should be used in further studies. Furthermore, information on the life history of the various mite species is still insufficient, as is the actual diversity of mites compared to the number of species currently recognized [57].

5. Conclusions

Our study of mites associated with *I. typographus* has improved the inadequate knowledge of the regional diversity of this potentially important group and also represents an extension of the known distribution of each species. As our study highlighted, some species play only a phoretic role, using the bark beetles only to transport themselves to different locations, while other species can be a good natural enemy, reducing the population by feeding on the eggs or transporting spores of entomopathogenic fungi. In addition, the knowledge gained about the diversity and biology of mites could serve as a potential tool for future biological control research.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13101586/s1; Table S1: The diversity of mites reported from various European countries.

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Data Availability Statement: Data is contained within the article or Supplementary Materials. The data presented in this study are available in Table S1.

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