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A NEW SAPROXYLIC PALEONURINI (COLLEMBOLA, NEANURIDAE) SPECIES FROM NORTH AMERICA WITH THE FIRST RECORD OF *GALANURA AGNIESKAE* SMOLIS, 2000 FROM THE CONTINENT

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ABSTRACT

Paleonura saproxylica **sp. nov.** was discovered in the Cascade Range of Oregon State, where it can be observed in rotten logs of coniferous tree species. This new species has the most northerly distribution within this mostly tropical and subtropical genus. It is most similar to 2 other North American species *Paleonura*, *P. anops* (Christiansen & Bellinger, 1980) and *P. petebellingeri* Palacios-Vargas & Simón Benito, 2007. These species differ in many chaetotactic features. The first record of the other saproxylic Paleonurini from North America, *Galanura agnieskae* Smolis, 2000, is also provided. This species was found in rotten logs in boreal balsam-fir-white birch forests of the Canadian province of Quebec.

Key Words: Entomology, taxonomy, saproxylic springtails, Neanurinae, *Paleonura*, *P. saproxylica*, USA, Canada

RESUMEN

La *Paleonura saproxylica* **sp. nov.** (Collembola, Neanuridae: Paleonurini) fue descubierta en la Cordillera de Cascada del Estado de Oregon, EE.UU., donde se puede observar solamente en troncos podridos de árboles de especies de coníferas. La nueva especie es actualmente la especie con distribución más al norte de este género que es en su mayor parte tropical y subtropical. Es muy similar a 2 otras especies Norte Americanas *Paleonura anops* (Christiansen et Bellinger, 1980) y *P. petebellingeri* Palacios-Vargas et Simón Benito, 2007. Estas especies difieren en varias características chaetotacicas. También se provee el primer registro de otro Paleonurini saproxilico de América del Norte, *Galanura agnieskae* Smolis, 2000. Esta última especie se encontró en troncos podridos en bosques boreales de abeto balsámico y abedul blanco en la provincia Canadiense de Quebec.

Palabras Clave: abeto balsámico, coníferas, abedul blanco, *Galanura agnieskae*, colémbolos saproxilicos, Neanurinae, *Paleonura*, *P. saproxylica*

During the few last decades dead, dying and living trees with hollows or dead limbs have been recognised as a key element of the forest ecosystem. The presence of dead wood strongly and positively affects their biodiversity, nutrient and water cycling, decomposition and soil development processes, and natural regeneration (e.g., Harmon et al. 1986; Müller & Schnell 2003; Bobiec et al. 2005; Stokland et al. 2012). Probably almost one quarter of all forest species are dependent on dead wood, and some of them, the so-called saproxylic, cannot live in woods devoid of old and dead trees (Siitonen 2001; Schuck et al. 2004). Speight (1989) defined a saproxylic organism as one "that is dependent, during some part of its life cycle, upon the dead or dying wood of moribund or dead trees, or upon wood-inhabiting fungi, or upon the presence of other saproxylics". Such organisms use different kinds of dead wood

not only as a source of food, but also as habitat, seasonal or daily shelter, construction material, a mating substrate or a location for other reproduction purposes. To date, the largest fraction of saproxylic arthropods are described and recognised within beetles (Coleoptera), flies, gnats (Diptera), wasps, ants and bees (Hymenoptera) (Harmon et al. 1986; Hammond 1997; Dajoz 2000; Buddle 2001; Siitonen 2001; Stokland et al. 2012). Nevertheless, knowledge of many other groups of dead wood-dependent invertebrates, especially microarthropods, is still incomplete and far from satisfactory.

Springtails (Collembola) belong to the smallest group of hexapodous arthropods (most are only a few millimeters in length) and are the most diverse and widespread among (Hopkin 1997). At present, more than 8000 species and 600 genera are described worldwide (Bellinger et al. 2014).

Collembola are generally polyphagous, however, the majority of them consume fungal hyphae and fruiting bodies, decaying vegetation, organic detritus, algae and micro-organisms (Hasegawa & Takeda 1995; Chen et al. 1995; Ponge 2000). Due to their feeding habits and abundance in forest litter and soil (where their densities can reach more than 10,000 individuals/m²) springtails play an important role in decomposition and soil development processes (e.g., Heneghan et al. 1998; Berg et al. 2001; Bradford et al. 2002). Unfortunately, data with respect to Collembola and their dead wood dependence is very sparse, fragmented and notably incomplete.

To improve this unsatisfactory knowledge some research on saproxylic springtails was conducted in 2006, 2007 and 2009 at the H. J. Andrews Experimental Forest Long Term Ecological Research site, located in the western Cascade Range (Oregon, USA). A large part of this area is covered by old-growth forests characterized by a high amount (more than 1000m³/ha) of high quality and structurally complex dead wood. These forests, presently unique in the temperate zone of the Northern Hemisphere, seem to be one of the best places to study diversity of saproxylic assemblages. Analysis of materials collected from rotten logs allowed the identification of a hitherto unknown member of the genus *Paleonura* Cassagnau, 1982. This genus was established by the eminent French collembologist Paul Cassagnau in 1982 and later assigned by him to the tribe Paleonurini (Cassagnau 1989), one of the 6 tribes within the subfamily Neanurinae. The type species of the genus, *P. spectabilis* Cassagnau, 1982, was described from Nepal (the Himalaya). Presently *Paleonura* is one of the most species-rich within the tribe and the whole subfamily, with most of 51 described taxa distributed in mountainous tropical regions. Previously, only 2 members of *Paleonura* have been identified in the Nearctic region, i.e., *P. anops* (Christiansen & Bellinger, 1980), previously identified in California (Petaluma, Sonoma County) and *P. peterbellingeri* found in Porter's Cave in Virginia (Bath Co.) (Palacios-Vargas & Simón 2007). Interestingly, the aforementioned cave is the northernmost locality of the whole genus. It should be also mentioned that *P. anops* was first described in the genus *Paranura* Axelson, 1902, and later transferred to *Paleonura* by Palacios-Vargas & Simón Benito (2007).

In addition, here we document the first occurrence of *Galanura agnieskae* Smolis, 2000 from Canada and North America. This member of the Paleonurini species was described recently from Poland (Europe) and has only been found in one locus typicus so far. The new finding notably extends the known distribution of the species. Specimens of the taxon were found in rotten logs of white birch in boreal forests of South Quebec

(Canada) during an excursion of the International Symposium "On dynamics and ecological services of deadwood in forest ecosystems" (15-19-V-2011, Rouyn-Noranda).

MATERIALS AND METHODS

Specimens were collected under bark and inside rotting wood using a mechanical aspirator. In addition, some deadwood samples were extracted in Tullgren traps. The specimens were cleared in Nesbitt's fluid, subsequently mounted on slides in Hoyer's solution and observed using a phase contrast microscope Nikon Eclipse 80i®. Figures were made using a camera lucida. Photographs were taken with a Canon 500D® (Taiwan) camera under a Nikon Eclipse 80i® (Tokyo, Japan). Image stacks were processed using Combine ZM® (Hadley 2010). Materials are deposited in the Department of Invertebrate Biology, Evolution and Conservation, Institute of Environmental Biology, Faculty of Biological Science, University of Wrocław, Poland (DIBEC) and in the Muséum National d'Histoire naturelle in Paris, France (MNHN). Terminology for the description follows those of Deharveng (1983), Deharveng & Weiner (1984), Greenslade & Deharveng (1990) and Smolis (2008).

The following abbreviations were used in this study:

General morphology: abd.—abdomen, ant.—antenna, AOIII—sensory organ of antennal segment III, Cx—coxa, Fe—femur, Scx2—subcoxa 2, T—tibiotarsus, th. —thorax, Tr—trochanter, VT—ventral tube.

Groups of chaetae: Ag—antegenital, An—chaetae of anal lobes, ap—apical, ca—centroapical, cm—centromedial, cp—centroposterior, d—dorsal, Fu—furcal, vc—ventrocentral, Ve or ve—ventroexternal, Vea—ventroexternoanterior, Vem—ventroexternomedial, Vep—ventroexternoposterior, Vel—ventroexternolateral, Vec—ventroexternocentral, Vei—ventroexternointernal, Vi or vi—ventrointernal, Vl—ventrolateral.

Tubercles: Af—antenna-frontal, Cl—clypeal, De—dorsoexternal, Di—dorsointernal, Dl—dorsolateral, L—lateral, Oc—ocular, So—subocular.

Types of chaetae: Ml—long macrochaeta, Mc—short macrochaeta, Mcc—very short macrochaeta, me—mesochaeta, mi—microchaeta, ms—s-microchaeta, S or s—chaeta s, bs—s-chaeta on ant. IV, miA—microchaetae on ant. IV, iv—ordinary chaetae on ventral ant. IV, or—organite of ant. IV, brs—border s-chaeta on ant. IV, i—ordinary chaeta on ant. IV, mou—cylindrical s-chaetae on ant. IV, L'—ordinary lateral chaeta on abd. V, B4, B5—ordinary chaetae on tibiotarsi.

RESULTS

PALEONURA SAPROXYLICA **SP. NOV.**
(Figs. 1-6, Tables 1 and 2)

Type Material

HOLOTYPE: female on slide, USA: Oregon State, western Cascade Range, H. J. Andrews Experimental Forest, Blue River Ranger District of Willamette National Forest, Lane Co., 6.5 km East of Blue River town, 520 m asl, “Cougar 1” site, old-growth forest of *Tsuga heterophylla* zone (tree species: Douglas fir *Pseudotsuga menziesi*, western hemlock *Tsuga heterophylla*, western red-cedar *Thuja plicata*), ex decayed log, 22.IX.2006, A. Smolis coll. Holotype deposited in DIBEC. **PARATYPES:** 15 females, 14 males and 17 juveniles, same locality as holotype, ex decaying logs, 20.IX–8.X.2006, 10–28.X.2007, 15.V–8.VI.2009, A. Smolis coll. 34 (13 females, 11 males and 10 juveniles) and 12 (2 females, 3 males and 7 juveniles) paratypes are deposited respectively in DIBEC and MNHN.

Other material: numerous individuals on slides and in alcohol, USA: Oregon State, western Cascade Range, H. J. Andrews Experimental

Forest, Blue River Ranger District of Willamette National Forest, Lane Co., 6.5 km North–East of Blue River town, 420–610 m above sea level, “Mona Creek” site, valley of Mona Creek, mixed forest (tree species: red alder *Alnus rubra*, big-leaf maple *Acer macrophyllum*, black cottonwood *Populus trichocarpa*, Douglas fir *Pseudotsuga menziessi*, western hemlock *Tsuga heterophylla*, western red-cedar *Thuja plicata*), ex decayed log, 2–10.X.2006, leg. A. Smolis, deposited in DIBEC.

Description

Habitus typical for the genus *Paleonura* Casagnau, 1982. Buccal cone elongated. Body length (without antennae) 0.5-1.90 mm (holotype: 1.75 mm). Color of the body when alive and in alcohol: white. Tubercles not developed, except on 2 last abdominal segments (Fig. 4). Ordinary dorsal chaetae (Figs. 1-4) differentiated into short, thin, acuminate microchaetae, medium size, smooth, acuminate mesochaetae and rather long size, smooth, thin, acuminate (without denticles) macrochaetae. No plurichaetosis on the body.

Head. Antennae shorter than head. 8 S-chaetae of ant. IV relatively short and thick. Apical

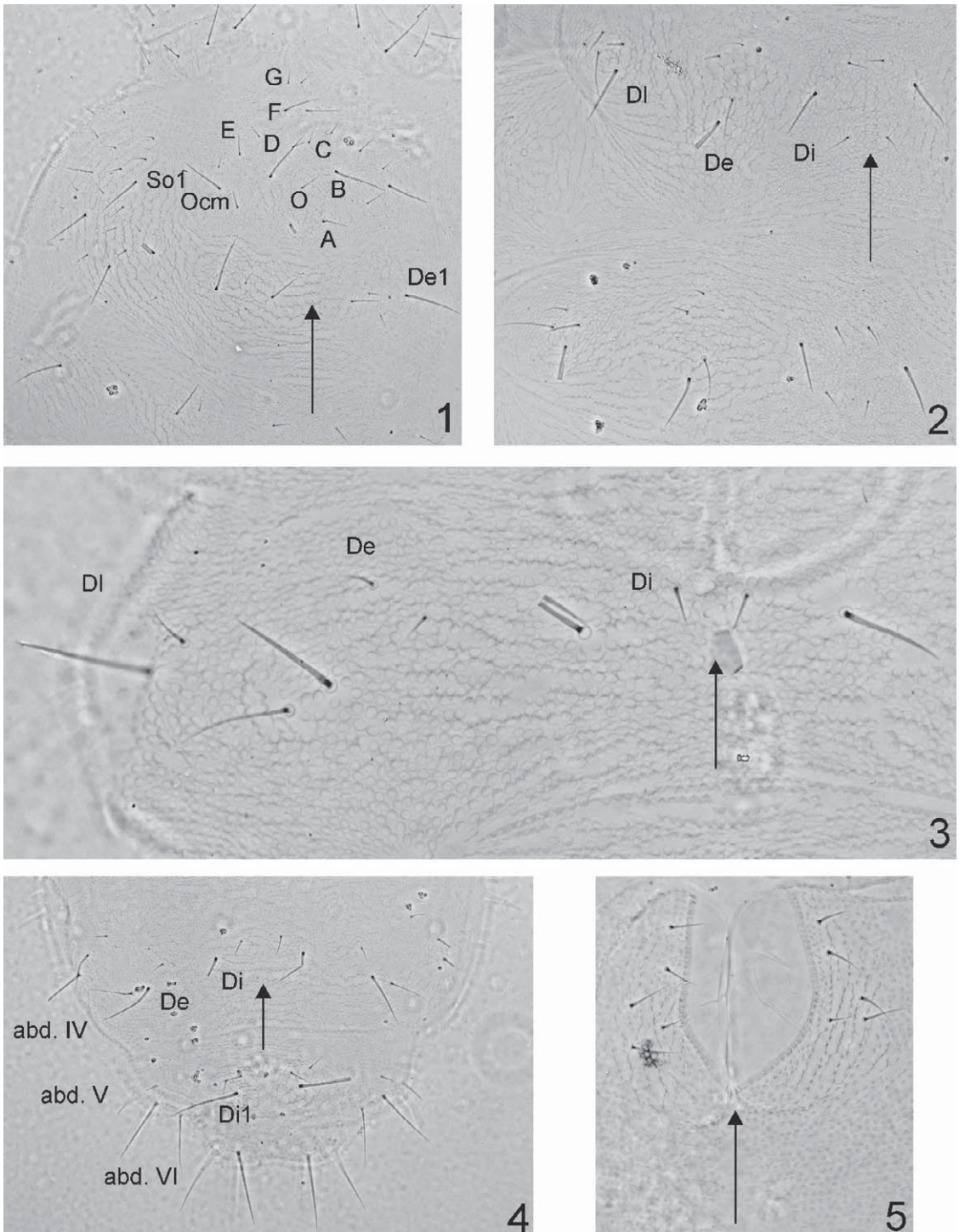
TABLE 1. CEPHALIC CHAETOTAXY OF *PALEONURA SAPROXYLICA* **SP. NOV.**

a) Cephalic chaetotaxy–dorsal side.

Group of chaetae	Number of chaetae	Types of chaetae	Names of chaetae
Cl	4	M me	F G
Af	11	M me	B A, D, E, C, O
Oc	3	M me mi	Ocm Ocp Oca
Di	2	M mi	Dil Di2
De	2	M mi	De1 De2
D1	6	M me	D11, D15 D12-4, D16
(L+S0)	10	M me	L1, L4 So1 So4-6, L2-3

b) Chaetotaxy of antennae.

Segment, Group	Number of chaetae	Segment, Group	Number of chaetae adult
I	7	IV	
II	11		or, 8 S, i, 12 mou, 6 brs, 2 iv
III	5 sensilla AO III		
ve	5	ap	8 bs, 5 miA
vc	4	ca	2 bs, 3 miA
vi	4	cm	3 bs, 1 miA
d	4	cp	8 miA, 1 brs



Figs. 1–5. *Paleonura saproxylica* **sp. nov.** 1, dorsal and lateral chaetotaxy of head and thorax 1 (holotype); 2, dorsal chaetotaxy of th. II–III; 3, dorsal chaetotaxy of abd. III; 4, dorsal chaetotaxy of abd. IV–VI; 5, ventral tube. Black arrows show axis of symmetry and orientation for position of the head. Black horizontal lines show borders of the segments.



Fig. 6. Old-growth forest of *Tsuga heterophylla* zone, “Cougar 1” site, type locality of *Paleonura saproxyllica* **sp. nov.**

bulb bilobate. Chaetotaxy of antennae as in Table 1b. Buccal cone relatively long and rounded at apex. Maxilla needle-like, mandible tridentate. Labium with 11+11 chaetae, labial papillae x absent. Labrum chaetotaxy 2/4, 4. Group Vi of ventral side with 6+6 chaetae. Groups Vea, Vem and Vep with 4, 3 and 4 chaetae respectively. Dorsal chaetotaxy of the head as in Table 1a and Fig. 1. Dorsal chaetotaxy of central area on head complete, with 3 chaetae Oc and chaetae A, B, C, D, E, F, G, O. The line of setae Di2–De2 crosses the line Di1–De1 on head (the cross-type, Deharveng 1983). Eyes absent.

Thorax, abdomen, legs. Dorsal chaetotaxy as in Figs. 2-4 and in Table 2. Ventral chaetotaxy as in Table 2. S-chaetae very thin and long, slightly shorter than nearby macrochaetae (Figs. 2-4). Sensillar formula of the body: 022/11111, s-microchaeta on D1 of th. II present. Ventral tube with 5+5 chaetae (Fig. 5). Furcal remnant consisting of 8 microchaetae and 4–5 mesochaetae. Male ventral organ absent. Claw without internal tooth. Chaeta M present on tibiotarsus. Chaetotaxy of legs as in Table 2. Abd. VI slightly bilobed (Fig. 4).

Etymology

The name of the species refers to its habitat, decaying and rooting coniferous wood.

Remarks

Because of body shape, dorsal chaetae type and absence of eyes, *Paleonura saproxyllica* **sp. nov.** is similar to both known North American *Paleonura* species: *P. anops* (Christiansen & Bellinger, 1980) and *P. petebellingeri* Palacios-Vargas & Simón Benito 2007. The mentioned taxa can be easily distinguished by the following set of characters: size of sensillum S1 on ant. IV (distinctly smaller than other sensilla S in *P. petebellingeri*, similar in length to other S sensilla in *P. saproxyllica* and *P. anops*), chaetotaxy of central area of head (chaetae O and E present in *P. saproxyllica*, chaeta O present and chaeta E absent in *P. petebellingeri*, chaetae O and E absent in *P. anops*), number of ordinary chaetae De on abd. I–III (2 in *P. anops*, 3 in others), number of ordinary chaetae De on abd. IV (2 in *P. anops*, 3 in others), number of dorsal chaetae Di on abd. V (2+2 in *P. pe-*



Fig. 7. Habitat of *Galanura agnieskae* in Quebec, Canada.

tebellingeri, 3+3 in others), number of ordinary chaetae De on abd. V (6 in *P. saproxylica*, 5 in *P. anops*, 4 in *P. petebellingeri*), number of chaetae on ventral tube (5+5 in *P. saproxylica*, 4+4 in *P. petebellingeri*, unknown in *P. anops*), number of microchaetae on furca remnant (4+4 in *P. saproxylica*, 3+3 in others), number of trochanteral chaetae (6 in *P. saproxylica*, 5 *P. petebellingeri*, unknown in *P. anops*).

Biology

The new species is an inhabitant of mixed conifer/deciduous forest of the *Tsuga heterophylla* Zone (Franklin & Dyrness, 1988) at lower elevations (Fig. 6). It lives in rotting wood and under bark of decaying logs of coniferous trees – Douglas fir, western red cedar and western hemlock. Logs inhabited by the new species are very rotten, soft and moist inside. Despite intensive field investigations it was not found in decayed wood of deciduous trees and in litter/soil samples (see discussion). Additionally, it has not been recorded from sites located at upper elevation forests (from 700–1400 m) of both *Tsuga heterophylla* and *Abies amabilis* Zones.

GALANURA AGNIESKAE SMOLIS, 2000 (Figs. 7 and 8)

Material Examined

Five females on slides, CANADA, Quebec Province, boreal balsam-fir-white birch forests, ca. 15 km North of Rouyn-Noranda city, in decaying white birch logs (Fig. 7), 15.V.2011, A. Smolis coll., deposited in authors' collections.

Remarks

To date, *G. agnieskae* has only been described and recognised in locus typicus in the Sudety Mountains (SW Poland, Fig. 8), where it has been collected from inside rotting birch logs on the bottom of an old calcareous stone pit. In order to confirm the taxonomic status of the new finding, we studied type material of the species, and there is no doubt that Polish and Canadian specimens are conspecific. In addition, no differences in the morphology of these specimens have been found. As in the Polish population, no males have been observed in Canada, which confirms Smolis' hypothesis (2000) that the species is parthenogen-

TABLE 2. POSTCEPHALIC CHAETOTAXY OF *PALEONURA SAPROXYLICA* SP. NOV.

Terga					Legs				
	Di	De	DI	L	Scx2	Cx	Tr	Fe	T T
th. I	1	2	1	—	0	3	6	13	19
th. II	3	3+s	3+s+ms	3	2	7	6	12	19
th. III	3	4+s	3+s	3	2	8	6	11	18
Sterna									
abd. I	2	3+s	2	3	VT: 5				
abd. II	2	3+s	2	3	Ve: 4 Vel- present				
abd. III	2	3+s	2	4	Ve: 4				
abd. IV	2	3+s	2	8	Vel:4 Vec:2 Vei:2				
abd. V	3	6+s			Ag: 3 chaetae L' and VI present				
abd. VI	7+2mi				Ve:14				
								An:2 mi	

ic. The confirmed occurrence in rotten trunks of deciduous trees, as well as an apparent preference for birch trees, undoubtedly requires further study. The distribution of this species should also be explored as its occurrence suggests a wide holarctic range.

DISCUSSION

Knowledge of saproxylic Collembola is poor in quality and quantity. Fragmented and general data can be found in some taxonomic and faunistic papers (e.g., Fjellberg 1985; Christiansen & Bellinger 1998; Babenko & Fjellberg 2006). The latest studies suggest that Collembola occur in rotten wood, and many Collembola could and should be treated like typical saproxylic organisms (Stevens et al. 2007; Garrick et al. 2008; Smolis 2008; 2011) - including the species described in this paper. Despite sampling of soil and litter, both species have, so far, only been found in dead wood. Thus, we can clearly state that we are dealing with saproxylic organisms. Interestingly, the morphology of these 2 species is similar. It is characterized by lack of the pigment and total reduction of the eyes (in the subfamily Neanurinae usually 2 or 3 eyes are situated on each side of the head), and by the strong reduction of cuticular prominences. Two of the first mentioned characteristics are common for Collembola, but they are mostly limited to springtails living in deep layers of the soil (edaphic forms) and inside caves. Without a doubt these characteristics have developed to support a life inside dead wood, where the light is heavily limited. Many of the representatives of the subfamily Neanurinae have developed strong cuticular prominencies (named tubercles), which in extreme cases may take the form of fingerlike papillae (e.g. in *Rambutanura* genus). The reduction of these morphological structures in both described species can be also an adaptation to tight and narrow spaces in dead wood.

It is interesting that *Paleonura saproxylica* was found exclusively in wood of coniferous trees, despite of the presence of fallen trunks of deciduous trees at Mona.

Moreover, another species from a related tribe Neanurini - *Xylanura oregonensis* Smolis (Smolis 2011) was discovered in the same place (Mona) inside similar trunks of deciduous trees. Surprisingly, this species has well-developed eyes (3 eyes on each side of the head), yet, a hypodermal pigment is present (Smolis 2011). This raises the question of why this taxon shows none of the reduction observed in the saproxylic species, despite the fact that it has only been found in dead wood habitats and is deemed to be saproxylic. A comparison of the diam and the degree of decay of deciduous stumps harboring *Xylanura* versus conifers where *P. saproxylica* was found may provide a hint. The first of these, namely hardwood



Fig. 8. Habitat of *Galanura agnieskae* in Poland (locus typicus).

stumps have a much smaller diam. Moreover, the rate of decay of these hardwoods is several times faster than that of coniferous trees in the area. This means that populations of *Xylanura* are forced to move between the stumps far more often than those species living in coniferous logs. In addition, deciduous species in the area are much harder to find and can be found mostly in along stream channels and disturbed places affected by anthropogenic or natural factors such as landslides or avalanches (Franklin & Dyrness 1988).

Recent decades have brought about significant progress in our knowledge of the biodiversity of dead wood. We hope that this trend will expand to include small arthropods and will help with determining not only the species richness, but also the role that they play in this little-known habitat.

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