

Integrating morphology and DNA barcodes for species delimitation within the species complex *Xenylla maritima* (Collembola: Hypogastruridae)

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Abstract. The species complex *Xenylla maritima* is examined using morphological and molecular characters. These independent datasets allowed for the identification of species which previously were overlooked and the review of the taxonomic status of nine forms in the *maritima* species group. Six are here recognized as distinct species and three as synonyms: *X. maritima* (= *X. maritima meridionalis*, *X. nova-zealandia*), *X. asiatica* comb.n. (= *X. maritima asiatica*), *X. nitida* bona species (= *X. brevisimilis*), *X. szeptyckii* sp.n., *X. pomorskii* sp.n. and *X. mediterranea*.

Key words. *Xenylla szeptyckii* sp.n., *Xenylla pomorskii* sp.n., *Xenylla asiatica*, *Xenylla nitida*, redescription, synonymy, overlooked diversity, DNA barcoding.

1. Introduction

Collembola have developed many effective life strategies that favoured their dominance in a variety of terrestrial environments. Moist habitats such as forest litter are inhabited by species communities where abundance may exceed 100.000 individuals per m². In dry habitats, Collembola diversity and abundance is lower, adaptation to survival in these environments has been achieved (MAS-SOUD et al. 1968; CASSAGNAU 1971; BELGNAOUI & BARRA 1989; ALVAREZ et al. 1999; SJURSEN et al. 2001; KAERSGAARD et al. 2004; MARX et al. 2012).

This is the case with the genus *Xenylla* Tullberg, 1869 in the family Hypogastruridae. With 131 species, it is the third largest genus in the family, after *Hypogastrella* Bourlet, 1839 and *Ceratophysella* Börner, 1932 (BELLINGER et al. 2015). BABENKO et al. (1994) defined *Xenylla* as a genus comprising mostly xero-resistant species dwelling in habitats sustaining recurrent droughts, such as mosses and lichens, under bark on tree trunks or within crevices in rocks. These authors distinguished three main ecological groups: forest, steppe and littoral-

compost species. The genus currently can be found both in the northern and southern hemisphere and exhibits a high degree of local endemism (BABENKO et al. 1994).

As species often live in harsh conditions like temporary deficit of moisture, oxygen and high or low temperatures, they have developed different adaptive mechanisms to tolerate different environmental conditions (GREENSLADE 1981). Because of their small and flat bodies they can colonise narrow crevices. The partial loss of the eyes and the reduction of the furca are adaptations to habitats such as under bark. The dark pigmentation of the body protects them against ultraviolet light, but also allows absorption of the sun-heat (GREENSLADE 1981). Several *Xenylla* species remain active in hot and dry conditions, thus exhibiting a considerable physiological tolerance by comparison with many other groups of Collembola. A *Xenylla maritima* Tullberg, 1869 population, from southern Norway, showed high resistance to desiccation in laboratory conditions (20°C and 50% RH) and lived up to 14 days, while other xerophilous forms,

Anurophorus laricis Nicolet, 1842 and *Tetracanthella wahlgreni* Axelson, 1907, persisted only 3 days and 3–4 hours respectively (LEINAAS & SOMME 1984). By comparison, mesohygrophilous species such as *Desoria hiemalis* (Schött, 1893), *Lepidocyrtus lignorum* (Fabricius, 1793) survived 1.5 hours and a typical soil inhabitant, *Parisotoma notabilis* (Schäffer, 1896), only 3 minutes (LEINAAS & SOMME 1984). A high resistance to desiccation may facilitate passive and active dispersal.

X. maritima, the type species of the genus, was not fully described (TULLBERG 1869) and has never been re-described based on types, therefore its taxonomic status remains unclear. There are two main definitions of this species in present-day literature. One is by GAMA (1969) and THIBAUD et al. (2004) defined *X. maritima* as follows: outer lobe of maxilla with 2–3 sublobal hairs, retinaculum with 3+3 teeth, abd. III without setae on the retinaculum, mucrodens 1.5–2.25 × longer than inner edge of claw III, with a low mucronal lamella not reaching the apex, apex of mucro narrow and weakly upturned. *X. nitida* Tullberg, 1871, *X. nova-zealandia* Salmon, 1941, *X. maritima meridionalis* Stach, 1949 and *X. maritima asiatica* Martynova, 1975 are considered synonymous with *X. maritima*, while *X. brevisimilis* Stach, 1949 is regarded as a separate species with two subspecies: *X. brevisimilis brevisimilis* (outer lobe of maxilla with 2–3 sublobal hairs, retinaculum with 3+3 teeth, abd. III with 2 setae on the retinaculum, mucrodens 1.25 × longer than inner edge of claw III, mucro without a lamella and with an apex shaped as a small hook) and *X. brevisimilis mediterranea* Gama, 1964, which differs from the former in outer lobe of maxilla with only 1 sublobal hair and retinaculum with 2+2 teeth.

The other concept (BABENKO et al. 1994) considers *X. maritima*, *X. maritima meridionalis*, *X. maritima asiatica*, *X. nova-zealandia* and *X. brevisimilis brevisimilis* as forms of unclear taxonomic position and include them into *X. maritima* s.l., a collective taxon characterised by outer lobe of maxilla with 2–3 sublobal hairs, retinaculum with 3+3 teeth, abd. III with 0–2 setae on the retinaculum, mucrodens 1.2–2.2 × longer than inner edge of claw III, tapering, with long mucronal lamella. Four morphological forms are recognised within *X. maritima* s.l. distinguished by a set of commonly used characters. According to this concept *X. brevisimilis mediterranea* is a separate, well-defined species (*X. mediterranea*) and this species status was accepted by FJELLBERG (1998).

Until now, this species complex has been defined morphologically. However the morphological approach did not allow for the resolution of the status of all the putative species and subspecies in the group. The diagnostic value of each morphological character has differed among taxonomists. A new set of characters is needed, and here we used DNA barcodes to understand the status of problematic forms. This tool, employed with other characters, has allowed a clearer delineation of a number of Collembola groups (PORCO et al. 2010a, 2012). This integrated approach was used here to resolve the status of the different species and forms in the *X. maritima* complex.

2. Material and methods

2.1. Species/forms studied

Nine species/forms of the *X. maritima* complex were studied: *X. maritima*, *Xenylla* sp. 1, *Xenylla* sp. 2, *X. brevisimilis brevisimilis*, *X. brevisimilis mediterranea*, *X. nitida*, *X. nova-zealandia*, *X. maritima meridionalis* and *X. maritima asiatica*. Combined morphological-genetic analyses were focused on the first five mentioned. Concerning the last four species, only morphology was studied (Table 1). As a reference for the genetic divergence among species in the genus, the sequences from three other *Xenylla* species barcoded in a previous study (PORCO et al. 2014): *X. humicola* (O. Fabricius, 1780), *X. betulae* Fjellberg, 1985 and *X. canadensis* Hammer, 1953) were used.

2.2. Morphology

A set of characters commonly used in the taxonomy of the genus (THIBAUD et al. 2004), supplemented by structure of maxilla and labium (FJELLBERG 1984, 1998, 1999) and the chaetotaxy of legs (BUŞMACHIU & WEINER 2008), was analysed. Specimens stored in alcohol were cleared in Nesbitt's fluid (chloral hydrate, concentrated hydrochloric acid, distilled water) and subsequently mounted on slides in Swann's medium (distilled water, arabic gum, glacial acetic acid, glucose, chloral hydrate). Observations were made using a Nikon Eclipse E600 phase contrast microscope. Figures were drawn with the camera lucida. Photographs were made using Nikon D5100. The following nomenclatural systems were used: for body chaetotaxy (GAMA 1988; THIBAUD et al. 2004), tibiotarsal chaetotaxy (LAWRENCE 1977; DEHARVENG 1983), chaetotaxy of anal valves (HÜTHER 1962), chaetotaxy of labium (MASSOUD 1967), labial palp (FJELLBERG 1999) and maxilla (FJELLBERG 1984, 1998).

Abbreviations: ant. I–IV – antennomeres I–IV, th. I–III – thoracic segments I–III, abd. I–VI – abdominal segments I–VI. Abbreviations of depositories are listed in Table 2.

2.3. DNA barcoding

2.3.1. Molecular analyses

DNA was extracted from entire specimens in 30 µl of lysis buffer (http://www.ccdp.ca/docs/CCDB_DNA_Extraction.pdf) and proteinase K incubated at 56°C overnight. DNA extraction followed a standard automated protocol using 96-well glass fibre plates (IVANOVA et al. 2006). Specimens were recovered after DNA extraction using a specially designed work flow allowing their morphological examination (PORCO et al. 2010b). The 5' region of COI used as a standard DNA barcode was amplified us-

Table 1. Studied species/forms of *Xenylla maritima* complex. ¹⁾ Since types are probably lost (see subsection 5.2.), specimens from Norwegian Skagerrak coast were used for the description, and individuals from Polish Baltic coast (morphologically identical with Norwegian ones) for DNA barcoding. ²⁾ See subsection 5.2. ³⁾ See subsection 5.6. ⁴⁾ See subsection 5.7. ⁵⁾ See subsection 5.4. ⁶⁾ See subsection 5.5.

Species/form studied	Original description	Position in BABENKO et al. (1994) system	Position in THIBAUD et al. (2004) system	Type locality	Types studied	Other material studied	Material used for DNA barcoding
<i>X. maritima</i>	TULLBERG (1869)	<i>X. maritima</i> form 1	<i>X. maritima</i>	Seaweed washed up on the shore of Skagerrak near Fiskebackskil (Bohuslan, Sweden)	— ¹⁾	Bulgaria, Norway, Poland ²⁾	7 specimens, mosses and lichens between scarce vegetation in the front part of sand dunes near Mielenko, Baltic Coast, Poland, 20.viii.2010, leg. D. Skarżyński (IEBW)
<i>X. maritima meridionalis</i>	STACH (1949)	<i>X. maritima</i> form 1	<i>X. maritima</i>	“Some Mediterranean territories” — Slovenia, Croatia (former Yugoslavia), Malta, France, Spain	Syntypes	—	—
<i>X. maritima asiatica</i>	MARTYNOVA (1975)	<i>X. maritima</i> form 3	<i>X. maritima</i>	Lichens on rocks and <i>Larix sibirica</i> , 1650–1750 m a.s.l., Tevshruleh, Ara-Khangai aimak, Khangai Mountains, Mongolia	Holotype	—	—
<i>X. nova-zealandia</i>	SALMON (1941)	<i>X. maritima</i> form 1	<i>X. maritima</i>	Lake Monowai, under the bark of manuka trees on the river bank, South Island, Southland, New Zealand	Holotype, paratypes	—	—
<i>X. nitida</i>	TULLBERG (1871)	<i>X. maritima</i> form 4	<i>X. maritima</i>	Under the bark of a log by the distillery outside Svartbäckstull (Uppsala, Sweden)	Syntype	—	—
<i>X. brevisimilis</i>	STACH (1949)	<i>X. maritima</i> form 4	<i>X. brevisimilis brevisimilis</i>	Short moss growing on wooden tiles of a country-house, Czarny Dunajec, Poland	Syntypes, topotypes	Czech Republic, Germany, Poland ³⁾	5 specimens, mosses on buildings, fences and roofs, Wrocław, Poland, 6.ix.2010, leg. D. Skarżyński (IEBW)
<i>X. brevisimilis mediterranea</i>	GAMA (1964)	<i>X. mediterranea</i>	<i>X. brevisimilis mediterranea</i>	Young pine forest on sand dunes, Mira, near Coimbra, Portugal	Topotypes	Italy, Norway, Poland ⁴⁾	4 specimens, mosses on rocks near Mori village, 450 m a.s.l., neighborhood of Garda Lake, Italian Alps, 15.viii.2010, leg. M. Filistowicz (IEBW)
<i>Xenylla</i> sp. 1		<i>X. maritima</i> form 4	<i>X. maritima</i>			France, Hungary, Poland, Slovakia, Sweden ⁵⁾	4 specimens, mosses and lichens on trees, pine-oak forest, Kałna near Wrocław, Nizina Śląska Lowland, Poland, 7.ix.2010, leg. D. Skarżyński; 4 spp, ant-hills in pine-oak forest, Potasze village, Zielonka Forest near Poznań, Poland, 10.iv.2011, leg. D. Skarżyński (IEBW)
<i>Xenylla</i> sp. 2		<i>X. maritima</i> form 4	<i>X. maritima</i>			Poland ⁶⁾	5 specimens, ant-hills in pine-oak forest near Potasze village, Zielonka Forest near Poznań, Poland, 18.iii.2012, leg. D. Skarżyński (IEBW)

Table 2. A list of institutions and countries in which specimens are deposited, with abbreviations.

Abbreviation	Depository	Country
AF	Collection of Dr. Arne Fjellberg	Norway
DZC	Department of Zoology, Faculty of Science and Technology, Coimbra University	Portugal
IEBW	Institute of Environmental Biology, Wrocław University	Poland
ISEAC	Institute of Systematics and Evolution of Animals Polish Academy of Sciences, Cracow	Poland
MEU	Museum of Evolution, Uppsala University	Sweden
MNZW	Museum of New Zealand Te Papa Tongarewa, Wellington	New Zealand
ZIP	Zoological Institute Russian Academy of Sciences, Petersburg	Russia

ing M13 tailed primers LCO1490 and HCO2198 (FOLMER et al. 1994). Samples that failed to generate an amplicon were subsequently amplified with a pair of internal primers combined with full length ones (C_LepFolF/C_LepFolR) (Ivanova – published on www.boldsystems.org). The standard PCR reaction protocol of the Canadian Center for DNA Barcoding was used for amplifications (<http://www.dnabarcodes2011.org/conference/preconference/CCDB-Amplification-animals.pdf>), and products were checked on a 2% E-gel 96Agarose (Invitro-

gen). Unpurified PCR amplicons were sequenced in both directions using M13 tailed primers, with products subsequently purified using Agencourt CleanSEQ protocol and processed using BigDye version 3.1 on an ABI 3730 DNA Analyzer (Applied Biosystems). Sequences were assembled and edited with Sequencher 4.5 (GeneCode Corporation, Ann Arbor, MI, USA). The alignment was obtained using BIOEDIT version 7.0.5.3 (HALL 1999). Sequences are publicly available on BOLD in the dataset [DS-XEMAC] accessible through the following DOI

Table 3. Morphological characteristics of studied *Xenylla* species/forms. ¹⁾ Integument only slightly verrucose. ²⁾ Retinaculum with 2 + 2 teeth. ³⁾ Interior of the body pink, antennal segment IV with 4 equally large sensilla, inner tooth of claws distinct.

Character	<i>X. maritima</i> (= <i>X. maritima meridionalis</i> , <i>X. nova-zealandia</i>)	<i>X. asiatica</i> (= <i>X. maritima asiatica</i>)	<i>X. nitida</i> ¹⁾ (= <i>X. brevisimilis</i>)	<i>X. mediterranea</i> ²⁾ (= <i>X. brevisimilis mediterranea</i>)	<i>X. szeptyckii</i> sp.n. (= <i>Xenylla</i> sp. 1)	<i>X. pomorskii</i> sp.n. ³⁾ (= <i>Xenylla</i> sp. 2)
Size	1.1–1.6 mm	1.3 mm	0.7–1.3 mm	0.7–1 mm	0.7–1.3 mm	0.6–1.1 mm
Number of sublobal hairs on outer lobe of maxilla	3	3	2	1	2	2
Setae m ₅ on abd. IV	absent	present	present	present	absent	present
Number of setae on leg III subcoxae 1	3	3	2	2	3	3
Number of setae in front of retinaculum on abd. III	0	1	1–2	1–2	1–2	1–2
Ratio: mucrodens/claw III	1.9–2.4	2.3	1–1.3	1–1.6	1.6–2	2–2.3
Apex of mucro	narrow, weakly upturned	narrow, weakly upturned	moderately broad and spoon-like	narrow, weakly upturned	narrow, weakly upturned	broad, strongly spoon-like

(<http://dx.doi.org/10.5883/DS-XEMAC>) and on GenBank (GU657106–GU657108, GU657184–GU657187, GU657191, GU657256, GU657257, GU65727, GU657275, HM390617, HM390619, HM390653, HM390656, HQ987412–HQ987429, KF641975, KF642098, KF642176, KF642288, KF642424, KF642591, KU565132–KU565142).

2.3.2. Data analyses

Distance analyses were performed with MEGA6 (TAMURA et al. 2013), utilizing a Neighbor-Joining (SAITOU & NEI 1987) algorithm with the Kimura-2 parameter model (KIMURA 1980) to estimate genetic distances. The robustness of nodes was evaluated through bootstrap re-analysis of 1000 pseudoreplicates. The tree was replotted using the online utility iTOL (LETUNIC & BORK 2007).

3. Results

3.1. Morphology

Three forms were found identical after examination: *X. maritima*, *X. maritima meridionalis* and *X. nova-zealandia*. Also morphological characteristics of *X. nitida* and *X. brevisimilis* appeared to be the same. The other forms *X. maritima asiatica*, *X. brevisimilis mediterranea*, *Xenylla* sp. 1 and *Xenylla* sp. 2 were found well defined morphologically (Table 3).

3.2. DNA barcoding

Molecular data showed that the divergences between eight taxonomic *Xenylla* units taken into consideration are high, all reaching over 19%. This was true for the five forms of the studied species complex – *X. maritima*, *Xenylla* sp. 1, *Xenylla* sp. 2, *X. brevisimilis brevisimilis*, *X. brevisi-*

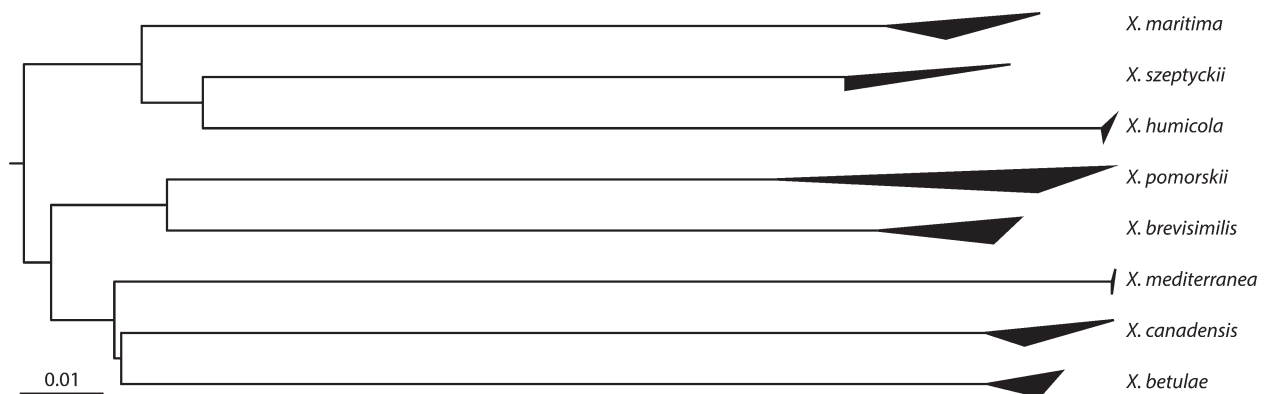
milis mediterranea – as well as the three others included as a reference for the genetic divergence among species in the genus: *X. betulae*, *X. humicola*, and *X. canadensis* (Fig. 1, Table 4). The mean divergence found among them was 0.87% (intraspecific) and 24.4% (interspecific). Among the five species of the *X. maritima* complex the mean intraspecific/form distances is 1.19% (ranging from 0 to 2.96%) and the mean interspecific/form divergence is 24.01% (ranging from 19.20 to 27.27%). The highest intraspecific divergence was measured in *Xenylla* sp. 2 with one of the specimens exhibiting a maximum of 7.28% divergence with the sequences from other conspecifics. The lowest interspecific distance in the whole dataset, 15.84%, was measured between two sequences respectively from a *X. maritima* specimen and a *Xenylla* sp. 1 one. Thus, even if this high intraspecific divergence has to be noted, it has no impact on the species delineation as the barcode gap is well defined here. The five *X. maritima* forms exhibited the same amount of genetic divergence between them than species well characterised morphologically, supporting the specific status of these entities.

3.3. Combined morphological-genetic analysis

All the remains of the specimens with DNA extracted, following the PORCO et al. (2010b) protocol, were morphologically examined and have been assigned accordingly to the different species and forms. Results of molecular analysis showed that typical morphological characters used so far in taxonomy of the *X. maritima* complex provide reliable information on species status. Consequently, they can be used, even alone, for species identification. Combination of independent datasets allowed us to revise the taxonomic status of the nine studied forms. Six of them are recognized as distinct species and three as synonyms: *X. maritima* (= *X. maritima meridionalis*, *X. nova-zealandia*), *X. asiatica* comb.n. (= *X. maritima asiatica*), *X. nitida* bona species (= *X. brevisimilis*), *X. szeptyckii* sp.n. (= *Xenylla* sp. 1), *X. pomorskii* sp.n.

Table 4. Intraspecific and interspecific K2P distances in *Xenylla maritima* complex, measured in %.

		Intraspecific / form	Interspecific / form						
			1	2	3	4	5	6	7
1	<i>X. betulae</i>	1.54							
2	<i>X. brevisimilis</i>	1.93	21.99						
3	<i>X. canadensis</i>	0.82	22.51	24.90					
4	<i>X. humicola</i>	0.06	25.33	24.73	24.88				
5	<i>X. maritima</i>	1.69	27.27	24.25	26.35	21.92			
6	<i>X. szepteyckii</i> sp.n. (= <i>Xenylla</i> sp. 1)	0.55	23.99	23.43	26.33	20.03	19.20		
7	<i>X. pomorskii</i> sp.n. (= <i>Xenylla</i> sp. 2)	2.96	23.31	21.33	23.54	25.93	23.91	24.52	
8	<i>X. mediterranea</i>	0.00	23.56	26.75	23.30	26.34	22.87	25.29	24.42

**Fig. 1.** Neighbor joining tree (K2P) based on the COI 5' sequences of specimens from the five species of the *X. maritima* complex along with the three reference species *X. humicola*, *X. betulae* and *X. canadensis*. The upper and lower sides of the triangle represent respectively the maximum and minimum of genetic distances within the species as found in our sample. All the nodes for species clusters are supported by 100% bootstrap value, no other (deeper) node exhibited such a high support.

(= *Xenylla* sp. 2) and *X. mediterranea* (= *X. brevisimilis mediterranea*). In the light of these results, the *X. maritima* complex conceptions (BABENKO et al. 1994; THIBAUD et al. 2004) mentioned in the Introduction are not supported. Descriptions of distinguished species are given in section 5. 'Taxonomy'.

4. Discussion

The present study, which included forms already characterised morphologically but not assignable to species status, illustrates the value of integrating molecular tools into the taxonomic process. The addition of these new data combined with previously explored source of morphological data allowed to gain a higher level of proof for describing a part of the diversity which would have otherwise remained overlooked (*X. szepteyckii* sp.n. and *X. pomorskii* sp.n.).

This first pass with DNA barcode on this species complex shows the need for a more extensive study in the future. An exploration of the intraspecific variability for some of the species studied here would provide information on their delineation and potential cryptic or overlooked diversity. For example, *X. szepteyckii* sp.n. exhibited the widest range of habitats in inland sites under

different ecological conditions. This might suggest the presence of a possible undescribed diversity adapted to this wide range of conditions which could be detected by a barcode screening of the different populations from the various habitats.

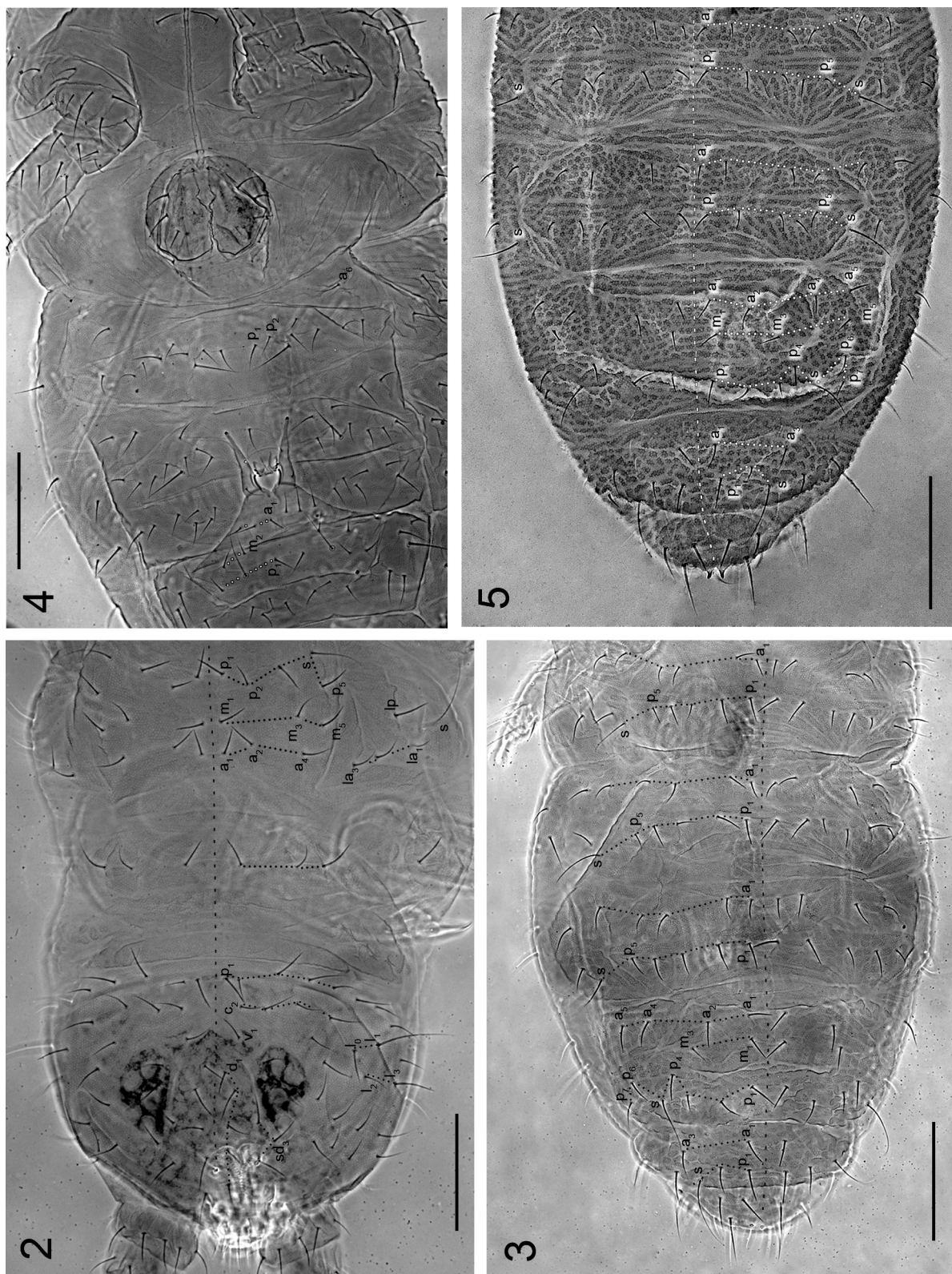
5. Taxonomy

5.1. Description of *Xenylla maritima* complex

Body length 0.6–1.6 mm. Colour (in alcohol): dorsal side blue-grey, violet or black, ventral side paler. Interior of the body white or pink. Integument more or less verrucose with small primary hexagons (Figs. 2–5).

Dorsal chaetotaxy (Figs. 2, 3, 5): setae short and serrated. Body sensilla (s) 2–3 × longer than ordinary setae, fine and smooth. Head with seta c_1 absent, seta L_1 longer than seta L_3 . Th. II and III with seta a_2 displaced posteriorly compared with seta a_1 , seta p_2 displaced anteriorly compared with seta p_1 , with setae m_3 and la_1 present. Abd. I–III with seta p_5 present. Abd. IV without setae a_3 and setae m_5 present or absent. Setae a_2 on abd. V absent.

Ventral chaetotaxy: head with setae p_1 and m_3 . Th. II and III with 1 + 1 setae. Abd. II with setae a_5 absent and



Figs. 2–5. Chaetotaxy of *Xenylla* species. **2:** *X. szepiyczkii* sp.n. head and thorax, dorsal side. **3:** *X. szepiyczkii* sp.n. abdomen, dorsal side. **4:** *X. szepiyczkii* sp.n. abdomen, ventral side. **5:** *X. mediterranea* abdomen, dorsal side. (Scale bar: 0.1 mm)

setae p_1 and p_2 present, abd. III with or without setae in front of retinaculum, abd. IV without seta m_1 (Fig. 4). Two anterior anal valves with 2 setae hr each.

Ant. IV with simple apical vesicle (av), subapical organite (so), microsensillum (ms) and 4 (3 dorsoexternal and 1 dorsointernal) cylindrical, thickened sensilla (Figs. 6, 7). Ant. III-organ with two long (outer) and two short

(inner) sensilla. Microsensillum on ant. III present. Ant. I with 7 setae.

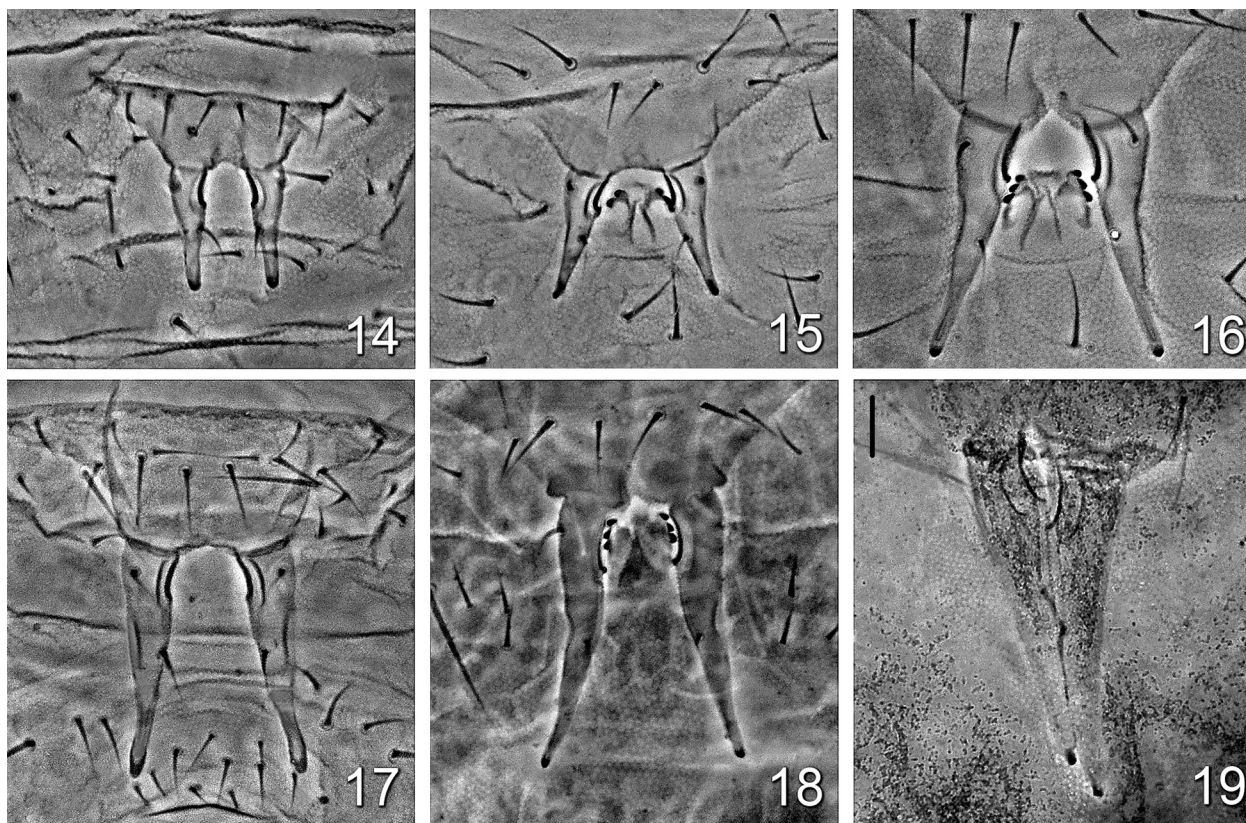
Ocelli 5+5 (Fig. 2). Labrum with apical papillae. Labral setae 5, 5, 4, prelabrals 4. Maxillary head as in Fig. 11. Labium with seta F ca. $2.5\times$ longer than seta E. Labial palp as in Fig. 12. Outer lobe of maxilla with 1, 2 or 3 sublobal hairs (Figs. 8–10).



Figs. 6–13. 6, 7: Sensorial chaetotaxy of terminal antennal segment IV of *Xenylla szepteyckii* sp.n. (a bit rotated left compared to Fig. 7) (6), and *X. pomorskii* sp.n. (a bit rotated right compared to Fig. 6) (7). 8–10: Outer lobe of maxilla of *Xenylla mediterranea* (8), *X. szepteyckii* sp.n. (9), and *X. maritima* (10). 11: Head of maxilla of *X. maritima*, ventral view. 12: Labium of *X. maritima*, ventral view. 13: Leg III of *X. maritima*, dorsolateral view. (Scale bar: 0.01 mm)

Tibiotarsi I, II and III with 19, 19 and 18 setae respectively, with setae A₂ and A₇ capitate (ratio capitate setae/claw III = 1.5). Femora I, II and III with 12, 11 and 10 se-

tae respectively, trochantera with 5, 5 and 4 setae respectively, coxae I, II and III with 3, 7 and 7 setae, subcoxae 2 of legs I, II and III with 0, 2 and 2 setae, subcoxae 1 of



Figs. 14–19. Furca of *Xenylla* species. **14:** *X. nitida*. **15:** *X. mediterranea*. **16:** *X. szeptyckii* sp.n. **17:** *X. pomorskii* sp.n. **18:** *X. maritima*. **19:** *X. asiatica* stat.n. (Scale bar: 0.01 mm)

legs I, II and III with 1, 2 and 2 or 3 setae respectively. Claws with inner tooth (Fig. 13).

Ventral tube with 4+4 setae. Retinaculum with 3+3 (Figs. 16, 18) or 2+2 (Fig. 15) teeth.

Mucrodens 1–2.4× longer than inner edge of claws III, with 2 posterior setae, with or without marked ventral bend, with low mucronal lamella, not reaching the apex, which is narrow and weakly upturned or more or less broad and spoon-like (Figs. 14–19).

Anal spines small, situated on low basal papillae (Figs. 3, 5).

5.2. *Xenylla maritima* Tullberg, 1869

Figs. 10–13, 18

Xenylla maritima Tullberg, 1869: 11

Xenylla maritima meridionalis Stach, 1949: 231

Xenylla nova-zealandia Salmon, 1941: 287

Material. 19 specimens, seashore wrack on a beach, Skagerrak coast, Ringshaugstranda near Tønsberg, Vestfold county, Norway, 19.iii.1995, leg. A. Fjellberg (AF); numerous specimens, dry seaweed on a beach near Międzyzdroje, Baltic Coast, Wolin Island, Poland, 26.vi.1971, leg. A. Szeptycki (ISEAC); numerous specimens, mosses and lichens between scarce vegetation on the front part of sand dunes near Świnoujście, 28.vi.1958, 2.vii.1958, Międzyzdroje, 19.vi.1959, 30.vii.1959, Wiselka, 25.vii.1961, 15.vii.1958, Międzywodzie, 19.vii.1958, 5.vi.1960, 25.vii.1967, 30.vi.1958, 14.vii.1959, 29.vii.1959, Dziwnów, 25.vii.1961, 5.vi.1960, Baltic

Coast, Wolin Island, Poland, leg. A. Szeptycki (ISEAC); numerous specimens, mosses and lichens between scarce vegetation in the front part of sand dunes near Mielno, 14.viii. 2000, 23.vii. 2001, 22.vii.2004, 7.viii.2009, Mielno 20.viii. 2010 (**barcoded** specimens), 27.vii.2011 and Pobierowo 13.viii.2007, Baltic Coast, Poland, leg. D. Skarżyński (IEBW); 5 specimens, dry seaweed on the beach near Tshernomorec, Black Sea Coast, Bulgaria, leg. R.J. Pomorski, D. Skarżyński (IEBW); *Xenylla maritima meridionalis*: 3 specimens, Saintes Maries de la Mer, France, 10.ii.1925, leg. K. Łukaszewicz (ISEAC); 5 specimens, Arles, France, 21.ii.1925, leg. K. Łukaszewicz (ISEAC); 15 specimens, Ajaccio, Corsica, France, 11.iii.1925, leg. K. Łukaszewicz (ISEAC); 5 specimens, Malta, 1926, leg. Gatto (ISEAC); *Xenylla nova-zealandia*: holotype 3/245, paratypes 3/246 and 3/247, Lake Monowai, under the bark of manuka trees on the river bank, South Island, Southland, New Zealand, 8.i.1940, leg. J.T. Salmon (MNZW).

Description. Body length 1.1–1.6 mm. Colour (in alcohol): dorsal side from blue-grey to violet-black, ventral side paler. Interior of the body white. Integument verrucose. Abd. tergum IV without setae m_5 . Abd. sternum III without setae in front of retinaculum (Fig. 18). Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla (A and B thicker than C and D). Outer lobe of maxilla with 3 sublobal hairs (Fig. 10). Subcoxae 1 of legs III with 3 setae. Claws with indistinct inner tooth. Retinaculum with 3+3 teeth (Fig. 18). Mucrodens 1.9–2.4× longer than inner edge of claws III, with 2 posterior setae, marked ventral bend, low mucronal lamella, not reaching the apex, which is narrow and weakly upturned (Fig. 18). — Several specimens examined for

this redescription were barcoded. Their COI sequences, representing the ‘barcoding type’ of the species, are deposited on BOLD and Genbank under the sampleID: BIOUG00172-19, BIOUG00172-20, BIOUG00172-21, BIOUG00172-22, BIOUG00172-23. Identification of unknown specimens could be achieved through the comparison of their barcode sequences taking into account the intraspecific variability observed for this marker in Collembola (e.g. PORCO et al. 2010a, 2012, 2014).

Remarks. *X. maritima* was described based on specimens collected in seaweed washed up on the shore of Skagerrak near Fiskebackskil (Bohuslan, Sweden) (TULLBERG 1869). Unfortunately, we could not examine them as types could not be found in the collections of the Swedish Museums of Uppsala, Lund and Stockholm (in litt. Hans Mejlon, Arne Fjellberg, Niclas Jonson). *X. maritima* individuals from Värmland and Gotland (MEU, labels: „1789, *Xenylla maritima* Tullb. Gottl., Hoburg., T.Tullberg.” and “1789b, *Xenylla maritima* Tullb. Kristinehamn, i en rännsten. 1870. ----stedt”) mentioned by TULLBERG (1871, 1872) appeared to be *X. humicola* after re-examination. Consequently we decided to use for the description specimens from Norwegian Skagerrak coast collected by Dr. Arne Fjellberg and for DNA barcoding, individuals from Polish Baltic coast, morphologically identical with Norwegian ones. This choice seems well founded, since only two species of the *maritima* complex live on the beaches of the Skagerrak and Baltic. One of them is *X. mediterranea* which is easily distinguishable from *X. maritima* by its small size and short furcula. Other species of this complex do not occur in strictly coastal habitats.

The detailed examination of *X. maritima meridionalis* Stach, 1949 syntypes from Stach’s collection showed a complete correspondence with the *X. maritima* description presented here. Consequently, the synonymous status of the subspecies (GISIN 1960; BABENKO et al. 1994; THIBAUD et al. 2004) was confirmed. Stach’s remaining material mentioned under the name *X. maritima* in his monography (STACH 1949) belongs to *X. szeptyckii* sp.n. or *X. pomorskii* sp.n.

Also, the review of the type material of *X. novaezealandia* revealed a high similarity with *X. maritima*. Despite the poor condition of the types, some noticeable holotype features: outer lobe of maxilla with 3 sublobal hairs, abd. III without setae in front of retinaculum and mucrodens 2 × longer than inner edge of claws III, with 2 posterior setae, marked ventral bend, low mucronal lamella not reaching the apex which is narrow and weakly upturned make synonymy suggested by GAMA (1969) justified.

X. maritima is most similar to *X. asiatica* comb.n. and *X. szeptyckii* sp.n., from which it differs in features presented in Table 3 and the key. *X. maritima* defined as above is known from Norway, Sweden, Poland, Bulgaria, France, Malta and New Zealand. It lives in seashore sites and especially in mosses and lichens covering open sand dunes and rocks and in drying seaweed washed up on the shore. On Skagerrak and Baltic coasts it can coexist

with *X. mediterranea*. In New Zealand it was collected from tree barks.

5.3. *Xenylla asiatica* Martynova, 1975 comb.n.

Fig. 19

X. maritima asiatica Martynova, 1975: 14

Material. *Holotype* ♀ on slide, lichens on rocks and *Larix sibirica*, 1650–1750 m a.s.l., Tevshruleh, Ara-Khangai aimak, Khangai Mountains, Mongolia, 4.viii.1971, leg. Medvedev (ZIP).

Redescription. Body length 1.3 mm. Colour (in alcohol): violet. Interior of the body white. Integument verrucose. Head with seta a_0 present. Abd. tergum IV with seta m_5 present. Abd. sternum III with 1 setae in front of retinaculum. Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla (A and B thicker than C and D). Outer lobe of maxilla with 3 sublobal hairs. Subcoxae 1 of leg III with 3 setae. Claws with indistinct inner tooth. Retinaculum with 3+3 teeth. Mucrodens 2.3 × longer than inner edge of claws III, with 2 posterior setae, marked ventral bend, low mucronal lamella, not reaching the apex, which is narrow and weakly upturned (Fig. 19).

Remarks. This species was described from Mongolia as *X. maritima asiatica* (MARTYNOVA 1975). The examination of the holotype revealed the morphological distinctiveness of this form and allowed us to regard it as a separate species. *X. asiatica* comb.n. is most similar to *X. maritima*, but it differs in features presented in Table 3 and the key. This species is known from the mountains of the Mongol steppe zone, where it lives in lichens covering rocks and trees.

5.4. *Xenylla szeptyckii* sp.n.

Figs. 2–4, 6, 9, 16

Material. *Holotype* ♀ on slide, mosses and lichens on trees, pine-oak forest, Kałna near Wrocław, Nizina Śląska Lowland, Poland, 17.iv.2006, leg. D. Skarżyński. – *Paratypes*: 6♀, 2♂, 17.iv.2006, 7.ix.2010 (*barcoded* specimens), other data as holotype (IEBW). – **Other material**: numerous specimens, Poland, leg. D. Skarżyński (IEBW): mosses and lichens on trees, pine-oak forest, Jelcz-Laskowice near Wrocław, Nizina Śląska Lowland, 5.iii.2006; mosses and lichens on buildings, fences and roofs, Wrocław, 10.vi.1991, 23.iv.2008; mosses and lichens on dry sandy soil, sparse pine forest on inland sand dunes near Mierków, Bory Dolnośląskie Forest, Nizina Śląska Lowland, 18.xi.2012, leg. D. Skarżyński and A. Piwnik; mosses and lichens on trees and rocks, spruce-beech forest, 600 m a.s.l., near Michałowice, Karkonosze Mountains, Sudetes, 24.x.2003, 5.vi.2009; mosses and lichens on trees and rocks, beech forest, 500 m a.s.l., near Wojcieszów, Kaczawskie Mountains, Sudetes, 4.xii.1999; mosses and lichens on trees and rocks, spruce-beech forest, 600 m a.s.l., near Ustroń, Beskid Śląski Mountains, Carpathians, 12.x.2006, 7.vi.2007; mosses and lichens on trees, fir-beech forest, 1000 m a.s.l., near Rycerka Górna, Beskid Żywiecki Mountains, Carpathians, 24.v.2003; mosses and lichens on trees, spruce forest, 1000 m a.s.l., near Zawonia, Babia Góra Massif, Carpathians, 4.vi.2005; mosses and lichens on trees,

spruce forest, 1000 m a.s.l., Kościeliska Valley, Tatra Mountains, 1.vi.2001, 20.x.2002; mosses and lichens on wooden fences and roofs of old houses, Czarny Dunajec, Carpathians, 21.vi.2004, 19.ix.2004, 28.vii.2007, 3.x.2007; mosses and lichens on rocks, spruce forest near Jaworki, Pieniny Mountains, Carpathians, 9.iv.2005, 12.viii.2005; mosses and lichens on trees, lime forest near Muszyna, Beskid Sądecki Mountains, Carpathians, 1.v.2004; mosses and lichens on trees, pine forest near Skwierzyzna, Pojezierze Wielkopolskie Lakeland, 16.viii.2007; mosses and lichens on trees in pine-oak forest, mosses on buildings, Potasze village, Zielonka Forest near Poznań, 14.x.2007, 14.xi.2010, ant-hills in pine-oak forest, Potasze village, Zielonka Forest near Poznań, 31.viii.2010, 10.iv.2011 (*barcoded* specimens); 18.iii.2012; mosses and lichens on trees, Baltic Coast: Pobierowo, 13.viii.2007, Mielno, 7.viii.2009, Mielno, 27.vii.2011; det. by J. Stach as *X. maritima* (ISEAC): 3 specimens, on a branch of *Pinus montana*, c. 1750 m a.s.l., Gąsienicowa Valley, Tatra Mountains, Poland, 15.viii.1910, leg. J. Stach; numerous specimens, bird nest on birch, Jordan park, Kraków, Poland, 5.vii.1916, leg. J. Stach; numerous specimens, under moist bark of a poplar stump, Botanical Garden, Kraków, Poland, 12.vi.1918, leg. J. Stach; 1 specimen, dry lichens on a spruce, Krasnobród near Zamość, Poland, 16.i.1923, leg. J. Fudakowski; 3 specimens, mouldy oak branches lying on the ground, Jednaczewo forest near Łomża, Poland, 9. and 26.vii.1935, leg. J. Stach; 3 specimens, lichens and under loose bark of *Pinus montana*, Śnieżnik, 1425 m a.s.l., Sudetes, Poland, 5.vi.1932, leg. K. Schubert; 2 specimens, Slovakia, Kremnica (Körmöcbánya, Kremnitz), Skalka, 1088 m a.s.l., 26.v.1933, leg. E. Dudich; 2 specimens, Hungary, Simontornya, iv.1927, leg. F. Pilich; 1 specimen, Mont Alban, France, in dead cones in a forest, 4.iv.1926, leg. H. Hoyer; female on slide, formerly in alcoholic vial labeled: „*Xenylla nitida* Tullb. Under the bark of a log by the distillery outside Svartbäckstull. T. Tullberg” (MEU).

Description. Body length 0.7–1.3 mm. Colour (in alcohol): dorsal side spotted blue-grey, ventral side pale. Interior of the body white. Integument verrucose (Figs. 2, 3). Abd. tergum IV without setae m_5 (Fig. 3). Abd. sternum III with 1–2 setae in front of retinaculum (Figs. 4, 16). Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla (A and B thicker than C and D) (Fig. 6). Outer lobe of maxilla with 2 sublobal hairs (Fig. 9). Subcoxae 1 of leg III with 3 setae. Claws with indistinct inner tooth. Retinaculum with 3+3 teeth (Fig. 16). Mucrodens 1.6–2 × longer than inner edge of claws III, with 2 posterior setae, marked ventral bend, low mucronal lamella, not reaching the apex, which is narrow and weakly upturned (Fig. 16). — Several specimens from the type series were barcoded. Their COI sequences, representing the ‘barcoding type’ of the species, are deposited on BOLD and Genbank under the sampleID: BIOUG00172-34, BIOUG00172-35, BIOUG00172-36. Identification of unknown specimens could be achieved through the comparison of their barcode sequences taking into account the intraspecific variability observed for this marker in *Collembola* (e.g. PORCO et al. 2010a, 2012, 2014).

Etymology. Dedicated to Professor Andrzej Szeptycki, the excellent specialist in *Collembola* and *Protura*.

Remarks. The new species is morphologically close to *X. maritima*, from which it differs in characters summarised in Table 3 and the key. *X. szepteyckii* sp.n. is known from Poland, Slovakia, Hungary, France and Swe-

den, but considering its common occurrence in Poland in a wide range of habitats, we suspect that the global range of distribution of the species is potentially much wider. The species was found in mosses and lichens growing on trees, rocks, fences, buildings, on dry sandy soil, in forest litter, ant-hills, birds’ nests on trees, in the mountains and lowlands, in synantropic (often with *X. nitida*) and natural habitats.

5.5. *Xenylla pomorskii* sp.n.

Figs. 7, 17

Material. *Holotype* ♀ on slide, ant-hills of *Formica polyctena* Först. in pine-oak forest near Potasze village, Zielonka Forest near Poznań, Poland, 14.x.2007, leg. D. Skarżyński (IEBW). — *Paratypes*: 5♀, 3♂, 14.x.2007; 3♂, 14.xi.2010; 3♂, 35 specimens in alcohol, 18.iii.2012 (*barcoded* specimens), same data as holotype (IEBW). — *Other material*: numerous specimens on slides and in alcohol, ant-hills of *Formica polyctena* Först. in pine-oak forest near Potasze village, Zielonka Forest near Poznań, Poland, 15.i–4.xi.1964, leg. J. Wiśniewski, (ISEAC); numerous specimens on slides and in alcohol, foot of a large spruce, Dendrological Garden, Sołacz, Poznań, 27.viii.1934, leg. K. Stecki (ISEAC); 4♀, 1♂, 6 juv., clump of grass *Corynephorus canescens* (L.) P. Beauv. on open inland sand dune near Wilkocin village, Bory Dolnośląskie Forest, SW Poland, 16.x.2012, leg. A. Piwnik, D. Skarżyński (IEBW); 1 juv., mosses and lichens on open inland sand dune near Ławiszowa village, Bory Dolnośląskie Forest, SW Poland, 16.x.2012, leg. A. Piwnik, D. Skarżyński; 1♀, 1♂, 4 juv., sparse vegetation on sand on „Pustynia Błędowska desert” near village Chechło, Krakowsko-Wieluńska Upland, S Poland, 29.viii.2014, leg. A. Piwnik, D. Skarżyński.

Description. Body length 0.6–1.1 mm. Colour (in alcohol): in freshly preserved specimens dorsal side black, ventral side paler. Interior of the body pink, apical part of ventral tube red. In older specimens dorsal side from blue-grey to violet, ventral side paler, interior of the body pink, apical part of ventral tube pale. Integument verrucose. Abd. tergum IV with seta m_5 present. Abd. sternum III with 1–2 setae in front of retinaculum. Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla of nearly the same size (Fig. 7). Outer lobe of maxilla with 2 sublobal hairs. Subcoxae 1 of leg III with 3 setae. Claws with distinct inner tooth. Retinaculum with 3+3 teeth. Mucrodens 2–2.3 × longer than inner edge of claws III, with 2 posterior setae, marked ventral bend, low mucronal lamella, not reaching the apex, which is broad, spoon-like (Fig. 17). — Several specimens from the type series were barcoded. Their COI sequences, representing the ‘barcoding type’ of the species, are deposited on BOLD and Genbank under the sampleID: 20799-H04, 20799-H06, 20799-H08, 20799-H09. Identification of unknown specimens could be achieved through the comparison of their barcode sequences taking into account the intraspecific variability observed for this marker in *Collembola* (e.g. PORCO et al. 2010a, 2012, 2014).

Etymology. Dedicated to Professor Romuald J. Pomorski, an excellent specialist in *Collembola*.

Remarks. The new species resembles morphologically *X. szeptyckii* sp.n., but clearly differs in features summarised in Table 3 and the key. Up to now, it is known only from some localities in S and W Poland, however its distribution range is probably wider, European at least. It dwells in extremely hot and dry microhabitats: sunny ant-hills in forests and tufts of plants growing on open inland sand dunes.

5.6. *Xenylla nitida* Tullberg, 1871 bona species

Fig. 14

Xenylla nitida Tullberg, 1871: 154
Xenylla brevisimilis Stach, 1949 syn.n.

Material. *Lectotype* ♀ on slide (by present designation), formerly in alcoholic vial labeled: „*Xenylla nitida* Tullb. Under the bark of a log by the distillery outside Svartbäckstull. T. Tullberg” (MEU). — **Other material:** 4 syntypes of *Xenylla brevisimilis* on slides, short moss growing on wooden tiles of a country-house, Czarny Dunajec, Poland, 21.vii.1919, leg. J. Stach (ISEAC); det. as *X. brevisimilis* by J. Stach (ISEAC); numerous specimens, stable and pigsty, in masses, Templin, Mecklenburg, Germany, 3.viii.1936; 6 specimens, Velke Losiny (Gross-Ullersdorf), Moravia, Czech Republic, 5.viii.1924, leg. H. Hoyer; numerous specimens, Poland, leg. D. Skarżyński (IEBW): mosses on wooden fences and roofs of old houses, Czarny Dunajec, Carpathians, 21.vi.2004, 19.ix.2004, 28.vii.2007, 3.x.2007; mosses on buildings, fences and roofs, Wrocław, 10.vi.1991, 23.iv.2008, 6.ix.2010 (*barcoded* specimens); mosses on buildings, Potasze village, Zielonka Forest near Poznań, 14.x.2007, 14.xi.2010, 18.iii.2012; Baltic Coast, mosses on trees in villages: Pobierowo, 13.viii.2007, Mielno, 7.viii.2009, Mielenko, 27.vii.2011.

Redescription. Body length 0.7–1.3 mm. Colour (in alcohol): in freshly preserved specimens dorsal side dark violet, ventral side only somewhat paler. In older specimens dorsal side from blue-grey to violet, ventral side pale. Interior of the body white. Integument only slightly verrucose. Abd. tergum IV with seta m_5 present. Abd. sternum III with 1–2 setae in front of retinaculum. Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla (A and B thicker than C and D). Outer lobe of maxilla with 2 sublobal hairs. Subcoxae 1 of leg III with 2 setae. Claws with indistinct inner tooth. Retinaculum with 3+3 teeth. Mucrodens 1–1.3× longer than inner edge of claws III, with 2 posterior setae, low mucronal lamella, not reaching the apex, which is moderately broad and spoon-like (Fig. 14). — Several specimens examined for this redescription were barcoded. Their COI sequences, representing the ‘barcoding type’ of the species, are deposited on BOLD and Genbank under the sampleID: BIOUG00172-29, BIOUG00172-30, BIOUG00172-31, BIOUG00172-32. Identification of unknown specimens could be achieved through the comparison of their barcode sequences taking into account the intraspecific variability observed for this marker in Collembola (e.g. PORCO et al. 2010a, 2012, 2014).

Remarks. *X. nitida* was originally described from the neighborhood of Uppsala (Sweden) (TULLBERG 1871) and lately subjectively synonymized with *X. maritima* by Gi-

SIN (1944). STACH (1949) described from Czarny Dunajec (South Poland) similar species characterized by short mucrodens – *X. brevisimilis*. The re-examination of *X. brevisimilis* syntypes and topotypes and the only extant *X. nitida* syntype revealed that they are conspecific, resulting in the synonymization of the former with the latter. *X. nitida* is most similar to *X. mediterranea*, from which it differs in characters summarised in Table 3 and the key. It is known from Sweden, Poland, Germany and Czech Republic. Numerous Polish records suggest a wide range of distribution for the species. *X. nitida* is a synantropic species living in mosses and lichens growing on shaded parts of fences, buildings and trees in human settlements. This species often coexists with *X. szeptyckii* sp.n.

5.7. *Xenylla mediterranea* Gama, 1964

Figs. 5, 15

Xenylla brevisimilis mediterranea Gama, 1964: 73

Material. Numerous topotypes, young pine forest on sand dunes, Mira, near Coimbra, Portugal, 3.vi.1959, leg. M.M. Da Gama (DZC); 2 specimens, seashore wrack on a beach, 95.004, Skagerrak coast, Ringshaugstranda near Tønsberg, Vestfold county, Norway, 19.iii.1995, leg. A. Fjellberg (AF); numerous specimens, mosses between scarce vegetation on frontal parts of sand dunes, Baltic Coast, Poland, leg. D. Skarżyński (IEBW): Mielenko, 14.viii.2000, 23. vii. 2001, 27.vii.2011, Mielno, 7.viii.2009, Pobierowo 13.viii.2007; 8♀, 2♂, mosses on rocks near Mori village, 450 m a.s.l., neighborhood of Garda Lake, Italian Alps, 15.viii.2010 (*barcoded* specimens), leg. M. Filistowicz (IEBW).

Description. Body length 0.7–1.0 mm. Colour (in alcohol): blue-grey, ventral side paler. Interior of the body white. Integument verrucose. Abd. tergum IV with seta m_5 present (Fig. 5). Abd. sternum III with 1–2 setae in front of retinaculum (Fig. 15). Ant. IV with 4 (3 dorsoexternal and 1 dorsointernal) cylindrical sensilla (A and B thicker than C and D). Outer lobe of maxilla with 1 sublobal hair. Subcoxae 1 of leg III with 2 setae. Claws with indistinct inner tooth. Retinaculum with 2+2 teeth (Fig. 15). Mucrodens 1–1.6× longer than inner edge of claws III, with 2 posterior setae, low mucronal lamella, not reaching the apex, which is narrow and weakly up-turned (Fig. 15). — Several specimens examined for this redescription were barcoded. Their COI sequences, representing the ‘barcoding type’ of the species, are deposited on BOLD and Genbank under the sampleID: BIOUG00172-24, BIOUG00172-25, BIOUG00172-26, BIOUG00172-27, BIOUG00172-28. Identification of unknown specimens could be achieved through the comparison of their barcode sequences taking into account the intraspecific variability observed for this marker in Collembola (e.g. PORCO et al. 2010a, 2012, 2014).

Remarks. Described from Portugal as *Xenylla brevisimilis mediterranea* (GAMA 1964), raised to a species rank by BABENKO et al. (1994). Molecular data presented above fully confirmed this status. This species is similar

to *X. nitida*, from which it differs in characters presented in Table 3 and the key. Recorded from many European countries (Portugal, Spain, Italy, Croatia, Greece, Ukraine, Netherlands, Denmark, Sweden, Norway), Morocco and Canary Islands, where it lives in dry habitats (open sand dunes, meadows, forests) along coastline mostly (FJELLBERG 1998; THIBAUD et al. 2004). *X. mediterranea* can be found together with *X. maritima* in the same samples from seashore sites.

5.8. Identification key to species of *Xenylla maritima* complex

- 1 Three sublobal hairs on outer lobe of maxilla (Fig. 10) 2
- 1' One or two sublobal hairs on outer lobe of maxilla (Figs. 8, 9) 3
- 2 Setae in front of retinaculum on abd. III (Fig. 18) and setae m_5 on abd. IV (Fig. 3) absent *X. maritima* Tullberg, 1869
- 2' Setae in front of retinaculum on abd. III (Figs. 15, 16) and setae m_5 on abd. IV (Fig. 5) present *X. asiatica* Martynova, 1975 comb.n.
- 3 One sublobal hair on outer lobe of maxilla (Fig. 8), retinaculum with 2+2 teeth (Fig. 15) *X. mediterranea* Gama, 1964
- 3' Two sublobal hairs on outer lobe of maxilla (Fig. 9), retinaculum with 3+3 teeth (Fig. 16) 4
- 4 Setae m_5 on abd. IV absent (Fig. 3), apex of mucro narrow, weakly upturned (Fig. 16) *X. szepteykii* sp.n.
- 4' Setae m_5 on abd. IV present (Fig. 5), apex of mucro broad spoon-like (Figs. 14, 17) 5
- 5 Ratio mucrodens/claw III 1–1.3, mucro spoon-like (Fig. 14), two setae on leg III subcoxae 1 *X. nitida* Tullberg, 1871
- 5' Ratio mucrodens/claw III 2–2.3, mucro strongly spoon-like (Fig. 17), three setae on leg III subcoxae 1 (Fig. 13) *X. pomorskii* sp.n.

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7. References

- ALVAREZ T., FRAMPTON G.K., GOULSON D. 1999. The effects of drought upon epigeal Collembola from arable soils. – *Agricultural and Forest Entomology* **1**: 243–248.
- BABENKO A.B., CHERNOVA N.M., POTAPOV M.B., STEBAEVA S.K. 1994. Collembola of Russia and adjacent countries: Family Hypogastruridae. – Nauka, Moscow. 336 pp.
- BELGNAOUI S., BARRA J.A. 1989. Water loss and survival in anhydrobiotic Collembola *Folsomides angularis* (Insecta). – *Revue d'Écologie et de Biologie du Sol* **26**: 123–132.
- BELLINGER P., CHRISTIANSEN K.A., JANSSENS F. 2015. Checklist of the Collembola of the World. – Available from: <http://www.collembola.org> (date of access: 31.xii.2015).
- BUSMACHIU G., WEINER W.M. 2008. Species of the genus *Xenylla* Tullberg, 1869 (Collembola: Hypogastruridae) from the Republic of Moldova. – *Zootaxa* **1959**: 65–68.
- CASSAGNAU P. 1971. Les différents types d'écomorphose chez les collemboles Isotomidae. – *Revue d'Écologie et de Biologie du Sol* **8**: 55–57.
- DEHARVENG L. 1983. Morphologie évolutive des Collembolles Neanurinae en particulier de la lignée Neanurienne. – *Travaux du Laboratoire d'Ecobiologie des Arthropodes Edaphiques, Toulouse* **4**: 1–63.
- FJELLBERG A. 1984. Maxillary structures in Hypogastruridae (Collembola). – *Annales de la Société Royale Zoologique de Belgique* **114**: 89–99.
- FJELLBERG A. 1998. The Collembola of Fennoscandia and Denmark. Part 1 Poduromorpha. – *Fauna Entomologica Scandinavica*. Brill, Leiden, Boston, Köln. 184 pp.
- FJELLBERG A. 1999. The labial palp in Collembola. – *Zoologischer Anzeiger* **237**: 309–330.
- FOLMER O., BLACK M., HOEH W., LUTZ R., VRIJENHOEK R. 1994. DNA primers for amplification of mitochondrial cytochrome c oxidase subunit i from diverse metazoan invertebrates. – *Molecular Marine Biology and Biotechnology* **3**: 294–299.
- GAMA M.M. DA 1964. Collembolos de Portugal Continental. – *Memórias e Estudos do Museu Zoológico Universidade da Coimbra* **292**: 1–252.
- GAMA M.M. DA 1969. Notes taxonomiques et lignées genealogiques de quarante deux especes et sous especes du genre *Xenylla*. – *Memórias e Estudos do Museu Zoológico Universidade da Coimbra* **308**: 1–61.
- GAMA M.M. DA 1988. Filogenia des espécies de *Xenylla* à escala mundial (Insecta, Collembola). – *Evolución Biológica, Coimbra* **2**: 139–147.
- GISIN H. 1944. Materialien zur Revision der Collembolen II. Weiteres Basler Material. – *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* **19**: 121–155.
- GISIN H. 1960. Collembolenfauna Europas. – *Museum D'Histoire Naturelle, Genève*. 312 pp.
- GREENSLADE P. 1981. Survival of Collembola in arid environments: observations in South Australia and the Sudan. – *Journal of Arid Environments* **4**: 219–228.
- HALL T.A. 1999. Bioedit: A user-friendly biological sequence alignment editor and analysis program for windows 95/98/nt. – *Nucleic Acids Symposium Series* **41**: 95–98.
- HÜTHER W. 1962. Beitrag zur Gattung *Willemia* Börner (Collembola). – *Beiträge zur Entomologie* **12**: 511–526.
- IVANOVA N.V., DEWAARD J.R., HEBERT P.D.N. 2006. An inexpensive, automation-friendly protocol for recovering high-quality DNA. – *Molecular Ecology Notes* **6**: 998–1002.
- KAERGAARD C.W., HOLMSTRUP M., MALTE H., BAYLEY M. 2004. The importance of cuticular permeability, osmolyte production and body size for the desiccation resistance of nine species of Collembola. – *Journal of Insect Physiology* **50**: 5–15.
- KIMURA M. 1980. A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. – *Journal of Molecular Evolution* **16**: 111–120.

- LAWRENCE P.N. 1977. Studies on the tibiotarsal chaetotaxy of Collembola. — *Systematic Entomology* **2**: 313–317.
- LEINAAS H.P., SOMME L. 1984. Adaptations in *Xenylla maritima* and *Anurophorus laricis* (Collembola) to lichen habitats on alpine rocks. — *Oikos* **43**: 197–206.
- LETUNIC I., BORK P. 2007. Interactive tree of life (itol): An online tool for phylogenetic tree display and annotation. — *Bioinformatics* **23**: 127–128.
- MARTYNOVA E.F. 1975: On the fauna of Collembola of the Mongolian People's Republic. 1. New and little-known species of Collembola from Mongolia and adjacent regions of the USSR. — *Insects of Mongolia, Leningrad* **6**: 10–25 [in Russian].
- MARX M.T., GUHMANN P., DECKER P. 2012. Adaptations and predispositions of different Middle European arthropod taxa (Collembola, Araneae, Chilopoda, Diplopoda) to flooding and drought conditions. — *Animals (Basel)* **2**: 564–590.
- MASSOUD Z. 1967. Monographie des Neanuridae, Collemboles Poduromorphes à pièces buccales modifiées. Pp. 7–399 in: DELAMARE DEBOUTTEVILLE C., RAPOPORT E.H. (eds), *Biologie de l'Amérique Australe*, 3. — CNRS, Paris.
- MASSOUD Z.N., POINSOT N., POIVRE C. 1968. Contribution à l'étude du comportement constructeur chez les Collemboles. — *Revue d'Écologie et de Biologie du Sol* **5**: 283–286.
- PORCO D., BEDOS A., DEHARVENG L. 2010a. Description and DNA barcoding assessment of the new species *Deutonura gibbosa* (Collembola: Neanuridae: Neanurinae), a common springtail of Alps and Jura. — *Zootaxa* **2639**: 59–68.
- PORCO D., ROUGERIE R., DEHARVENG L., HEBERT P. 2010b. Coupling non-destructive DNA extraction and voucher retrieval for small soft-bodied arthropods in a high-throughput context: The example of Collembola. — *Molecular Ecology Resources* **10**: 942–945.
- PORCO D., BEDOS A., GREENSLADE P., JANION C., SKARŻYŃSKI D., STEVENS M.I., JANSEN VAN VUUREN B., DEHARVENG L. 2012. Challenging species delimitation in Collembola: Cryptic diversity among common springtails unveiled by DNA barcoding. — *Invertebrate Systematics* **26**: 470–477.
- PORCO D., SKARŻYŃSKI D., DECAENS T., HEBERT P.D.N., DEHARVENG L. 2014. Barcoding the Collembola of Churchill: A molecular taxonomic reassessment of species diversity in a sub-arctic area. — *Molecular Ecology Resources* **14**: 249–261.
- SAITOU N., NEI M. 1987. The neighbor-joining method — a new method for reconstructing phylogenetic trees. — *Molecular Biology and Evolution* **4**: 406–425.
- SJURSEN H., BAYLEY M., HOLMSTRUP M. 2001. Enhanced drought tolerance of a soil-dwelling springtail by pre-acclimation to a mild drought stress. — *Journal of Insect Physiology* **47**: 1021–1027.
- STACH J. 1949. The apterygotan fauna of Poland in relation to the world fauna of this group of insects. Families Neogastruridae and Brachystomellidae. — *Acta Monographica Musei Historiae Naturalis, Polish Academy of Sciences and Letters, Kraków*. 341 pp.
- TAMURA K., STECHER G., PETERSON D., FILIPSKI A., KUMAR S. 2013. Mega6: Molecular evolutionary genetics analysis version 6.0. — *Molecular Biology and Evolution* **30**: 2725–2729.
- THIBAUD J.-M., SCHULZ H.-J., GAMA M.M. DA 2004. Synopses on Palearctic Collembola. Hypogastruridae. Vol. 4. — *Abhandlungen und Berichte des Naturkundemuseums Görlitz* **75**: 1–287.
- TULLBERG T.F. 1869. Om skandinaviska Podurider af underfamiljen Lipurinae. — *Akademisk Afhandling, Uppsala*. 20 pp.
- TULLBERG T.F. 1871. Förteckning öfver Svenska Podurider. — *Öfversigt af Kongliga Vetenskaps-Akademiens Forhandlingar* **28**: 143–155.
- TULLBERG T.F. 1872. Sveriges Podurider. — *Kongliga Svenska Vetenskaps-Akademiens Handlingar* **10**: 1–70.

Electronic Supplement File

at <http://www.senckenberg.de/arthropod-systematics>

File 1: skarzynski&al-collembolaxenylla-asp2018-electronicsupplement.fas — Alignment of COI sequences.

Zoobank registrations

at <http://zoobank.org>

Present article: <http://zoobank.org/urn:lsid:zoobank.org:pub:4F841444-3FAE-4580-8CBB-34C1B7A20C5D>

***Xenylla pomorskii* Skarżyński, Piwnik & Porco, 2018:**

<http://zoobank.org/urn:lsid:zoobank.org:act:61B37219-8DE1-4CEC-8E9E-858ADF8D7698>

***Xenylla szeptyckii* Skarżyński, Piwnik & Porco, 2018:**

<http://zoobank.org/urn:lsid:zoobank.org:act:F5650711-18EB-4071-84C7-A029719FBF00>

