Arlea judithnajtae n. sp. (Collembola: Isotomidae), a temperate North American member of a Gondwanan genus

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ABSTRACT
Intensive collecting for the All-Taxa Biodiversity Inventory in Great Smoky Mountains National Park, United States, yielded many specimens of *Arlea judithnajtae* n. sp. (Collembola: Isotomidae). This new species differs from other species of *Arlea* Womersley, 1939 in having a combination of smooth setae, seven large sensilla on Ant. IV, dorsal sensilla of Th. II-III and Abd. I-III in middle setal rows and inconspicuous sensilla on Abd. V. It is most similar to *A. psammophila* Mendonça, Abrantes & Fernandes, 2006 but that species has eight or nine Ant. IV sensilla and has the dorsal thoracic and abdominal sensilla in the posterior row of setae. A key is provided for separation of known *Arlea* species. *Arlea judithnajtae* n. sp. is the first member of its genus reported from a non-Gondwanan continent (North America), suggesting that the southern Appalachian region of North America has been a refugium for otherwise extinct taxa. Alternatively, it may have been previously overlooked due to its small size and close resemblance to other white, eyeless isotomids.

KEY WORDS
Biogeography,
identification key,
Nearctic,
refugium,
new species.

RÉSUMÉ
Arlea judithnajtae *n. sp. (Collembola: Isotomidae), une espèce originaire de l'Amérique du Nord tempérée appartenant à un genre Gondwanien.*
Lors des collectes intensives effectuées pour l'Inventaire de Biodiversité (ATBI) dans le parc national Great Smoky Mountains, United States, de nombreux spécimens d'*Arlea judithnajtae* n. sp. (Collembola: Isotomidae) ont été collectés. Cette nouvelle espèce diffère des autres espèces d'*Arlea* Womersley, 1939 par une combinaison de soies lisses, sept larges sensilles sur Ant. IV, les sensilles dorsales des Th. II-III et Abd. I-III situées dans les rangées médianes de soies et des sensilles peu visibles sur l'Abd. V. *Arlea judithnajtae* n. sp. ressemble davantage à *A. psammophila* Mendonça, Abrantes & Fernandes, 2006, mais cette espèce possède huit ou neuf sensilles sur Ant. IV et ses sensilles thoraciques et abdominales dorsales se trouvent dans la rangée postérieure de soies. Une clé est proposée pour séparer les espèces d'*Arlea* connues. *Arlea judithnajtae* n. sp. est le premier membre du genre à être signalé dans un continent non Gondwanien (Amérique du Nord), ce qui pourrait signifier que la région sud des Appalaches, en Amérique du Nord, aurait servi de refuge pour les taxons autrement disparus. Une alternative est que ce taxon soit passé inaperçu du fait de sa petite taille et de sa ressemblance avec d'autres isotomids blancs et dépourvus d'yeux.

MOTS CLÉS
Biogéographie,
clé d'identification,
néarctique,
refuge,
espèce nouvelle.

INTRODUCTION

Arlea Womersley, 1939 is composed of seven described species (Table 1) united by possession of a large, ovate PAO, typical sensilla on Ant. IV, fusion of Abd. V and VI, and falcate mucro. This last character separates *Arlea* from the otherwise similar genera of the *Cryptopygus* Willem, 1901 complex, 1901 (Potapov *et al.* 2013), all of which have bidentate mucrones. *Folsomina onychiurina* Denis, 1931 has a falcate mucro but other *Folsomina* Denis, 1931 species have bidentate mucrones, and all lack a PAO, have Abd. IV-VI fused and possess a pair of large, club-shaped sensilla on Ant. IV (Greenslade 1999). All of the seven described *Arlea* spp. are known only from the southern hemisphere: six species have been described from South America and one species is known from South Africa.

Commencing in 1998 and continuing to the present, the Discover Life in America (dlia.org) All-Taxa Biodiversity Inventory in Great Smoky Mountains National Park (GRSM) in the US states of Tennessee and North Carolina has yielded many new species and new records of Collembola (Bernard & Felderhoff 2007). In one area of GRSM numerous specimens of *Arlea* were found among thousands of collected Collembola. This genus hitherto had not been reported from North America. A new species of *Arlea* is described herein and a key to the known species is presented.

MATERIAL AND METHODS

Leaf litter and upper fermentative layer samples were collected from an upland forest area in the Ravensford area of GRSM just to the South of Big Cove Road. Specimens were extracted from substrate into 95% ethanol by means of Tullgren funnels. Selected specimens were cleared in Marc André fluid I for 10-20 minutes, then mounted in Hoyer's medium on glass slides. Slides were cured in a 50°C oven for three days, then ringed with red insulating varnish (M.G. Chemicals, Burlington, Ontario). Whole specimens were imaged with a Canon EOS T3i camera mounted on a Zeiss Stemi 2000 stereo microscope. Body details were imaged with a 17-megapixel DP73 camera on an Olympus BX-53 phase contrast microscope system. Measurements were made with the measuring software on the microscope system. Drawings were made with the aid of a drawing tube on a Nikon DIC microscope or directly from the Olympus screen. Figure 1C was prepared according to the style of Potapov (2001). The holotype ♀ and some paratypes are deposited in the Florida State Collection of Arthropods. Additional paratypes are deposited in the Illinois Natural History Survey, Champaign, Illinois (INHS), the Great Smoky Mountains National Park Museum, Gatlinburg, Tennessee (GRSM), the University of Tennessee Entomology Collection and Muséum national d'Histoire naturelle, Paris (MNHN).

Abbreviations

Abd. I-VI	abdominal segments I, II, III, IV, V + VI;
Ant. I-IV	antennal segments I, II, III, IV;
f-seta (fs)	filiform, blunt-tipped sensillum-like seta of antenna.
PAO	postantennal organ;
s	sensillum;
Th. II, III	mesothorax, metathorax;

Abbreviations and terminology for the maxillary and labial palpi are from Fjellberg (1984, 1999). Other terminology generally follows Potapov (2001) and Potapov *et al.* (2013).

SYSTEMATICS

Family Isotomidae Schäffer, 1896
Genus *Arlea* Womersley, 1939

Arlea judithnajtae n. sp.
(Figs 1-3)

Type material. — **United States**. North Carolina, Swain County, Great Smoky Mountains National Park, Ravensford, All-Taxa Biodiversity Inventory, upland mixed Eastern hemlock-hardwoods forest, Tullgren funnel extracts, all samples within 200 m of 35°30'53.51"N, 83°17'49.00"W, elev. 600-640 m. Near pitfall 31, holotype ♀ and 2 paratype ♀ on slides, 7 paratypes in ethanol, 19.XII.2001, E. Bernard & A. Mayor, colls, deposited in the Florida State Collection of Arthropods. Thirty-seven additional paratypes, same locality: near pitfall 37, 2 ♀, 2 ♂, 3 juveniles on slides, 10 specimens in ethanol, 22.VIII.2001, P. L. Jennings & T. Goodrich, colls; near pitfall 31, 2 specimens in ethanol, 22.VIII.2001, P. L. Jennings & T. Goodrich, colls., and 1 ♀ on slide, 8 in ethanol, 28.XII.2001, E. Bernard & A. Mayor, colls.; near pitfall 33, one specimen in ethanol, 22.VIII.2001, P. L. Jennings & T. Goodrich, colls., and 8 specimens in ethanol, 28.XII.2001, E. Bernard & A. Mayor, colls. Additional paratypes and specimens deposited the INHS, the GRSM Museum, the University of Tennessee Entomology Collection, and the MNHN.

Etymology. — This species is named in memory of Dr Judith Najt, who brought a new level of descriptive precision and beautiful illustrations to the study of South American Collembola.

Description

Body, head

Body without pigment, posterior end rounded (Fig. 1A). Eyes absent. Female length 450-526 µm (n = 6), male length 409, 453 µm (n = 2). Ratio of Ant. I: II: III: IV as 1: 1.6: 2.0: 3.6. Cuticular surface minutely granulate, without thickenings or reticulations. Four slender prelabral setae; labrum with rounded apex, with 5-5-4 setal arrangement, middle three setae of proximal row and middle seta of middle row slender with typical sockets, other setae spine-like and arising from raised conoid bases (Fig. 2G). Outer lobe of maxillary palpus with strong terminal hair nearly twice the length of basal seta, accompanied by dorsolateral process equal in length to basal seta; ventral process present, longer than dorsal process; two sublobal hairs of approximately equal length (Fig. 2D). Labial palpus (Fig. 2E) with papillae A and B blunt, papillae C-E pointed; guard setae a1, b1-4, d1-4 and e1-6 present, tapering, pointed; guards a1 and b1 slender, b1 about twice the length of a1; b2 and b3 arising from a proximal prominence; lateral process (lp) large, rounded apically; 3 proximal setae, 5 basolateral setae, 4 basomedial setae. Hypostomal papilla H blunt. Postantennal organ large, broadly ovate, with 6 guard setae (Fig. 2C).

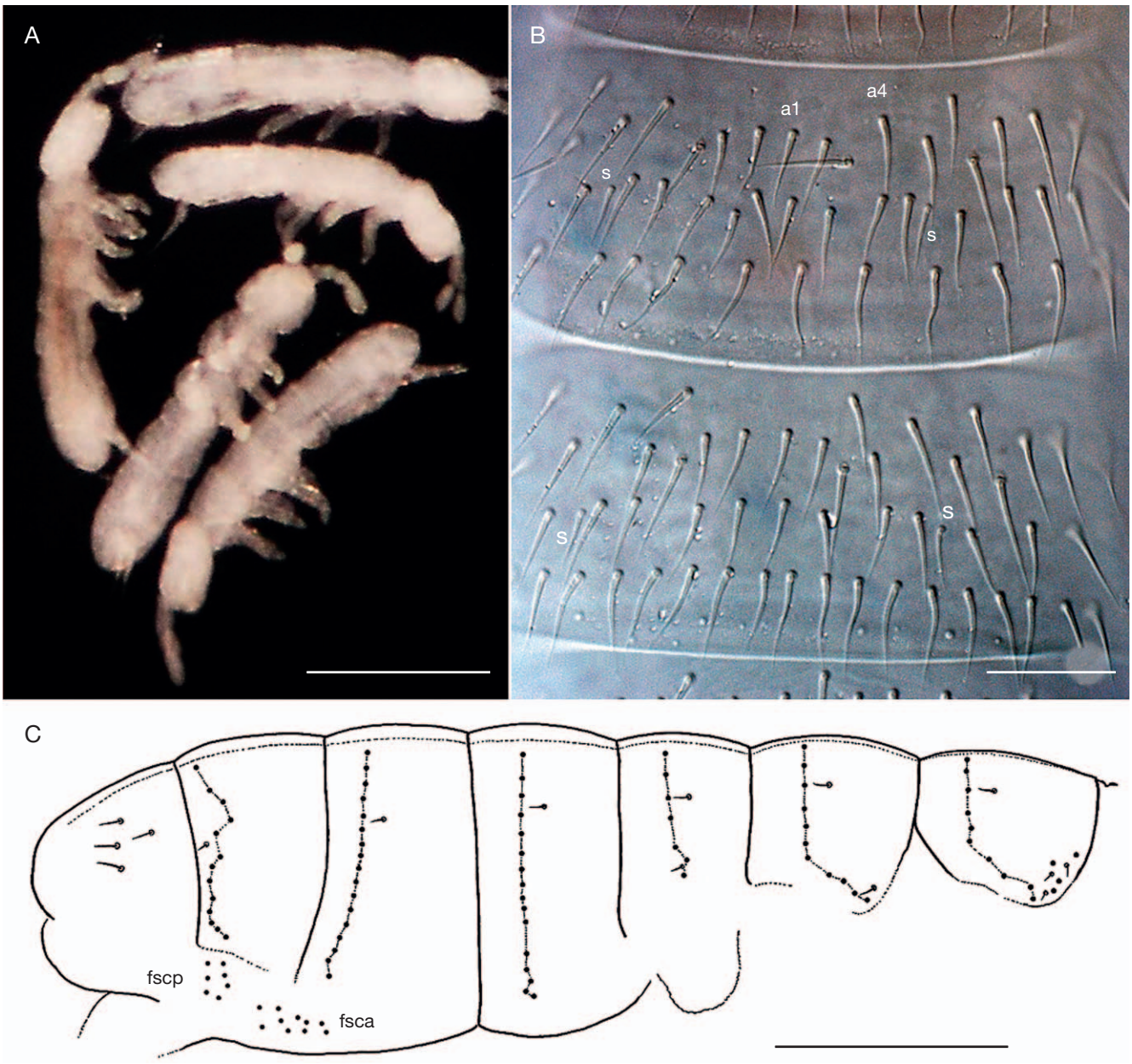

FIG. 1. — *Arlea judithnajtae* n. sp.: **A**, entire specimens; **B**, Abd. II and III, dorsal view; **C**, distribution of sensilla; posterior-row setae and furcal subcoxal setae indicated by black circles. Abbreviations: **a1** and **a4**, first and fourth setae of anterior row; **fsca**, anterior furcal subcoxa; **fscp**, posterior furcal subcoxa; **s**, sensillum. Scale bars: A, 250 µm; B, 20 µm; C, 100 µm.

Antennae

Antennal segment IV on dorsal side with 7 plump sensilla, approximately 6 f-setae, papilliform subapical organite near slender, curved subapical microsensillum (Fig. 2H); ventrally with about 8 f-setae and short, straight subapical sensillum (Fig. 2I). Sense organ of Ant. III with two weakly bent sense clubs embedded in shallow groove, flanked by one dorsal sensillum and two slightly more lateral and proximal sensilla; minute spine-like sensillum present in midregion (Fig. 2H, J). Ant. II with one sensillum on inner side; Ant. I dorsally with spine-like microseta, ventrally with sense organ comprised of basal spine-like microseta and more anterior sensillum, spine-like seta and two or more typical setae (Fig. 2H, K);

Legs

Longest setae of epicoxae and subcoxae sometimes weakly uniserrate (Fig. 3A), other leg setae smooth, acuminate, unmodified. Setal numbers of fore, middle and hind legs as follows: subcoxa I, 1-1-3; subcoxa II, 1-5-6; coxa, 4-11-10; trochanter, 9-9-9; femur, 15-15-18; tibiotarsus, 22-22-25 (Fig. 3A). Inner distal femoral setae shorter than outer setae. Unguis tapering, smooth, without teeth; unguiculus less than half length of unguis. Tenent hair pointed.

Abdominal appendages

Ventral tube with 4 + 4 valve setae and 2 + 2 posterior setae on corpus (Fig. 3B). Retinaculum with 1 seta on corpus and

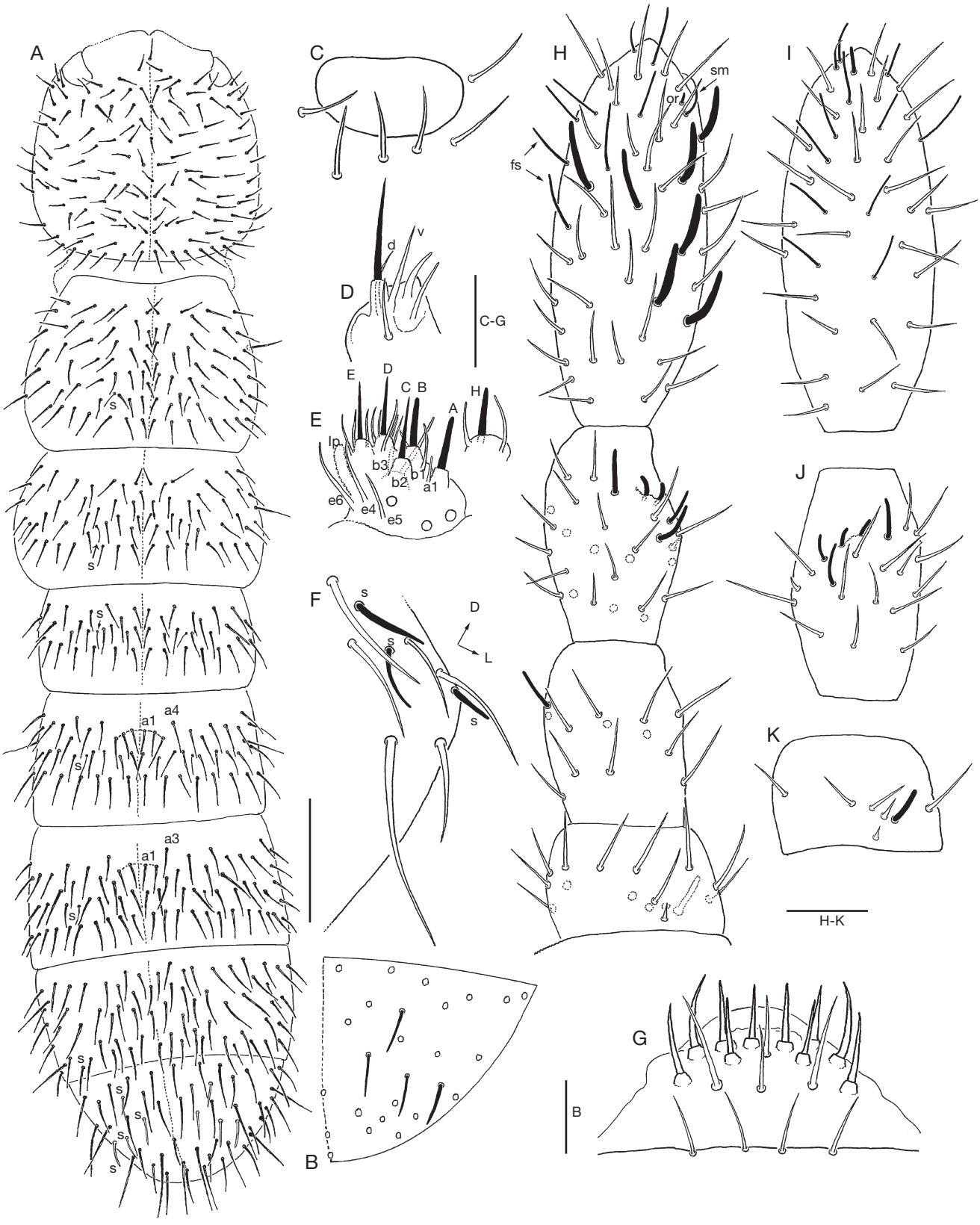

FIG. 2. — *Arlea judithnajtae* n. sp.: **A**, dorsal habitus and chaetotaxy; **B**, Abd. V+VI, right side, showing sensilla and sockets of typical setae; **C**, postantennal organ; **D**, maxillary palpus; **E**, labial palpus and hypostomal lobe, some guard setae not labeled; **F**, mesonotal sensory field, arrows indicate dorsal (**D**) and lateral (**L**) directions; **G**, labrum; **H**, antenna, dorsal view; **I**, Ant. IV, ventral view; **J**, Ant. III, subdorsal view; **K**, Ant. I, ventral view. Abbreviations: **d**, dorsal process; **v**, ventral process; **fs**, filiform seta; **or**, organite; **s**, sensillum; **sm**, subapical microsensillum. Scale bars: A, 100 µm; B, 20 µm; C-K, 10 µm.

4 + 4 teeTh. Mucro: dens: manubrium ratio 1: 15: 10. Furcal subcoxal region with 10-11 setae anteriorly, 7 setae posteriorly (Fig. 1C). Manubrium with 13 + 13 posterior setae, outermost basal setae the longest; anterior surface with 1 + 1 strong apical setae (Fig. 3C). Dens crenulated. Anterior surface of dens with 17 setae, posterior surface with three basal setae and two short setae in midregion (Fig. 3C). Mucro sickle-shaped (Fig. 3D). Female genital region with one pair of short setae each on anterior and posterior lips; 9 longer setae in one row between aperture and base of manubrium, with sensillum immediately posterior to each outer seta (Fig. 3E). Male genital plate with 2 + 2 setae, surrounded by 5 + 5 setae (Fig. 3F).

Chaetotaxy

All body setae smooth, longest on Abd. V + VI. Thoracic sterna and Abd. II sternum without setae. Head with three pairs of post-labial setae. Dorsally, head and body typically with medial setae and paired setae as follows: head with 9 pairs of medial setae and 4 unpaired medial setae (Fig. 2A); Th. II with 7 pairs of setae and one medial seta; Th. III with 5 pairs and one unpaired seta; Abd. I-III each with 3 pairs; Abd. IV with one pair and 3 unpaired setae; Abd. V + VI with 2 anterior pairs of setae and three unpaired setae (a0, m0, p0); formula 9+9(4)/7+7(1),5+5(1)/3+3,3+3,3+3,1+1(3),2+2(3). On Abd. II, 2 or 3 most medial anterior pairs of setae (a1, a2 or a1-a3) arranged in arch below level of next most medial pair (a3 or a4) (Fig. 2A); Abd. III with a1-a2 pairs arranged similarly. Body sensilla similar to typical body setae except slightly shorter and thinner (Fig. 1B); sensilla formula for Th. II-Abd. V 4,2/2,1,1,1,5 (Fig. 1C). Dorsal sensilla of Th. II-III and Abd. I-III in middle setal row, that of Abd. IV in posterior row (Figs 1B, C; 2A). Each side of mesonotum with one sensillum dorsally, antero-lateral corner with three sensilla, microsensillum absent (Fig. 2F); metanotum with dorsal and antero-lateral sensilla, microsensillum absent; one sensillum dorsally on Abd. I-III, Abd. I also with lateral sensillum; Abd. IV with one dorsal sensillum. Dorsal sensilla of Th. II-III and Abd. I-III in middle setal row, those of Abd. IV in posterior row (Figs 1B, C; 2A). Abd. V + VI dorsally with anterior sensillum and row of 3 posterior sensilla, outer sensillum of row approaching thickness of typical setae (Fig. 2B); one sensillum near genital plate (Fig. 3E).

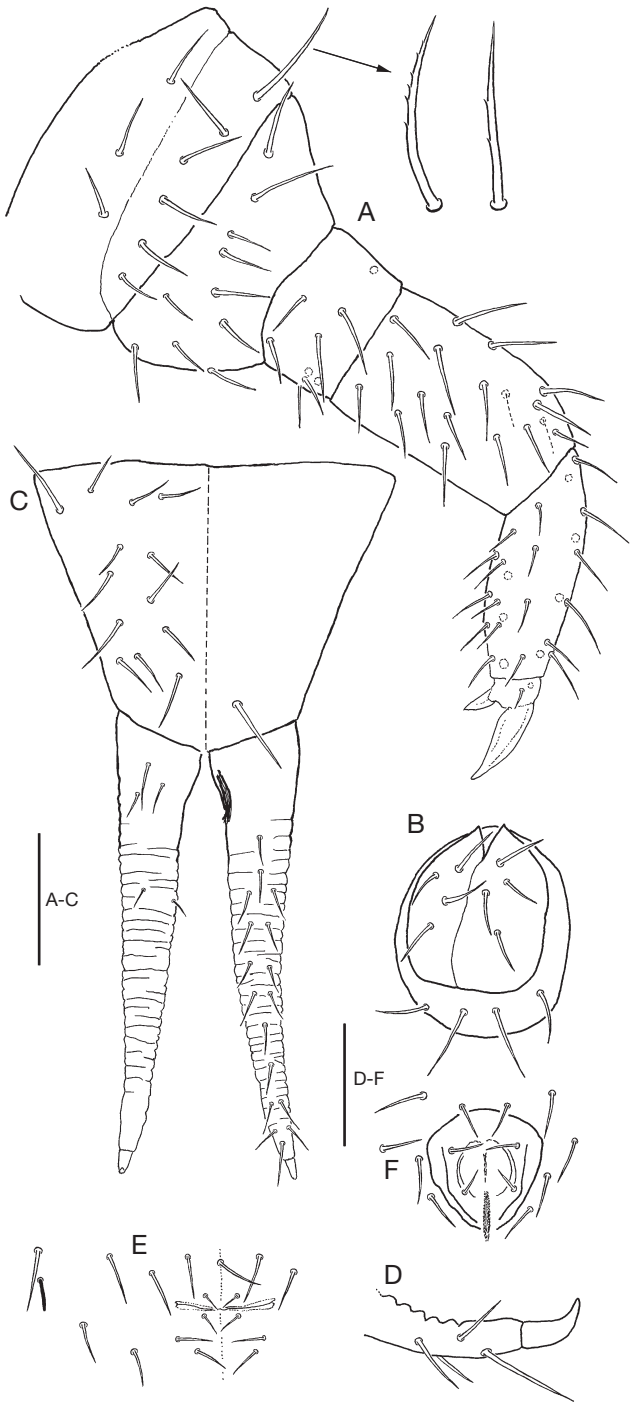

Fig. 3. — *Arlea judithnajtae* n. sp.: **A**, hind leg, external view and enlargements of longest epicoxal and subcoxal setae; **B**, ventral tube; **C**, furcula, posterior view (left), anterior view (right); **D**, mucro; **E**, female genital region; **F**, male genital plate. Scale bars: A-C, 20 µm; D-F, 10 µm.

Remarks

Among the seven previously described *Arlea* spp., *A. judithnajtae* n. sp. is most similar to *A. psammophila*. Both species have one pair of anterior manubrial setae, fewer than 20 posterior dental setae, and sensilla on Abd. V + VI are not greatly enlarged. The two species differ in the number of posterior manubrial setae (26 in *A. judithnajtae* n. sp., 18 in *A. psammophila*). They also appear to differ in setal density. The new species has eight pairs of medial setae and four unpaired medial setae on the head, whereas *A. psammophila* has seven pairs and three unpaired setae (Mendonça *et al.* 2006).

Arlea judithnajtae n. sp. is distinctive in the arrangement of anterior setae on Abd. II and III. On Abd. II the a1-2 or a1-3 setae are arranged in an arch posterior to the line a3-a3 or a4-a4. On Abd. III the four a1- a2 setae are arranged similarly and posterior to the line a3-a3. Of the five previously described species whose chaetotaxy has been illustrated (*A. adetolai*, *A. arenicola*, *A. psammophila*, *A. spinisetis*, *A. tridens*), only *A. arenicola* has a similar feature, with the a1 setae behind the a2 line on Abd. II.

KEY TO THE SPECIES OF *ARLEA* WOMERSLEY, 1939

1. Two pairs of ocelli present 2
— Ocelli absent 3

2. Mucro falcate; all setae smooth ..... *A. lucifuga* (Arlé, 1939)
— Mucro falciform with additional small ventral tooth; macrosetae strongly barbed ..... *A. spinisetis* Mendonça & Arlé, 1987

3. Anterior face of manubrium with 1 + 1 setae 4
— Anterior face of manubrium with 4 + 4 or 5 + 5 setae 7

4. Dens with at least 20 posterior setae ..... *A. arenicola* Abrantes & Mendonça, 2005
— Dens with 17 or fewer posterior setae 5

5. Dens with 10 posterior setae; all Abd. V sensilla conspicuous, plump ..... *A. adetolai* Mendonça, Abrantes & Fernandes, 2006
— Dens with at least 15 posterior setae; Abd. V sensilla slender 6

6. Dorsal sensilla of Abd. I-III in middle setal row; Ant. IV with seven prominent sensilla; posterior face of manubrium with 26 setae ..... *A. judithnajtae* n. sp.
— Dorsal sensilla of Abd. I-III in posterior setal row; Ant. IV with 8-9 prominent sensilla; posterior face of manubrium with 18 setae ..... *A. psammophila* Mendonça, Abrantes & Fernandes, 2006

7. Anterior face of manubrium with 4 + 4 setae; Ant. IV with five prominent sensilla ..... *A. tridens* Barra, 1997
— Anterior face of manubrium with 5 + 5 setae; Ant. IV with seven prominent sensilla ..... *A. caeca* Rapoport & Rubio, 1968

TABLE 1. — Species of *Arlea* Womersley, 1939 and their localities.

Species	Type localities and other records
A. adetolai Mendonça, Abrantes & Fernandes, 2006	Brazil: National Park of Tijuca, Rio de Janeiro State
A. arenicola Abrantes & Mendonça, 2005	Brazil: Maricá, Rio de Janeiro State
A. caeca Rapoport & Rubio, 1968	Chile: Santiago; Argentina: Córdoba Province (De Izarra 1973)
A. judithnajtae n. sp.	United States: North Carolina, Swain County
A. lucifuga (Arlé, 1939)	Brazil: Petropolis, Rio de Janeiro State; Minas Gerais State (Mendonca & Arle 1987)
A. psammophila Mendonça, Abrantes & Fernandes, 2006	Brazil: Maricá, Rio de Janeiro State
A. spinisetis Mendonça & Arlé, 1987	Brazil: Ceará State
A. tridens Barra, 1997	South Africa: Natal Province

DISCUSSION

In the original generic description of *Arlea*, Womersley (1939) wrote that Abd. IV-VI were fused. This statement probably was an unintentional error, since the type species, *A. lucifuga*, is described and illustrated as having Abd. IV separate from Abd. V + VI, which are fused (Arlé 1939). Unfortunately, this error was perpetuated by both Salmon (1964) and Uchida (1972) in their keys to Isotomidae and repeated more recently by Heckman (2001). *Arlea* cannot be properly traced in these keys. *Arlea* does not appear in the key of Potapov (2001), as the genus at that time was not known to be Holarctic, but appears later and is properly keyed in Potapov *et al.* (2013).

Prior to recognition of *Arlea judithnajtae* n. sp., all *Arlea* species were known only from South America and southern Africa. The new species represents a significant extension of the genus to the Nearctic. Another GRSM species with Gondwanan relatives, *Furculanurida langdoni* Bernard, 2007, also was recently described (Bernard 2007). The presence of these species in the same area of temperate North America suggests that GRSM serves as a refugium for part of an ancient springtail fauna previously widespread in the Americas. The collection sites in GRSM for the two species formerly were areas of diffuse settlement (Pyle 1985). These areas were a patchwork of settlements, uncut forest, farmlands and pasture. With the establishment of GRSM in 1934 farming and settlements were phased out, and timber harvest ceased. Therefore, the forest sites from which these species were collected have regenerated and been protected for more than 80 years.

Both *A. judithnajtae* n. sp. and *F. langdoni* were collected during an intensive survey of the Ravensford area under the auspices of Discover Life in America, which oversees the All-Taxa Biodiversity Inventory in GRSM. This effort resulted in a four-fold increase in the known number of Collembola species in GRSM (Bernard & Felderhoff 2007). This increase suggests that temperate North America has been severely undercollected despite the long and prolific careers of several distinguished specialists. For instance, collection efforts in GRSM and northeastern Tennessee over the past 15 years yielded five new species of Tullbergiidae Bagnall, 1935 (Bernard 2016).

The failure to find these taxa until now may simply be due to undercollection in North America, and species assumed to be relicts may actually be more widespread. Additionally, their small size and superficial similarity to other taxa (juvenile *Pseudachorutes* spp. for *F. langdoni*; *Folsomia* Willem, 1902, *Folsomina*, *Isotomiella* Bagnall, 1939 or *Micrisotoma* Bellinger, 1952 for *A. judithnajtae* n. sp.) could cause them to be overlooked during sample sorting.

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