



New records and ecological observations on Greek cave crickets (Orthoptera: Rhaphidophoridae)

Journal:	<i>Journal of Natural History</i>
Manuscript ID	Draft
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a
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Keywords:	Dolichopodainae, Troglophilinae, eutroglophile, subtroglaphile, Balkans

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Figure 1. Habitus photographs of female *D. lustriae* in Pades, Epirus. A) Female specimen (collected in July 2015); B) Female specimen climbing on the walls of the Stontzi rock formation (collected in July 2020); C) Gravid female foraging on the forest floor (July 2015 record, not collected).

160x175mm (300 x 300 DPI)



Figure 2. Habitus photographs of a male *D. lustriae* from Pades, Epirus. A) Lateral view, black arrows indicate position of femoral spines; B) Dorsal view.

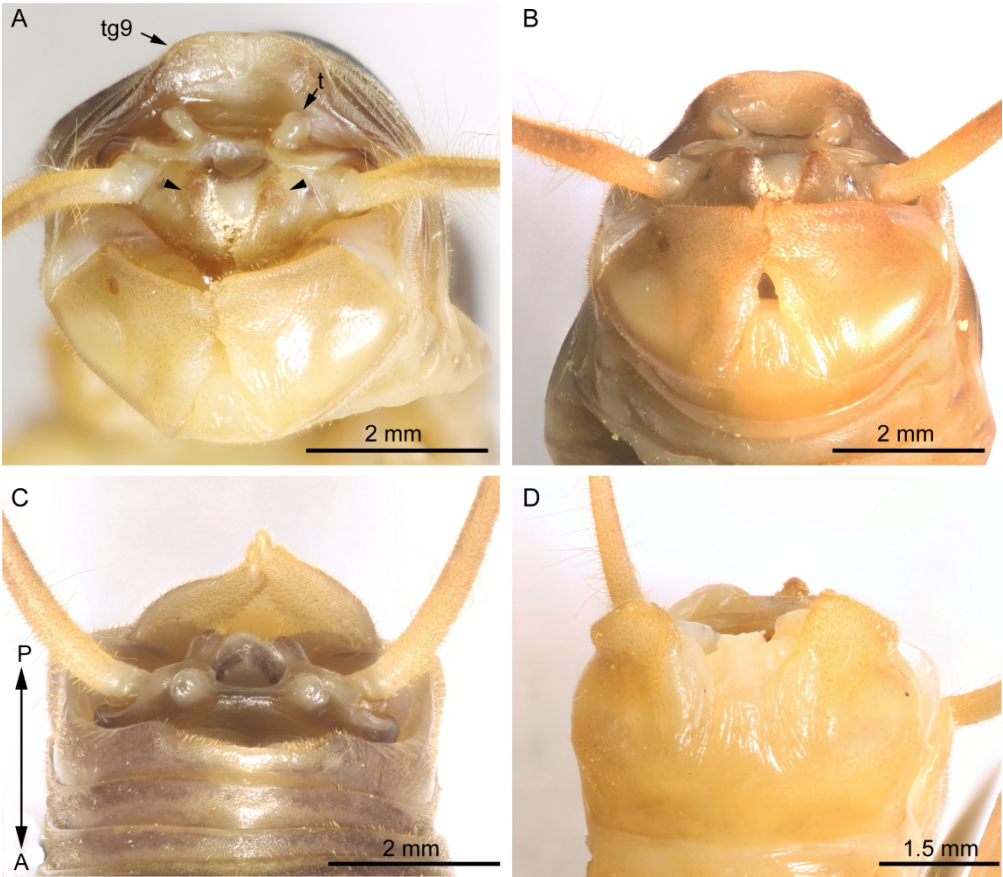


Figure 3. External male genitalia of *D. lustriae* from Pades, Epirus. A) Caudal view, tg9=tergum nine, t=tubercle of tergum ten, black unmarked arrows indicate the spines of the paraproct; B) Same, ventrocaudal view; C) Dorsal view, A=anterior, P=posterior; D) Ventral view.

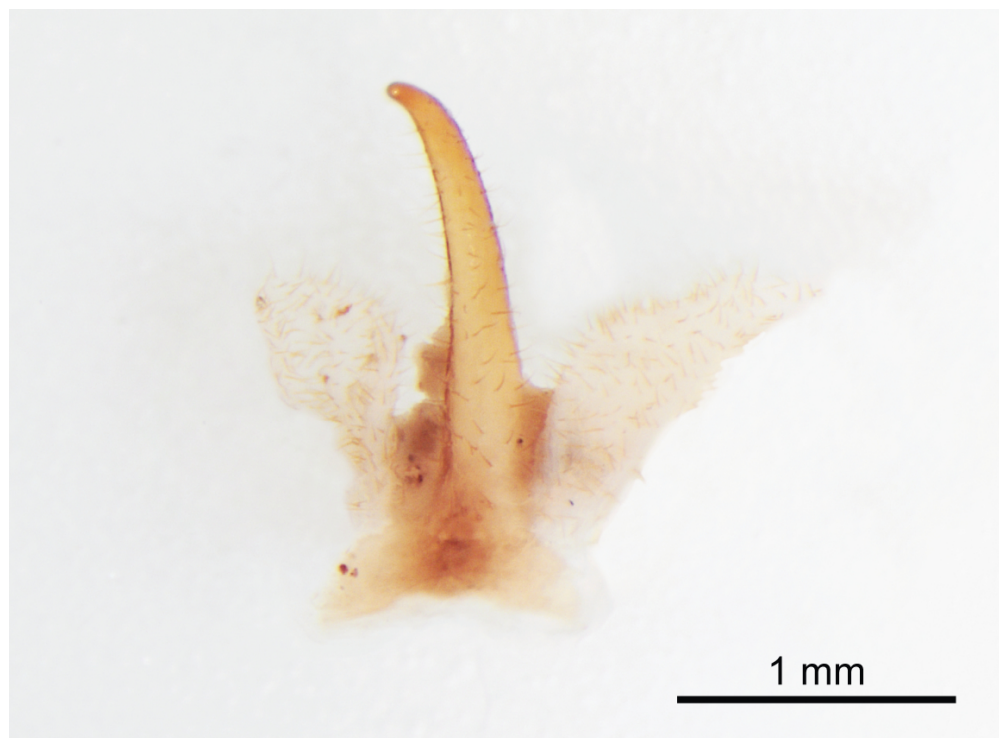


Figure 4. Epiphallus of *D. lustriae* from Pades, Epirus dorsal view.

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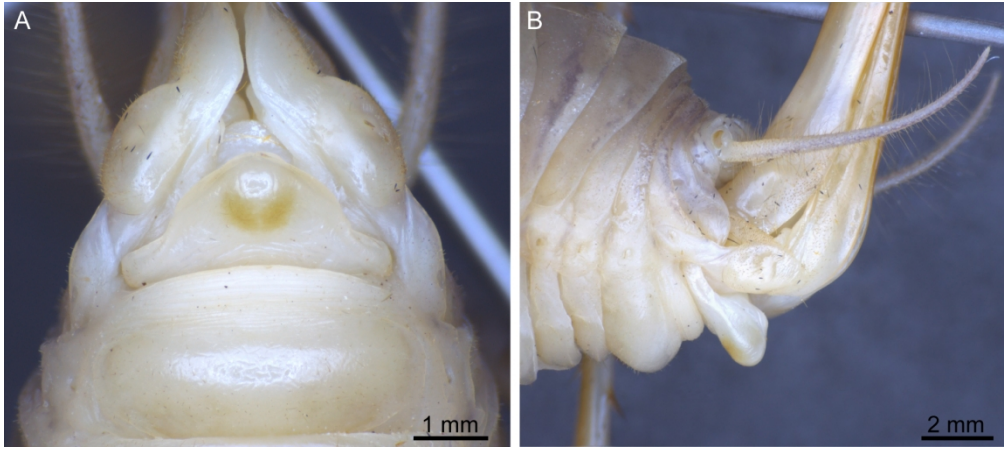


Figure 5. External female genitalia of *D. lustriae* from Pades, Epirus. A) Subgenital plate, ventral view; B) Base of ovipositor and subgenital plate, lateral view.

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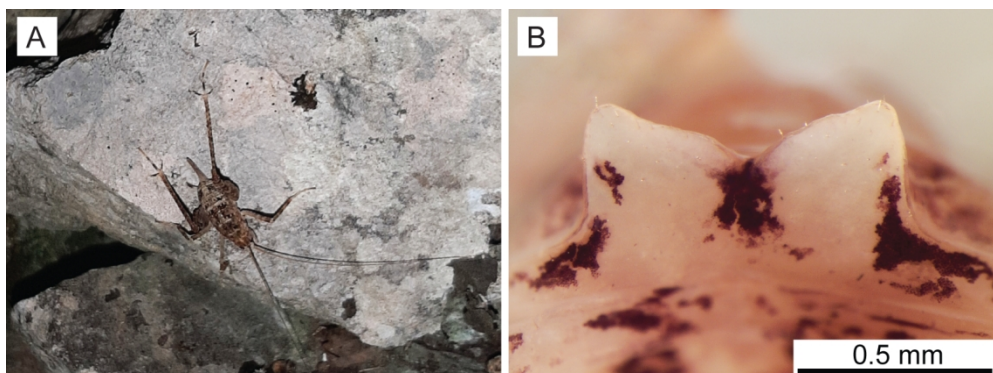


Figure 6. Specimens of *T. zorae* from Pades, Epirus. A) Immature female specimen on a man-made stone wall, showing colouration characteristic of this species; B) Tergum ten of an immature male specimen.

141x52mm (300 x 300 DPI)

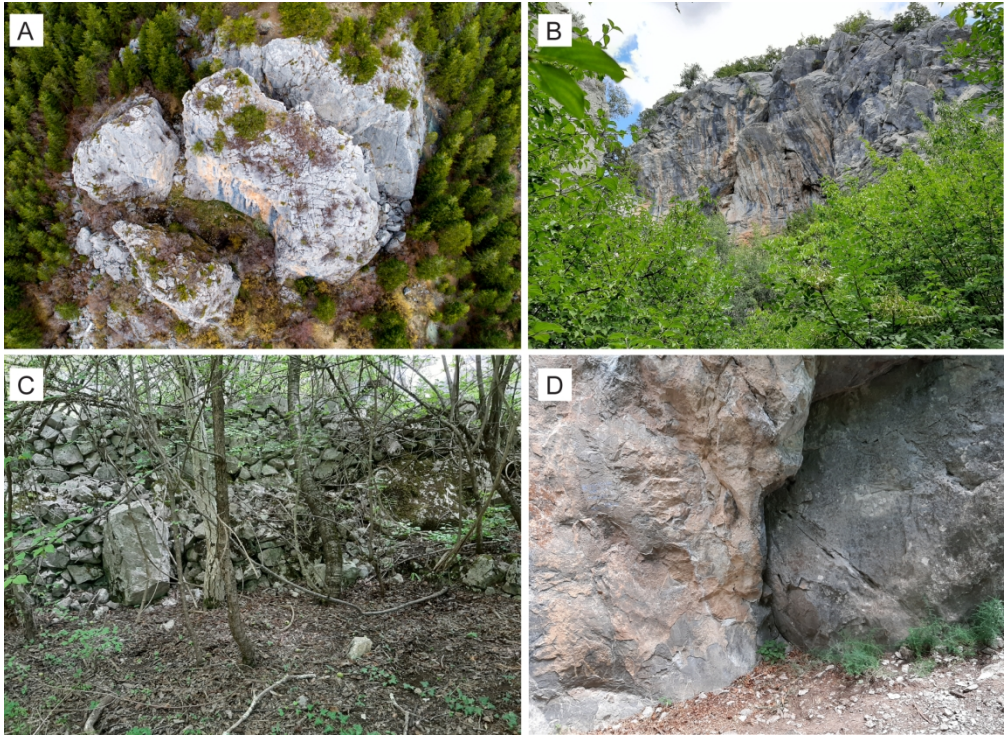


Figure 7. The site of the Stontzi rock formation in Pades, Epirus, where most of our biological observations took place. A) Stontzi, aerial view in late autumn. The fissure splits the rock into three main towers. Note that the formation is covered by a pine forest; B) Ground level view of Stontzi, from the deciduous forest islet contained in the fissures of the rock formation; C) Deciduous forest floor and man-made stone wall, which are used by *D. lustriae* and *T. zorae* for foraging; D) Example of a crevice on the Stontzi rock formation which is used as a shelter by *D. lustriae* and *T. zorae* during the day.

168x123mm (300 x 300 DPI)

New records and ecological observations on Greek cave crickets (Orthoptera: Rhaphidophoridae)

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Abstract

We record *Dolichopoda lustriae* Rampini & Di Russo, 2008 (Orthoptera: Ensifera: Rhaphidophoridae) from the Pindus mountain range in Epirus, Greece, more than 200 km to the north of the type locality in Aetolia-Acarnania. We show that this species has an unusually broad distribution for a Balkan cave cricket, and can also live independently from caves, instead inhabiting the crevices of large rock formations. We found *D. lustriae* to be sympatric with *Troglophilus zorae* Karaman & Pavićević, 2011, whose presence in Greece is recorded for the first time in this study. We provide high quality photographs of the habitus and genitalia of *D. lustriae*, and re-describe its morphology. Detailed information about the habitat, behaviour of the *D. lustriae* is also provided, and possible measures for its conservation are suggested.

Key words: Dolichopodainae, Troglophilinae, eutroglophile, subtroglophile, Balkans

Introduction

Lacking wings, with a depigmented exoskeleton and remarkably long legs and antennae, cave crickets of the family Rhaphidophoridae are among the most charismatic and specialised arthropods that are associated with caves and cave-like habitats such as ravines and rock-fissures. Rhaphidophorids comprise 9 subfamilies globally (Gorochoy, 2001), of which two are native in Europe, the Dolichopodainae and the Troglophilinae, and one is invasive, the Aemodogryllinae, represented by at least one species of East Asian origin (Rehn, 1944). European Rhaphidophoridae can be found across the northern Mediterranean, but reach their greatest diversity in the Balkans and Turkey (Alegrucci et al., 2009, 2011, 2017). Dolichopodainae is monogeneric, containing only 55 species in the genus *Dolichopoda* Bolívar, 1880, whose range extends from the Pyrenees to the Caucasus and comprises 38 European species, 32 of which are endemic to Greece, rendering this region as the global diversification centre for the subfamily (Cigliano et al., 2020; Di Russo et al., 2014, 2018). Troglophilinae is also monogeneric, with the genus *Troglophilus* Krauss, 1879, comprising 21 species globally (Alegrucci et al., 2011; Cigliano et al., 2020), with 10 European species, of which 5 occur in Greece (Di Russo et al., 2014). The exceptional endemism displayed by Greek raphidophorids is attributed to a combination of dispersal and vicariant events, the complex geological history of the region, and past climatic fluctuations (Alegrucci et al., 2009, 2011, 2017).

Dolichopoda species have been recorded in Greece from across the mainland and all island units (Cyclades, Dodecanese, Ionian, Sporades) (Di Russo et al., 2014, 2018; Rampini et al., 2008) – if

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suitable habitats are available, they are likely to be colonised by cave crickets. They are found in caves located in a broad range of habitats and altitudes, from caves by the seaside in scorching hot arid phrygana, to dense temperate woodland at 1673 m above sea level (asl) (Di Russo et al., 2019). Greek *Dolichopoda* spp. are generally more dependent on caves than *Troglophilus* spp. (which also live in epigeal habitats), and they are usually restricted to a single or a few adjacent caves, unlike their Western Mediterranean counterparts (Di Russo et al., 2014). However, certain *Dolichopoda* species may venture outside their sheltered habitats at night even in the driest of habitats (Di Russo et al., 2018), which likely serves as one of their main modes of dispersal and habitat colonisation. This behaviour may be considerably more frequent in higher latitude and altitude habitats, whose moist and cooler climate is more permissive for such ventures (Alegrucci et al., 2011; Di Russo et al., 2014).

Epirus, whose landscape is dominated by the Pindus mountain range, has received less attention with regards to its raphidophorine fauna compared to other areas of Greece – only two species are known from this region, *D. graeca* Chopard, 1964 from Perama cave in Ioannina (Chopard, 1964), and *D. kiriakii* Rampini & Di Russo, 2008 from a cave in Agia Kiriaki in Preveza (Rampini et al., 2008). During entomological expeditions to Smolikas mountain (Epirus, Konitsa Municipality) in July 2015 and July 2020, we collected and photographed unidentified species of *Dolichopoda* and *Troglophilus* from the village of Pades. After examination, we recognized that the specimens belong to *D. lustriae* Rampini & Di Russo, 2008, originally described from Agios Andreas cave in Chalkiopoulos, Aetolia-Acarnania, 200 km to the south, and *Troglophilus zorae* Karaman & Pavićević, 2011, previously known from North Macedonia and Albania (Karaman et al., 2011). In the present contribution, due to the addition of significant new material, we re-describe *D. lustriae*, we expand its distribution to the Pindus mountain range of Epirus, we provide novel information regarding its ecology and we confirm the presence of *T. zorae* in Greece.

Material and Methods

All specimens were hand-collected from rock crevices and the forest floor, and were subsequently euthanized with ethyl acetate and preserved in 70% ethanol. The epiphallus of an adult male *D. lustriae* was excised using Dumont#5 forceps, and was preserved in a microvial with glycerol, along with the specimen. Macrophotographs of live specimens were taken in the field using a Canon EOS 7D DSLR camera with an attached 100 mm macro lens, while the male habitus and genitalia were taken using a Canon EOS 2000D DSLR camera, and a Canon 100 mm macro lens. Photomicrographs of the female genitalia *D. lustriae* were taken using a Leica M165c binocular microscope equipped with a Leica DFC490 camera at the Oxford University Museum of Natural History, while those of *T. zorae* were images using an Olympus SC30 camera mounted on an Olympus SZX7 stereomicroscope at the Complutense University of Madrid, Spain. All photomicrographs were stacked and combined using Helicon Focus.

When describing the genitalia of both sexes, we use the terminology employed by previous studies (e.g. Di Russo et al., 2018) for consistency. However, we should note that what is referred in all previous studies on Greek raphidophorids as the “dorsal view of epiphallus”, actually refers to the dorso-caudally placed ventral surface of the epiphallus, and should be therefore referred to as “ventral view of epiphallus” in future studies. We also stress that morphological terminology should be based on homology (e.g. Chamorro-Rengifo & Lopes-Andrade, 2014), which has not yet been established between raphidophorids and their ensiferan relatives. We refer to spines as “internal” when they face the body of the animals, and “external” when they face outwards. We refer to immatures as larvae, following the terminology of Rédei & Štys (2016). We used the works of Di Russo et al. (2014), Rampini et al. (2008), and Karaman et al. (2011) for the identification of our specimens.

Specimens are deposited at the Natural History Museum (NHM) in London, and the Zoological Museum of the University of Athens (ZMUA).

Results and Discussion

1. Material.

Dolichopoda lustriae Di Russo & Rampini, 2008

New locations. Greece, Epirus, Konitsa Municipality, Pades, Stontzi geological formation, 40°2'40.85"N, 20°54'27.26"E, 1230 m, 21.vii.2020, collectors James Kempton and Leonidas-Romanos Davranoglou, 4m# (2 in NHM, 2 in ZMUA), 1f# (ZMUA), 3 larvae (ZMUA); same location as above, 24.vii.2015, collectors Leonidas-Romanos Davranoglou and Zestin Soh, 1f# (NHM).

Previously known locations. Type locality: Greece, Aetolia-Acarnania, Chalkiopoulos Valtou, Agios Andreas o Erimitis cave, 38°59'34.81"N, 21°23'1.01"E, 1150 m, 09.II.2007 (1 m#, 2f#, 7 larvae). Other locations: **Phokis, Mt Vardousia**, unnamed cave, 1110 m, 10.vi.2015 (5 larvae); Athanasios Diakos, Dafni cave, 20.X.2008 (1 m#) (Di Russo et al., 2014; Rampini et al., 2008).

Differential diagnosis

This species is diagnosed among its congeners by the following combination of characters: posterior margin of thoracic and abdominal terga dark brown-blackish (Fig. 1A–C), remaining portion of terga much paler; ventral surface of hind femur armed with spines (Fig. 2A); tergum nine medially emarginated (Fig. 3A, C); tergum ten medially emarginated (Fig. 3C), provided with a pair of prominent, diverging rounded tubercles (Fig. 3A–C); shape of epiphallus distinct (Fig. 4); female urosternite distinctly swollen (Fig. 5B), subgenital plate emarginated laterally, with rounded apex, provided with a medial dark spot (Fig. 5A).

Redescription

Colouration (same in both sexes). Overall colouration light brown-dark orange (Fig. 1A–C) (preserved specimens paler, Fig. 2A, B). Occiput light orange, rest of head paler (Fig. 1A–C). Anterior margin of pronotum dark-brown blackish, medially expanding posteriorly in the form of a half circle (Fig. 1A, C); mid-portion of pronotum pale brown, posterior margin of pronotum dark-brown blackish. Meso-and-meta-thorax anteriorly light greyish-brown, posterior margin distinctly dark-brown blackish (Fig. 1A–C). Abdominal terga distinctly bicolorous: anterior margin light brown-orange, posterior margin dark-brown blackish (Fig. 1A–C). Legs and antennae darker than rest of body, lighter at their base (Fig. 1A–C).

Structure. Male. Large (20–21 mm), more sclerotised than its Greek congeners (Figs. 1, 2). Fore femur unarmed; fore tibia armed dorsally with 3 internal and 3–5 external spines, ventrally with 5 internal and 4–5 external spines; mid femur unarmed; mid tibia dorsally with 8 internal and 6–7 external spines, ventrally with 5 internal and 5 external spines; hind femur armed ventrally with 9–10 external and 9–11 internal spines; hind tibia dorsally with 18–22 external and 19–21 internal spines, and ventrally with 3 spines at the apex of the article. Tergum nine distinctly emarginated in the middle (tg9; Fig. 3A–C), flap-like in caudal view, its posterior margin bearing short setae (Fig. 3A). Tergum ten anteriorly membranous, sclerotized posteriorly; emarginated medially in dorsal view, forming a narrow bridge (Fig. 3C); lateral lobes of tergum ten trapezoidal in dorsal view (Fig. 3A); tergum ten with a pair of diverging, fleshy, rounded tubercles (Fig. 3A–C), with a short puncture dorsally (Fig. 3C). Margins of paraprocts covered with short denticles (Fig. 3A, B). Epiphallus as in Fig. 4, with an acute, elongate and strongly curved median process; basal lobes wing-like, covered in denticles. Subgenital plate well-subdivided (Fig. 3D), its lateral lobes covered in small spine-like setae (Fig. 3A–D), ending on short styles.

Female. General structure as in male, but smaller (18 mm) and stouter (Fig. 1). Fore tibia dorsally with 4 external spines and 3 internal spines, ventrally with 4 internal and 5 external spines; mid tibia dorsally with 8 internal and 9 external spines, ventrally with 3 internal and 5 external spines; hind femur ventrally

with 6 internal and 5 external spines; hind tibia with dorsally with 20 internal and 21 external spines, ventrally with 3 ventral spines towards apex of article. Urosternite seven distinctly swollen (Fig. 5A). Subgenital plate laterally emarginated, apex rounded, globular, with a medial dark spot (Fig. 5A), Urosternite seven and subgenital plate distinctly protruding in lateral view (Fig. 5B). Inferior valves of ovipositor with 16 denticles.

Measurements (in mm). Males (n=4): Body length: 20–21; pronotum: 4; fore femur: 17.4–18; fore tibia: 19; mid femur: 18–18.7; mid tibia: 19.6–20; hind femur: 26–26.5; hind tibia: 32–33; hind tarsi: 11; hind basitarsus: 5.8–6; hind femur/pronotum ratio: 6.5–6.6. **Females (n=2).** Body length: 18; pronotum: 3.9; fore femur: 15; fore tibia: 15.8; mid femur 14; mid tibia: 17; hind femur: 24.3; hind tibia 28.9; hind tarsi: 10; hind basitarsus: 4.9; ovipositor: 17.

Variability. The specimens studied here bear all the diagnostic features of *D. lustriae* (Rampini et al., 2008) from the type locality in Aetolia-Acarnania. However, the Pades population is somewhat smaller in size, and presents some differences in spine patterns, in having fewer spines on the ventral surface of the hind femur, (9–10 external and 9–11 internal spines compared to 11 external and 23 internal spines in the type male), and three spines on the ventral surface of the hind tibia (two in holotype male). The female ovipositor also has 17 denticles, whereas in the paratype has 20. The subgenital plate of the female paratype, described as incised in the middle in Rampini et al. (2008) is rounded and smooth in our specimens (Fig. 5A). This difference may be attributed either to individual variation, or more likely, as a deformation that originates from the desiccation of the paratype.

***Troglophilus zorae* Karaman & Pavićević, 2011**

New record. Greece, Epirus, Konitsa Municipality, Pades, Stontzi geological formation, 40°2'40.85"N, 20°54'27.26"E, 1230 m, 21.vii.2020, collectors James Kempton and Leonidas-Romanos Davranoglou, 4 larvae [2m# (1 in NHM, 1 in ZMUA), 2f# (1 in NHM, 1 in ZMUA)].

Known distribution. Albania, North Macedonia (Karaman et al., 2011).

Diagnosis. Although the collected individuals are represented by larvae, they possess a combination of characters that separate them from all known Greek species and are diagnostic for *T. zorae* as described in Karaman et al. (2011), namely: (1) the species-specific shape of tergum ten (Fig. 6B) (2) colouration (Fig. 6A) (3) short ovipositor (Fig. 6A) 4) and (4) mid tibia armed with spines on dorsal side (not imaged here).

These characters are in agreement with those mentioned by Karaman et al. (2011) and with larval material in the Ivo Karaman collection (University of Novi Sad, Serbia) (Karaman, personal communication). We are therefore confident that our identification is correct. Karaman et al. (2011) speculated that a record of *T. neglectus* Krauss, 1879 from Naousa, Greece, may actually refer to *T. zorae*, although stressed that this remains unconfirmed. This makes our study the first confirmed record of this species in Greece.

2. Habitat and behaviour of *D. lustriae* and *T. zorae*. The primary collecting locality is situated at an elevation of 1220 m asl, and is part of the Pindus mountain mixed forest ecoregion. The local climate is characterised by snow-covered, cold winters, and wet, warm summers, with an annual precipitation of 1247 mm (Fotiadi, Metaxas & Bartzokas, 1999). All specimens were collected from an imposing rock formation locally known as Stontzi (probably from Aromanian stânci=cliffs, rocks), which dominates the village of Pades (Fig. 7A). Stontzi is composed of limestone which is interbedded with sandstone (Fig. 7B, D), which fits the geological description of a tilted marl. Stontzi is traversed by a broad fissure, which splits it into three distinct towers (Fig. 7A). Although Stontzi is surrounded by a dense *Pinus nigra pallasiana* forest (Fig. 7A), its fissure supports a deciduous mixed forest “islet” composed of *Alnus glutinosa*, *Cornus mas*, *Fraxinus excelsior*, *Ulmus* sp. and the invasive *Robinia pseudoacacia*. The floor of this diverse community forms a thick layer of leaf-litter (Figs. 1C, 7C), and

is enriched by the faeces and discarded fruits by a dense population of dormice (*Glis glis*). In spite of our intense efforts, no cave could be found in Stontzi or its environs. However, the rock formation is replete with deep crevices (Fig. 7D) which may extend deep underground to form a subterranean network of underground galleries. Furthermore, the forest floor at the base of the Stontzi formation is covered by large accumulations of enormous rock boulders (Fig. 7A), as well as an abandoned stone wall (Fig. 7C), which further enrich this habitat with hiding spaces.

We observed large numbers of *D. lustriae* specimens (up to 9 individuals per m²) emerging just after sunset from the crevices of Stontzi to forage on the rock formation walls, the forest floor and between the rock boulders. The highest number of specimens was found in the crevices and the forest floor, and there were representatives of both sexes of all life stages. Specimens were not found in the pine forest surrounding Stontzi, which does not imply their absence from that habitat, but that the population density may be lower there. Regarding the behaviour of *D. lustriae*, the brown colouration of this species makes it difficult to observe against leaf-litter, and specimens are highly agile and run away, retreat in the rock crevices or jump at the slightest disturbance (such as light or vibrations from footsteps). The other rhabdophorid species, *Troglophilus zorae* shares the same habitat with *D. lustriae* and both species were found together virtually everywhere at the collection locality, although the latter species is considerably more numerous than the former.

Based on the above, we conclude that *D. lustriae* is a high altitude specialist with a broad distribution across north-western Greece and the Pindus mountains. It is possible that this species will be found in southern Albania, as well as in western Macedonia, Greece. This distributional pattern is in stark contrast compared to all other Greek species of *Dolichopoda*, which are usually known from only a single or several adjacent locations (Di Russo et al. 2014). Although we cannot determine with certainty whether the broad range of *D. lustriae* is the result of ongoing or past epigeal dispersal events during different climatic conditions, several factors attest to the former scenario:

(1) We have recorded all life stage of this species from epigeal forest habitats where no apparent caves exist, where they forage (and likely reproduce). Records from caves (Agios Andreas or Erimitis cave), may represent temporary hiding spaces, or permanent shelters, in cases where the external habitat has been degraded.

(2) *D. lustriae* is characterised by a strong colouration and femoral spines, which may represent adaptations for a more epigeal lifestyle – most species of Greek *Dolichopoda* are generally paler and lack femoral spines. However, the hind femur-pronotum ratio [commonly used as a measure of cave specialization (Leroy, 1967; Di Russo & Sbordoni, 1998)] of *D. lustriae* ranges from 6 to 6.6, which is closer to the average of 6.7 in cave-adapted Greek species than to the average of 5.91 of epigeal Italian species (Di Russo et al., 2014).

(3) This species is sympatric with *T. zorae*, which belongs to a genus which is less dependent on caves for its survival than most *Dolichopoda* spp. The only other case of a Greek *Dolichopoda*-*Troglophilus* sympatry is in a cave in Crete (Di Russo et al., 2014), although we attribute this to the very dry conditions occurring in the external xerothermic habitat, which force the two species to share the same habitat.

It is likely that *D. lustriae* is a subtroglophile species that uses caves and cave-like habitats as a shelter, but requires external ventures to complete its life-cycle. This contrasts to most of its Greek congeners, that are eutroglophiles, i.e. can sustain permanent populations in caves (Di Russo et al., 1999).

(3) Conservation. Stontzi is a popular destination for climbers, and parts of the rock are covered with handles and other types of climbing gear. In both of our visits at the site (July 2015, 2020), the forest islet that appears to serve as a significant foraging site for *D. lustriae* is occupied by large numbers of camping climbers, who trample on the leaf-litter, light fires, and discard large amounts of waste.

Although we show that *D. lustriae* has a broader distribution than previously thought, it is possible that the available habitats are very small and highly fragmented.

Based on the above, the local population may be fragile, and we suggest to the Municipality of Konitsa to adopt the following conservation measures for the site:

1) Camping inside the fissures of Stontzi at night should be prohibited. This also prevents any accidents from rock falls, or potentially dangerous encounters with the locally-abundant bears and wild boars, which are attracted to the campers' waste at night. We also observed several nose-horned vipers [*Vipera ammodytes* (Linnaeus, 1758)] at the base of Stontzi, which could defensively bite campers at night if stepped upon.

2) Camping could instead be restricted to the area of the Saint Athanasius Church, which is less than 80 metres from the Stontzi formation, and is much safer for both the campers and the local wildlife.

Recognising that climbers contribute financially to the residents of Pades, we believe that these measures are realistic, easily implemented, and do not adversely affect tourism in the area.

Acknowledgements

We would like to thank the Christopher Welch Scholarship in Biological Sciences, University of Oxford, for funding our July 2020 expedition to the Pindus mountain range. We thank Munti Smolikas Guest House for providing the drone photograph of Stontzi (Fig. 7A). We would like to thank Ivo Karaman (University of Novi Sad, Serbia) for confirming our identification of *T. zorae* and sharing unpublished morphological information on the nymph of this species. We also thank Sotiris Alexiou for his help with the identification of *D. lustriae*. We thank Max Webb (Royal Holloway University of London, UK) for the geological interpretation of the Stontzi rock formation. We are grateful to Nicky Tzima and Michail Beis for their hospitality at the Smolikas Refuge, Paleoselli and their invaluable field advice. We are grateful to the residents of Pades and Konitsa for their world-famous Epirotan hospitality and their enthusiasm with our work. We are indebted to Eleni Tzima, who maintains the tradition of transhumance on Smolikas, and came to our aid when our car got stuck in a remote part of the forest during the 2015 expedition. We are grateful to the staff at the Oxford University Museum of Natural History and Eduardo Ruiz Piña (Complutense University of Madrid, Spain) for granting us access to their imaging facilities.

Declaration of interest statement

We have no financial or other benefit to disclose.

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Figure Legends

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Figure 1. Habitus photographs of female *D. lustriae* in Pades, Epirus. A) Female specimen (collected in July 2015); B) Female specimen climbing on the walls of the Stontzi rock formation (collected in July 2020); C) Gravid female foraging on the forest floor (July 2015 record, not collected).

Figure 2. Habitus photographs of a male *D. lustriae* from Pades, Epirus. A) Lateral view, black arrows indicate position of femoral spines; B) Dorsal view.

Figure 3. External male genitalia of *D. lustriae* from Pades, Epirus. A) Caudal view, tg9=tergum nine, t=tubercle of tergum ten, black unmarked arrows indicate the spines of the paraproct; B) Same, ventrocaudal view; C) Dorsal view, A=anterior, P=posterior; D) Ventral view.

Figure 4. Epiphallus of *D. lustriae* from Pades, Epirus dorsal view.

Figure 5. External female genitalia of *D. lustriae* from Pades, Epirus. A) Subgenital plate, ventral view; B) Base of ovipositor and subgenital plate, lateral view.

Figure 6. Specimens of *T. zorae* from Pades, Epirus. A) Immature female specimen on a man-made stone wall, showing colouration characteristic of this species; B) Tergum ten of an immature male specimen.

Figure 7. The site of the Stontzi rock formation in Pades, Epirus, where most of our biological observations took place. A) Stontzi, aerial view in late autumn. The fissure splits the rock into three main towers. Note that the formation is covered by a pine forest; B) Ground level view of Stontzi, from the deciduous forest islet contained in the fissures of the rock formation; C) Deciduous forest floor and man-made stone wall, which are used by *D. lustriae* and *T. zorae* for foraging; D) Example of a crevice on the Stontzi rock formation which is used as a shelter by *D. lustriae* and *T. zorae* during the day.