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Systematics and biology of *Eburnocauda* gen. nov., a cave cricket from Australian granite pseudokarst (Orthoptera: Rhaphidophoridae)

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Abstract

Cave crickets (Orthoptera: Rhaphidophoridae) are a globally-distributed group of insects found in cool, dark habitats of high relative humidity. In Australia, eight genera are described and several are known only from cave environments, though a far greater diversity likely remains undiscovered both underground and in forest habitats. Here, we use molecular and morphological evidence to describe ***Eburnocauda saxatilis* gen. et sp. nov.** Beasley-Hall & Iannello from Britannia Creek Cave (BCC), a granite cave system found in Victorian wet sclerophyll forest. *Eburnocauda saxatilis* sp. nov. is sympatric with an undescribed species of *Cavernotettix* Richards, 1966 and males can be easily identified by their extremely elongate styli. BCC experiences periodic flooding and is accessible year-round to recreational caving groups, who often directly disturb cricket populations via accidental trampling. We consider these threats, paired with the extremely restricted known range of *Eburnocauda saxatilis* sp. nov., justification for this species to receive conservation listing. We discuss the phylogenetic placement of *Eburnocauda* gen. nov. and the conservation implications of its establishment as a new genus.

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Introduction

Subterranean environments are the largest non-marine habitat on Earth and include caves, aquifers, lava tubes, talus slopes, and fissures in bedrock. Contrary to popular belief, such habitats—which are frequently overlooked in conservation agendas—are not devoid of life and often act as biodiversity hotspots safeguarding relictual faunas (Mammola et al., 2019; Vaccarelli et al., 2023). Invertebrates represent the bulk of biodiversity in the subterranean realm (Humphreys, 2008; Souza-Silva et al., 2021; Trajano, 2000; Zigler et al., 2020), but in Australia an estimated 80% of species associated with caves are yet to be discovered (Guzik et al., 2010). Biodiversity discovery through taxonomic research has been identified as a key first step in addressing this knowl-

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edge gap (Mammola et al., 2022). However, certain subterranean habitats are better-characterised than others with respect to taxonomic research. In Australia, granite caves are unusual in that they are composed of poorly soluble host rock, in contrast to the more numerous and widespread caves formed from calcareous or basaltic rock throughout the country (e.g., limestone caves, lava tubes) (Finlayson, 1980). As a result, granite cave faunas are particularly poorly known and the habitat has been identified as potentially housing unexplored biodiversity (Guzik et al., 2010).

One such system in the infancy of species discovery is Britannia Creek Cave (hereafter BCC), a lowland granite cave in southern Victoria, Australia. BCC consists of landslide-deposited boulders on a valley floor between which a maze of cavities and fissures have been carved out by the movement of an underground stream (Figure 1). Unlike other granite caves in the region, the vast majority of chambers at BCC have at least one entrance above-ground and nutrients are available in relative abundance. An initial characterisation of BCC's fauna was conducted by Iannello et al. (2017) and documented 17 species including spiders, glow worms, and platypuses. At least two species at BCC are thought to be troglophiles (that is, reliant on caves to complete their life cycles): the glow-worm *Arachnocampa* (*Campara*) *gippslandensis* Baker, 2010 and a new species of cave cricket (Orthoptera: Rhaphidophoridae) with an uncertain generic placement.

The family Rhaphidophoridae contains over 800 species worldwide and is a member of the infraorder Tettigoniidea Kevan, 1982 (the katydids and allies), the sister group to Gryllidea Vickery, 1977, the "true" crickets (Song et al., 2020). In Australia, the fauna is represented by the subfamily Macropathinae Karny, 1930 and contains eight described genera. Of these, *Cavernotettix* Richards, 1966 and *Speleotettix* Chopard, 1944 are found in Victoria. However, the difficulty in accessing such habitats and the cryptic nature of individuals therein means the diversity of the Australian biota is likely to be far greater than currently known. Accordingly, a recent phylogenetic study highlighted the existence of several undescribed genera in Australia, one of these being the population at BCC (Beasley-Hall et al. 2024; Figure 2). However, only a single male individual from BCC was sampled in that study, leaving the morphology of females unknown and not accounting for potential intraspecific variation. Here, we sample additional material from BCC to describe the new genus and discuss its biology and conservation status in the context of the broader Australian Rhaphidophoridae. The phylogenetic placement of the new genus was confirmed the aforementioned sister study; as such, while we base the generic description on both morphology and molecules, the focus of the present paper was on obtaining additional morphological data.

Methods

Crickets were collected by hand from Britannia Creek Cave in May 2024 and killed in propylene glycol in the field prior to being transferred into 100% ethanol. Morphological examination was conducted using a Zeiss Stemi 2000 stereo microscope. During this process, we uncovered two distinct forms of cave cricket which differed in the terminalia and armature of the legs; an undescribed species of *Cavernotettix* was subsequently found to be sympatric with the genus at BCC described here (see Remarks below). Specimens of the latter were imaged using a Canon EOS 5DS R and a Canon MP-E65mm f/2.8 1-5x Macro lens and stacked images were processed using Zerene Stacker, Adobe Photoshop, and Adobe Lightroom. Material has been lodged with Australian National Insect Collection (ANIC) in Canberra, Australia and the Melbourne Museum (MM) in Victoria, Australia.

Discussion

Here, we use multiple lines of evidence to describe the cave cricket *Eburnocauda saxatilis* gen. et sp. nov. known only from Britannia Creek Cave in Victoria, Australia. Our findings increase the number of described Australian rhaphidophorid genera in Australia to nine and described species to 24. However, based on extensive molecular sampling of the family, several additional genera remain to be described (Beasley-Hall et al., 2024), and it is likely that extensive cryptic diversity persists nationwide. More robust sampling efforts are sorely needed to characterise this diversity, particularly in forest and high-altitude habitats in Victoria, New South Wales, and Queensland. While *Eburnocauda* gen. nov. can be easily distinguished from other rhaphidophorid genera by the morphology of males, a high degree of intraspecific variation has been documented for the Australian and New Zealand Rhaphidophoridae (Richards, 1958, 1971a). As such, further biodiversity discovery and taxonomic research on the group will necessitate the use of molecular data, as we have used here.

Habitat and biogeography of **Eburnocauda**

The habitat of *Eburnocauda saxatilis* sp. nov. can be viewed as a "high energy" cave system relative to those in drier regions of Australia. BCC lies within the Highlands – Southern Fall (HSF) bioregion in the southern portion of the Great Dividing Range, an area predominantly composed of cool temperate wet sclerophyll forest characterised by a tall, eucalypt tree layer with a moist, shaded understory (Lindenmayer et al., 2023). Entrances at BCC (see Figure 1) are typically characterised by an abundance of shrubs, mosses, liverworts, leaf litter, and fungi, on which rhaphidophorids feed as part of daily foraging cycles (Department of Sustainability and Environment, 2004; Richards, 1966b) and the region houses several undescribed cave cricket taxa (PGBH, pers. obs.).

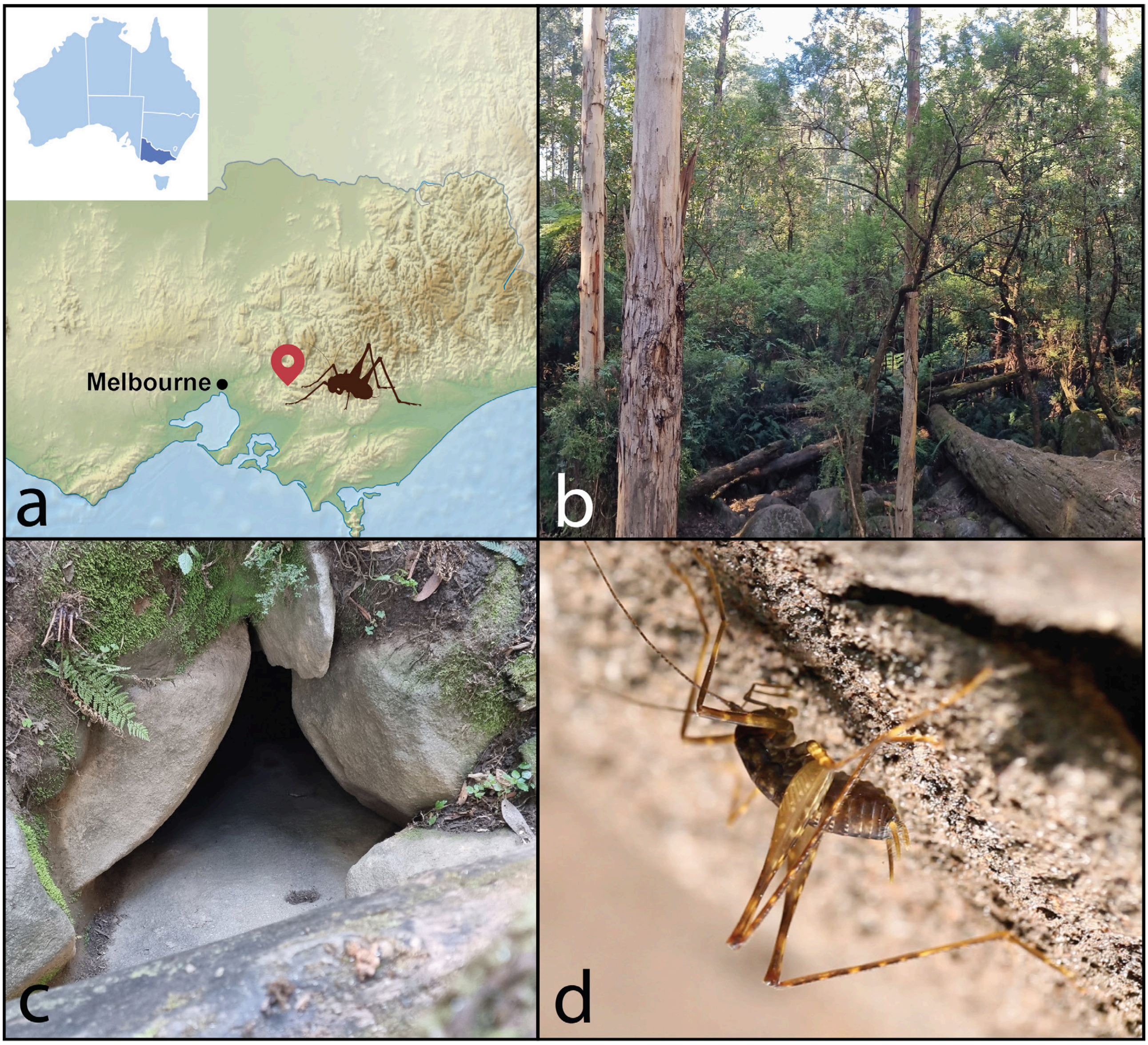

Figure 1. Top row: Location of Britannia Creek Cave (BCC) in Victoria (a) and typical mesic forest around BCC, dominated by mountain ash (b). Bottom row: a typical small entrance at BCC formed by granite boulders (c) and male *Eburnocauda saxatilis* gen. et sp. nov. on a cave wall with elongate styli visible below the cerci (d). Images © Sascha Grant (CC BY-NC-ND licence) and Silvana Iannello.

In addition to these nutrient sources, the food web in deeper parts of BCC is likely sustained by Britannia Creek itself, which runs through the cave system in multiple directions and serves as a primary conduit for tributaries in the catchment area. Fluctuating water levels (including significant flooding events) deposit organic matter including leaf litter, twigs, and silt into the system (SI, pers. obs.). Subterranean rhaphidophorids are typically found in the twilight zone of Australian caves, but in some species a minority of individuals may extend into regions of total darkness (Richards, 1971b, 1970, 1968). At BCC, rhaphidophorids are numerous even in the dark zone, with individuals having been sighted amongst boulders and within fissures in the granite (Iannello et al., 2017), though we note these individuals were not identified to the genus level and may belong to *Cavernotettix* sp. (see Remarks in the generic description). In any case, rhaphidophorid subsistence in cave zones that are usually otherwise starved of nutrients may be facilitated by these water-borne nutrient inputs at BCC. In flooded locations, individuals have been found in elevated chambers above the flowing stream characterised by still air, compacted mud floors, and walls of protruding boulders (SI, pers. obs.).

Australian rhaphidophorids found in the dark zone of caves have been most extensively documented in the western half of Tasmania, a region also characterised by wet sclerophyll forest and enormous cave systems prone to flooding (Bradstock, 2010; Fordyce, 2023). Interestingly, *Eburnocauda* gen. nov. was recovered as the sister group to the Tasmanian *Micropathus* Richards, 1964 in molecular phylogenetic analysis (Beasley-Hall et al., 2024). Central Victoria was periodically connected

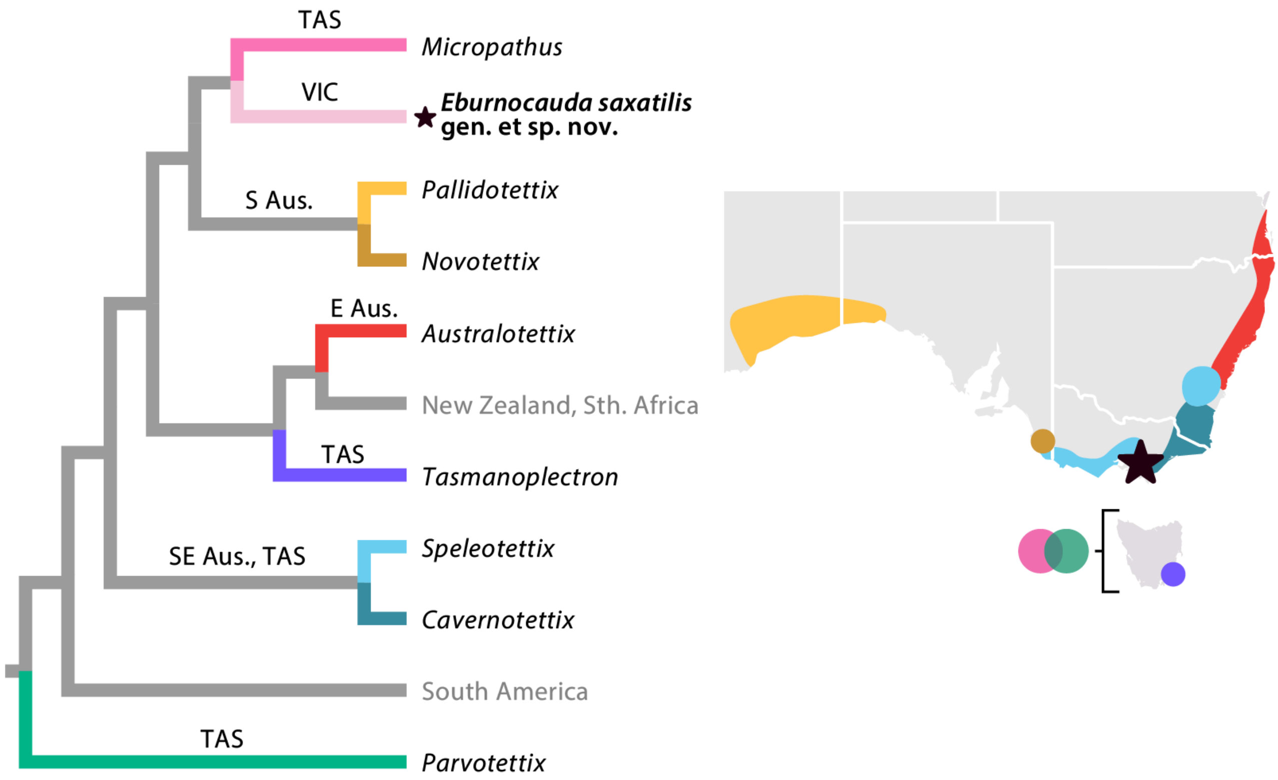

Figure 2. Phylogenetic relationships among described genera of Macropathinae showing placement of *Eburnocauda* gen. nov. Distributions in the Bass Strait are not shown for clarity. TAS = Tasmania; VIC = Victoria. Figure adapted from Beasley-Hall et al. (2024).

to Tasmania via the Bassian Land Bridge during glacial periods in the Quaternary and the two landmasses were eventually separated by post-glacial rising sea levels approximately 11,000 years ago in the middle Pleistocene (Lambeck and Chappell, 2001; Porch and Allen, 1995). As the Australian fauna appears to have had multiple evolutionary origins in Tasmania (Beasley-Hall et al., 2024), the ancestor of *Eburnocauda* gen. nov. likely originated on the island and migrated to Victoria via the Bassian Land Bridge (or rafting) prior to the geographic isolation of Tasmania from Australia's mainland. Contraction of appropriately mesic habitat may then have isolated *Eburnocauda saxatilis* sp. nov. to the foothills of the Great Dividing Range. We note undiscovered, additional populations and/or species may expand the known range of the genus at a later date given the high biodiversity in the region. Further, *Micropathus* might not represent the closest extant relative of *Eburnocauda* gen. nov. due to the cryptic nature of the Australian Rhaphidophoridae and biassed molecular sampling of the group as a result.

Conservation considerations

Eburnocauda gen. nov. is not known from outside Britannia Creek Cave and frequent, significant human disturbance to the site places cricket populations at risk of decline. The cave experiences year-round foot traffic from recreational caving tour groups, often receiving over 50 visitors a day (Iannello et al., 2017), and a lack of fencing or gating means the entirety of the cave is accessible to visitors at any time, making vandalisation frequent (Finlayson, 1980). Invertebrates at BCC are impacted by this visitation via direct damage to surrounding habitat (e.g., breakage of glow-worm lures) and individuals (e.g., trampling of rhaphidophorids on the cave floor) (Iannello et al., 2017; SI, pers. obs). Whereas all other species recorded at BCC have been sampled elsewhere, a threat distinct to *E. saxatilis* sp. nov. is its exceptionally restricted known range, which qualifies the species as an ultra short-range endemic (i.e., with a distribution of <100 km2) and therefore at greater risk of extirpation compared to more cosmopolitan taxa (Guzik et al., 2019). Several Australian rhaphidophorids have been granted conservation listing for this reason, such as the critically endangered *Tasmanoplectron isolatum* Richards, 1971 found only on Tasman Island and its adjoining peninsula (Orthopteroid Specialist Group, 1996). Given the multiple threats faced by *Eburnocauda saxatilis* sp. nov., we believe the species deserves similar formal recognition as at risk of decline to ensure its protection from human disturbance. Further sampling at nearby granite caves in the Highlands - Southern Fall bioregion, such as Labertouche, will be necessary to more confidently determine the distribution of *Eburnocauda* gen. nov. Additional exploration within BCC is also required to determine whether *Eburnocauda saxatilis* sp. nov. and the undescribed, sympatric species of *Cavernotettix* occupy different cave zones or microhabitats in the granite. More generally, management efforts at the whole-cave level will be necessary to maintain the ecological integrity and biodiversity of Britannia Creek Cave.

Taxonomy

Eburnocauda Beasley-Hall & Iannello, gen. nov.

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Type species: *Eburnocauda saxatilis* Beasley-Hall & Iannello sp. nov.

Diagnosis. *Eburnocauda* can be distinguished from other rhaphidophorids by the extremely robust and long styli projecting from the male subgenital plate, reaching over half the length of the cerci. *Eburnocauda* also bears, on average, two ventral linear spines on either side of the fore and mid tibiae (prolaterally and retrolaterally); except for *Parvotettix* Richards, 1968 (which lacks these spines), all other Australian genera have at least three.

Description. Fore coxae armed with an anterolateral spine, all other coxae unarmed. Apical spination of femora variable, but all lack ventral linear spines. Fore femora unarmed apically, mid femora with a retrolateral apical spine only, hind femora unarmed prolaterally but variably bearing a retrolateral apical spine. All tibiae with both apical and linear spines. Fore and mid tibiae with two pairs of apical spines, one prolateral and the other retrolateral, with each pair containing one spine facing dorsally and the other ventrally; two rows of linear spines on the ventral surface, one prolateral and the other retrolateral, each row containing an average of 2 spines (range 2–3) (Fig. 3 i). Hind tibiae with apical spines as on the fore and mid tibiae, but also bearing a pair of subapical spines between each primary pair; linear spines on the dorsal surface variable. Fore and mid tarsi unarmed. Hind tarsi with a pair of apical spines on the first and second segments; third and fourth segments unarmed. Dorsal linear spines on first and second hind tarsal segments variable. Male styli robust, dramatically elongate, measuring more than double length of the suranal plate (Fig. 3 b, c). Female subgenital plate trilobed.

Remarks. Additional sampling was performed at BCC and surrounds following the placement of a single specimen of *Eburnocauda* as sister to *Micropathus* by Beasley-Hall et al. (2024). However, microscopy subsequently revealed two morphologically divergent populations separated by differences in leg spination and terminalia. One of these we describe here as *Eburnocauda saxatilis* sp. nov., the other being a new species of *Cavernotettix*. The latter also occurs at Sherbrooke Forest approximately 30 km to the southwest of BCC. The generic placement of *Cavernotettix* sp. at Sherbrooke has been confirmed using both morphological and molecular data and will form the basis of an upcoming taxonomic paper. In contrast, *Eburnocauda saxatilis* sp. nov. is only known from BCC, suggesting the two species may have divergent microhabitat requirements; it remains unknown as to whether they occupy different cave zones.

Eburnocauda can be considered unusual in its possession of dramatically elongate male styli, which are thought to assist in positioning the abdomen during copulation; these sensory structures have been shortened or lost in other Rhaphidophoridae, potentially a result of the development of other terminal structures which prevent displacement of males in mating pairs (Gorochov, 2001, 2014). *Eburnocauda* also has a notable arrangement of apical spines on the fore and middle femora. These segments are typically armed on both the prolateral and retrolateral surfaces—i.e., on either side of the “knee”—in other Australian Rhaphidophoridae, with the exception of *Tasmanoplectron* Richards, 1971 (variably present) and *Parvotettix* (always absent) (Richards, 1968, 1971a). In *Eburnocauda*, the fore femur is unarmed and the middle only armed on the retrolateral side. However, given the small number of individuals examined, we cannot rule out the absence of these structures owing to breakage in life.

Etymology. From the Latin *eburno* (ivory) and *cauda* (tail), alluding to the tusk-like styli found on the posterior of males. It is a feminine noun in the nominative singular case.

Eburnocauda saxatilis Beasley-Hall & Iannello sp. nov.

Figs. 1d, 3a–i

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Type material. Holotype: Adult ♂, Britannia Creek Cave, Wesburn, VIC, -37.793817, 145.671536, coll. S. Iannello, May 18, 2024, ANIC 14-009154. **Paratypes**: 2♀, same collection information as holotype, ANIC 14-009155 and MM OTH 268. Adult ♂, Britannia Creek Cave (twilight zone, near entrance GP48), Wesburn, VIC, coll. S. Iannello, April 16, 2015, MM OTH 269.

Diagnosis. A medium-sized cave cricket with diagnostic features as per the monotypic genus and an adult body length of 12–14 mm. Currently only known from the Highlands – Southern Fall bioregion of Victoria, Australia.

Description. ***Measurements.*** Body length 12–14 mm (holotype 12 mm), hind tibia 18–21.5 mm (holotype 21.5 mm). Ovipositor 9–11 mm.

Head. Head mid brown with dark brown patterning on the vertex and frons. Eyes black. Fastigium approximately twice as long as high, indented medianly and divided into two dark brown, laterally-compressed tubercles. A single median ocellus present.

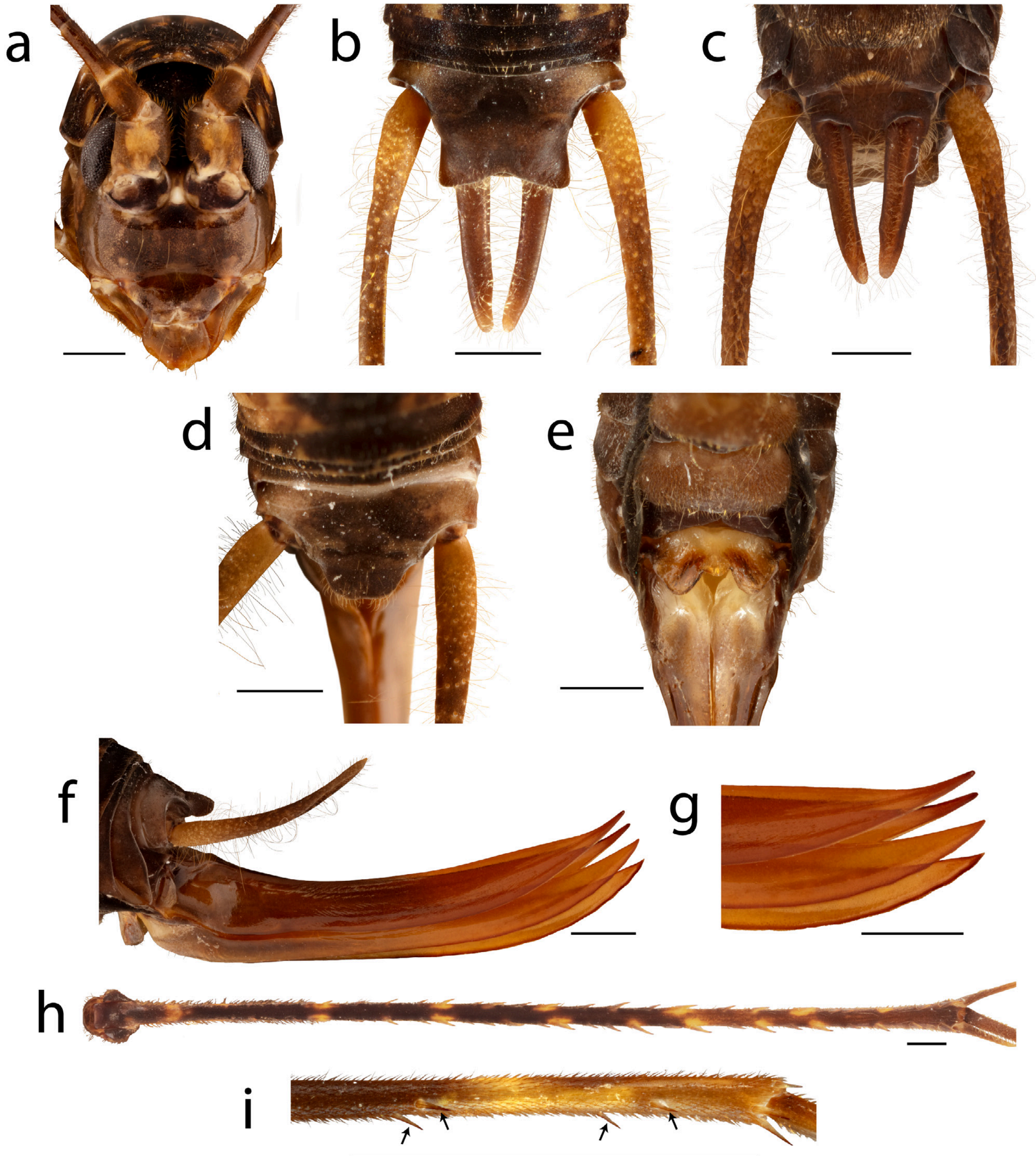

Figure 3. *Eburnocauda saxatilis* Beasley-Hall & Iannello sp. nov. Head (a); dorsal view of terminalia (b ♂, d ♀); ventral view of terminalia (c ♂, e ♀); lateral view of ovipositor (f, g); dorsal view of hind tibia (h); ventral view of middle tibia, showing rows of paired linear spines (arrows) and apical spines to the right. Scale bars = 1 mm.

Body. Basic body colour light to mid brown with dark brown patterning. Dorsal surface of the body moderately clothed with short, mid brown setae. Ventral surface of the body densely setose, particularly at the distal margins of abdominal sclerites. Thoracic nota with light brown patches laterally, often glabrous, and interspersed by light brown mottling which extends to the abdominal tergites. Legs light to mid brown and interspersed with light brown striations and patches on hind femora. Ovipositor a saturated orange.

Legs. Apical spination as in generic description. Dorsal surface of hind tibiae with an average of 26 linear spines prolaterally (min. 24, max. 29, holotype 26) and 26 retrolaterally (24–30, holotype 25). First segment of hind tarsi with an average of 3 dorsal linear spines prolaterally (1–4, holotype 2) and 2 retrolaterally (2–3, holotype 2). Second segment of hind tarsus with an average of 1 dorsal linear spine each prolaterally and retrolaterally (1-2 for both, same for holotype). No apparent sexual dimorphism in armature of the legs.

Male terminalia. Suranal plate mid brown, rectangulate, with distolateral corners forming two convex, square lobes. Distal margin of plate weakly to moderately emarginate. Subgenital plate mid brown, rectangulate, truncate distally; densely setose at distal and lateral margins and bearing styles. Styli densely setose, broad, and very long, reaching around two-thirds length of the cerci. Ventral surface of each style curved inward, forming a cylindrical indentation along the length.

Female terminalia. Suranal plate mid brown, broadly square in shape and weakly convex laterally; distolateral corners rounded and weakly emarginate at distal margin. Plate setose at the distal margin but otherwise glabrous. Plate indented medianly with a crease-like horizontal depression terminating in two indentations on either side. Subgenital plate beige, trilobed, with lateral lobes at least twice length of the median lobe and sclerotised such that they appear orange. Median lobe small and with a rounded apex. Plate weakly setose at the distal margin but otherwise glabrous. Ovipositor 0.8x length of body with very weakly produced teeth on the dorsal margin, of which 5–6 are visible.

Remarks. The individual collected in 2015 (MM OTH 269) was subjected to phylogenetic analysis by Beasley-Hall *et al*. (2024) and is referred to as *gen. nov. 1* in that paper.

Distribution. Britannia Creek Cave, Wesburn, Victoria, Australia (Fig. 1a).

Etymology. From Latin *saxatilis*, meaning that which lives amongst rocks. It is a feminine adjective in the nominative singular case.

Disclosures

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