Article

The enigmatic *Notolathrus sensitivus* Remes Lenicov, 1992 (Hemiptera: Fulgoromorpha: Cixiidae): supplementary description and conservation status

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Abstract

Notolathrus sensitivus holds the distinction of being the first cave-restricted planthopper species documented in South America, and currently stands as the sole known troglobitic Fulgoromorpha species in Argentina. This paper presents a comprehensive supplementary description of *N. sensitivus*, incorporating newly collected male and female specimens. Notably, this study provides the first-ever description of females for this species. In addition to photographs of structural details, we include images showcasing live specimens within their natural habitat. Furthermore, we highlight the primary threats that pose risks to the species' survival. Based on these significant findings, we strongly advocate for the inclusion of *N. sensitivus* on the Argentine endangered species list, emphasizing the urgent need for conservation measures.

Key words: cave, troglobitic, planthopper, taxonomy, IUCN

Introduction

Recent expeditions conducted in the Cuchillo Curá Cave System (CCCS), situated in the Province of Neuquén, Argentina, with the objective of sampling cave invertebrates, have yielded a significant finding: the rediscovery of the enigmatic species *Notolathrus sensitivus* Remes Lenicov, 1992. This species holds particular significance as it represents the first documented troglobitic Fulgoromorpha in South America and remains the only known planthopper species identified as exclusively restricted to caves in Argentina to date.

Remes Lenicov, who first described the species in 1992, erected the genus *Notolathrus* to accommodate it. To date, the genus remains monotypic. This species was originally described based on three male specimens, and thus, information regarding the morphology of females and morphological variations within the species remains unknown. In South America, there are currently three genera and five species of troglobitic cixiids recognized: *Notolathrus* Remes Lenicov, 1992 with *N. sensitivus* Remes Lenicov, 1992 from Argentina, *Ferricixius* Hoch & Ferreira, 2012 with *Ferricixius davidi* Hoch & Ferreira, 2012, *F. michaeli* Santos *et al.*, 2023, and *F. goliathi* Santos *et al.*, 2023 from Brazil and *Oliarus* Stål, 1862 with *Oliarus hernandezi* Hoch & Izquierdo, 1996 from Galápagos (Bourgoin 2023). Globally, 70 species of Fulgoromorpha troglobites are recognized, of which more than 40 belong to the Cixiidae Spinola, 1839 (Bourgoin 2023, Le Cesne *et al.* 2024). It is worth noting that all cixiid nymphs are

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subterranean, and this subterranean lifestyle is recognized as a significant factor contributing to the evolution of cave-restricted species within this family (Hoch 2002, Le Cesne *et al.* 2024).

Troglobitic species are characterized by their remarkable sensitivity and high degree of endemism (Wynne *et al.* 2021). It is common to find examples of troglobitic cixiids that are confined to a single cave, as evidenced by previous studies (e.g., Fennah 1975; D'Urso & Grasso 2009; Hoch & Ferreira 2012; Hoch 2013; Le Cesne *et al.* 2022). Species with restricted distributions are particularly vulnerable to habitat loss, rendering them more susceptible to the risk of extinction. *N. sensitivus*, for instance, is exclusively known from its type locality. Therefore, it is essential to employ appropriate conservation measures in accordance with the standards established by the IUCN. Such measures will play a pivotal role in safeguarding the species habitat and ensuring its long-term survival.

This study presents a comprehensive supplementary description of *N. sensitivus*, based on recently discovered specimens to provide a detailed characterization, including the previously undocumented female specimens. Our primary objective is to unravel the distinctive identifying characteristics specific to *N. sensitivus*, while emphasizing the utmost importance of conserving this extraordinary species. *N. sensitivus* is still around, we provide new records within the CCCS, a supplementary description, plus for the first time, some information on ecology as well as on conservation status. Furthermore, we highlight the primary threats that pose risks to the species' survival. Finally, we present the first photographs of living specimens (and from their habitat) as well as advocate for the inclusion of this taxon on the Argentine endangered species list.

Materials and methods

Collection, preservation, and depository

Specimens were collected using wet brushes and subsequently transferred to vials containing 96% ethanol for preservation (Wynne *et al.* 2019). One specimen was kept 96% ethanol and stored in a freezer for future DNA extraction. The other specimens were then stored in 70% ethanol for morphological studies and deposited in the MACN (1♂ and 3♀) and ISLA (1♀) collections.

Morphological examination techniques and visualization

We used a Zeiss Axio Zoom V16 stereomicroscope and Zen 2.3 software to examine the morphological characters of the specimens, capture images and take measurements (when necessary). In order to ensure consistent and standardized color descriptions, we employed the sRGB Centroids for the ISCC-NBS Color System, following the standard names provided by Centore (2016).

Digital images of the holotype were taken at the MACN under visible light, using a digital camera (Leica DFC290) attached to a stereomicroscope (Leica M165C), and the focal planes stacked with Helicon Focus 3.10.3 (http://helicon.com.usa/heliconfocus/).

Male genitalia preparation and examination

The male genitalia were dissected from the specimens using entomological pins and scissors. Subsequently, they were transferred to ethanol gel with a layer of 70% liquid ethanol to minimize reflections during photographic documentation.

Terminology

The morphological terminology utilized in this study largely adheres to the classification proposed by Löcker *et al.* (2006) and Löcker (2014). While the terminology for venation and tegmina cells aligns with the system outlined by Bourgoin *et al.* (2015) and the terminology of the terminalia with Bourgoin (1988) and Bourgoin & Huang (1990) for the males and Bourgoin (1993) for the females.

Measurements

Measurements were made as follows:
Body length: Dorsally, from the middle of the apical transverse carinae of the vertex to the anterior margin of the pygofer. *Length of vertex*: Medially, from the apical transverse carina to the caudal margin. *Width of vertex*: At the level of the caudal border medially. *Length of frons*: medially, from the frontoclypeal suture to the apical transverse carina. *Width of frons*: Maximum width in facial view. *Length of tegmina* (fore wings): Of the posterior margin of tegulae to distal margin of tegmen/fore wing. *Length of hind tibia*: from the base of the hind tibia to the base of apical teeth.

Abbreviations

ARG:	Argentina.
BPBM:	Bernice Pauahi Bishop Museum. Entomology Collection.
BR:	Brazil.
CA:	Central America.
CCCS	Cuchillo Curá Cave System.
CNC:	Canadian National Collection of Insects, Arachnids and Nematodes.
EC:	Ecuador.
EUA:	United States of America.
ICZN:	International Code of Zoological Nomenclature.
ISLA:	Invertebrados subterrâneos de Lavras.
JAM:	Jamaica.
MACN:	Museo Argentino de Ciencias Naturales.
MCNT:	Museo de Ciencias Naturales, Santa Cruz de Tenerife.
MX:	Mexico.
NAM:	North America.
NMNH:	National Museum of Natural History.
NQN:	Neuquén Province.
SA:	South America.
TNHC:	Texas Memorial Museum.

Maps

We utilized QGIS 3.16.15 software to generate the maps presented in this paper (Fig. 10). For the distribution map of *N. sensitivus*, the vectors from the CCCS maps were obtained from Grupo Espeleológico Argentino (GEA) source and edited using Adobe Illustrator CC 2020 24.3.

Photographs

We employed an Olympus Tough TG-5 camera (figs. 8 B, C, D) and a Canon EOS 80D for capturing images of live specimens (fig. 8 E). Aerial photographs of the landscape were obtained via a Dji Mini 2 Pro Drone (figs. 9 A, D). Photographs of the cave interior and its surroundings (figs. 9 B, C) were taken using a Samsung S20 smartphone.

Results

Taxonomy

Order Hemiptera Linnaeus, 1758

Suborder Fulgoromorpha Evans, 1946

Superfamily Delphacoidea Leach, 1815

Family Cixiidae Spinola, 1839

Subfamily Cixiinae Spinola, 1839

Tribe Oecleini Muir, 1922

Notolathrus **Remes Lenicov, 1992**

Type species. *Notolathrus sensitivus* Remes Lenicov, 1992
Type locality. **ARG**, **NQN**, Departamento Picunches, Sistema Cuchillo Cura, Caverna del Arenal.

Etymology. Remes Lenicov (1992) provided the etymology only for the generic name *Notolathrus*, which comes from the Greek *notos* = 'South' and *lathrus* = 'Hidden'. The etymology of the epithet was not given, but it may have been referred to the Latin *sensitivus* = 'sensitive', possibly referring to the 'sensitivity' or low tolerance to environmental changes experienced by this species.

Original diagnosis (Remes Lenicov 1992). The following text (in italics) is transcribed from the original description of the genus *Notolathrus* provided by Remes Lenicov, 1992 (pp 155–156). After each paragraph, we provide an English version.

Diagnosis: *Vertex alrededor de 2 veces más ancho que largo, con una carena traversal muy próxima al margen posterior con el cual delimita un área deprimida dividida en dos por una carena longitudinal poco marcada. Frente casi tan ancha como larga, convexa en perfil; márgenes laterales foliáceos; carena mediana sólo marcada en la mitad basal, visualizada como un leve reborde en vista lateral; sutura frontoclipeal convexa, evanescente en su parte media; clípeo, en perfil, deprimido, más corto que la frente en la línea media. Ojos y ocelos ausentes. Antena, con el segmento 2 globular, tan largo como ancho, tercer antenito con una arista apical pequeña que supera ligeramente su longitud y que parte de la base del flagelo.*

Vertex approximately 2 times wider than long, with a transverse carina located very close to the posterior margin, delimiting a depressed area divided into two by a faint longitudinal carina. Frontal area nearly as wide as long, convex in profile, with foliaceous lateral margins. Median carina only well-marked in the basal half, appearing as a slight ridge in lateral view. Frontoclypeal suture convex, becoming indistinct in the middle. Clypeus, in profile, depressed and shorter than the frons at the midline. Eyes and ocelli absent. Antenna with segment 2 (pedicel) globose, as long as it is wide and the third antennal segment featuring a small apical arista that slightly exceeds its length and originates from the base of the flagellum.

Pronoto corto; carenas laterales divergentes. Mesonoto poco más ancho que largo; disco mediano convexo y sin carenas. Postibia con 6 espinas apicales, inerme lateralmente; metatarsitos I y II con 3 espinas apicales, Uñas pretarsales delgadas y divergentes, arolio reducido.

Short pronotum; divergent lateral carinae. Mesonotum slightly wider than long; median disc convex and without carinae. Post-tibia with 6 apical spines, unarmed laterally; metatarsi I and II with 3 apical spines. Pretarsal claws thin and divergent, arolium reduced.

Braquíptero. Tegminas dispuestas horizontalmente sobrepasando el segundo segmento abdominal, con nervaduras longitudinales únicamente con débiles microtriquias implantadas en toda su longitud. Alas reducidas a escamas que no superan el largo del metanoto.

Brachypterous. Tegmina horizontally arranged, extending beyond the second abdominal segment, with longitudinal veins bearing only weak microtrichia throughout their length. Wings reduced to scales that do not exceed the length of the metanotum.

Genitalia: Pigofer expandido ventro-lateralmente, profundamente escotado en aspecto dorsal; proceso medio ventral amplio, de forma espatulada, cerrando en parte la cámara genital. Aedeagus y falobase tubular, con un flagelo espiniforme terminal dirigido oblicuamente cefalo-ventral, proyectado más allá de la falobase. Estilos convergentes, más anchos en la mitad basal; apice bífido. Segmento anal relativamente largo, convexo en vista lateral.

Genitalia: Pygofer expanded ventro-laterally, deeply notched dorsally; ventral median process broad, spatulate-shaped, partially closing the genital chamber. Aedeagus and phallobase tubular, with a terminal spiniform flagellum directed obliquely cephalo-ventrally, projecting beyond the phallobase. Styles convergent, wider at the basal half; apex bifid. Anal segment relatively long, convex in lateral view.

Supplementary description

Type material. *Holotype*: Male, AGR, NQN. Picunches Department, Cueva del Arenal cave, (UTM 378551.57W, 5725338.53S, 19H), 04–06. i.1987 (MACN_En 41439) (Fig, 1 A–C). Holotype condition: as informed by Bachmann (2012). *Paratypes*. 2 ♂ same data as holotype (the specimens should be at MACN_En but could not be located).

Material examined. Templo cave, (UTM 379039.46W, 5725354.07S, 19H), 17.x.2022, (Iuri H.A.), 1♂ (MACN_En 41440) and 2♀, (MACN_En 41441–41442) and 1♀ (ISLA 117714). Material condition: Male with dissected genitalia, stored in an individual vial in ethanol 70%. Females (not dissected) stored in an individual vial in ethanol 70%.

Coloration (preserved specimen): As in figs. 2 A–D, predominantly Yellowish white (92) with some areas Light yellow (86) on thorax and Strong yellowish brown (74) on male and female terminalia as in Figs. 6–7, tegmina hyaline with Light yellow (86) veins as in Figs. 4 A–D.

Body length. Female. 3.46 mm (n = 1) (Figs. 2 C, D); Male. 3.53 mm (n = 1) (Figs. 2 A, B).

Head. Vertex (Figs. 3 A, C): approx. 2.6 times wider (0.34) than long (0.13); in dorsal view, apical transverse carina evanescent and irregular medially; caudal border arched medially; in lateral view caudal border surpassing to apical transverse carina. Frons (Fig. 3 B): in lateral view, totally curved (Figs 3 D); in facial view slightly wider (0.50) than long (0.48), approx. 1.3 times wider at the height of the antennae than apically (0.36); anterior region of the frons (apically) large laterally and apically weakly depressed in the middle; median carina evanescent, most visible in lateral view (Figs. 2 B, b1, D). Frontoclypeal suture convex (bent up wards). Postclypeus (Fig. 3 B): with median carina evanescent apically. Anteclypeus (Fig. 3 B): median carina moderately developed distally, evanescent near of frontoclypeal suture. Rostrum not surpassing the hind coxae. Antennae (Figs. 3 A–C, c1): Scape short, pedicel subglobose, flagellum as in other planthoppers reduced to a thin arista (see Wang et al 2018); basal flagellar swelling equipped with an additional elongate thin tubular process ressembling the arista in shape (Figs. c1).

Thorax. Pronotum (Figs. 3 A, C): In dorsal view, short medially; submedian carinae weakly developed, occurs near of hind margin medially and distant laterally; hind margin curved; in lateral view, angulate in approx. 90° basally. Mesonotum (Fig. 3 A): slightly wider (0.73) than long (0.66); median and lateral carina absent. Tegmina (fore wings) (Figs. 4 A–D): Length (1.17): Vestigial, slightly surpassing the first segments of the abdomen; fork ScP+R present; MP present, distally forked; Pcu and A1 present sometimes not forked distally, with Pcu+A1 vein usually absent in one of the tegminae (asymmetry) or absent on all two of the tegminae (symmetry) (see taxonomic remarks); Rp vein evanescent. Hind wings: very reduced, no observable venation patterns. Hind legs (Figs. 5 A, B): hind tibia with 6 apical teeth with approximately the same size, without lateral spines; 1st tarsomere with 3 apical teeth with approx. the same size; 2nd tarsomere with 2 apical teeth with approx. the same size (vs. 3 teeth on male), without thin setae or platellae; pretarsal claws rather long and well developed, arolia reduced.

Female terminalia. Segment X (Figs. 6 A–C): in lateral view very short, longer basally; epiproct and paraproct as on the male. Segment IX (Figs. 6 A–B, D): in ventral view, truncated, smaller apically; in lateral view, lateral margins irregular. Ovipositor (Figs. 6 A–D): sabre-shaped (curved upwards), not surpassing the segment X; gonapophysis VIII with small overlapping squama-like lines (similar as in *Ferricixius* Hoch & Ferreira, 2012).
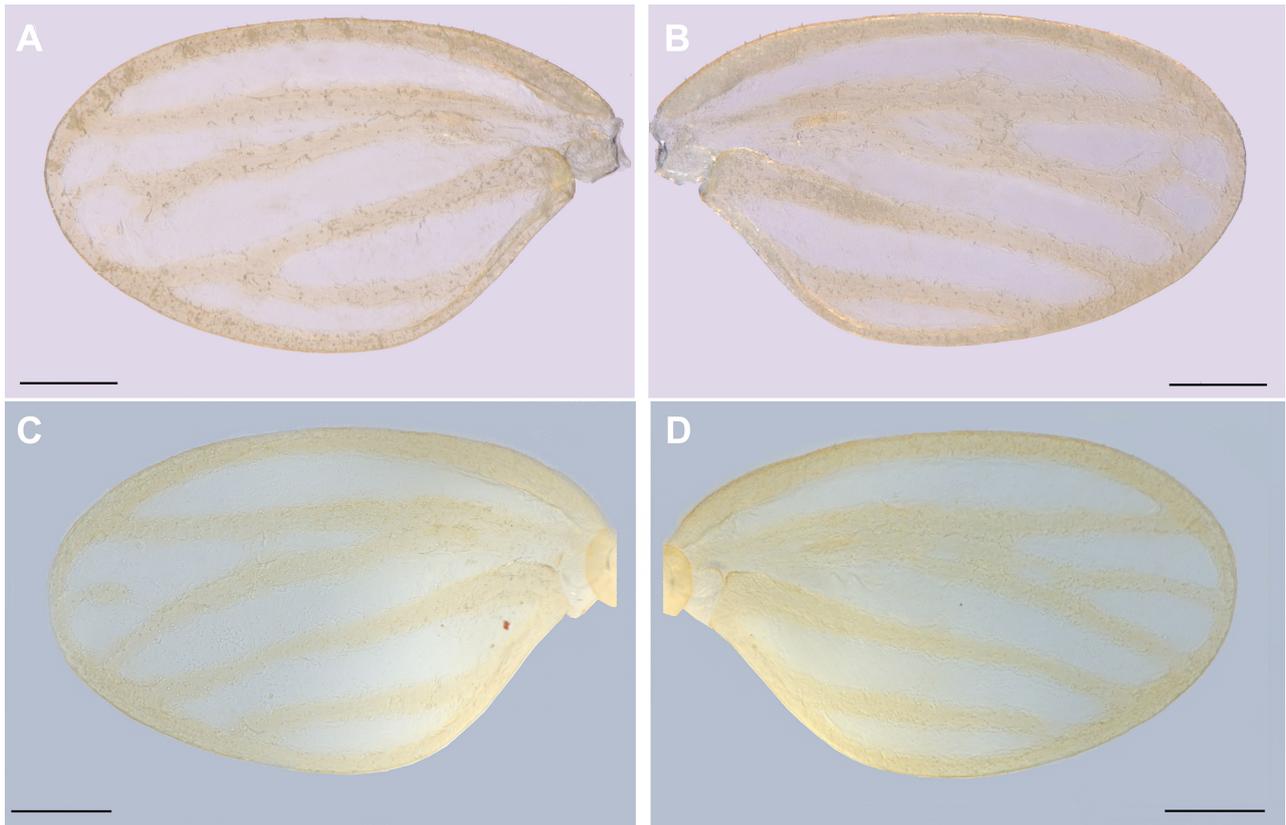
FIGURE 1. Holotype *Notolathrus sensitivus* Remes Lenicov, 1992, A–B: dorsal view (A); focus on male head in dorsal view (a1); lateral view (B); focus on male head in lateral view (b1). Scale bar: 0.5mm.
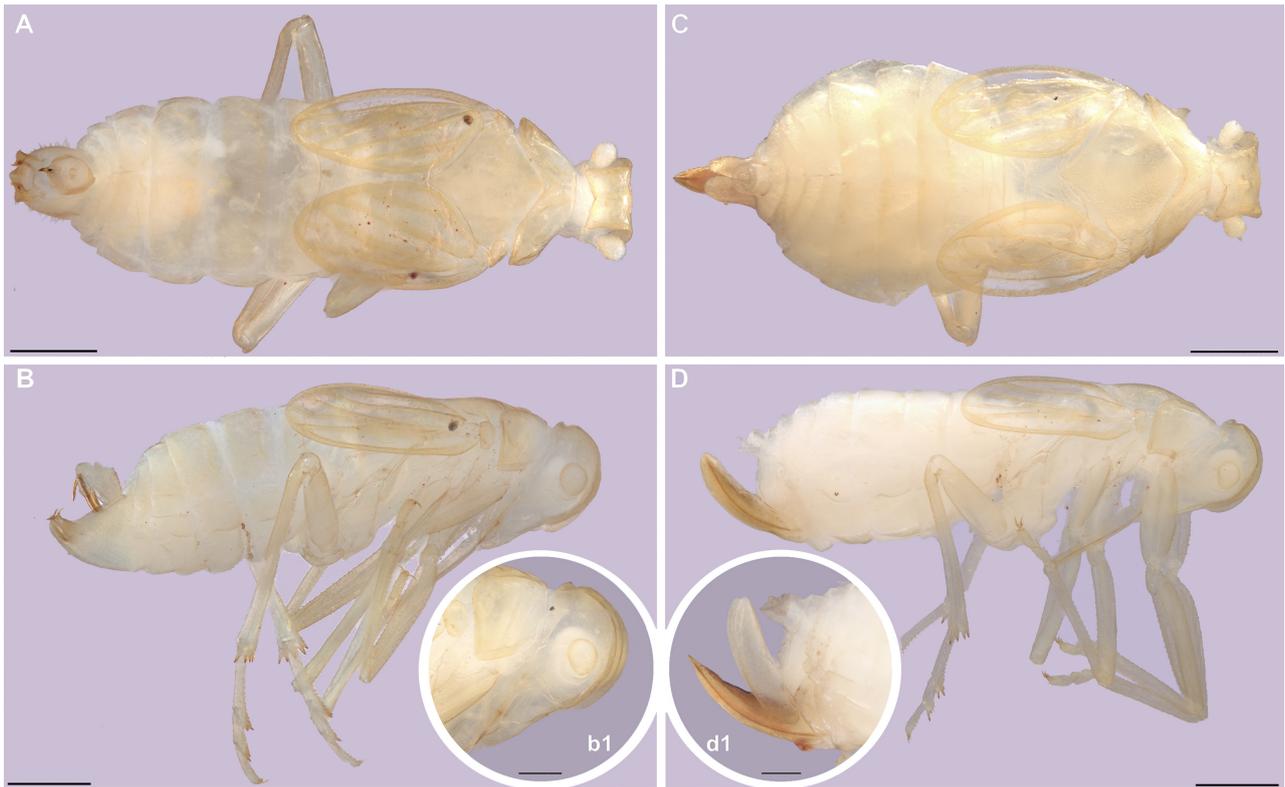
FIGURE 2. *Notolathrus sensitivus* Remes Lenicov, 1992, A–D: male in dorsal view (A); male in lateral view (B); focus on male head (b1); female in dorsal view (C); female in lateral view (D); focus on female genital segment (d1). Scale bar: A, B, C, D—0.5mm; b1, d1—0.2 mm.
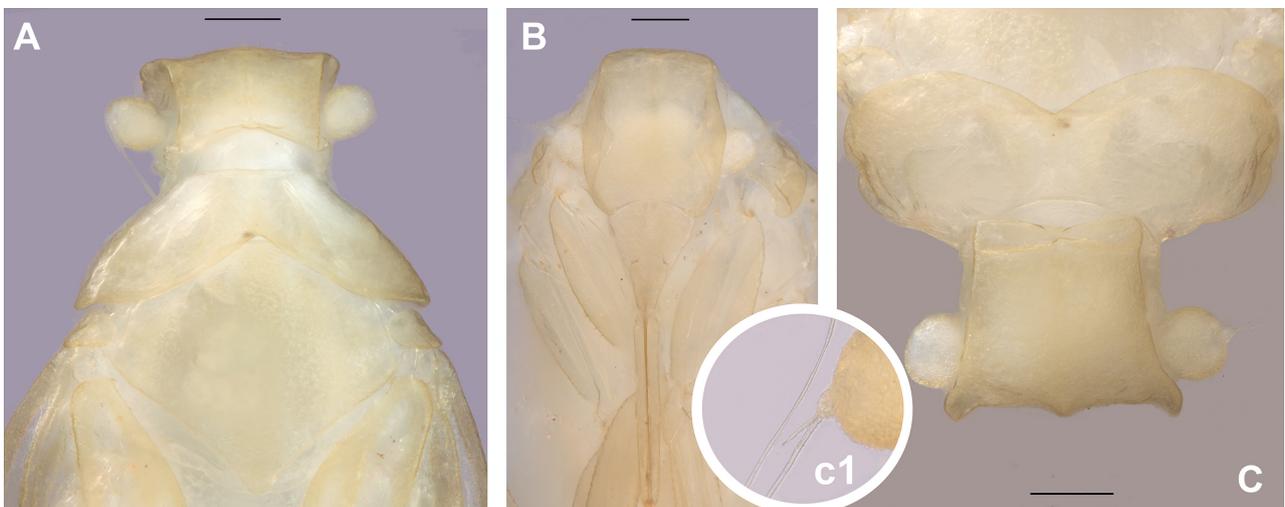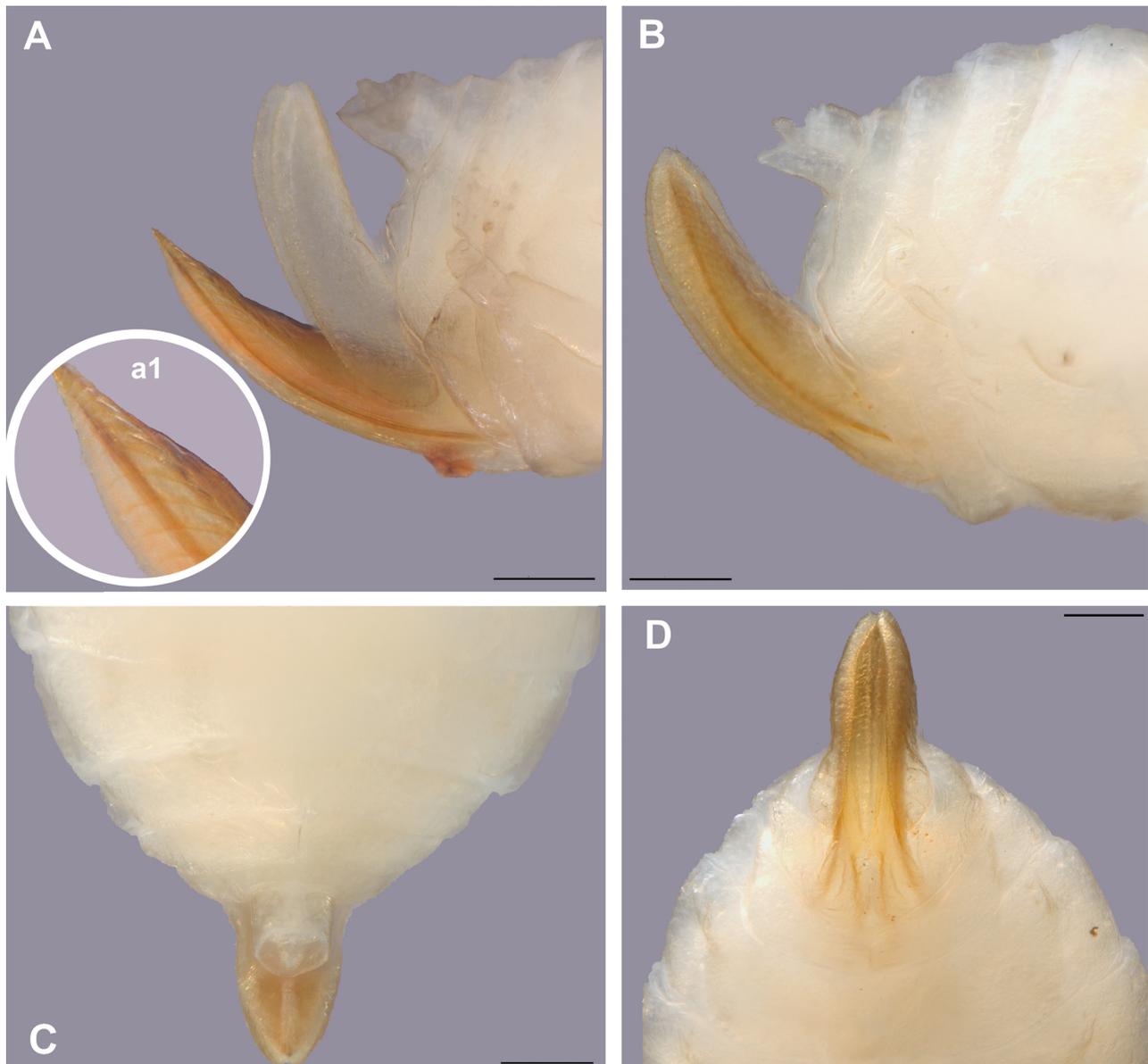

FIGURE 3. *Notolathrus sensitivus* Remes Lenicov, 1992 (Female), A–C: head and thorax in dorsal view (A); head in frontal view (B); head in front dorsal view (C); pedicel with flagellum and arista (c1). Scale bar: A, B, C—0.2 mm; c1—0.05 mm.

FIGURE 4. *Notolathrus sensitivus* Remes Lenicov, 1992, tegmina (fore wings), female (A–B), male (C–D). Scale bar: A–D—0.2 mm.
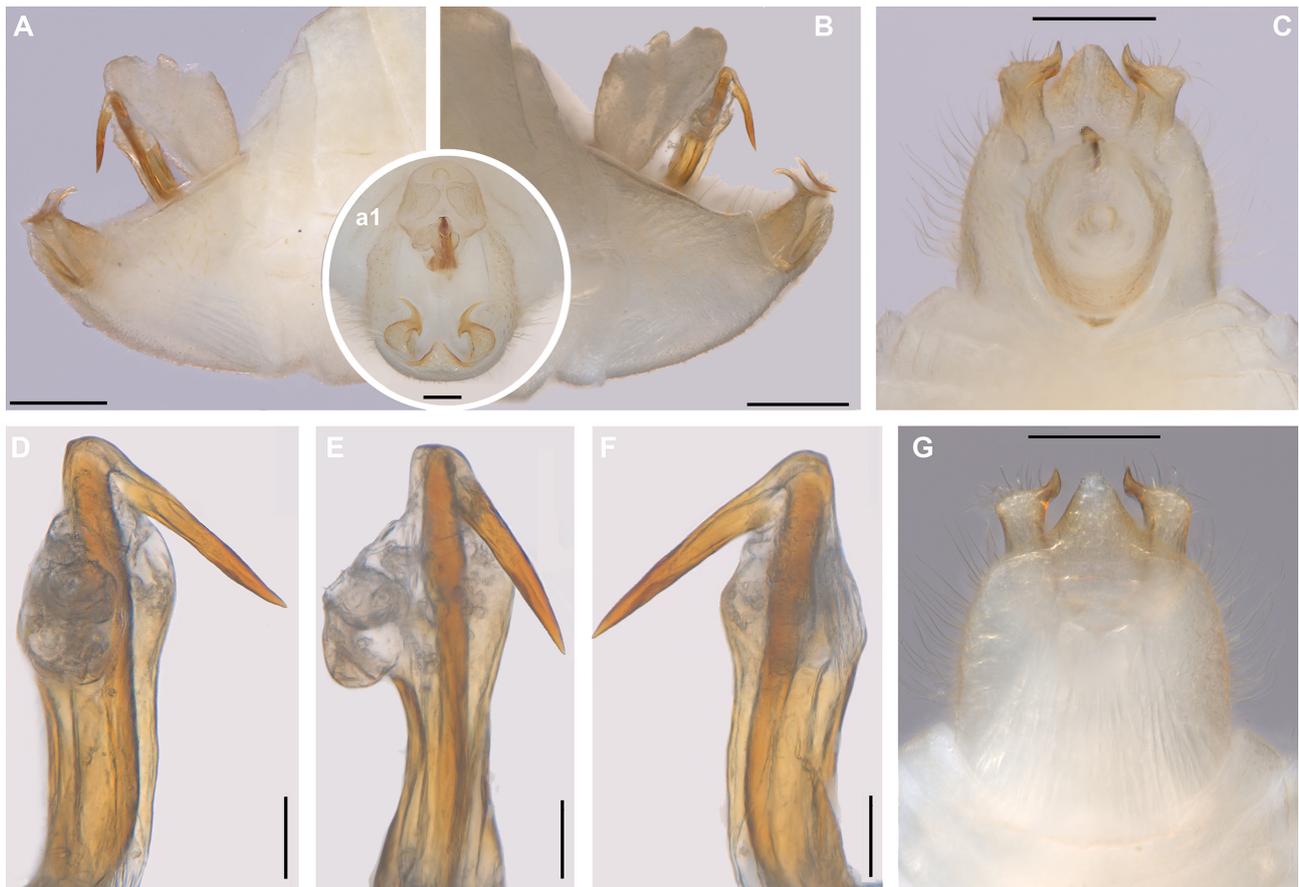

FIGURE 5. *Notolathrus sensitivus* Remes Lenicov, 1992, hind legs, A–D: Female (A–B); Male (C–D). Scale bar: A, B, C—0.2 mm; D—0.1 mm.

FIGURE 6. *Notolathrus sensitivus* Remes Lenicov, 1992, female terminalia, A–D: Genital segment in lateral view (A); gonocoxa VIII apically (a1); in lateral view (B); segment-X in dorsal view (C); ovipositor in ventral view (D). Scale bar: A, B, C, D—0.2 mm.

Male terminalia. Pygofer (Figs. 7 A–C, G): bilaterally symmetrical; in lateral view without conspicuous processes, larger basally; dorsal margin straight/inclined; caudal margin concave; ventral margin convex; ventromedial process well developed, triangular, large, laterally at the same height as or slightly below the caudal margin; with moderately long bristles. Anal tube (Figs. 7 A–C): bilaterally symmetrical; dorsally wider at the distal border than at the base; approx. 1.3 times longer (0.31) than wide (0.23); in caudal view, distal border with large notch medially; epiproct and paraproct flattened dorsoventrally; in dorsal view, paraproct weakly wide, almost triangular. Gonostyles (Figs. 7 A–C, G): converging, in lateral view smaller than pygofer, wider at base than apically; bifid apically with 2 spine-like processes; dorsal margin sinuous, ventral margin convex; with moderately long bristles. Aedeagus (Figs. 7 D, F): tubular, asymmetrical. Shaft of the aedeagus tubular, a single conspicuous spine of moderate length apically arising at the transition from the rod to the flagellum; flagellum short, in repose not surpassing midlength of aedeagal shaft.

FIGURE 7. *Notolathrus sensitivus* Remes Lenicov, 1992, male terminalia, A–G: Pygofer in right lateral view (A); pygofer in caudal view (a1); genital segment in left lateral view (B); pygofer in dorsal view (C); aedeagus in left lateral view (D); aedeagus in left dorsal view (E); aedeagus in right lateral view (F); pygofer in ventral view (G). Scale bar: A, B, C, G—0.2 mm; a1—0.1 mm; D, E, F—0.05 mm.

Diagnosis. *N. sensitivus* can be distinguished from all other Cixiidae species by the unique combination of male genital characters: gonostyli bifid apically with 2 hook-shaped spine-like processes, and aedeagus shaft displaying a single conspicuous spine arising apically at the transition to the flagellum; flagellum very short, in repose not surpassing midlength of aedeagal shaft. The antenna, in addition to the main (long) arista, bears a short and thin tubular process arising from the basal flagellar swelling.

Distribution. ARG. NQN; Cuchillo Curá Cave system, Arenal cave **(Type locality)**, El Templo cave (additional specimens).

Taxonomic remarks. In this supplementary description, the information provided regarding the characters of the head, thorax, and appendages (including measurements) was based on the female specimens. However, it is important to note that males and females exhibit considerable similarities, with the main differences lying on the terminalia naturally, number of teeth of the second tarsomere of the hind leg (Figs. 3 A–D), and in parts, in veins of tegmina (Figs. 4 A–D). In all two male specimens examined the Pcu+A1 vein was absent (symmetry) while in two of three female specimens examined, the absence of the Pcu+A1 vein was observed only one of the tegmina (asymmetry). Therefore, this aberration is regarded a variation (rather than sexual dimorphism), most likely due to the reduction of the tegmina.

Habitat and Ecology. Remes Lenicov (1992) did not provide details regarding the collection of specimens, as their specific location within the cave or the substrate from which they were obtained. The author merely suggested referring to Maury (1988) for information on the ecology, paleontology, and geology of the Cave CCCS. However, it is important to note that all specimens used in the original description originated from the Arenal cave, which is a component of the CCCS.

The CCCS is located within the borders of the Cuchillo Curá Protected Natural Area, designated by Provincial Decree No. 0161 in 2003 (Barredo *et al.*, 2012) (Fig. 8 A). This cave system comprises four distinct caves: El Arenal Cave (837.60 meters), El Templo Cave (1,827.00 meters), El Gendarme Cave (1,691.18 meters—Fig. 8 A), and Los Cabritos Cave (83.10 meters), with the first three being interconnected. Collectively, these cavities span a total length of 4,438.88 meters, establishing it as the most extensive cave system in Argentina (Redonte 2010). The caves' entrances are usually associated to collapse sinkholes (Figs. 9 A–D). The relative humidity within the caves remains proximate to saturation levels, while temperature readings exhibit a range of approximately 13°C (Barredo *et al.* 2002), closely aligning with the annual average surface temperature of 14°C as recorded by meteorological data obtained from the Las Lajas station (Barredo *et al.* 2012).

The area belongs to the Austral Payunia biogeographical district (Arana et al 2021), with sand and clay substrate. The vegetation is mostly shruby and grassy steppe, in the area of the cave is constituted mostly by *Colliguaja integerrima* Gill & Hook*, Senecio filaginoides* DC.*, Senecio subulatus* D. Don ex Hook. & Arn.*, Senecio miser* Hook. f., *Festuca pallescens* (St.-Yves) Parodi, *Stipa* spp., and *Schinus* spp. among others. Unfortunately, it is difficult to tell which of these plants specimens of *N. sensitivus* feed, or if they exhibit any preference, there are many different species of plants found above the cavity, and a molecular analyzes of the roots that reach into the cavities are recommended for this purpose.

The El Arenal Cave represents the initial cave within the CCCS (considering the upstream direction of the intermittent drainage that traverses the caves). It is important to emphasize that the specimens used in the original description were exclusively recorded within this cave, which constitutes the farthest upstream location within the system. The region encompassing the CCCS has undergone significant changes, particularly over the past two decades. A lagoon located in the cave surroundings is no longer observed since 2015 (Fig. 9 D—yellow arrow). Furthermore, the caves used to harbor bodies of water throughout the year, persisting even during the dry seasons. It is important to mention that these caves are traversed by a seasonal drainage system, which would typically form during the snowmelt from the nearby mountains.

Expeditions conducted to the CCCS in the last decade, have revealed a significantly different situation from that described by Maury (1988): the once-existing water bodies within the caves (particularly in El Templo and Gendarme) have completely disappeared, leading to pronounced desiccation of various substrates within the CCCS caves. The stygobiotic species occurring in the system (such as amphipods and an isopod) have not been sighted for years, according to the conservation unit rangers. Additionally, the cave located furthest downstream in the system (Cueva del los Cabritos) has been heavily silted, with sand completely covering the entrance and rendering the cave currently inaccessible.

Despite several efforts to relocate specimens of *N. sensitivus*, specimens have not been sighted in El Arenal cave since its discovery, most likely due to a pronounced desiccation of its substrates, as this cave is one of the farthest from the former lagoon. Specimens of *N. sensitivus* recently collected and described in this study were observed in deeper regions of El Templo cave, specifically in three moist galleries (Sala del sumidero [Sump room], Galería "Dedo de Dios" ["Finger of God" gallery], and Galería de las Chimeneas [Gallery of chimneys]—Fig. 8 A). The specimens were observed freely walking on the sandy cave floor, particularly near root tufts (Figs. 8 B–E). The individuals showed no reactions to light. When touched, they quickly jumped in an attempt to escape. Other troglobiotic species observed in the cave included the amphipods *Patagongidiella danieli* and *Grossogidiella mauryi* (Bogidiellidae), a species of nicoletiid silverfish (Zygentoma), a species of Japygidae (Diplura), the highly troglomorphic harvestman *Pichunchenops spelaeus* (Triaenonychidae), the spider *Pseudotyphistes pallidus* (Linyphiidae) among others (Grosso & Fernández, 1993; Millidge, 1991; Trajano, 1991; Iuri unpublished data).

Although currently situated within a Protected Natural Area, the caves of the CCCS and the surrounding region have experienced several impacts in recent decades. A small limestone mining operation was established in the area, resulting in the removal of rock formations (Fig. 9 D—red arrow). Additionally, as previously mentioned, the former seasonal lagoon has ceased to exist in the past decade. The disappearance of the lagoon is probably a consequence of the lowering of the water table in the region, which has also led to the disappearance of pools within the caves. This has consequently caused a continuous loss of moisture within the CCCS caves, thereby altering numerous microhabitats for the species inhabiting them. Despite the protected status of the cave interiors (gates have been installed at the entrances to prevent unauthorized access—Figs. 9 B–C), the surface changes occurring in the area may generate impacts that are even more severe than human visitation. Therefore, it is imperative to implement projects aimed at monitoring *N. sensitivus*, as well as other threatened species occurring in the CCCS, in order to assess potential changes in their distributions and population densities.

Gendarme-Templo Cave (Templo cave section)
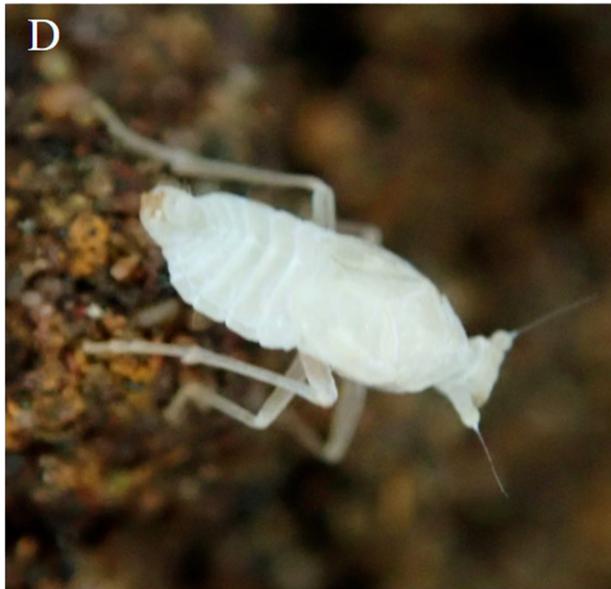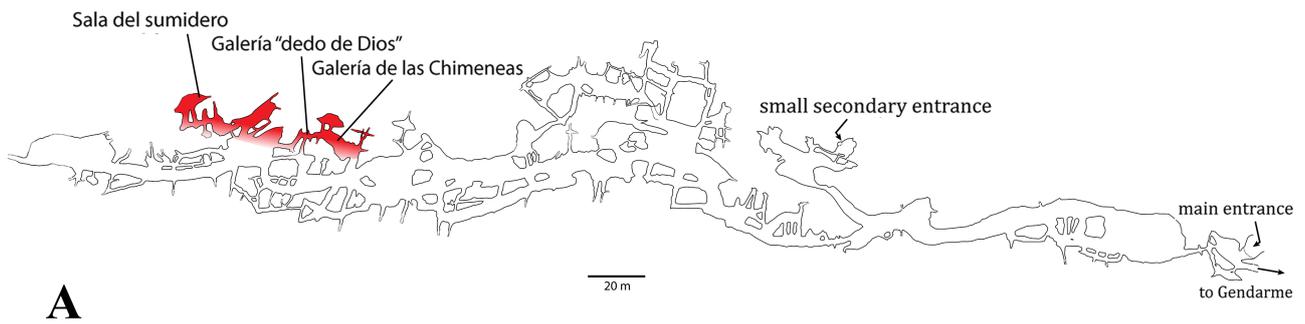
FIGURE 8. Habitat and living specimen, A–E: El Templo cave map illustrating the specific locations (highlighted in red) where the specimens of *N. sensitivus* utilized in this study were discovered (A); female specimen of *N. sensitivus* in dorsolateral view (B–C); male specimen of *N. sensitivus* in dorsal view (D); nymph of *N. sensitivus* in dorsal view (E).
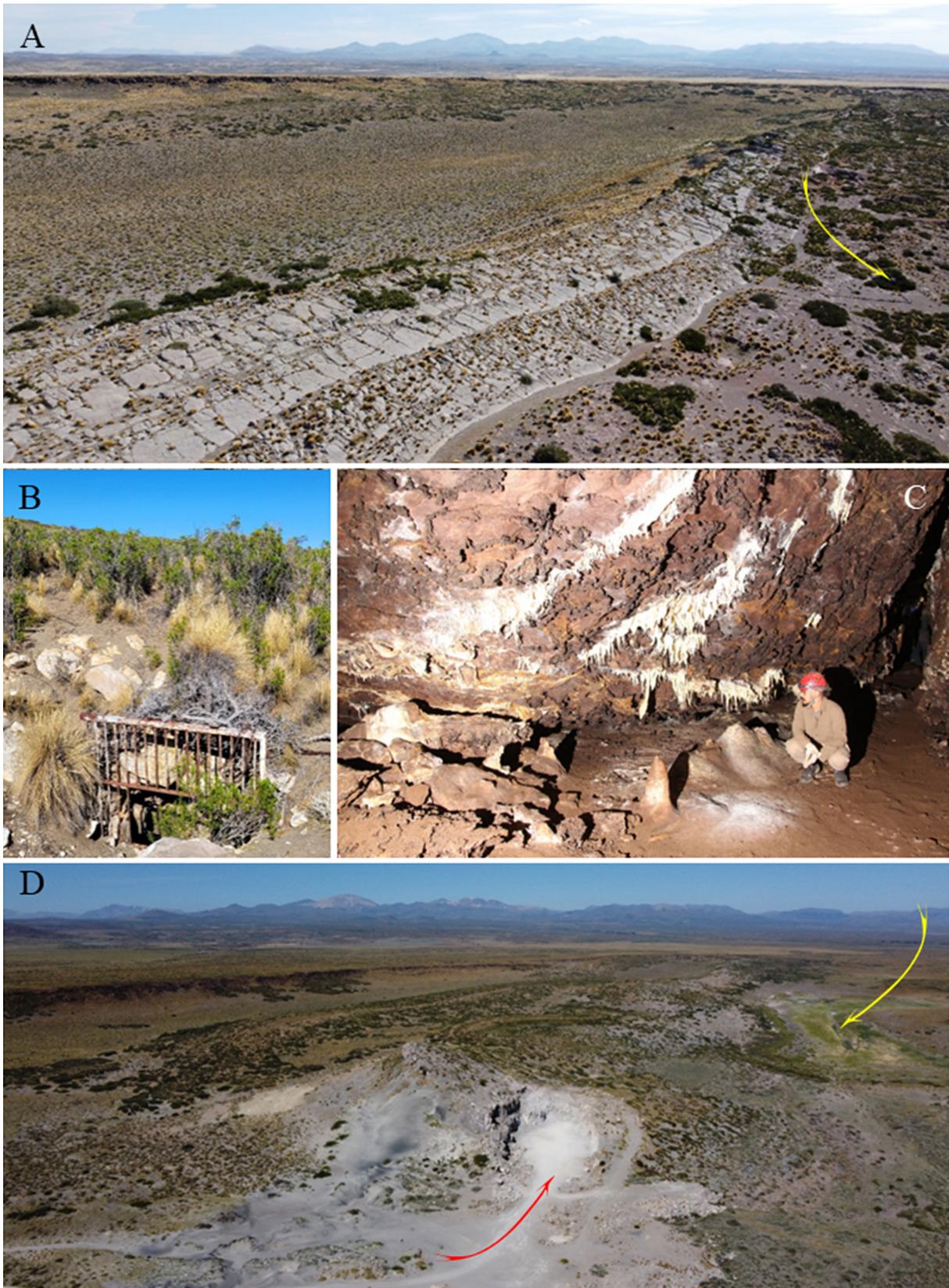
FIGURE 9. Locality, A–E: Cutillo Curá Protected Natural Area. Limestones outcrops are prominent in the landscape, and the yellow arrow indicates the entrance of the El Templo/Gendarme caves (A); Entrance of the Arenal cave, secured with an iron gate to restrict unauthorized access (B); Entrance of the El Templo/Gendarme caves, also protected by an iron gate (C); Interior of the Gendarme cave (D); Aerial view of the Cutillo Curá Protected Natural Area (E). The yellow arrow indicates the former location of the seasonal lagoon, while the red arrow indicates the previous quarry site.

Discussion

*Troglobitic Fulgoromorpha in the Americas*

Worldwide, there are 70 described species of cave-dwelling Fulgoromorpha (Le Cesne *et al.* 2024), and out of the 20 species described for the Americas, 15 belong to the family Cixiidae Spinola, 1839 (Table 1). This accounts for approximately one third of all cave-dwelling cixiids worldwide, which totals to 45 species (Le Cesne *et al.* 2024). While *N. sensitivus* was the first troglobitic Fulgoromorpha species described for South America, it was the seventh cave planthopper species documented on the American continent (Table 1). It was also the fourth of the eight present genus with troglobitic species described for the American continent (Fig. 10). Fennah (1973–1980) made the initial contributions by describing species from Mexico and Hawaii. Subsequently, Hoch & Izquierdo (1996), Hoch (1988), Hoch & Howarth (1999) and Hoch *et al.* (2024) described several species from Galapagos, Hawaii, and Mexico, respectively. In the past decade, significant progress has been made in inventorying the troglobitic planthopper fauna of South America, with the description of five species in Brazil, distributed among the families Cixiidae (3) and Kinnaridae (2) (Table 1).

TABLE 1. Troglobite species of the infraorder Fulgoromorpha described so far in the American continent.

Family	Genus	Species	Author's	Locality	Depository
Cixiidae	*Notolathrus*	*Notolathrus sensitivus*	Remes Lenicov, 1992	Nequém, ARG, AS	MACN
	Iolania	*Iolania frankanstonei*	Hoch & Porter, 2024	Hawaii, EUA, NAM	BPBN
	Cixius	*Cixius orcus*	Fennah, 1973	Querétaro, MX, CA	NMNH
		Cixius actunus	Hoch, 1988	Oaxaca, MX, CA	TNHC
	Oliarus	*Oliarus hernandezi*	Hoch & Izquierdo, 1996	Galápagos, EC, SA	MCNT
		Oliarus lorettae	Hoch & Howarth, 1999	Hawaii, EUA, NAM	BPBN
		Oliarus makaiki	Hoch & Howarth, 1999	Hawaii, EUA, NAM	BPBN
		Oliarus priola	Fennah, 1973	Hawaii, EUA, NAM	BPBN
		Oliarus gagnei	Hoch & Howarth, 1999	Hawaii, EUA, NAM	BPBN
		Oliarus waikau	Hoch & Howarth, 1999	Hawaii, EUA, NAM	BPBN
		Oliarus kalaupapae	Hoch & Howarth, 1999	Hawaii, EUA, NAM	BPBN
		Oliarus polyphemus	Fennah, 1973	Hawaii, EUA, NAM	BPBN
	Ferricixius	*Ferricixius davidi*	Hoch & Ferreira, 2012	Minas Gerais, BR, SA	ISLA
		Ferricixius michaeli	Santos et. al. 2023	Minas Gerais, BR, SA	ISLA
		Ferricixius goliathi	Santos et. al. 2023	Minas Gerais, BR, SA	ISLA
Kinnaridae	*Oeclidius*	*Oeclidius antricola*	Fennah, 1980	Clarendon, JAM, CA	CNC
		Oeclidius hades	Fennah, 1973	San Luis Potosi, MEX, CA	CNC
		Oeclidius minos	Fennah, 1980	Clarendon, JAM, CA	NMNH
	Kinnapotiguara	*Kinnapotiguara troglobia*	Hoch & Ferreira, 2013	Rio Grande do Norte, BR, SA	ISLA
	Iuiuia	*Iuiuia caeca*	Hoch & Ferreira, 2016	Bahia, BR, AS	ISLA

The context of the supplementary descriptions

Species descriptions play a crucial role in enhancing our understanding of biodiversity and supporting conservation efforts (Cowie *et al.* 2022). However, many of these descriptions were conducted in the early 19th century, when resources for visualizing anatomical structures were limited (Bourgoin 2023). Additionally, type specimens used in these descriptions may have been lost or damaged over time (Tessarolo *et al.* 2017). In this context, supplementary descriptions that utilize modern resources are valuable for recovering information and obtaining accurate morphological details, ultimately contributing to the precise taxonomic treatment of species (e.g., Löcker *et al.* 2006, Weglarz & Bartlett 2020). On the American continent, coloration and wing characteristics have often been used to define species and genera of Fulgoromorpha (Insecta: Hemiptera), particularly in the diverse family Cixiidae, where these traits can exhibit variation or convergence (Bourgoin 2023).

Legend:
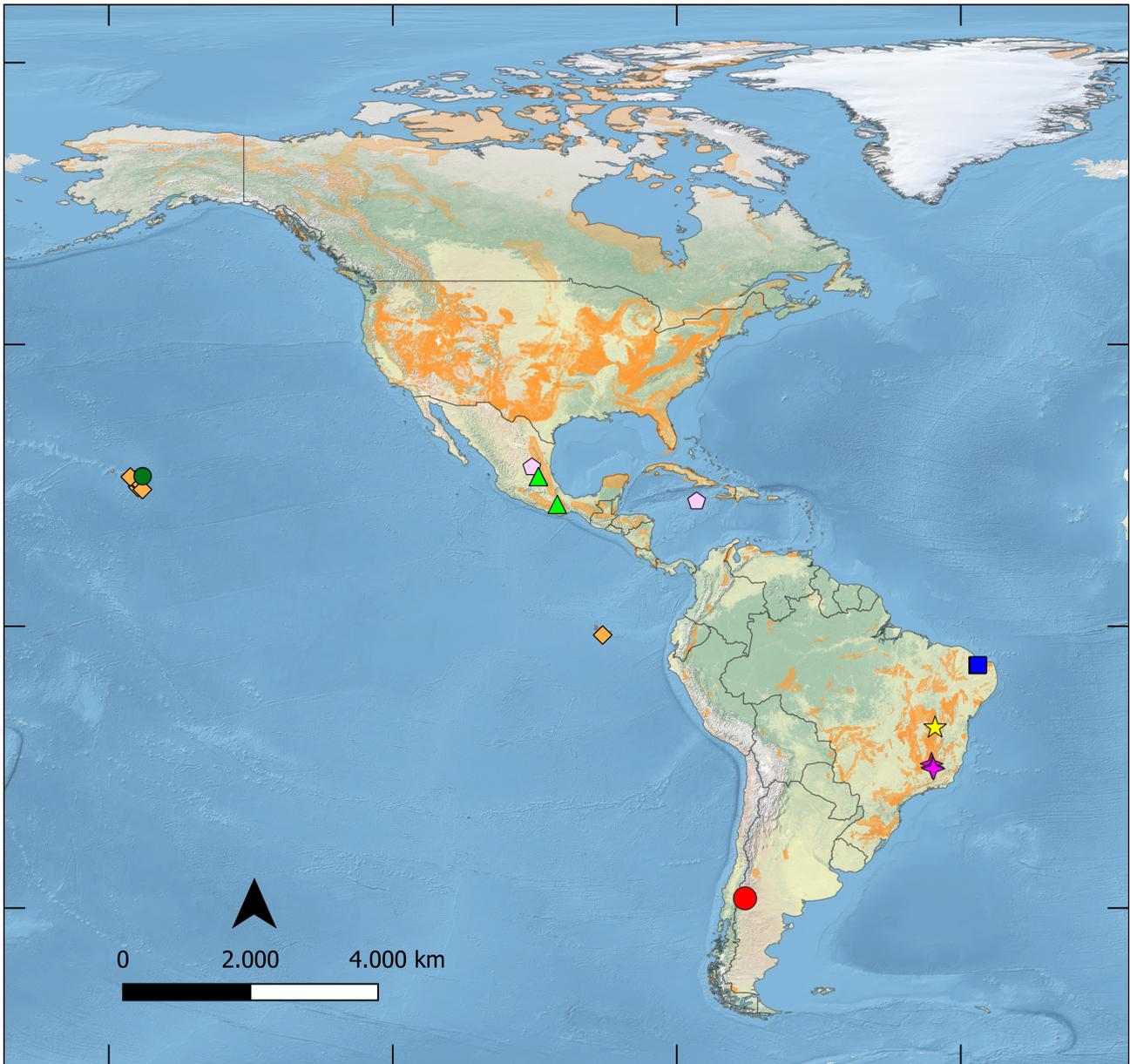
- 🔴 *Notolathrus* Remes Lenicov, 1992
- ✦ *Ferricixius* Hoch & Ferreira, 2012
- ◆ *Oliarus* Stål, 1862
- ⭐ *Iuiuia* Hoch & Ferreira, 2016
- 🟢 *Iolania* Kirkaldy, 1902
- 🟦 *Kinnapotiguara* (Hoch & Ferreira, 2013)
- 🔺 *Cixius* Latreille, 1804
- ⬠ *Oeclidius* Van Duzee, 1914
- ▭ Karst areas

FIGURE 10. Distribution map of Fulgoromorpha genera with troglobiont species in the Americas (SA, CA, NA).

Moreover, despite enormous progress in the digitalization of older literature, much information is still not available on-line, as is the case in the original description of *N. sensitivus*. We here provide this information and expand the knowledge about the morphology of previously unstudied characters of this remarkable species.

Main troglomorphisms and sexual dimorphism

Notolathrus sensitivus displays morphological features which are characteristic for obligate cavernicolous Cixiidae, and other Fulgoromorpha, such as the absence of compound eyes, vestigial wings and bodily pigmentation (Hoch 1994). The acquisition of these or similar troglomorphies in the course of the transition from epigean to subterranean habitats is correlated with other morphological features. The stepwise reduction of these characters, ranging from fully flighted, vividly pigmented species with well-developed compound eyes to entirely blind, flightless, and unpigmented species within a single lineage has been documented for the cixiid genus *Solonaima* Kirkaldy, 1906 (Hoch & Howarth 1989, Soulier-Perkins 2005), and has since been observed in other taxa. Reduction of compound eyes is correlated with the broadening of the vertex and the frons, and the eventual loss of head carination. As tegmina and wings cease to function, venation patterns show increased variation, presumably resulting from relaxed selection pressure (Hoch & Howarth 1989; Hoch 1994). In *Notolathrus*, in two of three female specimens studied the tegmina exhibit asymmetrical venation of right and left tegmina, with the Pcu+A1 vein is present on the right side and absent on the left side (see Figs. 4 A–B), while in male, the venation is almost symmetrical, with Pcu+a1 vein absent in the left and right tegmina (see Figs. 4 C–D). Interestingly, this same pattern of asymmetry is observed in the holotype (Figs. 1 A–C). Although the capture of the specimens occurred at different moments and distant in time (1987–2022), the number of specimens collected remains quite limited. Consequently, it is challenging to definitively determine whether sexual dimorphism beginning exists in this characteristic or if this observation is influenced by the small sample size.

In addition to the troglomorphic characters expressed by reductive features, specialized structures have been documented in troglobitic Cixiidae and other Fulgoromorpha. Among these, a prominent blueish-white wax fringe along the costal vein of the tegmina have been observed in all cave-dwelling species of the cixiid *Solonaima* from Australia (Hoch & Howarth 1989) as well as in the troglobitic Kinnarid *Valenciolenda fadaforesta* Hoch & Sendra from Spain (Hoch *et al.*, 2021). It has been hypothesized that the wax filaments making up the fringe serve as a protection against moisture or may repel potential predators (Hoch & Howarth 1989). Moreover, both species display a particular behavior: when disturbed, they exercise escape jumps with the tegmina resembling tiny parachutes, presumably slowing down the jump, thus preventing the jumping planthopper to be catapulted too far away from its host root (Hoch *et al.*, 2021).

Another possible specialization to rocky environments concerns the spinulation of the hind tarsomeres. While in epigean Cixiidae the first and second tarsomere exhibit approximately 8–10 apical denticles, *Notolathrus sensitivus* exhibit are only three apical teeth on the 1st tarsomere, and on the 2nd tarsomere two teeth in the females, and three teeth on the male. Also, the pretarsal claws are rather long and well developed. Presumably, this configuration may enhance the skill to walk on wet or rocky substrates. A similar reduction of hind leg spinuation, however concerning the apical teeth of the tibiae, has been observed in the troglobitic species *Solonaima baylissa* Hoch & Howarth from Australia (Hoch & Howarth 1989). It remains to be studied whether the difference in denticle numbers among males and females of *Notolathrus sensitivus* is a small sample size bias, or whether sexual dimorphism exists in this character.

The presence of an elongate, thin tubular process arising from the basal flagellar swelling in addition to the main (long) arista is unusual in Cixiidae, and it cannot be assessed on the basis of current knowledge whether or not it constitutes a specialization related to cave adaptation, perhaps providing enhanced sensory function. It appears worth noting, though, that Fennah (1975) also reported a rather elongate and filiform basal flagellar process for the cavernicolous cixiid *Confuga persephone* Fennah, 1975 from New Zealand (see also Fig. 9 in Santos *et al.* 2018). The sensory world of cave planthoppers is vastly unstudied, but certainly deserves more attention in order to better understand how these species orientate in their environment, locate mating partners and detect food resources as well as potential predators.

Conservation

Notolathrus sensitivus was the first troglobitic Fulgoromorpha described from South America and is currently one of the 20 know troglobitic Fulgoromorpha species from the Americas (Table 1). The type series (three males) were collected in 1987, and the species where not seen again until recently (October 2022), where the first known females

of this species were found, more than 30 years from the first collection. This was mostly because the original collection occurred in the Arenal cave from the CCCS, and this cave is suffering an extreme desiccation through the last years, probably affecting the abundance, or even the presence of this species in that cave. In Arenal the galleries with big roots, where *N. sensitivus* may be originally found, are close to the main entrance and are currently much more dried than other sections of the cave. Many other species previously reported for this cave have not been seen in the last visits from the past 10 years, or its abundance seems to be lower than the previous decades.

Currently, the area of distribution for *N. sensitivus* corresponds to a small section of the El Templo cave (Fig. 7 A), with high humidity and roots. After exploring the whole cave system through last years, this is the only area where we can go and see this species, and is extremely small, approximately 60x20 meters, at aprox. 7.7 meters below the surface level. The sighting of individuals in each exploration performed was low (8 specimens at most). Many other cave species that haven't been seen since the 1990ties', and that were previously only known for Arenal cave (e.g., the japygid species), were recently founded there also. Interestingly, *N. sensitivus* has not been observed in El Gendarme cave, that is probably the cave with the highest humidity and most roots of the whole CCCS.

Notolathrus sensitivus is an important endemic component of the unique ecosystem of CCCS, where others unique species occur such as the troglobitic opilionid *Picunchenops spelaeus* Maury, 1988, a species confirmed to be relictual in recent molecular phylogenies (Derkarabetian et al 2021), being the only living species of his lineage. This also may be the case for *N. sensitivus* and other species of the CCCS yet to be described, but these hypotheses are still pending to be studied.

Our current knowledge of the biology of *N. sensitivus* concerning annual activity, mating behavior, and reproductive biology in general, is practically zero. The other species found exactly in the same section of the El Templo cave, are the opilionid *P. spelaeus*, three diplurans' species (Campodeidae, Japygidae, and Projapigidae), a nicoletiid silverfish, a palpigrade, and a terrestrial isopod. Despite our lack of knowledge of the biology of this species, there are arguments for considering for conservation. First, the species is highly endemic of to CCCS and has an extremely small known distribution area. The CCCS was completely explored through the last years and the only section where this species was observed is small portion of the cave (Fig. 8 A), but even if considering the whole cave system as the distribution area, it is still a small area for a species. Second, the desiccation occurring in the area represents a possible threat for the cave environment. Its desiccation results in the complete disappearance of the epigean lagoon, that used to harbor several bird species, including flamingos. The desiccation seems to be affecting the cave, especially Arenal cave, were many water bodies observed in the 1980ties and 1990ties are completely dried out, and many sections of the cave seem to have less humidity than observed in the previous decades. Third, the effect of the desiccation in the cave seems to be also affecting the species distribution. Many species previously recorded from Arenal (the cave with more severe desiccation suffered) were not found and others were seen only in very low numbers of individuals. Many of these species are now found in the humid areas of Templo-Gendarme cave.

The above-mentioned arguments are suggested for considering this species at least as vulnerable according to the IUCN. From the perspective of conservation actions, the CCCS belongs to a Natural Protected Area, this helped to regulate the impact of human activity in the cave since 2003. However, there are other possible threats that have been overlooked as the local livestock activity that still occurs in the area with cattle breeding, and more importantly, the dehydration that the area has been suffering from for more than 10 years that seems to be affecting the cave environment. It is important to promote the research of the area, especially to understand why this desiccation is occurring and what is the impact of these phenomenon in the cave ecosystem.

Acknowledgments

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