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Two new hypogean species of *Triplophysa* (Cypriniformes: Nemacheilidae) from the River Yangtze drainage in Guizhou, China

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Abstract. Two hypogean species of genus *Triplophysa* are herein described from two subterranean tributaries of the River Yangtze drainage in Guiyang City, Guizhou Province, China. *Triplophysa wudangensis*, new species, can be distinguished from its congeners by the combination of the following characters: eye reduced, with diameter 5.1-6.5% HL; interorbital width 33.1-35.8% HL; body scaleless; lateral line complete; posterior chamber of air bladder degenerated; anterior nostril with elongated barbel-like tip; distal margin of dorsal fin truncate; dorsal fin with 7, anal fin with 5, and caudal fin with 14 branched fin rays; vertebrae 4 + 34. *Triplophysa qingzhenensis*, new species, can be distinguished from its congeners by the combination of the following characters: eye reduced, with diameter 2.1-4.4% HL; interorbital width 25.1-30.4% HL; body scaleless; lateral line complete; posterior chamber of air bladder degenerated; anterior nostril with elongated barbel-like tip; distal margin of dorsal fin truncate; dorsal fin with 7-8, anal fin with 5, and caudal fin with 14 branched fin rays; vertebrae 4 + 36. Molecular phylogenetic analysis supported the validity of these two new species and indicated their close relationship with *Triplophysa rosa*.

Key words: cavefish, morphology, phylogenetic analysis

Introduction

The genus *Triplophysa* Rendahl is a large group of loaches in the family Nemacheilidae of order Cypriniformes, which comprises over 180 valid species or subspecies distributed in the Qinghai-Tibet Plateau and adjacent regions (Zhu 1989, Eschmeyer et al. 2022). Species of *Triplophysa* are further subdivided into two groups based on their living habits and life-history traits: the epigeal group and the hypogean group. Till now, 33 hypogean species of *Triplophysa*

have been described, mainly found in the limestone caves or underground rivers of karst areas in southwestern China (Lan et al. 2013, Zhang et al. 2020, Chen et al. 2021, Deng et al. 2022). Meanwhile, the monophyly of both ecological groups of *Triplophysa* was also supported by recent phylogenetic analyses (Chen & Peng 2019, Chen et al. 2021).

Guizhou Province is located in southwestern China and has been recognised as a hotspot for cavefishes (Zhao & Zhang 2009). Nine hypogean species related to

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Triplophysa have been described in Guizhou Province, of which six are now valid, namely *T. nasobarbatula* Wang & Li, 2001 and *T. zhenfengensis* Wang & Li, 2001, *T. longliensis* Ren, Yang & Chen, 2012, *T. guizhouensis* Wu, He, Yang & Du, 2018, *T. baotianensis* Li, Liu, Li & Li, 2018, *T. sanduensis* Chen & Peng, 2019. Notably, all of the known *Triplophysa* species from Guizhou were captured from the River Pearl drainage. In addition, a recent ichthyological survey yielded two hypogean species of *Triplophysa* from the River Wujiang, a tributary of the upper River Yangtze in Guizhou Province, which could not be assigned to any of the other recorded species and are herein described as new species.

Material and Methods

Fish specimens were collected by dipnet. After anaesthesia, a small piece of muscle tissue was dissected from the right side of the dorsum and preserved in 95% ethanol for DNA extraction. The specimens were fixed in 10% formalin and later transferred to 5% formalin for long-term preservation. Morphological measurements were made point-to-point with a dial calliper and recorded to the nearest 0.1 mm from the left side of the specimens whenever possible. All measurements, counts and terminology follow Kottelat (1984). Inter-nostril width was regarded as the distance between both anterior nostrils. One specimen of each species was dissected to examine the intestine shape, the chambers of the air bladder, and the inner gill rakers. Vertebrae counts were conducted using images of micro-computed tomography (Siemens Somatom Definition X-ray machine) reconstructed in CTvox software. Comparative specimens of this study were deposited at the Institute of Hydrobiology, Chinese Academy of Sciences (IHB) in Wuhan, Kunming Institute of Zoology, Chinese Academy of Sciences (KIZ) in Kunming, Guizhou Normal University (GZNU) in Guiyang, and Southwest University (SWU) in Chongqing.

Genomic DNA was extracted from ethanol-preserved muscle tissues using a modified salt-extraction method (Tang et al. 2008). Mitochondrial cytochrome *b* (*cytb*) gene sequences were amplified by polymerase chain reaction (PCR) with the primers L14724 (5'-GACTTGAAAAACCACCGTTG-3') and H15915 (5'-CTCCGATCTCCGGATTACAAGAC-3') (Xiao et al. 2001). Amplifications were performed in a 30 μ L reaction volume, containing 3 μ L 10 \times PCR buffer, 30-50 ng DNA template, 1 μ L each primer (each 10 μ M), 1.5 μ L dNTPs (each 2.5 mM), and 2.5 U Taq DNA polymerase. Sterile water was added to reach the final volume. PCR procedures followed

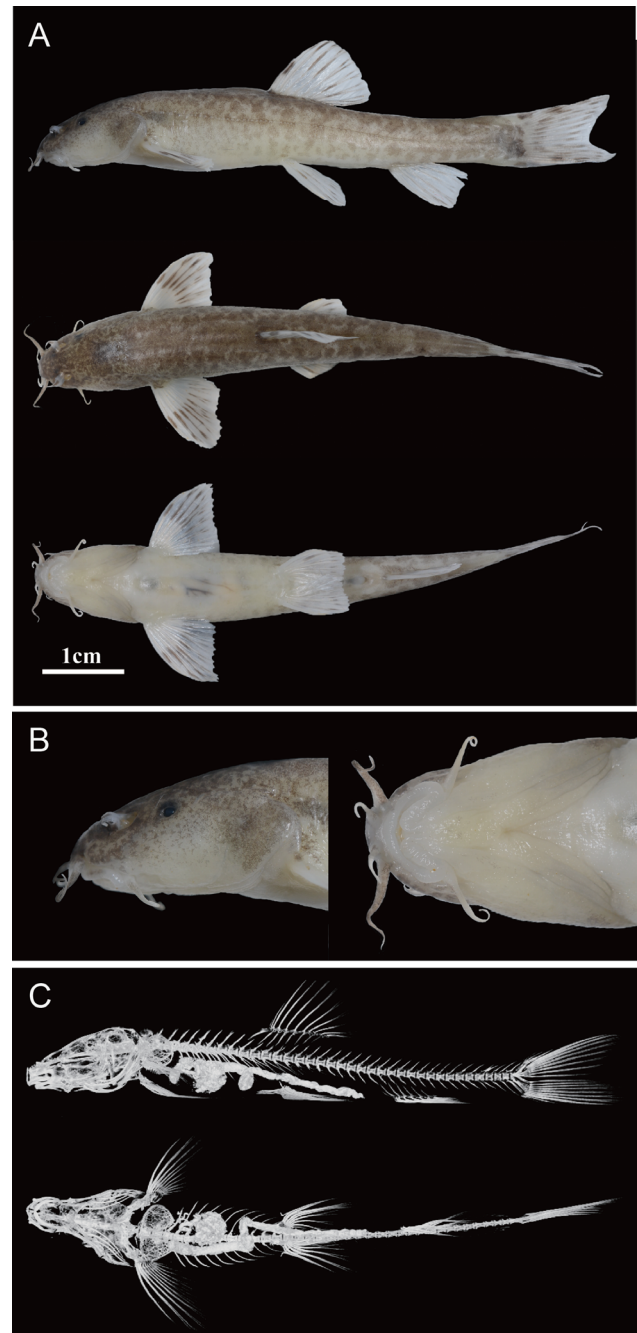


Fig. 1. *Triplophysa wudangensis*, holotype, IHB 2019080901 53.4 mm SL; from a subterranean tributary of the River Wujiang in the River Yangtze drainage in Wudang District, Guiyang City, Guizhou Province, China. A) lateral, dorsal and ventral views; B) lateral and dorsal views of the head; C) lateral and ventral views of the micro-CT graph.

Tang et al. (2008). The amplified products were sent to a commercial sequencing company for purifying and sequenced in both directions with the same primers mentioned above.

Phylogenetic analysis was performed based on four newly generated *cytb* sequences of the two new species and already published data from NCBI GenBank for additional 27 sequences, including

24 formally described *Triplophysa* species and two species of *Homatula* (outgroup) (Table 1). The sequences were aligned with ClustalX v2 (Larkin et al. 2007) and revised manually with SEAVIEW (Galtier et al. 1996). The Maximum Likelihood (ML) method was employed to reconstruct the phylogenetic relationship in IQ-TREE v1 (Nguyen et al. 2015), with optimal nucleotide substitution model (GTR + F + I + G4) based on Bayesian inference criterion; nodal support values were estimated from 1,000 nonparametric bootstrap replicates. Calculation

of pairwise genetic distances based on the Kimura-2-parameter (K2P) model (Kimura 1980) was conducted in MEGA v7 (Kumar et al. 2016).

Results

Triplophysa wudangensis Liu F., Zeng Z.-X. & Gong Z., new species (Figs. 1, 2A; Table 2)

Type series: Holotype: IHB 201908090001, 53.4 mm SL; a subterranean tributary of the River Wujiang in the

Table 1. GenBank accession numbers of included species in the molecular phylogenetic analysis.

| Taxon | Locality | Drainage | Accession number |
|-------------------------------------------------------|------------------|-----------------------|------------------|
| <i>Triplophysa wudangensis</i> 1 (IHB 201908090003) | Guizhou, China | The River Yangtze | MT700460 |
| <i>Triplophysa wudangensis</i> 2 (IHB 201908090004) | Guizhou, China | The River Yangtze | MT700461 |
| <i>Triplophysa qingzhenensis</i> 1 (IHB 201911150004) | Guizhou, China | The River Yangtze | MT700458 |
| <i>Triplophysa qingzhenensis</i> 2 (IHB 201911150005) | Guizhou, China | The River Yangtze | MT700459 |
| <i>Triplophysa rosa</i> 1 | Chongqing, China | The River Yangtze | MG697587 |
| <i>Triplophysa rosa</i> 2 | Chongqing, China | The River Yangtze | JF268621 |
| <i>Triplophysa qini</i> | Chongqing, China | The River Yangtze | ON528184 |
| <i>Triplophysa wulongensis</i> | Chongqing, China | The River Yangtze | MW582823 |
| <i>Triplophysa xiangxiensis</i> | Hunan, China | The River Yangtze | KT751089 |
| <i>Triplophysa erythraea</i> | Hunan, China | The River Yangtze | MG967615 |
| <i>Triplophysa xuanweiensis</i> | Yunnan, China | The River Pearl | OL675198 |
| <i>Triplophysa nandanensis</i> | Guangxi, China | The River Pearl | MG697588 |
| <i>Triplophysa huapingensis</i> | Guangxi, China | The River Pearl | MG697589 |
| <i>Triplophysa tianeensis</i> | Guangxi, China | The River Pearl | MW582826 |
| <i>Triplophysa nasobarbatula</i> | Guizhou, China | The River Pearl | MK610357 |
| <i>Triplophysa baotianensis</i> | Guizhou, China | The River Pearl | MK610353 |
| <i>Triplophysa longliensis</i> | Guizhou, China | The River Pearl | MW582825 |
| <i>Triplophysa sanduensis</i> | Guizhou, China | The River Pearl | MW582822 |
| <i>Triplophysa siluroides</i> | Gansu, China | The River Yellow | KJ781206 |
| <i>Triplophysa bleekeri</i> | Chongqing, China | The River Yellow | JX135578 |
| <i>Triplophysa anterodorsalis</i> | Sichuan, China | The River Yellow | KJ739868 |
| <i>Triplophysa lixianensis</i> | Sichuan, China | The River Yellow | KT966735 |
| <i>Triplophysa robusta</i> | Unknown | Unknown | KM406486 |
| <i>Triplophysa tibetana</i> | Xizang, China | The River Brahmaputra | KT122845 |
| <i>Triplophysa venusta</i> | Unknown | The River Yangtze | KT008666 |
| <i>Triplophysa stoliczkai</i> | Unknown | Unknown | JQ663847 |
| <i>Triplophysa dorsalis</i> | Xinjiang, China | The River Irtysh | KT241024 |
| <i>Triplophysa strauchii</i> | Xinjiang, China | The River Irtysh | KP297875 |
| <i>Triplophysa zhenfengensis</i> | Guizhou, China | The River Pearl | MK610360 |
| <i>Homatula pycnolepis</i> | Yunnan, China | The River Lantsang | MT783421 |
| <i>Homatula potanini</i> | Yunnan, China | The River Yangtze | KM017732 |

Table 2. Morphometric characters of *Triplophysa wudangensis*, *T. qingzhenensis* and *T. rosa*. Ranges include values of holotype and paratypes. SD – standard deviation.

| | <i>Triplophysa wudangensis</i> | | <i>Triplophysa qingzhenensis</i> | | <i>Triplophysa rosa</i> |
|-----------------------------|--------------------------------|-----------------------------|----------------------------------|-----------------------------|-------------------------|
| | Holotype | Range (Mean, SD) (n = 4) | Holotype | Range (Mean, SD) (n = 5) | Holotype |
| Standard length (SL, mm) | 53.4 | 46.8-58.6 | 103.9 | 60.2-104.6 | 56.4 |
| Head length (HL, mm) | 14.3 | 11.6-14.3 | 23.7 | 14.7-25.9 | 14.1 |
| As percentage of SL (%) | | | | | |
| Head length | 26.8 | 24.2-26.8 (25.1, 1.2) | 22.8 | 22.6-24.8 (23.5, 1.0) | 24.9 |
| Body depth | 15.9 | 13.6-16.4 (15.3, 1.2) | 15.0 | 13.0-15.6 (14.6, 1.0) | 12.3 |
| Body width | 14.4 | 12.3-15.1 (13.9, 1.2) | 12.5 | 11.8-13.8 (12.6, 0.7) | 11.1 |
| Pre-dorsal length | 47.6 | 47.6-52.5 (49.8, 2.1) | 47.8 | 46.4-50.6 (48.0, 1.6) | 52.8 |
| Pre-pectoral length | 24.5 | 23.3-26.3 (24.8, 1.2) | 24.1 | 22.8-25.3 (24.0, 0.9) | 25.2 |
| Pre-pelvic length | 48.6 | 48.2-51.8 (49.7, 1.6) | 49.5 | 47.3-50.6 (49.3, 1.2) | 55.5 |
| Pre-anal length | 71.0 | 68.8-75.3 (71.4, 2.8) | 71.6 | 69.0-73.2 (71.4, 1.5) | 71.8 |
| Pre-anus length | 67.9 | 63.7-72.0 (67.6, 3.4) | 67.6 | 65.3-68.6 (66.9, 1.3) | 67.3 |
| Dorsal fin length | 20.1 | 20.1-23.7 (21.5, 1.5) | 18.8 | 18.8-20.8 (19.6, 1.0) | 22.4 |
| Pectoral fin length | 19.3 | 18.6-19.7 (19.3, 0.5) | 17.6 | 17.1-19.3 (17.7, 0.9) | 25.5 |
| Pelvic fin length | 15.9 | 15.1-17.7 (16.6, 1.2) | 14.6 | 13.8-15.1 (14.6, 0.6) | 18.1 |
| Anal fin length | 14.5 | 14.5-17.5 (16.3, 1.3) | 14.4 | 14.1-15.7 (14.7, 0.6) | 13.3 |
| Caudal peduncle length | 20.0 | 20.0-21.4 (20.7, 0.6) | 18.2 | 16.9-20.7 (18.4, 1.4) | 17.6 |
| Caudal peduncle depth | 9.0 | 7.0-9.0 (8.1, 0.8) | 8.1 | 7.2-8.1 (7.9, 0.4) | 7.3 |
| In percentage of HL (%) | | | | | |
| Head depth | 46.3 | 46.3-55.6 (51.3, 3.8) | 49.4 | 46.3-49.4 (47.6, 1.3) | 48.3 |
| Head width | 55.3 | 55.3-65.6 (59.8, 4.3) | 57.8 | 50.6-62.2 (56.4, 4.2) | 58.6 |
| Snout length | 34.8 | 34.8-48.5 (42.4, 5.7) | 43.6 | 35.9-43.6 (41.4, 3.2) | 41.9 |
| Mouth width | 24.2 | 23.0-25.5 (24.3, 1.0) | 25.0 | 21.8-27.2 (24.7, 2.2) | 22.5 |
| Eye diameter | 5.5 | 5.1-6.5 (5.8, 0.6) | 2.5 | 2.1-4.4 (3.0, 1.0) | 0.0 |
| Interorbital width | 33.1 | 33.1-35.8 (34.3, 1.1) | 29.6 | 25.1-30.4 (28.1, 2.5) | 26.8 |
| Inter-nostril width | 21.8 | 20.1-23.8 (22.0, 1.5) | 21.2 | 18.8-22.8 (20.3, 1.7) | 14.2 |
| Inner rostral barbel length | 17.6 | 17.6-22.2 (19.1, 2.1) | 15.9 | 15.9-24.7 (20.6, 3.2) | 19.9 |
| Outer rostral barbel length | 30.8 | 29.9-41.8 (33.7, 5.5) | 40.7 | 26.2-41.6 (37.5, 6.4) | 40.7 |
| Maxillary barbel length | 20.8 | 20.8-30.3 (26.4, 4.3) | 34.2 | 24.6-35.0 (30.7, 4.2) | 37.4 |

River Yangtze drainage in Wudang District, Guiyang City, Guizhou Province, China (26°39'30" N, 106°46'0" E; 1,105 m elevation); August 2019.

Paratypes: IHB 201908090002-201908090004, 3, 46.8-58.6 mm SL; other data same as holotype.

Diagnosis: *Triplophysa wudangensis* differs from its congeners by the combination of the following characters: eye reduced, with diameter 5.1-6.5% HL; interorbital width 33.1-35.8% HL; body scaleless; lateral line complete; posterior chamber of air bladder degenerated; anterior nostril with elongated barbel-like tip; distal margin of dorsal fin truncate; dorsal fin with 7, anal fin with 5, and caudal fin with 14 branched fin rays; vertebrae 4 + 34. The primary

diagnostic characters for cave species of *Triplophysa* were summarised in Table 3.

Description: Morphometric characters of four type specimens are shown in Table 2. Body elongated, anterior part subcylindrical and posterior part laterally compressed. The dorsal profile of the head is near sloping, and that of the body convex. The ventral profile from snout tip to anal-fin origin is almost straight, and from anal-fin origin to caudal-fin base is slightly concave. Body depth increases to its maximum before dorsal-fin origin, slightly declining towards the caudal fin base. Body smooth and scaleless, lateral line complete. Cephalic lateral-line system with 3 + 8 infraorbital, 6 supraorbital, 3 supratemporal and 10 preoperculo-mandibular pores.



Fig. 2. Live photo of A) *Triplophysa wudangensis*; B) *Triplophysa qingzhenensis*.

Head moderately depressed, head width slightly greater than head depth. Snout slightly blunt, snout length 34.8-48.5% of HL. Eye reduced, diameter 5.1-6.5% HL, located in the upper part of head laterally. Both anterior and posterior nostrils are closely situated, the anterior one in a short tube with an elongated barbel-like tip, the tip of the nostril appendage not reaching to anterior margin of the eye. Mouth inferior and curved. Lip thick, with shallow furrows on its surface. The upper lip is complete and connected with the lower lip at the corners of the mouth. Lower lip with median interruption and well-marked V-shaped median incision. Upper jaw without processus dentiformis and lower jaw without a median notch. Three pairs of barbels, inner rostral barbel reaching to corner of the mouth, outer rostral barbel longest, extending beyond posterior margin of eye, maxillary barbel surpassing eye and not reaching to the anterior edge of the opercula.

Dorsal fin with 3 unbranched and 7 branched fin rays, origin at mid-point between snout tip and caudal-fin



Fig. 3. Habitat of *Triplophysa wudangensis*.

base and close to the insertion of the pelvic fin origin, distal margin truncate, length greater than body depth. Pelvic fin with 1 unbranched and 5 branched fin rays, origin closer to the anal fin origin than the pectoral fin origin, tip not reaching the anus. Pectoral fin with 1 unbranched and 8 branched fin rays, extending beyond the halfway to pectoral-fin origin. Anal fin with 3 unbranched and 5 branched fin rays, origin closer to pelvic-fin insertion than to caudal-fin base. The caudal fin forked, with 14 branched fin rays, with the upper lobe slightly longer than the lower.

Intestine short, with a zigzag-shaped bend behind the stomach. The bony capsule of the air bladder is dumbbell-shaped (Fig. 1C), posterior chamber of the air bladder degenerated. Inner gill rakers on the first gill arch 7. Vertebrae 4 + 34 (holotype).

Colouration: In live specimens, the body is yellowish, densely distributed with small black pigments laterally and dorsally on the head and body, and each fin with 2-3 interrupted black stripes (Fig. 2A). In 10% formalin-preserved specimens, the body greyish, with black pigments on head, body and fins (Figs. 1A, 1B).

Sexual dimorphism: No sexual dimorphism is observed based on the present type specimens of *T. wudangensis*.

Distribution and habitat: This new species is presently only known from the outlet of a subterranean tributary of the River Wujiang in the River Yangtze drainage in Wudang District, Guiyang City, Guizhou Province, China (Figs. 3, 4). The water temperature was 15.0 °C during the survey period in August 2019. The species co-occurred with some endemic fishes of Guizhou Province, including *Sinocyclocheilus multipunctatus* and *Linichthys laticeps* in its type locality.

Etymology: The specific epithet is derived from its type locality, Wudang District.

Triplophysa qingzhenensis Liu F., Zeng Z.-X. & Gong Z., new species (Figs. 2B, 5; Table 2)

Type series: *Holotype:* IHB 201911150001, 103.9 mm SL; a subterranean tributary of the River Wujiang in the River Yangtze drainage in Qingzhen County, Guiyang City, Guizhou Province, China (26°47'0" N, 106°16'0" E; 1,258 m elevation); November 2019.

Paratypes: IHB 201911150002-201911150005, 4, 60.2-104.6 mm SL; other data same as holotype.

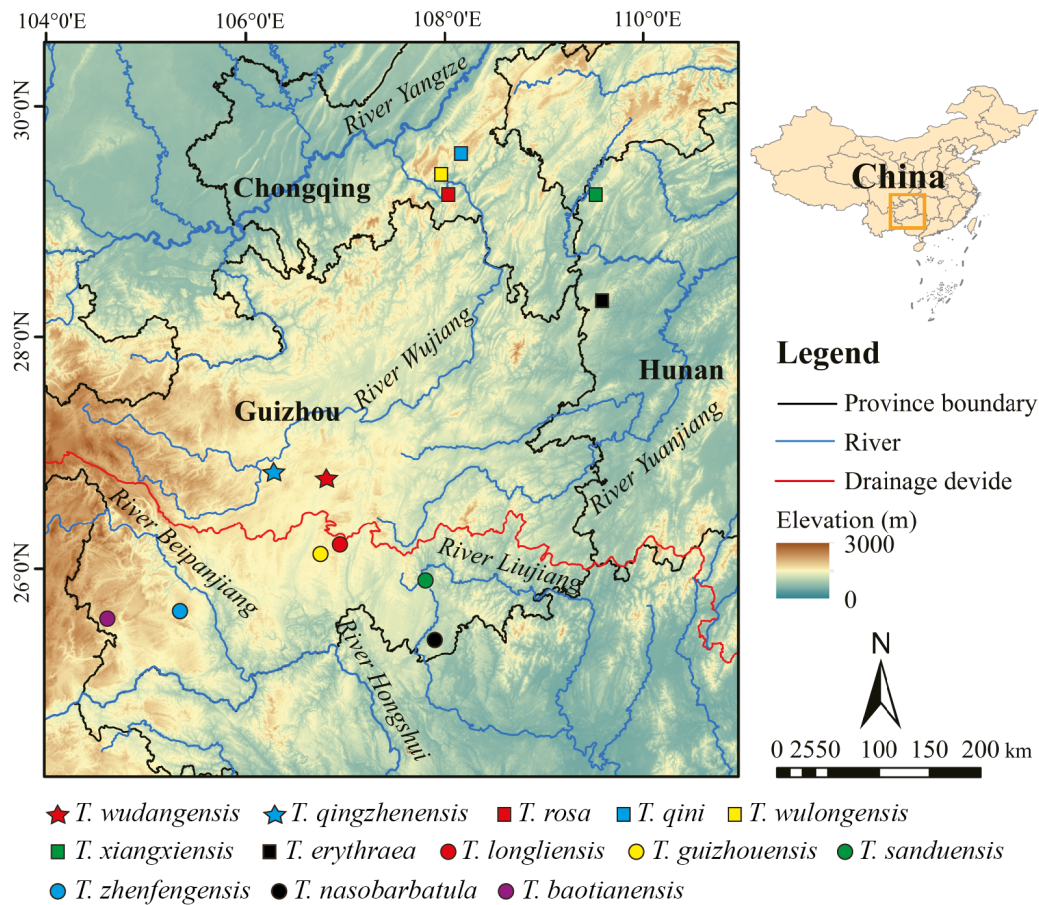


Fig. 4. Type localities of hypogean species of *Triplophysa* in Guizhou Province and the River Yangtze drainage.

Diagnosis: *Triplophysa qingzhenensis* can be distinguished from all of its congeners by the combination of the following characters: eye reduced, with diameter 2.1–4.4% HL; interorbital width 25.1–30.4% HL; body scaleless; lateral line complete; posterior chamber of air bladder degenerated; anterior nostril with elongated barbel-like tip; distal margin of dorsal fin truncate; dorsal fin with 7–8, anal fin with 5, and caudal fin with 14 branched fin rays; vertebrae 4 + 34. The primary diagnostic characters for cave species of *Triplophysa* were summarised in Table 3.

Description: Morphometric characters of five type specimens are shown in Table 2. Body elongated, anterior part subcylindrical and posterior part laterally compressed. Dorsal profile of head near flat, and that of the body convex. The ventral profile from the snout tip to the anal fin origin is almost straight; it is slightly concave from the anal fin origin. Body depth increases to its maximum before dorsal-fin origin, slightly declining towards the caudal fin base. Body smooth and scaleless, lateral line complete. Cephalic lateral-line system with 3 + 8 infraorbital, 6 supraorbital, 3 supratemporal and 10 preoperculo-mandibular pores.

Head moderately depressed, with its width slightly greater than depth. Snout pointed, snout length 35.9–43.6% of HL. Eye reduced, diameter 2.1–4.4% of HL, located in the upper part of head laterally. Both anterior and posterior nostrils are closely situated, the anterior one in a short tube with an elongated barbel-like tip, the tip of the nostril appendage not reaching the anterior margin of the eye. Mouth inferior and curved. Lip thick, with shallow furrows on its surface. The upper lip is complete and connected with the lower lip at the corners of the mouth. Lower lip with median interruption and well-marked V-shaped median incision. Upper jaw without processus dentiformis and lower jaw without a median notch. Three pairs of barbels, inner rostral barbel reaching to corner of the mouth, outer rostral barbel longest, extending beyond posterior margin of eye, maxillary barbel surpassing eye and not reaching to the anterior edge of the opercula.

Dorsal fin with 3 unbranched and 7 (n = 1) or 8 (n = 4) branched fin rays, origin at mid-point between snout tip and caudal-fin base and anterior to the pelvic fin origin, distal margin truncate, length greater than body depth. Pelvic fin with 1 unbranched

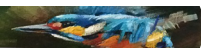


Table 3. Major diagnostic characters for hypogean species of *Triplophysa*. % HL – percentage of head length; P – pectoral fin; D – dorsal fin; V – ventral fin (pelvic fin); A – anal fin; C – caudal fin; n/a – not available.

| Species | Eye diameter (% HL) | Interorbital width (% HL) | Scales | Lateral line | Posterior chamber of air bladder | P tip reaching to V origin | V tip reaching to anus | D distal margin | Branched fin rays | | | Anterior nostril with barbel-like tip | Vertebrae |
|-----------------------------|---------------------|---------------------------|---------|--------------|----------------------------------|----------------------------|------------------------|-----------------|-------------------|-----|-------|---------------------------------------|-----------|
| | | | | | | | | | D | A | C | | |
| <i>T. aluensis</i> | 5.6 | 22.2 | Absent | Complete | Degenerated | No | No | Truncate | 7 | 5 | 13 | Yes | n/a |
| <i>T. anshuiensis</i> | Absent | n/a | Absent | Complete | Developed | No | Yes | Truncate | 7-8 | 6 | 14 | Yes | n/a |
| <i>T. baotianensis</i> | 6.7-7.1 | 21.9-29.4 | Absent | Complete | Degenerated | No | No | Truncate | 6-7 | 4-5 | 11-13 | Yes | n/a |
| <i>T. erythraea</i> | Absent | n/a | Absent | Complete | Developed | No | Yes | Truncate | 8 | 6 | 17 | No | n/a |
| <i>T. fengshanensis</i> | Absent | n/a | Absent | Complete | n/a | No | No | Truncate | 8 | 6 | 16 | Yes | n/a |
| <i>T. flavicarpus</i> | 14.7-19.6 | 19.2-27.0 | Present | Complete | Degenerated | No | Yes | Concave | 10 | 6-7 | 16 | No | 4 + 34 |
| <i>T. gejiuensis</i> | Absent | n/a | Absent | Complete | Developed | No | Yes | Truncate | 7-8 | 4-6 | 14-15 | Yes | n/a |
| <i>T. guizhouensis</i> | 9.4-12.1 | 20.3-24.3 | Present | Complete | Developed | No | No | Truncate | 8 | 6 | 14 | Yes | n/a |
| <i>T. huapingensis</i> | 10.4-14.3 | 27.6-30.8 | Present | Complete | Developed | No | No | Truncate | 8 | 5 | 16 | No | n/a |
| <i>T. langpingensis</i> | 2.7-5.9 | 30.6-34.5 | Absent | Incomplete | Degenerated | No | Yes | Truncate | 7-8 | 5-6 | 14 | Yes | n/a |
| <i>T. longipectoralis</i> | 11.8-16.4 | 21.2-25.3 | Present | Complete | Degenerated | Yes | Yes | Concave | 8 | 5-6 | 16 | Yes | 4 + 35 |
| <i>T. longiensis</i> | 9.5-11.5 | 31.4-37.5 | Absent | Complete | Developed | No | Yes | Concave | 8 | 5 | 15-16 | Yes | 4 + 38 |
| <i>T. luochengensis</i> | 7.5-8.6 | 18.4-21.3 | Present | Complete | Degenerated | No | No | Truncate | 8 | 6 | 16-17 | Yes | 4 + 33-34 |
| <i>T. macrocephala</i> | 3.6-8.0 | 22.9-25.8 | Absent | Complete | Degenerated | No | No | Truncate | 8 | 5 | 16 | Yes | n/a |
| <i>T. nandanensis</i> | 11.1-21.3 | 24.4-27.8 | Absent | Complete | Degenerated | No | No | Concave | 8 | 5 | 15-16 | Yes | 4 + 36 |
| <i>T. nanopanjiangensis</i> | 12.0-16.5 | 30.3-34.5 | Absent | Complete | Degenerated | No | No | Truncate | 7-8 | 5 | 13-16 | Yes | 4 + 38 |
| <i>T. nasobarbatula</i> | 9.1-13.3 | 27.0-33.3 | Present | Complete | Degenerated | No | No | Truncate | 8 | 5 | 15 | Yes | 4 + 36 |
| <i>T. posterodorsalis</i> | Absent | n/a | Absent | Complete | n/a | No | No | Truncate | 6 | 4 | 15 | Yes | n/a |
| <i>T. qingzhenensis</i> | 2.1-4.4 | 25.1-30.4 | Absent | Complete | Degenerated | No | No | Truncate | 7-8 | 5 | 14 | Yes | 4 + 36 |
| <i>T. qini</i> | Absent | n/a | Absent | Complete | n/a | No | Yes | Concave | 8 | 5 | 14-16 | No | 4 + 34-35 |
| <i>T. qiubeiensis</i> | Absent | 17.4-24.0 | Absent | Complete | Degenerated | No | Yes | Concave | 7 | 5 | 14-15 | No | 4 + 35 |
| <i>T. rosa</i> | Absent | 26.8 | Absent | Complete | n/a | No | Yes | Concave | 9 | 6 | 14 | Yes | n/a |
| <i>T. sanduensis</i> | 11.9-15.4 | 31.2-40.2 | Present | Complete | Degenerated | No | No | Concave | 8-9 | 5 | 17-18 | Yes | 4 + 37 |
| <i>T. shilinensis</i> | Absent | n/a | Absent | Complete | Degenerated | No | Yes | Truncate | 7 | 5 | 14 | Yes | n/a |
| <i>T. tiancensis</i> | 3.0-5.9 | 21.3-25.6 | Absent | Complete | Degenerated | No | No | Truncate | 7 | 5 | 16 | Yes | 4 + 35 |
| <i>T. tianlinensis</i> | n/a | n/a | Absent | Complete | Degenerated | No | Yes | Truncate | 8-9 | 6 | 15-16 | Yes | n/a |
| <i>T. tianxingensis</i> | 4.2-6.7 | 17.4-24.0 | Absent | Complete | Developed | No | No | Truncate | 8 | 5 | 16 | No | 4 + 38 |
| <i>T. wudangensis</i> | 5.1-6.5 | 33.1-35.8 | Absent | Complete | Degenerated | No | No | Truncate | 7 | 5 | 14 | Yes | 4 + 34 |
| <i>T. wulongensis</i> | 11.1-19.1 | 38.5-43.1 | Absent | Complete | Degenerated | No | No | Concave | 8-9 | 5-6 | 18 | Yes | 4 + 38-39 |
| <i>T. xiangshuingsensis</i> | 7.5 | 32.3 | Absent | Complete | Degenerated | No | No | Concave | 6 | 5 | 14 | Yes | n/a |
| <i>T. xiangxiensis</i> | Absent | n/a | Absent | Complete | Developed | Yes | Yes | Concave | 8 | 6 | 16 | Yes | n/a |
| <i>T. xichouensis</i> | n/a | n/a | Absent | Complete | Developed | No | Yes | Truncate | 8 | 6 | 16 | Yes | 4 + 36 |
| <i>T. xuanweiensis</i> | Absent | n/a | Absent | Complete | Developed | No | Yes | Concave | 7-8 | 5 | 17-18 | Yes | n/a |
| <i>T. yunnanensis</i> | 7.2-8.3 | 27.0-27.8 | Present | Complete | Degenerated | No | No | Concave | 7 | 5 | 15-16 | Yes | n/a |
| <i>T. zhenfengensis</i> | 7.1-16.7 | 22.2-34.5 | Present | Complete | Degenerated | No | No | Truncate | 7 | 5 | 14-15 | Yes | 4 + 36 |

and 5 branched fin rays, origin closer to the anal fin origin than the pectoral fin origin; the tip of the pelvic fin does not reach the anus. Pectoral fin with 1 unbranched and 8 ($n=3$) or 9 ($n=2$) branched fin rays, extending beyond the halfway to pelvic-fin origin. Anal fin with 3 unbranched and 5 branched fin rays, origin closer to pelvic-fin insertion than to caudal-fin base. The caudal fin forked, with 14 branched fin rays, the upper lobe slightly longer than the lower.

Intestine short, with a zigzag-shaped bend behind the stomach. The bony capsule of the air bladder is dumbbell-shaped (Fig. 5C), posterior chamber of the air bladder degenerated. Inner gill rakers on first gill arch 6. Vertebrae 4 + 36 (holotype).

Colouration: In life specimens, the body is generally pale, slightly pinkish, with sparse and irregular pigments laterally and dorsally, semi-transparent ventrally, and interradiation membranes of all fins are transparent (Fig. 2B). In 10% formalin-preserved specimens, body pale, with slightly yellowish pigments faded in some specimens (Figs. 5A, 5B).

Sexual dimorphism: No sexual dimorphism is observed based on the present type specimens of *T. qingzhenensis*.

Distribution and habitat: This species is presently only known from a subterranean tributary of the River Wujiang in the River Yangtze drainage in Qingzhen County, Guiyang City, Guizhou Province, China (Fig. 4). The species inhabited in complete darkness at the bottom of the slowly-flowing underground river (Fig. 6), where the water temperature was 14.5 °C and pH value was 7.8 during the survey period in November 2019.

Etymology: The specific epithet is derived from its type locality, Qingzhen County.

Molecular phylogenetic analysis: After alignment, 1,061 bps of *cytb* gene sequences belonging to 31 individuals of 26 species of *Triplophysa* and two species of *Homatula* were involved in molecular phylogenetic analysis, including 592 conservative sites, 469 variable sites, 430 parsimony informative sites and 39 singleton sites.

Phylogenetic tree reconstructed by the ML method is shown in Fig. 7. Topology of the phylogenetic tree indicated that the sampled individuals of *T. wudangensis* and *T. qingzhenensis* grouped into a monophyletic clade with the bootstrap values of 99

and 86, respectively. These two species clustered closely with *T. rosa*. In addition, *T. xiangxiensis* was sister to the branch composed of *T. qini*, *T. sanduensis* and *T. longliensis*. *Triplophysa erythraea* formed an independent lineage.

Based on the K2P model, pairwise genetic distances between these two new species and their congeners are given in Table 4. The genetic distances between *T. wudangensis* and its cave-dwelling congeners ranged from 1.4% (*vs. T. rosa*) to 18.4% (*vs. T. zhenfengensis*); between *T. qingzhenensis* and its congeners ranged from 1.5% (*vs. T. rosa*) to 18.3% (*vs. T. baotianensis* and *T. zhenfengensis*). The genetic distance between both new species was 1.6%.

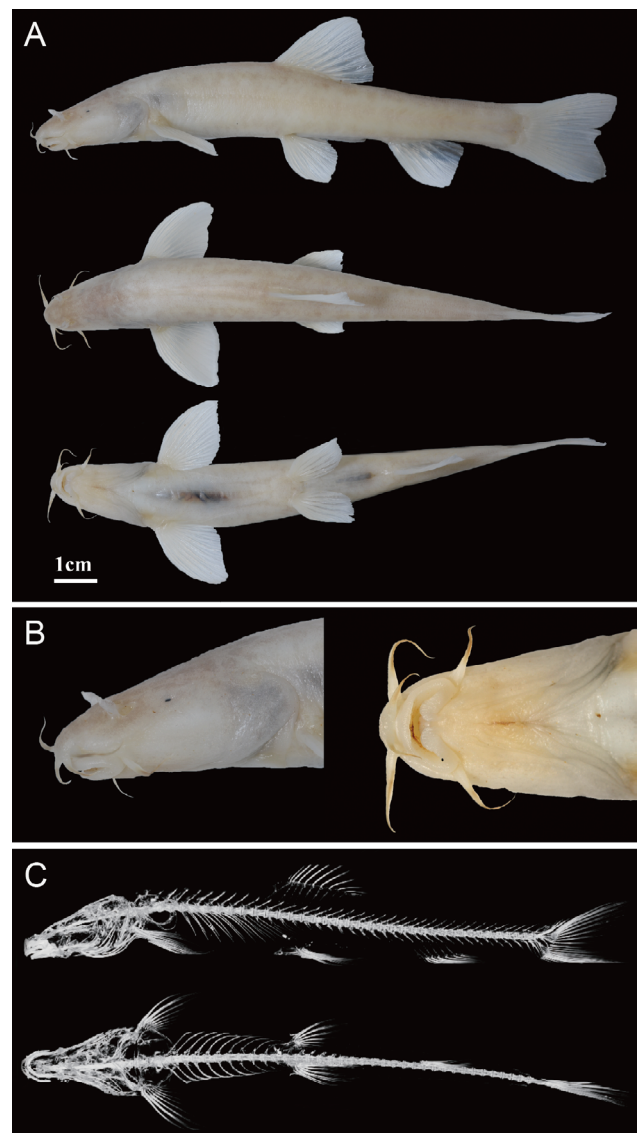


Fig. 5. *Triplophysa qingzhenensis*, holotype, IHB 2019111501 103.9 mm SL; from a subterranean tributary of the River Wujiang in the River Yangtze drainage in Qingzhen County, Guiyang City, Guizhou Province, China. A) lateral, dorsal and ventral views; B) lateral and dorsal views of the head; C) lateral and ventral views of the micro-CT graph.



Fig. 6. Habitat of *Triplophysa qingzhenensis*. A) entrance to the subterranean tributary; B) the pool where type specimens were collected.

Discussion

There is an increasing number of cave species of *Triplophysa* described in the karst areas in the River Yangtze drainage. The descriptions of these two new species bring the total number to seven: *T. rosa* Chen & Yang, 2005, *T. wulongensis* Chen, Sheraliev, Shu & Peng, 2021, *T. qini* Deng, Wang & Zhang, 2022, *T. xiangxiensis* Yang, Yuan & Liao, 1986, *T. erythraea* Liu & Huang, 2019. from Yuanjiang system of Lake Dongting. *Triplophysa wudangensis* and *T. qingzhenensis* are significantly distinguishable by eye diameter (5.1-6.5% HL in *T. wudangensis* vs. 2.1-4.4% HL in *T. qingzhenensis*), interorbital width (33.1-35.8% HL in *T. wudangensis* vs. 25.1-30.4% HL in *T. qingzhenensis*), and vertebrae (4 + 34 in *T. wudangensis* vs. 4 + 36 in *T. qingzhenensis*). *Triplophysa rosa* (Fig. 8) was the first described cavefish from the River Wujiang system (Chen & Yang 2005), which was the closest relative to *T. wudangensis* and *T. qingzhenensis* inferred from intraspecies genetic distances. The morphometric characters of *T. rosa* are summarised in Table 2. The two new species distinctly differ from *T. rosa* by the

presence of reduced eyes (*vs.* eye absent), a shorter pectoral fin (18.6-19.7% SL in *T. wudangensis* and 17.1-19.3% SL in *T. qingzhenensis* vs. 25.5% SL in *T. rosa*), distal margin of dorsal fin truncate (*vs.* concave), less branched dorsal-fin rays (7 in *T. wudangensis* and 7-8 in *T. qingzhenensis* vs. 9 in *T. rosa*), less branched anal-fin rays (5 in *T. wudangensis* and *T. qingzhenensis* vs. 6 in *T. rosa*). The two species are distinct from *T. qini*, *T. xiangxiensis* and *T. erythraea* by the presence of reduced eyes (*vs.* eye absent) and pelvic-fin tip not reaching to the anus (*vs.* reaching to); further differ from *T. qini* by the presence (*vs.* absence) of a barbel-like tip on the anterior nostril, and distal margin of pelvic fin truncate (*vs.* concave); from *T. xiangxiensis* by the posterior chamber of the air bladder degenerated (*vs.* developed), pectoral-fin tip not reaching to pelvic-fin origin (*vs.* reaching to), distal margin of dorsal fin truncate (*vs.* concave), and branched anal-fin rays 5 (*vs.* 6); from *T. erythraea* by the posterior chamber of air bladder degenerated (*vs.* developed), presence (*vs.* absence) of a barbel-like tip on the anterior nostril, branched anal-fin rays 5 (*vs.* 6), and branched caudal-fin rays 14 (*vs.* 16). *Triplophysa wulongensis* is a unique hypogean species in the River Yangtze drainage with normal-sized eyes (eye diameter 11.1-19.1% HL). The two species are further distinct from *T. wulongensis* by shorter interorbital width (33.1-35.8% HL in *T. wudangensis* and 25.1-30.4% HL in *T. qingzhenensis* vs. 38.5-43.1% HL in *T. wulongensis*), distal margin of dorsal fin truncate (*vs.* concave), branched caudal-fin rays 14 (*vs.* 18) and vertebrae (4 + 34 in *T. wudangensis* and 4 + 36 in *T. qingzhenensis* vs. 4 + 38 in *T. wulongensis*).

Molecular phylogenetic evidence corroborated the validities of *T. wudangensis* and *T. qingzhenensis* by the highly supported monophyly and sufficient genetic divergence from their congeners. Furthermore, the genetic distances between both species and their closest congener, *T. rosa*, were slightly less than the 2% threshold value, implying the differentiation of these species was at an early stage. Meanwhile, it should be noted that *T. rosa*, *T. qini*, *T. xiangxiensis* and *T. erythraea* are more analogous in morphology (eyes absent, loss of pigmentation, for instance), while the topology of the phylogenetic tree demonstrated that these hypogean species clustered neither by the river-system pattern nor by the morphological analogousness. On the one hand, this phenomenon was possibly caused by convergent evolution under similar selection pressure to other cave species (Wilkens & Strecker 2003, Xiao et al. 2005). On the other hand, it can be inferred that these hypogean species of *Triplophysa* may originate from

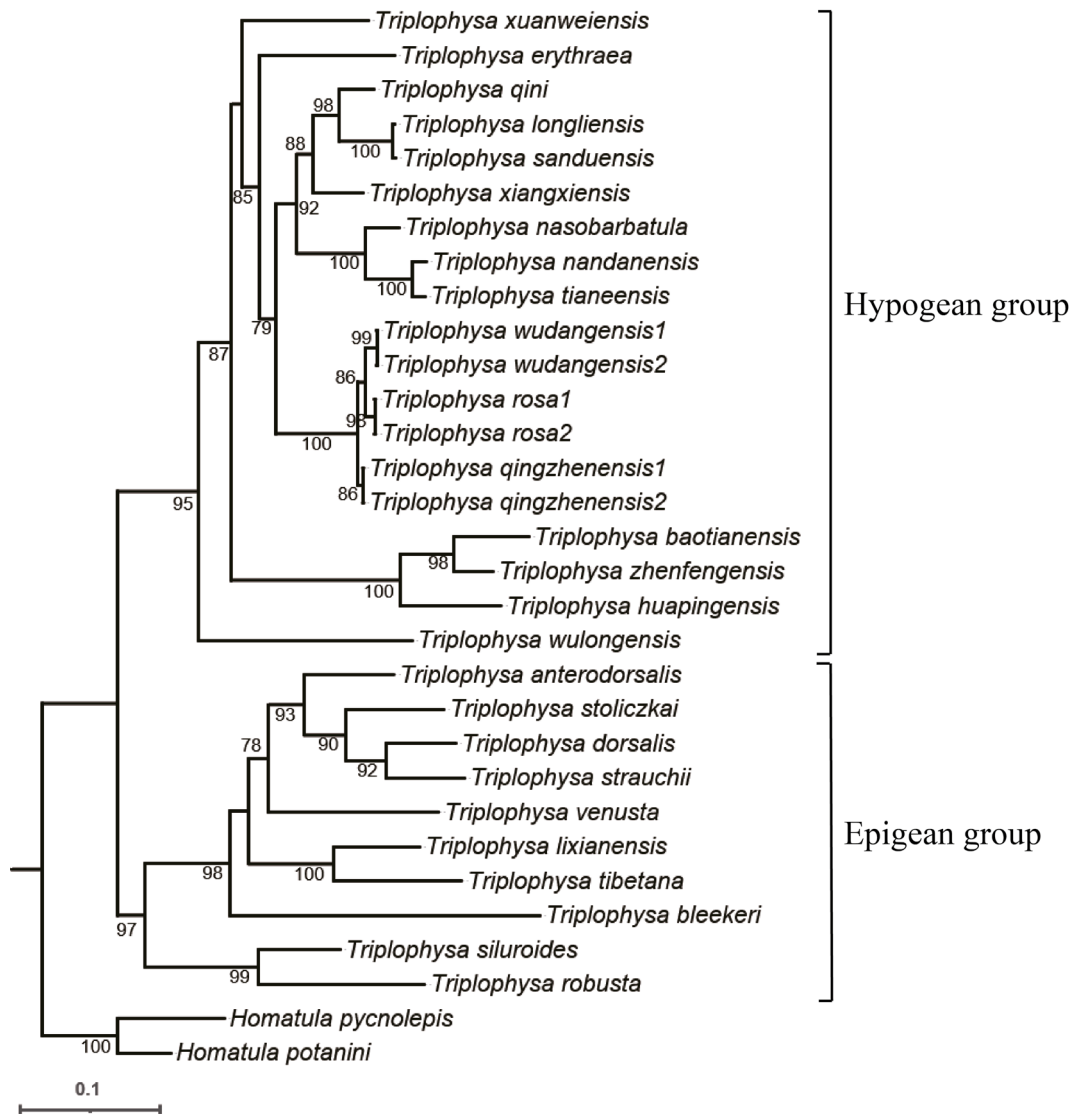


Fig. 7. Maximum likelihood tree derived from *cytb* gene sequences of 26 species of *Triplophysa*. Numbers below the branches represent bootstrap values (> 50 shown).

heterogeneous ancestors and spread across different river systems. To be specific, the diversified hypogean species originated from the River Pearl drainage may disperse to the Wujiang system through subterranean river capture and connection and then spread to the Wuling Mountain area in Chongqing City and Hunan Province, as Wujiang is the largest river in Guizhou Province with concentrative-distributed and well-developed karst landform (Che & Yu 1985). A similar conclusion has also been drawn in the study on the dispersal process of *Sinocyclocheilus cyphotergous* species complex in the River Yangtze drainage (Wen et al. 2022). Therefore, the evolutionary history and distribution pattern of hypogean *Triplophysa* species were rather complex. A detailed field survey in Wujiang and the adjacent drainages is warranted to clarify the diversity pattern of this taxon in the River Yangtze drainage.

Due to sampling difficulties, the current distribution range and population sizes of *T. wudangensis* and *T. qingzhenensis* remain unclear, while most reported cavefishes are deemed endemic to a narrow region, even a single cave (Zhao & Zhang 2006). In the survey, we found anthropogenic activities posed threats to the two species in their type localities. For *T. wudangensis*, the subterranean river has been utilised as a water source for a mineral water factory; and for *T. qingzhenensis*, factories have discharged sewage into the groundwater. Domestic pollution, illegal fishing and alien invasion (*Gambusia affinis*, *Procambarus clarkii* and *Rana catesbiana*, for instance) also threaten these two species. Guiyang City and its surrounding area is the type locality for many cavefishes, as well as endemic fishes of the River Yangtze (Zeng et al. 2022), which plays essential roles in biodiversity conservation and biogeographical research. At the same time, it is the

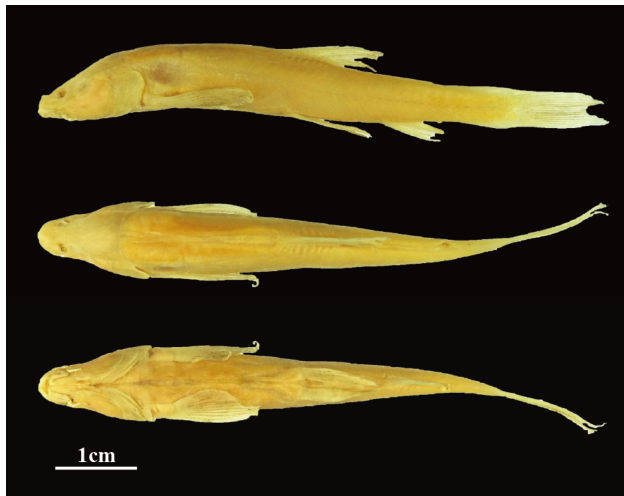


Fig. 8. Lateral, dorsal and ventral views of *Triplophysa rosa*, holotype, KIZ 200211001, holotype, 56.4 mm SL (photo Rui Min).

most urbanised area of Guizhou Province. Therefore, environmental conservation measures are urgently needed to protect these species and their habitats.

Comparative Materials

Triplophysa baotianensis: GZNU 20190524001, 69.08 mm SL; a tributary of the River Pearl at Baotian Town, Panzhou City, Guizhou Province.

Triplophysa guizhouensis: IHB 201906180001, GZNU 20200806001-20200806003, 4 specimens, 64.7-92.9 mm SL; a tributary of the Mengjiang system in the River Pearl drainage at Jialie Village, Huishui County, Guizhou Province.

Triplophysa nasobarbatula: GZNU 201731004-201731006, 3 specimens, 64.7-92.9 mm SL; a tributary

of the Liujiang system in the River Pearl drainage at Yaosuo Village, Libo County, Guizhou Province.

Triplophysa qini: IHB 201809049887, holotype, 76.8 mm SL; Erwang Cave of the Wujiang system in the River Yangtze drainage at Houping Village, Wulong County, Chongqing City.

Triplophysa rosa: KIZ 200211001, holotype, 56.4 mm SL; Dongba Cave, of the Wujiang system in the River Yangtze drainage at Tianxing Town, Wulong County, Chongqing City.

Triplophysa sanduensis: SWU 2017061301-2017061304, paratypes, 4 specimens, 45.2-71.5 mm SL; a cave of the Liujiang system in the River Pearl drainage at Dengguang Village, Zhonghe Town, Sandu County, Guizhou Province.

Triplophysa xiangxiensis: IHB 2015010001, IHB 2015010004, IHB 2015010006, IHB 2015010009, topotypes, 4 specimens, 48.3-85.7 mm SL; Feihu Cave of the River Yuanjiang in the River Yangtze drainage at Huoyan Village, Longshan County, Hunan Province.

Triplophysa zhenfengensis: GZNU 20190514002, 79.0 mm SL; a tributary of the River Beipanjiang in the River Pearl drainage at Gaoyan village, Xingren City, Guizhou Province.

Comparative data were acquired from literatures for the following species: *T. aluensis* from Li & Zhu (2000); *T. anshuiensis* from Wu et al. (2018); *T. erythraea* from Huang et al. (2019); *T. fengshanensis* from Lan et al.

Table 4. Kimura-2-Parameter genetic distance (in %) among 14 cave species of *Triplophysa* based on *cytb* gene sequences.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|----------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-----|
| 1 <i>T. wudangensis</i> | | | | | | | | | | | | | |
| 2 <i>T. qingzhenensis</i> | 1.6 | | | | | | | | | | | | |
| 3 <i>T. rosa</i> | 1.4 | 1.5 | | | | | | | | | | | |
| 4 <i>T. qini</i> | 10.5 | 9.9 | 10.3 | | | | | | | | | | |
| 5 <i>T. xiangxiensis</i> | 10.0 | 9.7 | 9.8 | 6.4 | | | | | | | | | |
| 6 <i>T. erythraea</i> | 12.7 | 12.8 | 13.2 | 12.0 | 13.1 | | | | | | | | |
| 7 <i>T. xuanweiensis</i> | 12.6 | 12.9 | 13.1 | 12.8 | 12.8 | 13.6 | | | | | | | |
| 8 <i>T. nasobarbatula</i> | 11.7 | 11.0 | 11.6 | 10.7 | 9.2 | 14.0 | 13.4 | | | | | | |
| 9 <i>T. nandanensis</i> | 11.9 | 11.5 | 12.1 | 11.7 | 10.9 | 14.0 | 13.3 | 5.9 | | | | | |
| 10 <i>T. baotianensis</i> | 17.6 | 18.0 | 18.0 | 18.8 | 18.0 | 16.8 | 17.1 | 18.2 | 20.3 | | | | |
| 11 <i>T. zhenfengensis</i> | 18.4 | 18.3 | 18.6 | 17.6 | 17.3 | 17.4 | 16.9 | 17.2 | 19.7 | 7.0 | | | |
| 12 <i>T. wulongensis</i> | 15.9 | 15.7 | 15.9 | 15.3 | 16.9 | 18.2 | 16.3 | 17.7 | 17.0 | 19.9 | 19.5 | | |
| 13 <i>T. longliensis</i> | 10.5 | 10.3 | 10.6 | 5.6 | 8.4 | 12.2 | 13.2 | 10.7 | 11.7 | 17.4 | 17.2 | 15.7 | |
| 14 <i>T. sanduensis</i> | 10.6 | 10.3 | 10.6 | 5.8 | 8.7 | 12.5 | 13.2 | 10.6 | 11.8 | 17.6 | 17.4 | 15.4 | 0.5 |



(2013); *T. flavicorpus* from Yang et al. (2004); *T. gejiuensis* from Chu & Chen (1979); *T. huapingensis* from Zheng et al. (2012); *T. langpingensis* from Lan et al. (2013); *T. longipectoralis* from Zheng et al. (2009); *T. longliensis* from Ren et al. (2012); *T. luochengensis* from Li et al. (2017a); *T. macrocephala* from Yang et al. (2012); *T. nandanensis* from Lan et al. (1995); *T. nanpanjiangensis* from Zhu & Cao (1988); *T. posterodorsalis* from Ran et al. (2006); *T. qiubeiensis* from Li et al. (2008); *T. shilinensis* from Chen et al. (1992); *T. tianeensis* from Chen et al. (2004); *T. tianlinensis* from Li et al. (2017b); *T. tianxingensis* from Yang et al. (2016); *T. wulongensis* from Chen et al. (2021); *T. xiangshuingensis* from Li (2004); *T. xichouensis* from Liu et al. (2017); *T. xuanweiensis* from Lu et al. (2022); *T. yunnanensis* from Chu & Chen (1990).

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Author Contributions

Z. Zeng designed the study, collected the specimens, and took photos of the type specimens and habitats. F. Liu measured the morphometric characters of the specimens, examined the comparative materials and prepared the manuscript draft. Z. Gong analysed the molecular data and revised the manuscript.

Data Availability Statement

The data supporting this study's findings are available in the FigShare Digital Repository: doi.org/10.6084/m9.figshare.21657677.



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