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# A new species of *Gyraulus* (Gastropoda: Planorbidae) from Ancient Lake Lugu, Yunnan-Guizhou Plateau, Southwest China

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A new aberrant species of the planorbid genus *Gyraulus*, *Gyraulus luguhuensis* n. sp., is described from Lake Lugu (Lugu-hu, in Chinese), Southwest China. The generic assignment with *Gyraulus* is based on features of the genital anatomy that are characteristic for members of that genus, in particular the presence of a chitinized penial stylet. *Gyraulus luguhuensis* n. sp. differs from most other congeners by its large, thick shell with an elevated spire. Similarly, aberrant shells are known from congeners in other Ancient Lakes worldwide indicating a potentially convergent evolution of shell characteristics in exclusively lacustrine species. *Gyraulus luguhuensis* differs from other lacustrine *Gyraulus* species with similarly large shells in having a sub-terminal penis pore and an unkeeled shell.

**Keywords:** taxonomy; genital anatomy; freshwater mollusca; lotic environments



## Introduction

The genus *Gyraulus* Charpentier, 1837 has a worldwide distribution except for South America south of Venezuela (Brown 1998, 2001). Species from Africa (Brown and Van Eeden 1969), Europe (Hubendick and Radoman 1959; Meier-Brook 1983) and Australia (Brown 1998, 2001) have been studied rather comprehensively, while our knowledge of Asian species is comparatively poor (Meier-Brook 1983). While species of the genus are typically small and planispiral, notable deviations from this general morphotype are exhibited by some species from the Ancient Lakes Ohrid and Prespa in Europe and Biwa in Japan, which have unusually large, high-spired and pseudodextral shells (Hubendick and Radoman 1959; Meier-Brook 1983).

The Yunnan-Guizhou Plateau in southwest China, Yunnan Province, comprises a multitude of tectonic lakes with a complex and ancient geological history. At 2685 m above the sea level, Lake Lugu [Lugu-hu, in Chinese] has the highest altitude of all ancient lakes of the Yunnan-Guizhou Plateau. It was formed during the Late Cenozoic (Nanjing Institute of Geography and Limnology, CAS *et al*. 1989).

In general, the Ancient Lakes of Yunnan are known to harbour a unique and diverse fauna of fish (Gao *et al*. 1989), oligochaetes (Li *et al.* 1963; Cui *et al.* 2008) and molluscs (Zhang *et al.* 1997). Lake Lugu contains four endemic species of fish (Kong *et al* 2006), but our knowledge of the lake's molluscan fauna is still patchy due to a lack of comprehensive survey data and current taxonomic treatment. To date, seven species of molluscs have been recorded from Lake Lugu, including two viviparids, *Angulyagra polyzonata* (Frauenfeld, 1862) and *Angulyagra oxytropoides* (Heude, 1889), four lymnaeids, *Radix ovalis* (Gray, 1862), *Radix impura* (Troschel, 1837), *Radix succinea* (Deshayes, 1834) and *Radix siamensis* (Sowerby, 1870) and one planorbid, *Polypylis hemisphaerula* (Benson, 1842) (Zhang *et al*. 1997), which is widely distributed in China, Japan, Korea, Russia and Thailand (Brandt 1974; Liu *et al*. 1979).

In the last decades, the biota of the Yunnan lakes, including many molluscan species, has become increasingly threatened due to pollution, eutrophication and overharvesting (Shu *et al.* 2010). In order to improve our understanding of the molluscan fauna of the lakes of the Yunnan-Guizhou Plateau, between 2007 and 2008, 13 lakes with surface areas larger than 10 km$^2$ were surveyed as part of on-going limnological studies. Gastropod specimens were collected from various lakes (Shu *et al*. 2010), amongst which there was the new aberrant *Gyraulus* species from Lake Lugu described herein.

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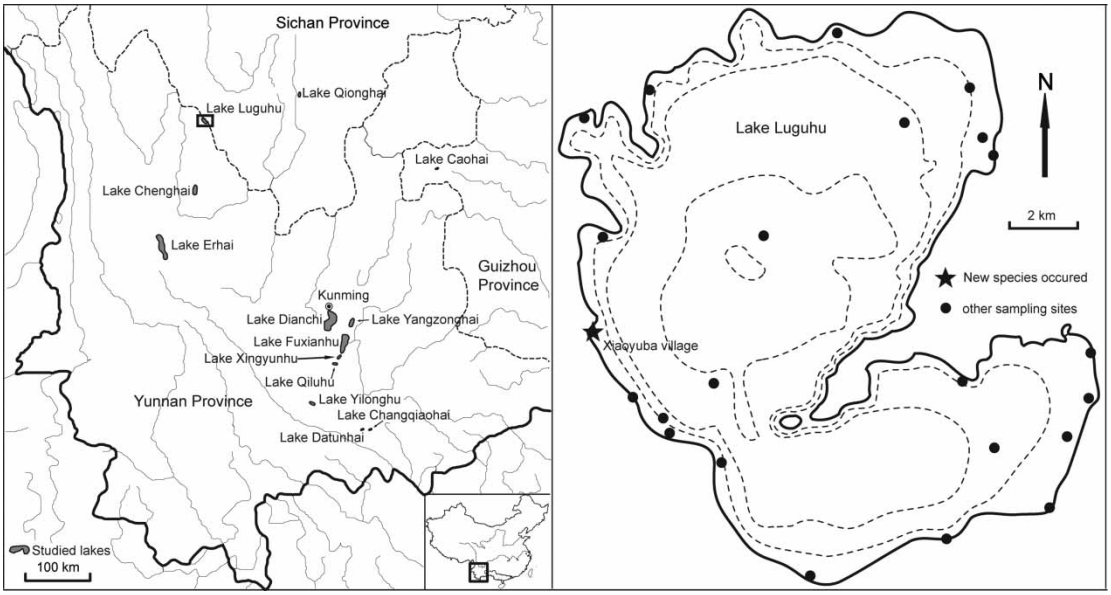


Figure 1. Map of sampling sites. **A**, Area covered by the on-going limnological survey of the lakes of the Yunnan-Guizhou Plateau showing location of Lake Lugu. **B**, Detailed map of Lake Lugu, showing survey sites and the type locality (asterisk) of the species described here.

## Material and methods

### *Environmental settings and sampling techniques*

Formed by faulting in the Late Cenozoic (Nanjing Institute of Geography and Limnology, CAS *et al*. 1989), Lake Lugu (N 27° 41′–27° 45′, E 100° 45′–100° 50′) is located at the boundary of the Ninglang County of Yunnan Province and Yanyuan County of Sichuan Province (Figure 1). The lake covers an area of 48.5 km$^2$ at an altitude of 2685 m. Its average depth of 40 m and maximum depth of 93 m renders it to be the third deepest lake in China. Visibility under water reaches up to 12 m, while the pH ranges from 7.7 to 8.6 (Nanjing Institute of Geography and Limnology, CAS *et al*. 1989). The lake is mainly fed by precipitation and the only outlet is through the Gaizu River in rainy seasons. Molluscs were collected using a weighted Petersen grab (1/16 m$^2$). When macrophytes occurred, a modified dredge (1/5 m$^2$) was used to collect epiphytic gastropods. Qualitative surveys were also conducted in the littoral zone (less than 0.5 m) with a pond-net (30 cm and 420 μm in diameter and mesh size, respectively) or by hand-picking.

### *Specimen preservation and morphological studies*

Specimens were fixed in 10% formalin after being relaxed by immersion in water for preservation for anatomical study or in 95% ethanol for later molecular study. Dimensions of shells were measured with Vernier callipers (precision 0.1 mm). Five specimens were dissected to examine gross anatomy. Drawings were made with a camera lucida. Radulae were extracted from three specimens and examined with a scanning electron microscope following standard mounting and coating techniques.

### *Abbreviations*

IHB—Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, China; QNU—Qufu Normal University, Qufu, China; FU—Fudan University, Shanghai, China.

## Systematic description

### *Family Planorbidae Rafinesque, 1815*

*Gyraulus* Charpentier, 1837

For synonymy, see Brown (2001).

*Diagnosis.* Small planorbid freshwater snails with discoid, planispiral (exceptionally pseudodextral) shell with rounded to acutely angular or keeled whorls. Penis with sub-terminal opening, tip with chitinized, dagger or hobnail-like stylet (Meier-Brook 1983; Brown 1998, 2001).

*Gyraulus luguhuensis* n. sp.

*Type material*

*Holotype.* China, Yunnan Province, Ninglang County, bay near Xiaoyuba Village, west shore of Lake Lugu, 27° 41.954′ N, 100° 45.009′ E, coll. Shu Feng-Yue, 26 July 2008 (IHB, YAN, 20080701). *Paratypes*. Same locality (five, IHB, YAN, 20080702; 32, QNU Moll. 20080703; eight, FU Moll. 20080704). All specimens preserved in 10% formalin or 95% ethanol.

*Etymology.* Named after the Chinese name of the type locality, Lugu-hu.


Figure 2. Shell of *Gyraulus luguhuensis* n. sp. holotype IHB YAN 20080701. **A** Frontal view. **B**, Apical view. **C** Umbilical view. Scale = 0.5 cm.

Table 1. Shell dimensions of holotype and 15 paratypes (range, means and standard deviation) of *Gyraulus luguhuensis* n. sp. (in mm).

| | Shell height | Shell width | Aperture length | Aperture width |
|---|---|---|---|---|
| Holotype | 7.24 | 11.52 | 6.24 | 7.08 |
| Paratypes | | | | |
| Range | 6.74–8.84 | 9.82–12.70 | 4.88–6.88 | 6.20–8.10 |
| Mean | 7.69 | 11.42 | 5.94 | 7.06 |
| SD | 0.63 | 0.72 | 0.50 | 0.49 |

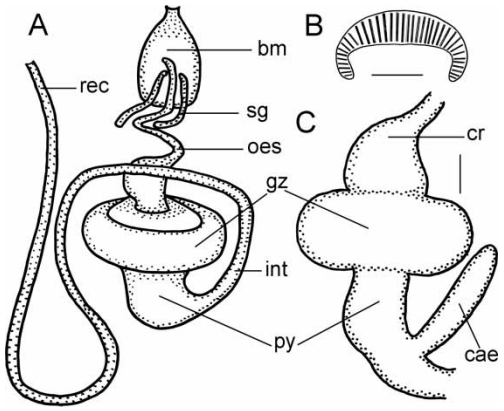


Figure 3. Digestive system of *G. luguhuensis* n. sp. paratype QNU Moll. 20080703. **A**, Outline of digestive system. **B**, Jaw. **C**, Ventral view of stomach.
bm—buccal mass; cae—caecum; cr—crop; gz—gizzard; int—intestine; oes—oesophagus; py—pyloris; sg—salivary gland; rec—rectum. Scale = 0.2 mm.

*Diagnosis.* Shell large for genus (up to 12.7 mm in maximum width), pseudodextral, thicker than most congeners with conspicuously inflated last whorl, narrowly winding umbilicus, periphery rounded.

*Description*

*Shell* (Figure 2A–C; Table 1). Pseudodextral, broadly conical with slightly to moderately elevated spire, large (width < 13 mm, height < 9 mm – see Table 1), thick; 3.5–4.0 whorls, apex blunt, last whorl greatly inflated, periphery rounded; aperture large, ovate, outer lip rather thin, inner lip thickened; umbilicus open, deep, narrowly winding; yellowish-brown, brown or reddish-brown; fine spiral striations and growth lines evenly distributed over shell surface.

*Digestive system* (Figures 3A, B, and 4A–F). Buccal mass ellipsoidal, with about one-third of radular sac protruding posteriorly. Jaw reddish-brown, comprising about 30 plates; dorsal bar 0.5–0.6 mm in length, 0.14–0.18 mm in height. Radula ribbon elongate-squarish, 8–10 mm in length, with about 57 teeth in each row; central teeth mostly unicuspid, blunt, a few with moderately subdivided cusp; lateral teeth slightly oblong, apex blunt or slightly subdivided; marginal teeth unicuspid, bluntly conic, not uniform. Oesophagus flat, 4–6 mm in length, interiorly with longitudinal stripes. Salivary glands sausage-shaped, salivary ducts open to buccal mass alongside oesophagus. Stomach divided into three: crop, gizzard and pyloris. Caecum opens to pyloris posteriorly.

*Reproductive system* (Figure 5). Ovotestis light yellow, embedded in digestive gland, consisting of two parallel rows, each of about 30 short diverticula with several yellowish-brown granules at their distal end. Spermoviduct broad anteriorly, gradually becoming narrower posteriorly, opening into seminal vesicle. Seminal vesicle slightly curved, with many short digitations on both sides, connected with carrefour (fertilization chamber) by slender hermaphroditic duct. Carrefour inflated, anteriorly connected with prostate gland and oothecal gland by sperm duct and oviduct, respectively. Albumen gland irregularly shaped, plate-like, composed of mass of short cylindrical granules, covered on back of stomach, opens to carrefour through short duct. Oothecal gland light yellow, inflated. Spermatheca elliptical in shape, 1.3–1.8 mm in length, 0.5–1.2 mm in width, spermathecal duct 0.8–1.8 mm in length and 0.2–0.4 mm in width. Oothecal gland and spermatheca merged into vagina.

Vas deferens thick in middle part, becoming gradually thinner towards both ends, 7.5–8.3 mm in length, about 0.2 mm in width. Prostate gland with about 30–40 diverticula, arranged in two rows. Penial sheath cylindrical, 2.5–3.6 mm in length, thick proximally (0.5–0.7 mm), thin distally (0.3 mm). Penis slender, nearly as long as penial sheath, thick proximally (0.4 mm), tapering towards distal end (0.1 mm), with hollow, brown stylet (0.4–0.5 mm in length) at distal end; penis pore opening at distal end of penis, about 0.4 mm apart from stylet, connected with stylet through penial groove. Praeputium cylindrical in shape, thin-walled, 1.8–2.6 mm in length, thick in middle part (0.7–0.8 mm), thinner at both ends; internally with two lateral muscular pillars comprising entire length of praeputium; small semi-spherical sarcobellum at base, 0.18 mm in height, surrounded by moderately developed velum. Retractor muscle attached to proximal end of praeputium, no muscle attached to penial sheath.

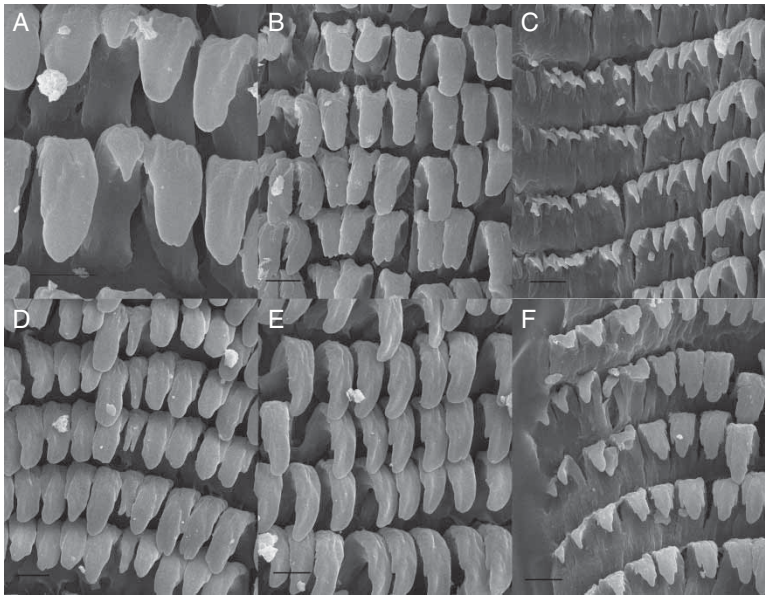


Figure 4. Radula of *Gyraulus luguhuensis* n. sp. **A–C**, Paratype QNU Moll. 20080703-1, **D–E**, Paratype QNU Moll. 20080703-2. **A**, **D**, Central teeth and lateral teeth; **B**, **E**, Lateral teeth; **C**, **F**, Marginal teeth. Scale = 10 μm.



*Distribution and habitat*

Known only from Lake Lugu, where it was collected on rocks and gravel in shallow water (less than 1.5 m depth) with sparsely distributed *Typha* sp. The habitat was comparatively undisturbed and surrounded by a steep hill, 0.5 km from the ring road.

*Remarks*

The coiling pattern of the intestine is typical of the family (Baker 1945) and the penis with a sub-terminal opening and chitinous stylet is typical of *Gyraulus* (Meier-Brook 1983; Brown 1998, 2001). However, the large, thick shell with an elevated spire is atypical for *Gyraulus*, although other species with aberrant shell forms are known from other ancient lakes and have been attributed to the genus. These include *Gyraulus lychnidicus* Hesse, 1928, *Gyraulus trapezoids* (Polinski, 1929), *Gyraulus crenophilus* Hubendick & Radoman, 1959 and *Gyraulus fontinalis* Hubendick & Radoman, 1959 from Lake Ohrid (Hubendick and Radoman 1959), *Gyraulus stankovici* Hadžišče, 1953 from Lake Prespa (Hadžišče 1953) and *Gyraulus biwaensis* (Preston, 1916) from Lake Biwa (Meier-Brook 1983).

The large, high-spired, pseudodextral, unkeeled shell is a characteristic feature of *G. luguhuensis* n. sp. With regard to characteristics of the radula, the new species has similarities (except the bicuspid form of a few central teeth) with lacustrine species from Lake Ochrid, such as *G. lychnidicus*, *G. trapezoids*, *G. crenophilus* and *G. fontinalis*, but differs markedly from *G. stankovici* from Lake Prespa in its unicuspid lateral teeth, *G. biwaensis* from Lake Biwa and usual *Gyraulus* species (Meier-Brook 1983) in its unicuspid central teeth. In addition, *G. stankovici* differs by having an almost sunken spire and two additional keels each above and below the periphery (Hubendick and Radoman 1959; Meier-Brook 1983).

## Discussion

Ancient Lakes have been identified as hotspots of freshwater biodiversity mainly due to the parallel occurrence of *in situ* speciation and radiation in various groups of organisms (Cristescu *et al*. 2010). Most of these lakes are also noted for their exceptionally diverse and highly endemic faunas of freshwater molluscs (Boss 1978; von Rintelen *et al*. 2007; Albrecht and Wilke 2008; Glaubrecht 2008; Albrecht *et al*. 2009).

The Yunnan-Guizhou Plateau in southwest China comprises about 60 tectonic lakes with a complex geological history, which are known to harbour a unique fauna of gastropod species, particularly of viviparids (Tchang and Tsi 1949; Zhang *et al*. 1981; Zhang *et al*. 1997; Du *et al*. 2011). In addition, the mountains of Yunnan also feed the most species-rich river systems in Asia. Major rivers that traverse or originate in this region include the Jingshajiang, Yalongjiang, Nujiang, Daduhe, Minjiang, the Yangtze and the Mekong Rivers (Conservation International & McGinley 2008).

However, while under increasing threat from urban development, pollution and over-harvesting, our knowledge of the molluscan fauna of Yunnan's diverse freshwater environment is still incomplete (Shu *et al*. 2010). While most lakes were surveyed in the past to some extent (Zhang *et al*. 1997), a comprehensive assessment of patterns of diversity and endemism of molluscs is hampered by the

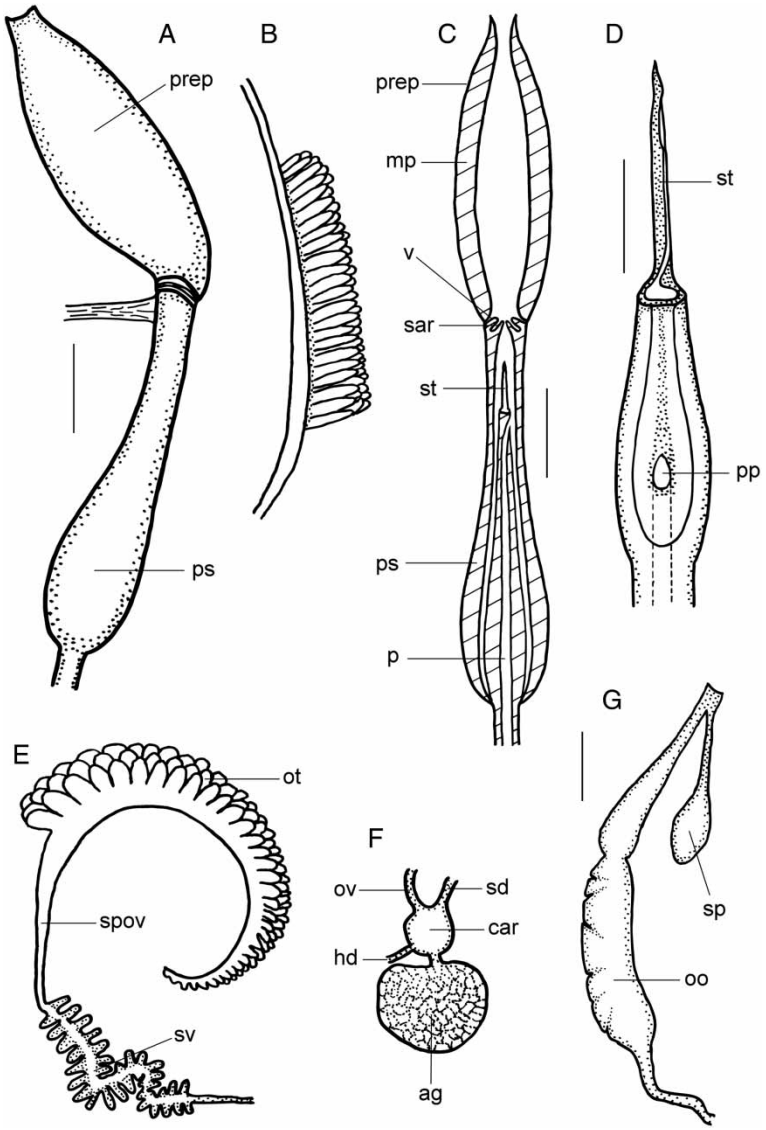


Figure 5. Reproductive anatomy of *Gyraulus luguhuensis* n. sp., paratype QNU Moll. 20080703. **A**, Outline of penis complex, scale = 0.5 mm. **B**, Prostate. **C**, Longitudinal section of penial complex, scale = 0.5 mm. **D**, Distal end of penis, scale = 0.2 mm. **E**, Ovotestis and seminal vesicle. **F**, Carrefour. **G**, Oothecal gland and spermatheca, scale = 1 mm.
ag—albumen gland; car—carrefour; hd—hermaphroditic duct; mp—muscular pillar; oo—oothecal gland; ot—ovotestis; ov—oviduct; p—penis; pp—penis pore; prep—praeputium; ps—penis sheath; sar—sarcobellum; sd—sperm duct; sp—spermatheca; spov—spermoviduct; st—stylet; sv—seminal vesicle; v—velum.

lack of a robust systematic framework that incorporates data from the watersheds of these lakes and the adjacent rivers. River faunas themselves are also very poorly known, as shown for pachychilids by Köhler *et al*. (2010).

The present paper adds another piece to the jigsaw, underscoring the need of a more complete documentation and revision of Yunnan's freshwater molluscan fauna as a pre-requisite for developing meaningful guidelines for conservation management and sustainable use.

*Gyraulus luguhuensis* n sp. is distinguished from most other congeners by its aberrant shell but does share interesting similarities with some species from certain ancient lakes from the Palaearctic and Oriental regions. In addition, pseudodextral shells also occur in another planorbid genus, *Choanomphalus* Gerstfeldt, 1959, from Lake Baikal. However, *Choanomphalus* can be easily distinguished from *Gyraulus* by its smaller shell size and key anatomical characters, such as a distal accessory gland complex of the male copulatory organ (Hubendick 1955; Meier-Brook 1983). Within the Planorbidae, species with aberrant shells have scattered and isolated occurrences in lotic environments throughout the Palaeartic and Oriental biogeographic regions. Because these species are apparently not closely related with each other, the lacustrine shell type such as that of *G. luguhensis* is likely to be the result of convergent evolution (Meier-Brook 1983).

In the only available comprehensive taxonomic revision, all forms of *Gyraulus* from continental South, Southeast and Central Asia were assigned to the *G*. (*Gyraulus*) *chinensis* (Dunker, 1848) species complex by Meier-Brook (1983), who also referred reports of *Gyraulus albus* (Müller, 1774) in China (Yen 1939) to *G. chinensis* due to misidentification. More recently, however, Zhang *et al*. (1997) reported *G. albus*, *Gyraulus compressus* (Hutton, 1849) and *Gyraulus convexiusculus* (Hutton, 1849) as distinct extant species in China. Consequently, the delimitation of species in *Gyraulus* in China is still controversial and requires revision. Such revision should also aim to resolve the phylogenetic position of the present species, which remains vague reflecting the general state of uncertainty regarding the status of *Gyraulus* taxa in China and elsewhere.



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