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A new species of *Behningia* Lestage, 1929 (Ephemerotera: Behningiidae) from China

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Abstract

A new species of sand-burrowing mayfly (Ephemeroptera: Behningiidae), *Behningia nujiangensis* Zhou & Bisset, is described based on more than 50 nymphs collected from the Nujiang River in Yunnan Province, P.R. China. This is the first species of the family Behningiidae discovered in China. It is also the second species of genus *Behningia*, and the third species of the family Behningiidae collected from the Oriental biogeographic region. The shapes of the labrum and the labium in *B. nujiangensis* are markedly different from those found in other species of *Behningia*. Differences in the mandibles, the galea-lacina of maxillae, and both the prothoracic and metathoracic legs differentiate *B. nujiangensis* from both *B. baei* and *B. ulmeri*. The biology of and conservation challenges for *B. nujiangensis* are also briefly discussed.

Key words: Ephemeroptera, differential diagnosis, taxonomy, Nujiang River, China, Oriental Realm

Introduction

Behningiidae is one of the smallest families of Ephemeroptera with a primarily Holarctic distribution. It is comprised of only four genera, including one Jurassic fossil genus, *Archaeobehningia* Tshernova, and three extant recent genera: *Behningia* Lestage, *Dolania* Edmunds & Traver, and *Protobehingia* Tshernova (Hubbard 1994). Prior to the new species found in China, only six extant species were recognized, including three Old World Palearctic species, two species from Thailand, and one from the United States (Bauernfeind & Soldán 2012).

Behningia nujiangensis Zhou & Bisset, sp. nov.

(Figs 1a–h, 2a–k, 3 and 4)

Description. Nymph (Fig. 1a). Body length of final instar 22.3 mm; caudal filaments 8.7 mm. General live coloration Tuscan yellow dorsally, pale peach ventrally (Fig. 3). Mouthparts heavily setaceous. Anteromedian margin of labrum shallowly emarginate, extending about 50% of labral width (Figs. 1b and 2a). Incisors of mandible greatly reduced except for outer denticle on outer incisor; molar area with short apical spine and heavy setae (Figs 1c and 2b). Maxillary palp tri-segmented; galea-lacinia elongated and apically acute (Figs 1d and 2c). Labium (Figs 1e, 2d and 2e) expanded; glossae fused; paraglossae as wide as long; labial palp tri-segmented; labial palp I expanded, with greatest width at 45% of length; palp II 50% length of palp I and 80% length of palp III. Prothoracic leg palp-like, with tarsus 35% length of tibia (Figs. 1f and 2i). Mesothoracic leg as in Figs 1g and 2j. Metathoracic leg: femur 1.5 times longer than wide; coxa as long as femur; tibia very short, as long as wide; tarsus 1.6 times longer than femur (Figs 1h and 2k). Veins of the forewing pad form geminate pairs (Fig. 2f). Abdomen with long and heavy setae laterally, setae orange near bases and white near edges; sterna pale with brownish to golden setae on anterior margin of sterna I to IX, posterior-most abdominal setae brownish, sparser and shorter. Gills white, on segments I–VII; gills

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on segment I single, more than 2 times as long as gills on segments II–VII (Figs 2g and 2h). Caudal filaments pale yellow; setae pale.

Material examined. Holotype: 1 late instar nymph, China, Yunnan Province, Lisaw Autonomous Prefecture of Nujiang, Shiyueliang County (Figs. 5a and 5b). A right-bank sandy bar on the main channel of the Nujiang River, 27.2612°N, 98.8810°E, 1,086 m a.s.l. Collected on February 13, 2019. Paratypes: 10 late instar nymphs, same data as holotype. Other materials: 6 late instar nymphs, 16 middle instar nymphs and 19 early instar nymphs. Collections are deposited in the Kunming Natural History Museum of Zoology, Kunming, Yunnan Province, China (holotype, KIZ0107183; paratypes, KIZ0107184–KIZ0107188), in the Insect Museum of the China Agriculture University, Beijing, China (paratypes: CAU-EPH-00001–CAU-EPH-00005), and in the State Key Laboratory of Hydroscience and Engineering, Beijing, China (other materials: LHE-001–LHE-041). Details of collection locality and date are provided in the Supporting Material Table S1.

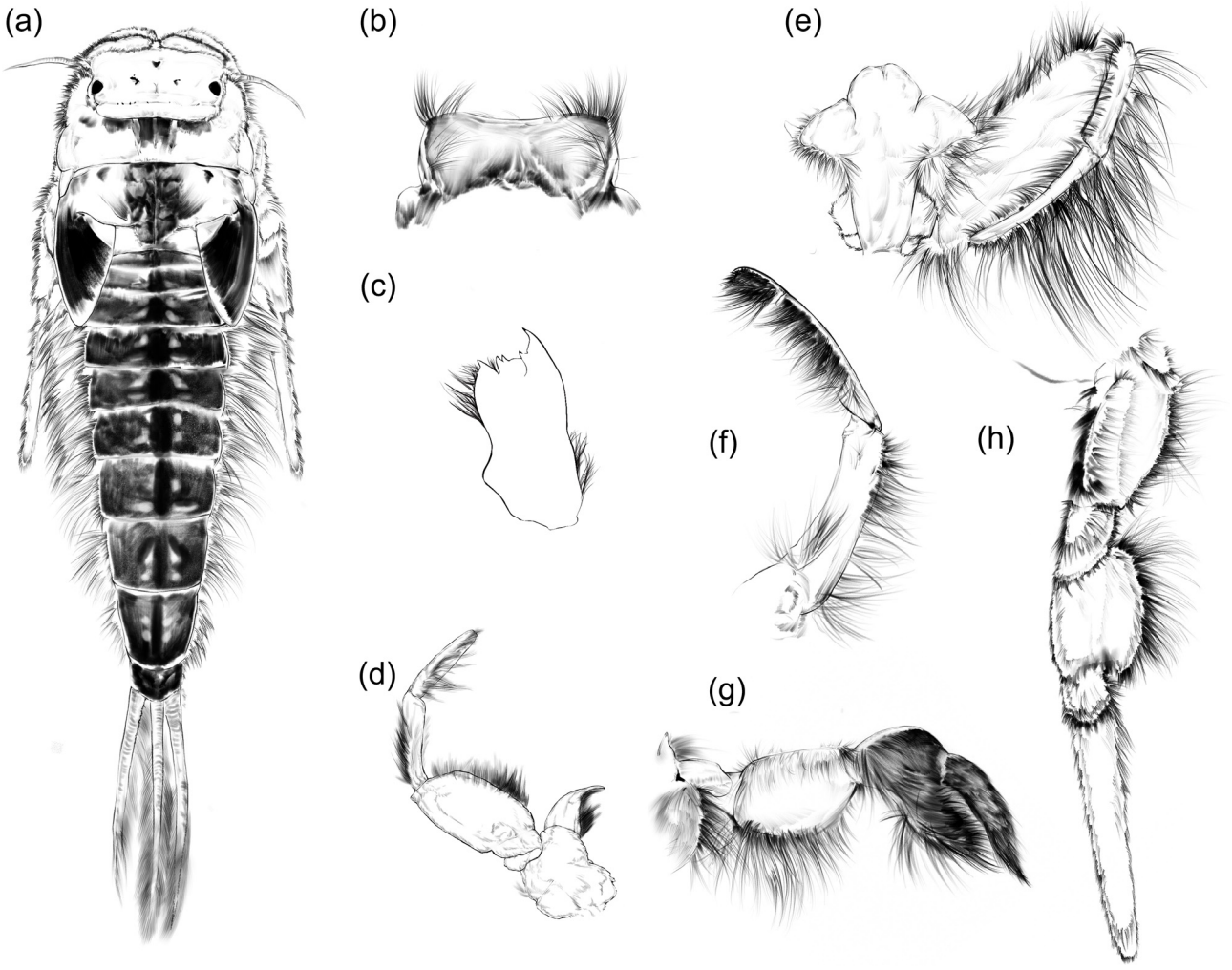

FIGURE 1. Drawings of (a) *Behningia nujiangensis,* **sp. nov.**, dorsal view of the nymph, holotype (gills not figured), (b) labrum, (c) left mandible, (d) left maxilla, (e) labium (with right palp), (f) prothoracic leg, (g) mesothoracic leg, and (h) metathoracic leg.

Etymology. The specific epithet refers to the Nujiang River in southwestern China (upper reach of the Salween River), where this species was discovered.

Habitat conditions. Collection locality habitat is depicted in Figure 5c. The sand bar where the type specimens were collected is located in a backwater area, with the marginal water flowing toward the bar recorded at 0.28 $m \cdot s^{-1}$ almost perpendicular to the direction of the main stream flow. Water at site: depth to approximately 0.60 m; pH = 6.86; dissolved oxygen content = 10.48 $mg \cdot L^{-1}$; electrical conductivity = 330 $\mu S \cdot cm^{-1}$. The bar is covered with a uniform layer of sand (median particulate diameter D_{50} = 0.3 mm). The specimens were collected by shoveling sand samples into a hand net, thus straining the sand to a depth of roughly 5–10 cm. The individual density was estimated to be more than 5 individuals$\cdot m^{-2}$ along the sediment surface. Other invertebrates collected in the samples

with *B. nujiangensis* were dipteran larvae, including species belonging to the genera *Hexatoma* (Tipulidae) and *Polypedilum*, *Pagastia* and *Orthocladius* (Chironomidae). Additionally, other shovel samples from the holotype site contained specimens of the hemipteran *Aphelocheirus* sp. (Aphelocheiridae) which were the most abundant aquatic insects observed, a *Davidius* sp. larvae (Odonata: Gomphidae), and a few specimens of other non-behningid mayflies (*Baetis* sp., *Ephemera* sp.). Notably, neither *Aphelocheirus* sp. nor the others mentioned were ever collected in the same shovel sample with a behningiid.

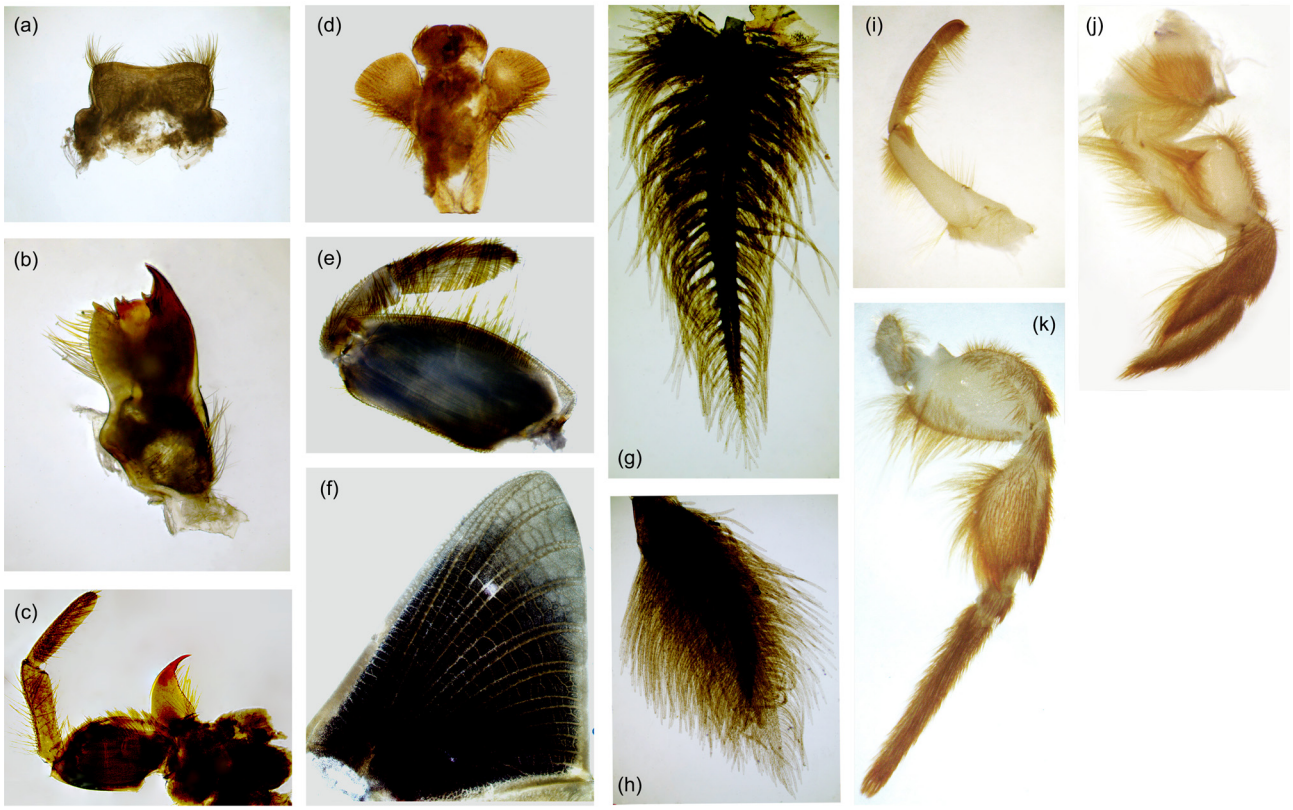

FIGURE 2. Photos of (a) labrum, (b) left mandible, (c) left maxilla, (d) labium (glossae and paraglossae), (e) left labial palp, (f) forewing pad, (g) gill on abdominal segment I, (h) gill on abdominal segment II, (i) prothoracic leg, (j) mesothoracic leg, and (k) metathoracic leg.

Taxonomy

Behningia nujiangensis represents the third species of family Behningiidae known from the Oriental geographical realm—the other two, *Protobehningia merga* Peters & Gillies and *Behningia baei* McCafferty & Jacobus, are known only from Thailand (Panrong *et al.* 2002). Morphological evidence indicates that *Behningia* (Palaearctic / Oriental) and the monotypic *Dolania* (Nearctic) are sister genera collectively distinguished from the third Behningiidae genus *Protobehningia* (Palaearctic / Oriental) by some specialized characteristics in the tarsus of the prothoracic leg and the tibia of the metathoracic leg (Peters & Gillies 1991; McCafferty & Jacobus 2006). The nymphal specimens collected in this study exhibit several trademark features of the family Behningiidae, including typical Ephemeroidea-like gills that are ventrally-positioned, an extremely-specialized labium with expanded, tri-segmented labial palpi, and an absence of claws on the tarsi.

The nymphal stages of the genera *Behningia* and *Dolania* are distinguished primarily by wing/wing pad venation and labial glossae and paraglossae. (1) Venation: veins of the forewing pad of *Behningia* form geminate pairs, while veins of *Dolania* do not; and (2) labial glossae fuse in *Behningia*, while those of *Dolania* do not.

Based on descriptions and figures from McCafferty & Jacobus (2006) and Edmunds & Traver (1959), as well as photos of *B. baei* (provided by R. W. Sites), *B. nujiangensis* is distinct from other *Behningia* spp. (in particular *B. ulmeri* and *B. baei*) in the following characters: (1) labrum—the medio-anterior emargination on labrum of *B. nujiangensis* is very shallow, while those of other *Behningia* spp. are much deeper and usually U- or V- shaped; (2) mandibles—the molar part of the mandible of *B. nujiangensis* possesses a small apical spine, while molar areas of *B.*

baei and *B. ulmeri* lack spines; (3) galea-lacinia of maxilla—the galea-lacinia in *B. nujiangensis* is conical, slender and tapered to a point; it is definitely not crudely-ovoid like those of either *B. baei* or *B. ulmeri*; (4) labial paraglossae—the paraglossae of *B. nujiangensis* are as long as wide, while those of other *Behningia* spp. are elongated and narrow; (5) prothoracic legs—tarsus is 40% the length of tibia in *B. nujiangensis*, while in both *B. baei* and *B. ulmeri* the tarsus and tibia are of equal length; (6) metathoracic legs—each coxa is as long as the femur in *B. nujiangensis*, while in *B. baei* and *B. ulmeri* a coxa is no more than 60% the length of the femur.

FIGURE 3. Photos of live specimens of *Behningia nujiangensis.* (a–d) Paratype KIZ0107184. (e–h) Paratype KIZ0107185.

Biology and conservation. *Behningia nujiangensis* nymphs are highly specialized, burrowing into the sandy bottom of the Nujiang River. A *B. nujiangensis* specimen was observed in the laboratory to easily dig down to a depth of 10 cm in a uniform sand substrate. A video (provided as Supporting Material Video S2) made at the *B. nujiangensis* type locality utilizing a narrow plastic aquarium documented its burrowing behavior: the *B. nujiangensis* began burrowing head-first into sand initially at an angle of 60°–70°, then gradually decreased the attack angle to 20°–30° until the whole body was covered by sand. It took less than 5 seconds for *B. nujiangensis* to completely bury itself in the substrate.

Behningiidae is one of the few predacious mayfly families, feeding on small benthic invertebrates. According to Tsui & Hubbard (1979), *D. americana* mainly preys on larvae of Chironomidae and Ceratopogonidae, and on nematodes. It is most likely that *B. nujiangensis* also feeds on sand-dwelling larvae of Chironomidae, and perhaps also on larvae of Tipulidae, since both of these were also collected at the holotype's location.

The specimens at different instar stages collected at the same locality and time (Fig. 4) imply that the nymphal development in *B. nujiangensis* requires more than one year, as is the case for *B. ulmeri* (Bauernfeind & Soldán 2012) and *Dolania americana* (Peters *et al.* 1987; Fink *et al*. 1991). Other aspects of the *B. nujiangensis* life-cycle remain unknown. No adults have been collected yet.

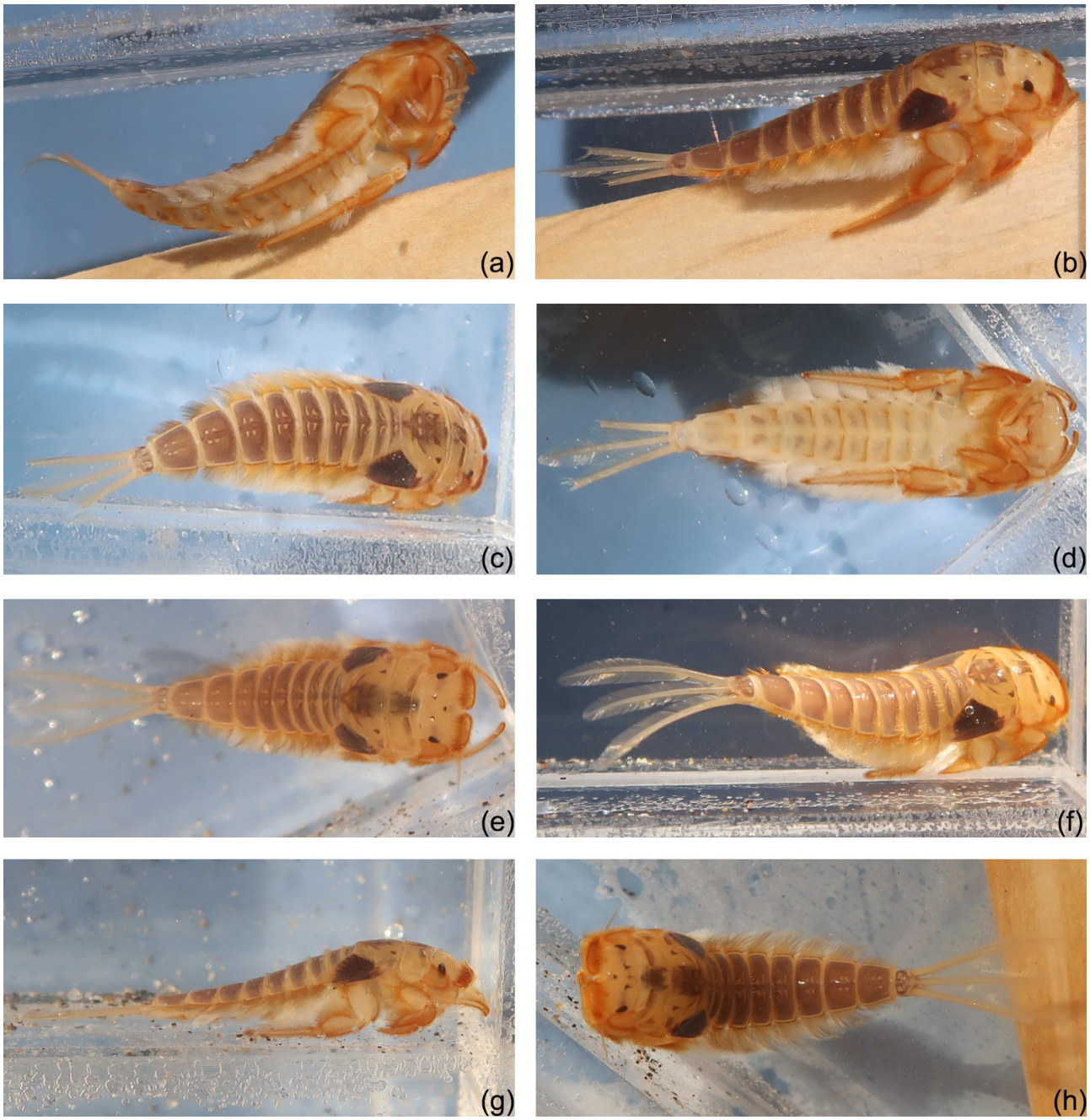

FIGURE 4. Nymphal instar variations of the *Behningia nujiangensis* specimens collected at the same locality (27.3842°N, 98.8344°E) on February 13, 2019. All specimens photographed are among the deposited materials.

The middle reaches of the Nujiang River flow through a deeply incised canyon, the Nujiang Great Canyon, where the channel might naively be assumed to be bedrock-bounded rather than with sandy bars. However, in reality intense channel incision has triggered the formation of natural debris-flow depositions. These natural depositions impound water upstream, where the marginal flow rate dramatically decreases and fine sediments are then deposited to form sandy bars (Wang *et al*. 2009). The existence of such massive natural debris-flow depositions in the Nujiang River is probably a critical factor creating habitats for this sand-burrowing mayfly (Zhou *et al.* 2019). However, such pasmmophilous mayflies may be threatened by habitat loss and pollution caused by anthropogenic activities (Jacobus 2013). Dozens of dark sandy bars similar to the holotype locality were observed along the river; the larger of such sites almost invariably showed evidence of past or current dredging operations. Observations suggest *B. nujiangensis* may avoid recently-disturbed sites. According to the recent hydropower development program (NEA 2016), planning is underway for four large dams to be constructed along the middle reaches of the Nujiang River before 2020, and nine more dams in the more distant future. With the huge volumes of water that will be impounded

upstream by these large dams, the existing sandy bars will be completely submerged while new sandy bars may be formed around the new highly-elevated water surface. Thus, the impact of regional hydropower development plans on the conservation of *B. nujiangensis* is uncertain.

Given the burrowing habits and the sparse population densities of behningiids, and also examining the previous localities of the known species as shown in Fig. 5, and considering the recent discoveries of new species, it is perhaps likely that additional undiscovered species await detection, particularly in Asia (central, southeastern, and/or far eastern).

Based in part on previous keys and illustrations in the literature (Edmunds & Traver 1959; Chernova & Baikova 1960; Hubbard 1994; McCafferty & Jacobus 2006), a key to the identification of the nymphs of the seven extant species of Behningiidae, excluding *B. tshernovae*, is provided below. According to McCafferty & Jacobus (2006), nymphal specimens attributed to *B. tshernovae* might actually belong to *B. lestagei* due to an incorrect nymph-adult specimen association. Due to this uncertainty, unlike in the nymph key of Hubbard (1994), *B. tshernovae* is not included in the following key. Bauernfeind & Soldán (2012) regarded *B. lestagei* as being probably a junior synonym of *B. ulmeri*. Deferring judgement on this issue, the entry for *B. lestagei* in the following key is retained. *Dolania* in the key is still treated as a monotypic genus even though Webb *et al*. (2012) have indicated that this North American genus might be a complex of more than one closely-related species.

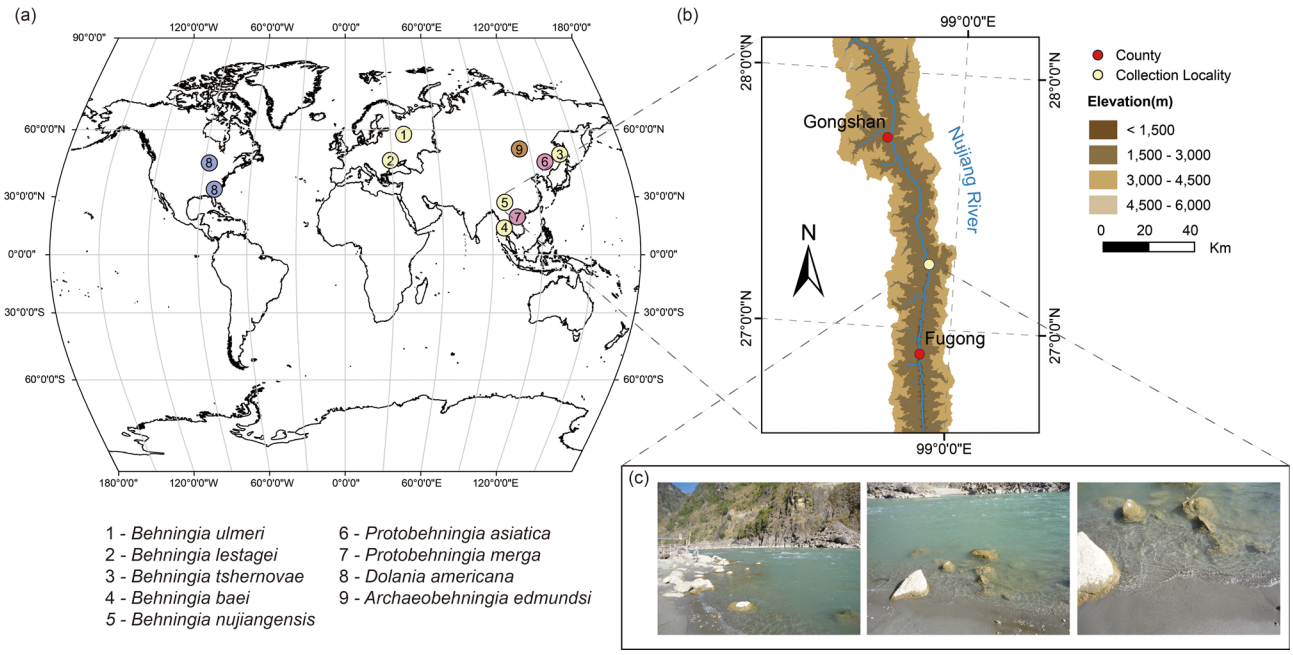

FIGURE 5. (a) Collection localities of species of Behningiidae, including *Behningia tshernovae* and the Jurassic fossil genus *Archaeobehningia*. (b) More detailed map for the collection locality of *Behningia nujiangensis* in the middle reach of the Nujiang River, Yunnan Province, China. (c) Habitat conditions at the collection locality.

Key to the seven extant species of Behningiidae (Nymph), excluding *B. tshernovae*

1 Tarsi of the prothoracic legs fused to tibiae; tibiae of the metathoracic legs not reduced . . . . . *Protobehningia*, 2
- Tarsi of the prothoracic legs not fused to tibiae; tibiae of the metathoracic legs reduced 3
2 Glossae and paraglossae with less than 5 long stout setae on the ventral surface . . . . . *Protobehningia asiatica* Tshernova
- Glossae and paraglossae with more than 20 long stout setae on the ventral surface . . . . *Protobehningia merga* Peters & Gillies
3 Forewing pads without gemination of veins; glossae of labium not fused; paraglossae of labium much wider than long . . . . . *Dolania americana* Edmunds & Traver
- Forewing pad with gemination of veins; glossae of labium fused; paraglossae of labium no wider than long . . . . . *Behningia*, 4
4 Medio-anterior emargination of labrum very shallow; paraglossae of labium as long as wide; coxa of metathoracic leg as long as femur . . . . . *Behningia nujiangensis,* **sp. nov.**
- Medio-anterior emargination of labrum deep, with U- or V-shape; paraglossae of labium much longer than wide; coxa of metathoracic leg less than 60% as long as femur. 5
5 Labial palp II more than 2/3 as long as labial palp III . . . . . *Behningia ulmeri* Lestage
- Labial palp II less than 1/2 as long as labial palp III 6
6 Labial palp I with straight margins from base, without marginal concavities . . . . . *Behningia baei* McCafferty & Jacobus
- Labial palp I with distinct concavities along the margins . . . . . *Behningia lestagei* Motas & Băcesco

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