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Letter to the editor Open Access

Challenging Wallacean and Linnean shortfalls: *Ectatosticta* spiders (Araneae, Hypochilidae) from China

Ectatosticta spiders from the Qinghai-Tibet Plateau were studied. Multilocus molecular and morphological data identified 16 putative species, including seven new species: *Ectatosticta wenshu* Lin & S. Li **sp. nov.**, *Ectatosticta baima* Lin & S. Li **sp. nov.**, *Ectatosticta helii* Lin & S. Li **sp. nov.**, *Ectatosticta shaseng* Lin & S. Li **sp. nov.**, *Ectatosticta puxian* Lin & S. Li **sp. nov.**, *Ectatosticta qingshi* Lin & S. Li **sp. nov.**, and *Ectatosticta baixiang* Lin & S. Li **sp. nov.** This increase in the number of *Ectatosticta* species from a single species in 2008 to 16 in the current study highlights the Linnean shortfall in China. The previously known distribution of *Ectatosticta* spiders was from one locality in Shaanxi and is now expanded to the east and south of the Qinghai-Tibet Plateau.

Taxonomists have described 1 438 769 species since binomial nomenclature began in 1753 (Mora et al., 2011), with an average of 5 576 species described each year for the past 258 years. Recent technological advances have accelerated the discovery of new taxa. However, the predicted total number of terrestrial species is 8 750 000 and marine species is 2 210 000 (Mora et al., 2011). It would take more than 1 000 years to document the remaining predicted species on the planet, even if we were able to describe 10 000 new species each year using advanced technologies. Clearly, knowledge of species diversity remains inadequate as most species are still not formally described (i.e., Linnean shortfall) and because geographical distributions of most species are poorly understood and usually contain many gaps (i.e., Wallacean shortfall) (Lomolino, 2004; Whittaker et al., 2005).

Spiders of the genus *Ectatosticta* Simon, 1892 (family Hypochilidae Marx, 1888) are an exemplary example of these shortfalls in China. Only two genera of hypochilids are known worldwide, i.e., *Hypochilus* Marx, 1888, which is endemic to the US (from California to New Mexico and the Appalachian Mountains), and *Ectatosticta*, which is endemic to China. Although 10 species of *Hypochilus* are now recognized in the US, the number of hypochilid species in China was limited to a single species, *Ectatosticta davidi* Simon, 1889, for 120 years due to Linnean and Wallacean shortfalls, with a second species not discovered until 2009 — *Ectatosticta deltshevi* Platnick & Jäger, 2009. These two species are known from the northern Qinghai-Tibet Plateau. However, recent discoveries (Lin & Li, 2020, 2021, Wang et al., 2021) have confirmed considerable *Ectatosticta* diversity in the southern Qinghai-Tibet Plateau, with higher species richness and wider distribution than that of *Hypochilus* in the USA. Thus, we conducted an in-depth study of *Ectatosticta* to challenge the Wallacean and Linnean shortfalls.

In total, 505 *Ectatosticta* specimens from 40 localities on the Qinghai-Tibet Plateau were studied, and seven genetic makers were analyzed to produce a robust phylogeny. Based on multilocus molecular and morphological data, we identified 16 putative species, i.e., *Ectatosticta deltshevi* Platnick & Jäger, 2009, *Ectatosticta wenshu* Lin & S. Li **sp. nov.**, *Ectatosticta davidi* (Simon, 1889), *Ectatosticta yukuni* Lin & S. Li, 2021, *Ectatosticta rulai* Lin & S. Li, 2021, *Ectatosticta baima* Lin & S. Li **sp. nov.**, *Ectatosticta helii* Lin & S. Li **sp. nov.**, *Ectatosticta shaseng* Lin & S. Li **sp. nov.**, *Ectatosticta wukong* Lin & S. Li, 2020, *Ectatosticta puxian* Lin & S. Li **sp. nov.**, *Ectatosticta bajie* Lin & S. Li, 2021, *Ectatosticta xuanzang* Lin & S. Li, 2020, *Ectatosticta baixiang* Lin & S. Li **sp. nov.**, *Ectatosticta dapeng* Lin & S. Li, 2021, *Ectatosticta qingshi* Lin & S. Li **sp. nov.**, and *Ectatosticta shennongjiaensis* Wang, Zhao, Irfan & Zhang, 2021 (Figure 1). New synonyms are proposed based on molecular analysis and morphological evidence, including *Ectatosticta nyingchiensis* Wang et al., 2021 **syn. nov.** as a junior synonym of *Ectatosticta dapeng*; *Ectatosticta pingwuensis* Wang et al., 2021 **syn. nov.** and *Ectatosticta songpanensis* Wang et al., 2021 **syn. nov.** as junior synonyms of

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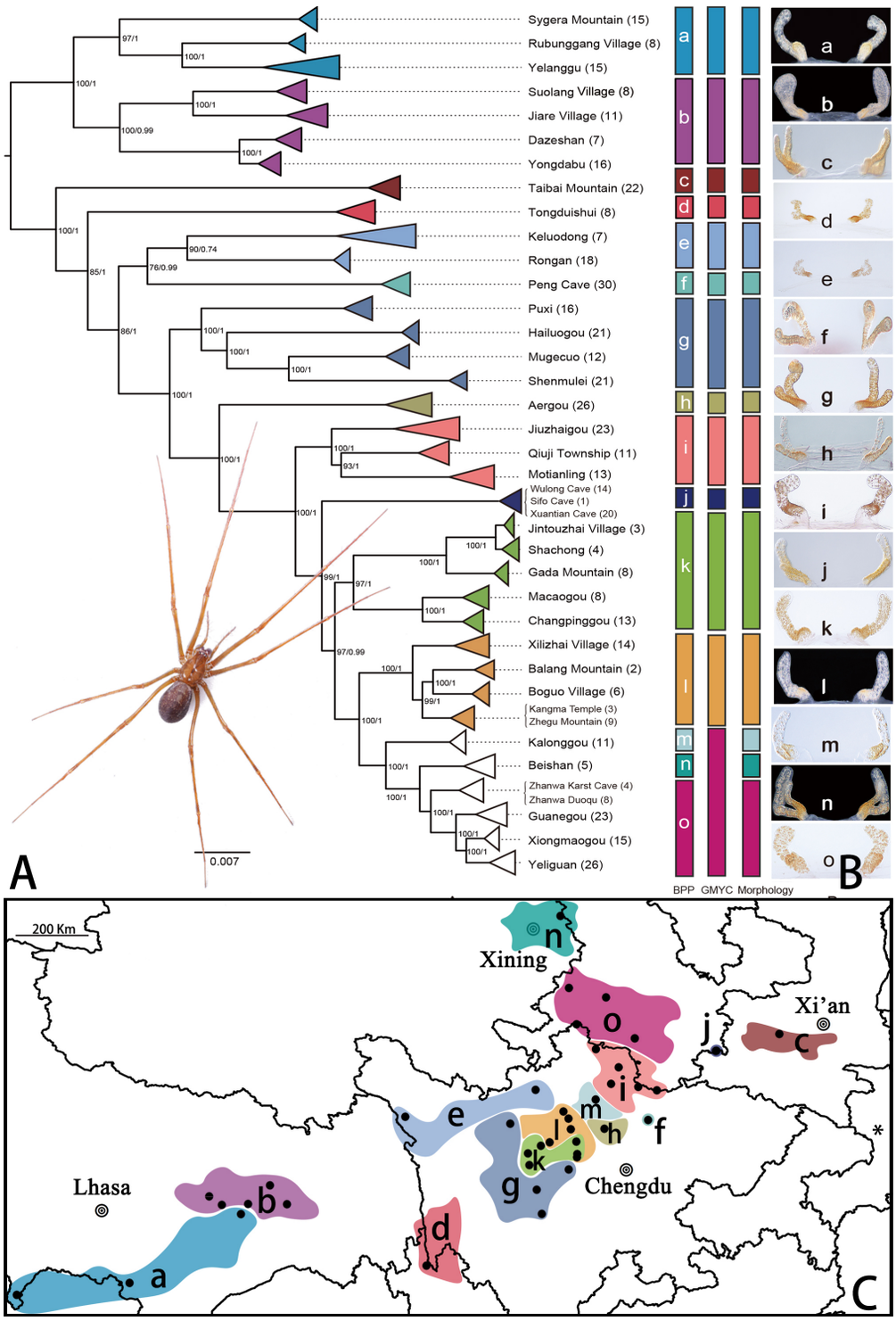

Figure 1 Phylogenetic tree and distribution of *Ectatosticta* species

A: Phylogeny of 505 specimens inferred from IQTree and MrBayes using seven genetic markers. Support for each branch is shown at the nodes, with bootstrap percentages given first, followed by posterior probabilities. Different species delimitation methods are shown on the right. Photo by Ye-Jie Lin. B: Genitalia of females (a: *Ectatosticta xuanzang*; b: *Ectatosticta dapeng*; c: *Ectatosticta davidi*; d: *Ectatosticta baixiang* **sp. nov.**; e: *Ectatosticta qingshi* **sp. nov.**; f: *Ectatosticta helii* **sp. nov.**; g: *Ectatosticta bajie*; h: *Ectatosticta shaseng* **sp. nov.**; i: *Ectatosticta rulai*; j: *Ectatosticta yukuni*; k: *Ectatosticta puxian* **sp. nov.**; l: *Ectatosticta wukong*; m: *Ectatosticta baima* **sp. nov.**; n: *Ectatosticta deltshevi*; o: *Ectatosticta wenshu* **sp. nov.**). C: Distribution of *Ectatosticta* spiders in China. Dark spots represent locations of samples and correspond to Supplemnetary Table S1. The asterisk represents the species *Ectatosticta shennongjiaensis*.

Ectatosticta rulai. For detailed morphological descriptions, diagnoses, illustrations, and identification key of all *Ectatosticta* species, please see the online Supplementary Material. The actual distribution of *Ectatosticta* spiders suggests that they are a psychrophilic species, mainly distributed east and south of the Qinghai-Tibet Plateau at an altitude of 2 000–4 000 m a.s.l. with strict temperature and humidity requirements.

Our study used a multi-gene approach, including non-protein-coding and protein-coding mitochondrial and nuclear genes. The seven markers included three mitochondrial gene fragments (*COX1*, *COX2*, and *COX3*), two nuclear protein-coding loci (*ANKRD50* and *MOGS*), and two nuclear rDNA genes (*18S* and *28S*). Phylogenetic reconstruction was performed using IQTree v1.5.5 (Nguyen et al., 2015) for fast maximum-likelihood (ML) analysis and MrBayes 3.1.2 (Ronquist & Huelsenbeck 2003) for Bayesian inference (BI) analysis. We used two different molecular methods combined with morphological data to detect putative cryptic species: i.e., generalized mixed Yule-coalescent (GMYC) and Bayesian multispecies coalescent approaches with Bayesian Phylogenetics and Phylogeography (BPP) software. The GMYC model was used to identify genealogical clusters that may also correspond to cryptic species lineages. ML was used to fit the GMYC model to an ultrametric tree to identify a threshold time (T) that corresponded to Yule-coalescent transition. The BPP method was used to detect signals of species divergence for putative cryptic species suggested by the phylogeny (Yang, 2015). The sequence alignments were analyzed under the multispecies coalescent model (MSC) with a reversible-jump Markov chain Monte Carlo (rjMCMC) algorithm. Each analysis was run for 200 000 iterations with a sampling frequency of 5 and burn-in of 10 000 iterations.

The phylogenetic tree was generally well resolved, with both ML and BI analyses producing an identical topology at the species level (Figure 1). The Tibet species were basal to the other species. BPP analysis identified 15 provisional species for the dataset, which were relatively consistent with morphology. GMYC analysis recognized 13 provisional species. The differences in the BPP and GMYC results focused on individuals mainly distributed in Gansu, Beishan in Qinghai, and Kalong in Sichuan. The GMYC analysis recognized three lineages as one species, whereas BPP analysis and morphological evidence supported their status as separate species. Specimens from Beishan were described as *Ectatosticta deltshevi*, and this location is geographically distant from *Ectatosticta baima* **sp. nov.** in Kalong and *Ectatosticta wenshu* **sp. nov.** in Gansu. Furthermore, *Ectatosticta baima* **sp. nov.** and *Ectatosticta wenshu* **sp. nov.** were easily distinguished from *Ectatosticta deltshevi* based on copulatory organs.

The known number of species of Chinese spiders—5 252 species in 827 genera of 69 families—only accounts for about 5% of the entire Chinese spider fauna (Yao & Li, 2021). The increase in *Ectatosticta* species from a single species in 2008 to 16 in the current study highlights the Wallacean and Linnean shortfalls in China.

TYPE MATERIAL AND NOMENCLATURAL ACTS REGISTRATION

Type material in the paper is housed in the Institute of Zoology, Chinese Academy of Sciences (IZCAS) in Beijing, China. The electronic version of this article in portable document format represents a published work according to the International Commission on Zoological Nomenclature (ICZN), and hence the new names contained in the electronic version are effectively published under that Code from the electronic edition alone (see Articles 8.5–8.6 of the Code). This published work and the nomenclatural acts it contains have been registered in ZooBank, the online registration system for the ICZN. The ZooBank LSIDs (Life Science Identifiers) can be resolved and the associated information can be viewed through any standard web browser by appending the LSID to the prefix http://zoobank.org/.

Publication LSID:
urn:lsid:zoobank.org:pub:9523E776-C186-4A51-A86F-49085A6791AA

Ectatosticta baima Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:85C4A158-8768-4CCB-A54C-24CA82229B7C

Ectatosticta baixiang Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:6D52EA91-9028-4ACC-8E33-6A2061FC1A75

Ectatosticta helii Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:532275A0-04E2-4C55-8655-AE60A5AD7E90

Ectatosticta puxian Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:178BC945-4596-419C-975C-CE6B724D2B2B

Ectatosticta qingshi Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:953D4F62-2ED2-446B-9152-555C799EA352

Ectatosticta shaseng Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:59E7F931-512F-4767-9C5B-DC9559646192

Ectatosticta wenshu Lin & S. Li, **sp. nov.** LSID:
urn:lsid:zoobank.org:act:19972091-924A-4398-A4EA-2B8C193FA39D

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Permission for field surveys in Gansu, Sichuan, Qinghai, and Tibet was granted by the National Forestry and Grassland Administration, China.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online and at Figshare (DOI: 10.6084/m9.figshare.14829459).

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

S.Q.L., X.Y.Y., and H.F.C. designed the study. Y.J.L. contributed to fieldwork and performed morphological species identification. J.N.L. acquired molecular data and completed descriptions. J.N.L. and S.Q.L. drafted and revised the manuscript. All authors read and approved the final version of the manuscript.

Jiang-Ni Li[1], Xun-You Yan[1,*], Ye-Jie Lin[1], Shu-Qiang Li[2,*], Hai-Feng Chen[1,*]

[1] *Hebei Key Laboratory of Animal Diversity*, *College of Life Science*, *Langfang Normal University*, *Langfang*, *Hebei* 065000, *China*

[2] *Institute of Zoology*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*

*Corresponding authors, E-mail: yanxunyou@163.com; lisq@ioz.ac.cn; chenhaifeng@lfnu.edu.cn

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