New fossil hangingflies (Mecoptera, Raptipeda, Bittacidae) from the Middle Jurassic to Early Cretaceous of Northeastern China

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ABSTRACT
A new genus with a new species, *Exilibittacus lii* n. gen., n. sp., and a new species, *Megabittacus spatiosus* n. sp., are described and illustrated. Both of them belong to the family Bittacidae (Mecoptera). These specimens were collected respectively from the Middle Jurassic of Jiulongshan Formation at Daohugou in Inner Mongolia and from the Late Jurassic to Early Cretaceous of Yixian Formation at Dawangzhangzi in Liaoning, China. In *Exilibittacus* n. gen., both RP+MA and MP have four branches in forewings, while both have three branches in hind wings, and RP1+2 and MP3 are not forked. This is the first time that the character 'MP with three branches in hind wings' is reported for the Bittacidae. Based on data on *Megabittacus spatiosus* n. sp., the diagnosis of *Megabittacus* is revised and a key to the known species is provided. Morphological changes in hangingflies from Middle Jurassic to present are discussed based on body length, wing length, and forewing/body length ratio.

KEY WORDS
Mecoptera,
Bittacidae,
Insect fossil,
Jiulongshan Formation,
Yixian Formation,
new species,
new genus.

RÉSUMÉ
De nouveaux fossiles de « mouches-scorpion » (Mecoptera, Raptipeda, Bittacidae) du Jurassique Moyen au Crétacé inférieur du nord-est de la Chine.
Exilibittacus lii n. gen., n. sp. et *Megabittacus spatiosus* n. sp. sont décrits et appartiennent à la famille des Bittacidae (Mecoptera). Les spécimens proviennent, respectivement, du Jurassique moyen de la Formation Jiulongshan (Daohugou, Mongolie intérieure) et du Jurassique supérieur au Crétacé inférieur de la Formation Yixian (Dawangzhangzi, Liaoning, Chine). Chez *Exilibittacus* n. gen., RP+MA et MP ont chacune quatre branches aux ailes antérieures, tandis que ces nervures ont trois branches aux ailes postérieures, et RP1+2 et MP3 ne sont pas branchées. C'est la première fois que le caractère « MP avec trois branches aux ailes postérieures » est observé chez les Bittacidae. Basée sur des données sur *Megabittacus spatiosus* n. sp., la diagnose de *Megabittacus* est révisée et une clé des espèces connues est fournie. Les changements morphologiques chez les « mouches-scorpion » du Jurassique Moyen à l'actuel sont discutés sur la base de la longueur du corps, la longueur des ailes, et du rapport de longueur ailes antérieures/corps.

MOTS CLÉS
Mecoptera,
Bittacidae,
insectes fossiles,
Formation Jiulongshan,
Formation Yixian.

INTRODUCTION

Bittacidae, a large family of Mecoptera which is one of the less diverse insect Orders, is considered to be a sister group of Cimbrophlebiidae. Together, Bittacidae and Cimbrophlebiidae form the infraorder of Raptipeda (Willmann 1977, 1989). Bittacids and cimbrophlebiids share the same special tarsi structure: the fifth tarsomere can be folded against the fourth and tarsus has only one claw. Their wing venations are similar, but cimbrophlebiids can be easily identified by long and branched 2A, which is short and unbranched in bittacids (Willmann 1977, 1989). Usually bittacids wings are slender and both RP+MA and MP veins have four branches, except for *Orobittacus* RP+MA with three branches. They are called hangingflies because they commonly hang their bodies by two fore legs from branches among low vegetation, while using free middle and hind legs to catch insects (Petrulevičius *et al.* 2007). At present, there are 16 extant genera including about 270 species of Bittacidae (Krzemiński 2007). Extant bittacids are distributed globally in both temperate and warm tropical climates. In addition to extant bittacids, about 29 fossil genera have been described (Tillyard 1933; Handlirsch 1939; Martynov 1951; Byers 1979; Villegas & Byers 1981; Ren 1993, 1997; Novokshonov 1997; Petrulevičius & Jarzembowski 2004; Petrulevičius *et al.* 2007). Fossil records show a broadest generic diversity occurring in the Jurassic (Novokshonov 2002).

To date, eight fossil genera of hangingflies from the Middle Jurassic to the Early Cretaceous have been recorded in China: *Liaobittacus* Ren, 1993 from the Haifanggou Formation; *Jichoristella* Ren, 1994 from the Lushanfeng Formation; *Megabittacus* Ren, 1997, and *Sibirobittacus* Sukatsheva, 1990 from the Yixian Formation; *Mongolbittacus* Petrulevičius, Huang & Ren, 2007, *Formosibittacus* Li, Ren & Shih, 2008, *Jurahylobittacus* Li, Ren & Shih, 2008, and *Decoribittacus* Li & Ren, 2009 from the Jiulongshan Formation.

A new hangingfly, *Exilibittacus lii* n. gen., n. sp., is described in this paper. The specimen was collected from the Jiulongshan Formation at Daohugou Village of Ningcheng County in Inner Mongolia, China. The age of the Daohugou fossil-bearing beds is considered to be the Middle Jurassic (Ren *et al.* 1995; Ren & Krzemiński 2002; Ren *et al.* 2002; Shen *et al.* 2003; Chen *et al.* 2004; Liu *et al.* 2004; Gao & Ren 2006; Huang *et al.* 2006; Ji *et al.* 2006).

A new species, *Megabittacus spatiosus* n. sp., was collected from the Yixian Formation at Dawangzhangzi in Lingyuan, western Liaoning, China. The

age of the Yixian Formation remains debatable. Three different opinions about the age: the Late Jurassic (Ren 1997; Zheng *et al.* 2003), transition from the Late Jurassic to Early Cretaceous (Chen *et al.* 2004; Wang *et al.* 2004, 2005), and the Early Cretaceous (Swisher *et al.* 1999; Li *et al.* 2001; Pang *et al.* 2002; Zhou *et al.* 2003), have been proposed based on both biostratigraphic and radiometric geochronologies. By comparing the Yixian biota with the Solnhofen biota of Germany, the Purbeck biota in England and the Late Jurassic Terori-type and Ryoseki-type floras in Japan, Wang *et al.* (2005) considered the synthetic age of the Yixian Formation as the Late Jurassic-Early Cretaceous (the Late Tithonian to the Berriasian).

MATERIAL AND METHODS

The fossil specimens were examined by a LEICA MZ12.5 dissecting microscope and illustrated with the aid of a camera lucida attached to the microscope. All specimens are deposited in the Key Laboratory of Insect Evolution & Environmental Changes, the College of Life Sciences, Capital Normal University, Beijing, China (CNU, Ren Dong, Curator). Photographs of whole specimens were taken by Nikon D100 digital camera coupled to a Nikkor 105 mm macro lens, and detailed photographs were made by using Nikon SMZ1000 stereomicroscope. The terminology for wing venation follows Kukalová-Peck (1983, 1991), "Kreuz der Bittaciden" is defined as the cross-veins of [RP3+4+MA-MP1+2, MP1+2-MP3] (Novokshonov 1993). The venational nomenclature of Kukalová-Peck is compared with that of Byers (1979) in Table 1 for easy reference.

ABBREVIATIONS

Venation nomenclature

RA	anterior radius;
RP	posterior radius;
MA	anterior media;
MP	posterior media;
CuA	anterior cubitus;
AA	anterior anal;
AP	posterior anal;
ScP	posterior subcosta.

TABLE 1. — Comparison of venation nomenclatures between Kukalová-Peck and Byers.

Kukalová-Peck system (1983, 1991)	Byers system (1979)
ScP	Sc
RA	R1
RP	RS
MA	R5
MP	M
MP4 + CuAl + 2	M4
CuA3 + 4	CuA
CuP	CuP
AA3 + 4	1A
AP1 + 2	2A
AP3+4	3A

SYSTEMATICS

Order MECOPTERA Packard, 1886
Infraorder RAPTIPEDA Willmann, 1977
Family BITTACIDAE Handlirsch, 1906

Genus *Exilibittacus* n. gen.

TYPE SPECIES. — *Exilibittacus lii* n. sp.

ETYMOLOGY. — The generic name is derived from the Latin word "*exil-*" (weak) and *bittacus* (a recent genus of Bittacidae). Gender masculine.

DIAGNOSIS. — One crossvein between ScP and RA; RA sharply bent distally; RP+MA forking before the fork of MP; "Kreuz der Bittaciden" aligned, MP3+MP4+CuA1+2 forking before posterior part of "Kreuz der Bittaciden" (if existing); one crossvein between MP4+CuA1+2 and CuA3+4; AA3+4 short; Forewing both RP+MA and MP with four branches, but hind wing, three branches.

REMARKS

Exilibittacus n. gen. can be assigned to the infraorder Raptipeda (Willmann 1977, 1989) on the characteristics of legs: long and slender, with a single, predatory claw, the fifth tarsomere folding back toward fourth. Furthermore, it can be classified into the Bittacidae by AA3+4 short and AP1+2 absent on a well-preserved forewing, in contrast to cimbrophlebiids with AA3+4 long and AP1+2 very long and branched.

Forewing of *Exilibittacus* n. gen. is similar to *Antiquanabittacus* Petrulevičius & Jarzembowski, 2004 and *Mongolbittacus* Petrulevičius, Huang &

TABLE 2. — A list of fossil and extant bittacid species examined. Abbreviation: **fm.**, formation; **LR**, Length ratio of forewing/body.

Species	Distribution	Age	Sex	Body (mm)	Forewing (mm)	LR
Liaobittacus longanteenatus Ren, 1993	Haifanggou Fm.	J2	Male	20	21	1.05
Mongolbittacus daohugouensis Petrulevičius, Huang & Ren, 2007	Jiulongshan Fm.	J2	?	9.5	12.5	1.32
Formosibittacus macularis Li, Ren & Shih, 2008	Jiulongshan Fm.	J2	Female	21	23	1.10
Jurahylobittacus astictus Li, Ren & Shih, 2008	Jiulongshan Fm.	J2	Male	18	12	0.67
Exilibittacus lii n. gen., n. sp.	Jiulongshan Fm.	J2	Female	12	7.5	0.63
Megabittacus colosseus Ren, 1997	Yixian Fm.	J3-K1	?	40	40	1.00
Sibirobittacus atalus Ren, 1997	Yixian Fm.	J3-K1	?	18	18.5	1.03
Megabittacus spatiosus n. sp.	Yixian Fm.	J3-K1	Male	38	41	1.07
Palaobittacus eocenicus Carpenter, 1928	Green River, Utah	Eocene	Female	13	14	1.08
Bittacus egestionis Carpenter, 1955	Green River, Utah	Eocene	Female	7	8	1.14
Bittacus succinus Carpenter, 1954	Baltic amber	Late Eocene	Male	15	17	1.13
Hylobittacus minimus (Carpenter, 1954) Krzemiński, 2007	Baltic amber	Late Eocene	Male	12.1	13 (11.5-13)	1.07
Hylobittacus antiquus (Pictet, 1854) Krzemiński, 2007	Baltic amber	Late Eocene	Female	17.1	19	1.11
Bittacus lii Zhou, 2003		Extant	Male	20	25.4	1.27
Bittacus obscures Huang, 2005		Extant	Male	13-13.5	18-19	1.39
Bittacus flavidus Huang, 2005		Extant	Male	17-17.5	23.5-24	1.37
Bicaubittacus longiprocessus Tan, 2009		Extant	Male	20	20	1
Bittacus trapezoideus Huang, 2005		Extant	Male	13	17	1.31
Bittacus choui Hua &Tan, 2007		Extant	Male	11	16	1.45
Bittacus maculosus Byers, 1965		Extant	Female	24	23	0.96
Kalobittacus hubbelli Byers, 1965		Extant	F/M	18	18	1
Terrobittacus implicates Tan & Hua, 2009		Extant	Male	11	15.3-15.5	1.4
Terrobittacus longisetus Tan & Hua, 2009		Extant	Male	13.8-14.6	20.3-20.7	1.44
			Female	13.7-15.8	20.2-21.4	1.41
Terrobittacus xiphicus Tan & Hua, 2009		Extant	Male	12	15	1.25
Issikiella byersi Penny, 1982		Extant	Male	13.2-15	15.4-16.8	1.14
			Female	12.5	15-15.5	1.22
Nannobittacus souzalopesi Penny, 1982		Extant	Male	15	16.5	1.1
			Female	14	17	1.21
Nannobittacus tjederi Byers, 1965		Extant	Male	19	20.6	1.08
Harpobittacus tillyardi Lambkin, 1994		Extant	Male	27.8 est.	25.3 (21.2-26.4)	0.91 est.
Symbittacus scitulus Byers, 1986		Extant	Female	13	14.1	1.08
Orobittacus obscures Villegas & Byers, 1981		Extant	Male	15.7	16.9	1.08
			Female	15.0	16.8	1.12
Pazius gracilis Byers, 1957		Extant	Male	23	17	0.74
Pazius obtusus Byers, 1957		Extant	Male	23	18	0.78

Ren, 2007 in the wing venation and size. But the new genus can be distinguished from *Antiquanabittacus* by these characters: MP3+MP4+CuA1+2 not short; no crossvein present between AA3+4 and CuP; only one crossvein between MP4+CuA1+2 and CuA3+4. It can also be differentiated from *Mongolbittacus* by one crossvein between ScP and RA; RA with one pterostigma crossvein to RP1 and RP+MA forking before the fork of MP. This new genus can be easily distinguished from all other fossil genera: hind wing both RP+MA and MP are with three branches; one crossvein between ScP and RA; RA with one pterostigma crossvein to RP1; RP+MA forking before the fork of MP; "Kreuz der Bittaciden" aligned, MP3+MP4+CuA1+2 forking before posterior part of "Kreuz der Bittaciden" (if existing); one crossvein between MP4+CuA1+2 and CuA3+4; and AA3+4 short.

The new genus *Exilibittacus* n. gen. has both RP+MA and MP with four branches in forewings,

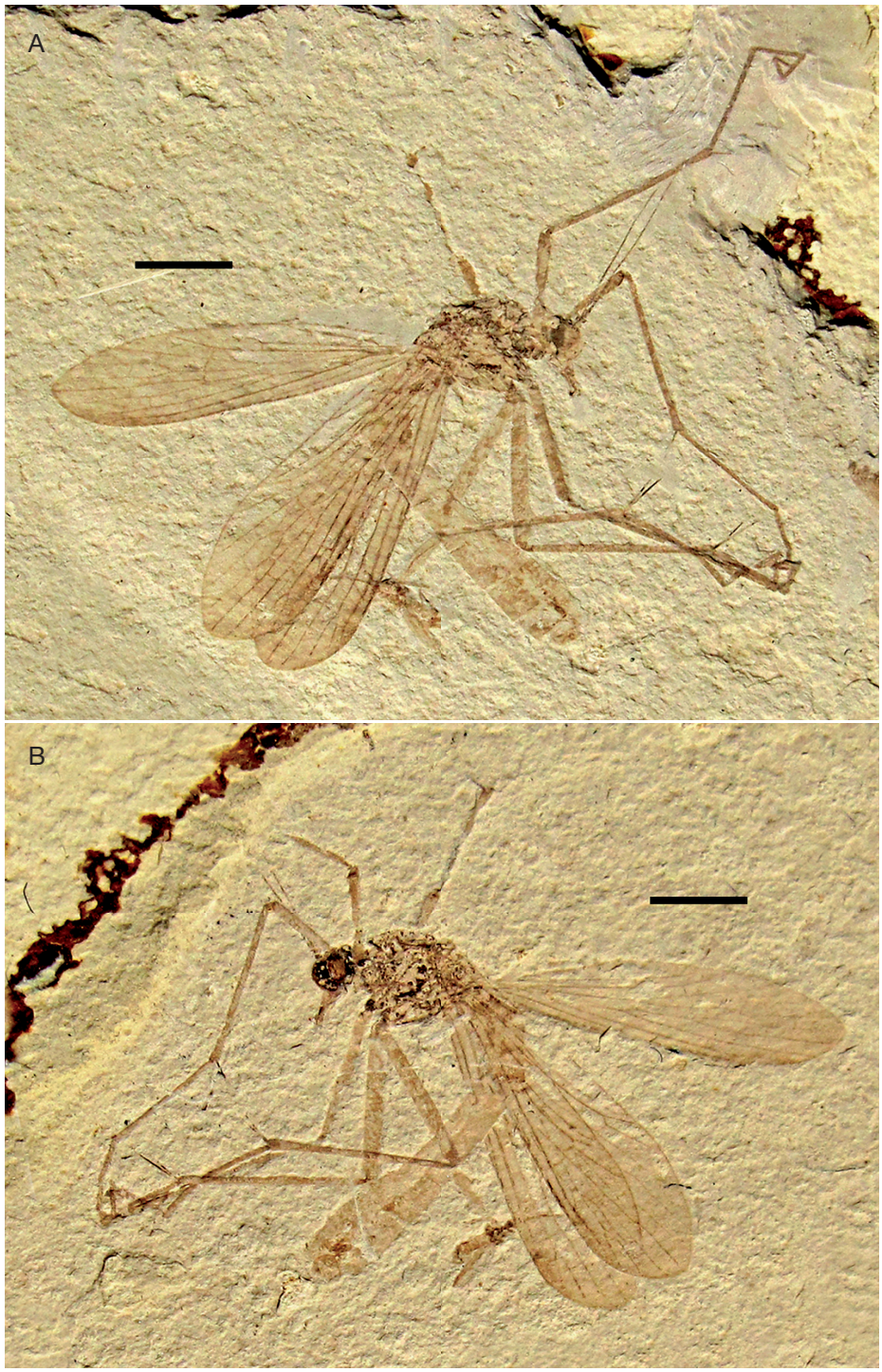

FIG 1. — *Exilibittacus lii* n. gen., n. sp., holotype: **A**, part (CNU-M-NN2010001p); **B**, counterpart (CNU-M-NN2010001c).

while both with three branches in hind wing; RP1+2 and MP3 not forking. Up to date, among the described bittacids, only *Orobittacus* has vein RP+MA with three branches (RP1+2 not forking). This is the first time that the character of MP with three branches in hind wings is reported for the Bittacidae.

Exilibittacus lii n. gen., n. sp.
(Figs 1A, B; 2A-F)

HOLOTYPE. — CNU-M-NN2010001p/c, part and counterpart, lateral view, preserved completely, except for missing right hind wing and partial left middle leg. Deposited at the Key Laboratory of Insect Evolution & Environmental Changes, the College of Life Sciences, Capital Normal University (CNU), Beijing, China.

ETYMOLOGY. — The specific name is dedicated to Mr. Junyan Li who kindly donated this important specimen to CNU from his private collection.

HORIZON AND LOCALITY. — Jiulongshan Formation, Middle Jurassic, Daohugou Village, Shantou Township, Ningcheng County, Inner Mongolia, China.

DIAGNOSIS. — As for the genus by monotypy.

DESCRIPTION
Female, small sized.

Head
Vertex of head raised, rostrum long and slender; eyes large; antenna filiform, with short scape, stout pedicel (Figs 1A, B; 2A).

Leg
Long and slender densely covered by short setae; femur strong, tibia with two terminal spurs; tarsus with five segments, the fifth tarsomere folded against the fourth, with a single, predatory tarsal claw. (Figs 1A, B; 2A, B).

Forewing
Without thyridium, basal part narrow, gradually broaden to apex; pterostigma slightly dark; ScP short, ending in the middle of forewing; one crossvein arising at 2/3 of ScP between ScP and RA; RA through pterostigma, slightly bent distally, not branched; both RP+MA and MP four branches; RP+MA forking before the fork of MP, almost at 1/3 of wing length; MP1+2 forking after RP3+4+MA; RA with two crossveins to RP1+2 and RP1 (one crossvein is pterostigma crossvein); one crossvein between MP1 and MP2; one crossvein between MP2 and MP3; no crossvein present between AA3+4 and CuP; AA3+4 short; AP1+2 absent. Right forewing one crossvein between RP2 and RP3+4; one crossvein between RP3+4 and MA; two crossveins between MA and MP1, but these four crossveins absent in left forewing. Left forewing part of "Kreuz der Bittaciden" (mp1+2-mp3 crossvein) preserved. (Figs 1A, B; 2A, C, D).

Hind wing
Slightly narrower than forewing, apical margin slightly sharp-pointed; one crossvein arising before the end of ScP between ScP and RA; both RP+MA and MP with three branches; MP1+2 forking after RP3+4+MA; RA with two crossveins to RP1 (one crossvein is pterostigma crossvein); one crossvein between RP1+2 and RP3+4; one crossvein between RP3+4 and MA; one crossvein between MA and MP1; one crossvein between MP1 and MP2; one crossvein between MP2 and MP3; one crossvein between CuA and CuP; AA3+4 very short, reaching posterior wing margin after the origin of RP; AP1+2 absent. (Figs 1A, B; 2A, E).

Abdomen
Eight segments visible, T9 fused with T8; terminal abdominal segments well preserved; subgenitalis (bearing a conspicuous patch of large setae), tergum octavum, supra-anale, cercus and subanale visible. (Figs 1A, B; 2A, F).

Measurement
Body 12 mm long; forewing 7.5 mm long, 2.2 mm wide; hind wing 7.0 mm long, 1.7 mm wide.

Genus *Megabittacus* Ren, 1997

TYPE SPECIES. — *Megabittacus colosseus* Ren, 1997.

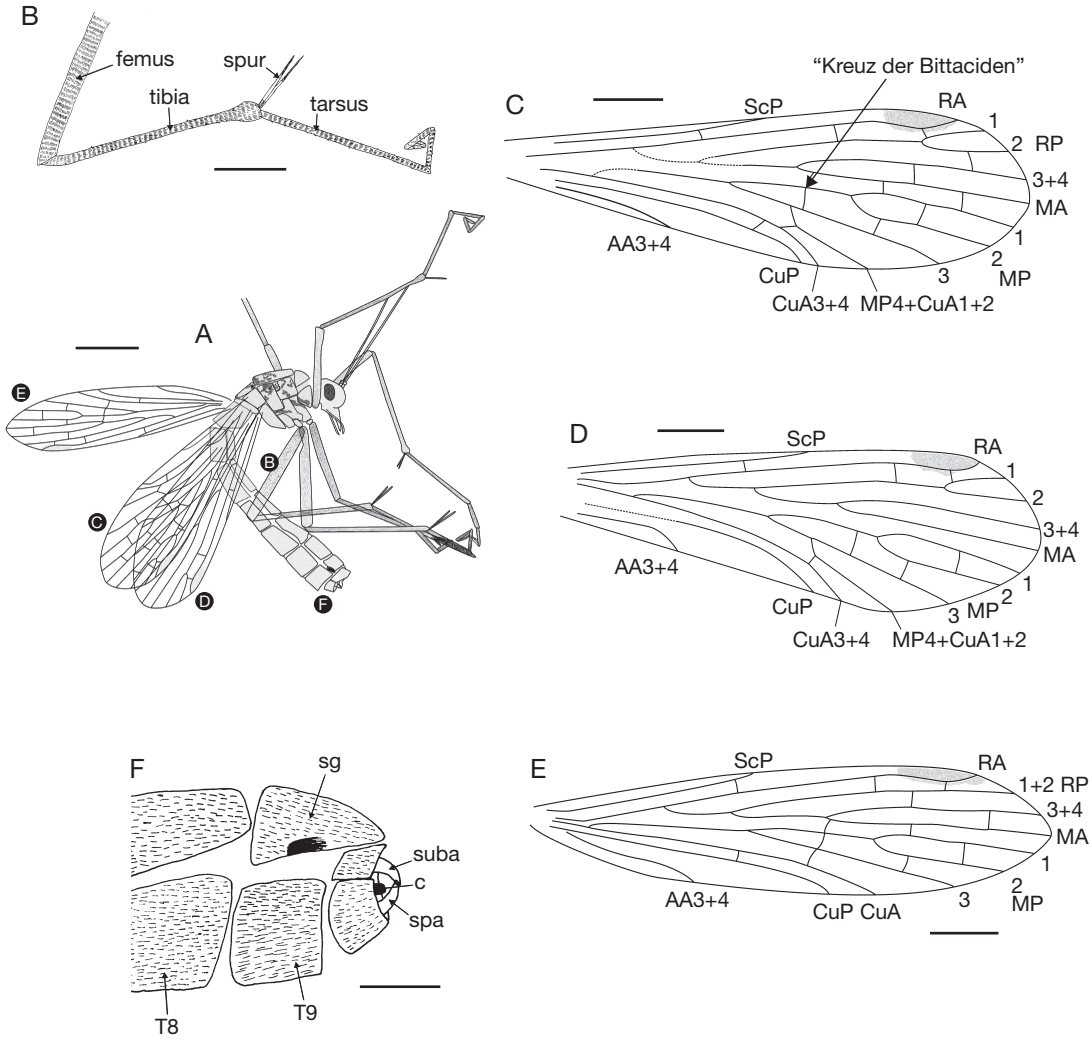

FIG 2. — *Exilibittacus lii* n. gen., n. sp., line drawings of holotype: **A**, body with wings; **B**, left hind leg; **C**, right forewing; **D**, left forewing; **E**, left hind wing; **F**, genitalia in ventral view. Abbreviations: **sg**, subgenitalis; **suba**, subanale; **c**, cercus; **spa**, supra-anale; **T8**, tergum octavum; **T9**, tergum nonum. Other abbreviations: see Material and methods. Scale bars: A, 2 mm; B-E, 1 mm; F, 0.5 mm.

INCLUDED SPECIES. — *M. colosseus*, *M. beipiaoensis* Ren, 1997 and *M. spatiosus* n. sp.

REVISED DIAGNOSIS. — Three or four crossveins between ScP and RA; RP and MP very long; RP1+2 and RP3+4 notably curved, distance between RP1+2 and RP3+4 very short and with one crossvein; "Kreuz der Bittaciden" aligned, MP3+MP4+CuA1+2 forking at the same point; AA3+4 long, extending to posterior wing margin before the level of RP+MA forking.

Based on the above discussion, a key to identify species of the genus of *Megabittacus* is given page 795.

REMARKS

Megabittacus Ren, 1997 was erected based on two species (one with nearly complete wing and body; the other with nearly complete wing but body not perserved). Here, we assign a new species, *Megabittacus spatiosus*

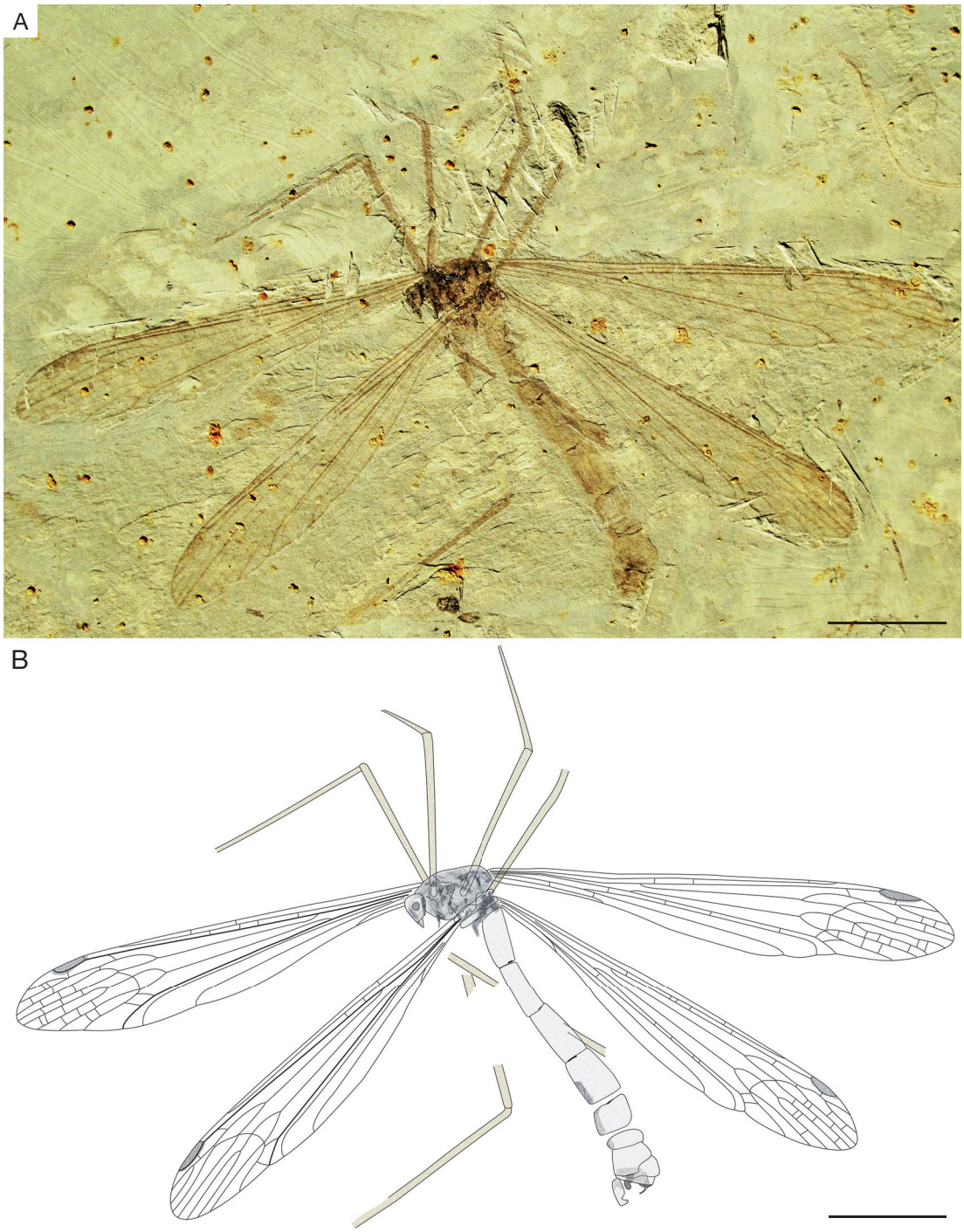

FIG 3. — *Megabittacus spatiosus* n. sp., photograph and line drawing of holotype: **A**, holotype (CNU-M-NN2010003); **B**, line drawing of holotype, body with wings. Scale bars: 10 mm.

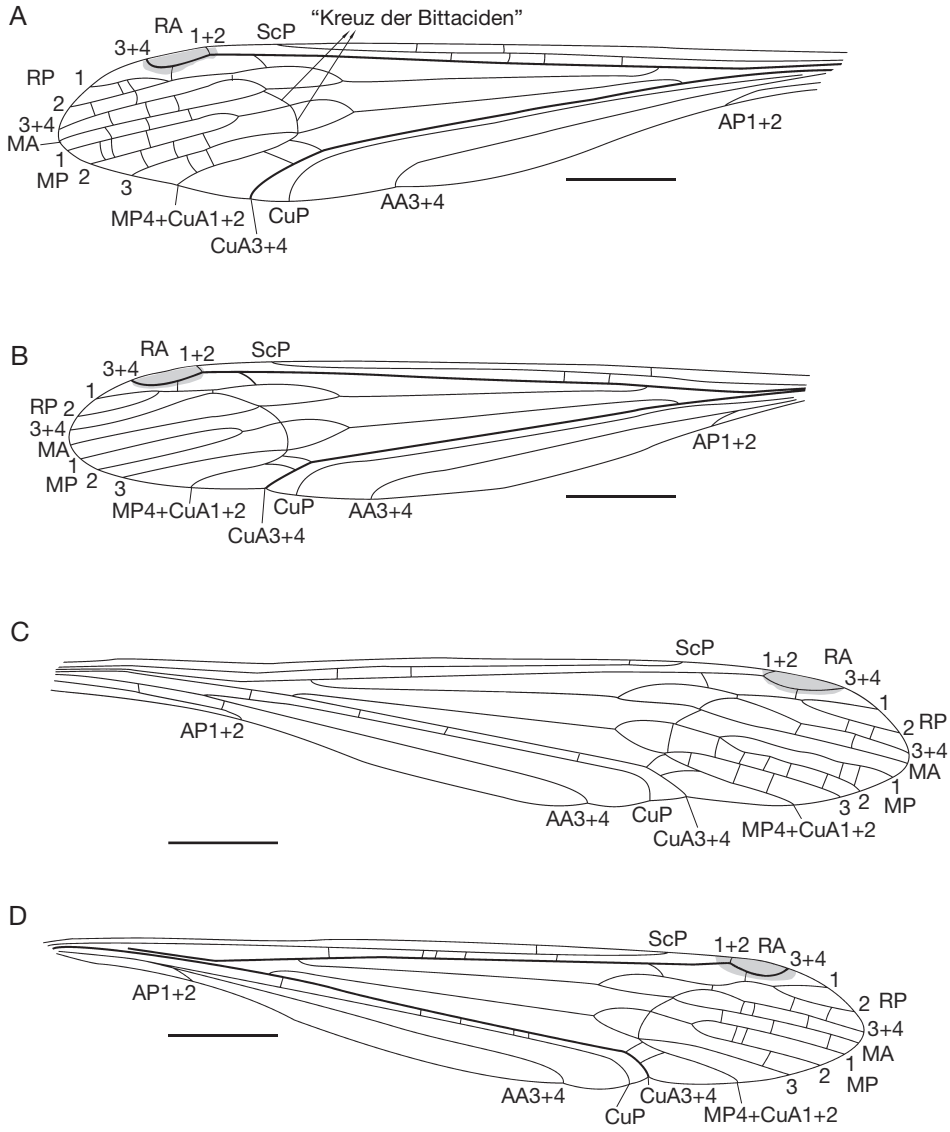

FIG 4. — *Megabittacus spatiosus* n. sp., line drawings of holotype: **A**, right forewing; **B**, right hind wing; **C**, left forewing; **D**, left hind wing. Abbreviations: see Material and methods. Scale bar: 5 mm.

n. sp., to this genus based on the following characters: body and wings quite large, wings narrow and long, more than 35 mm long; three or four crossveins between ScP and RA; RP and MP very long; RP1+2 and RP3+4 notably curved, distance between RP1+2 and RP3+4 very short and with one crossvein. This new species can be differentiated from *M. colosseus* and *M. beipiaoensis* by having an oblique crossvein from RA to RP1+2 before pterostigma and two crossveins between MP4+CuA1+2 and CuA3+4 (Fig. 5A, B). Based on this new species, we revised the generic diagnosis of *Megabittacus* Ren, 1997 as follows (see key).

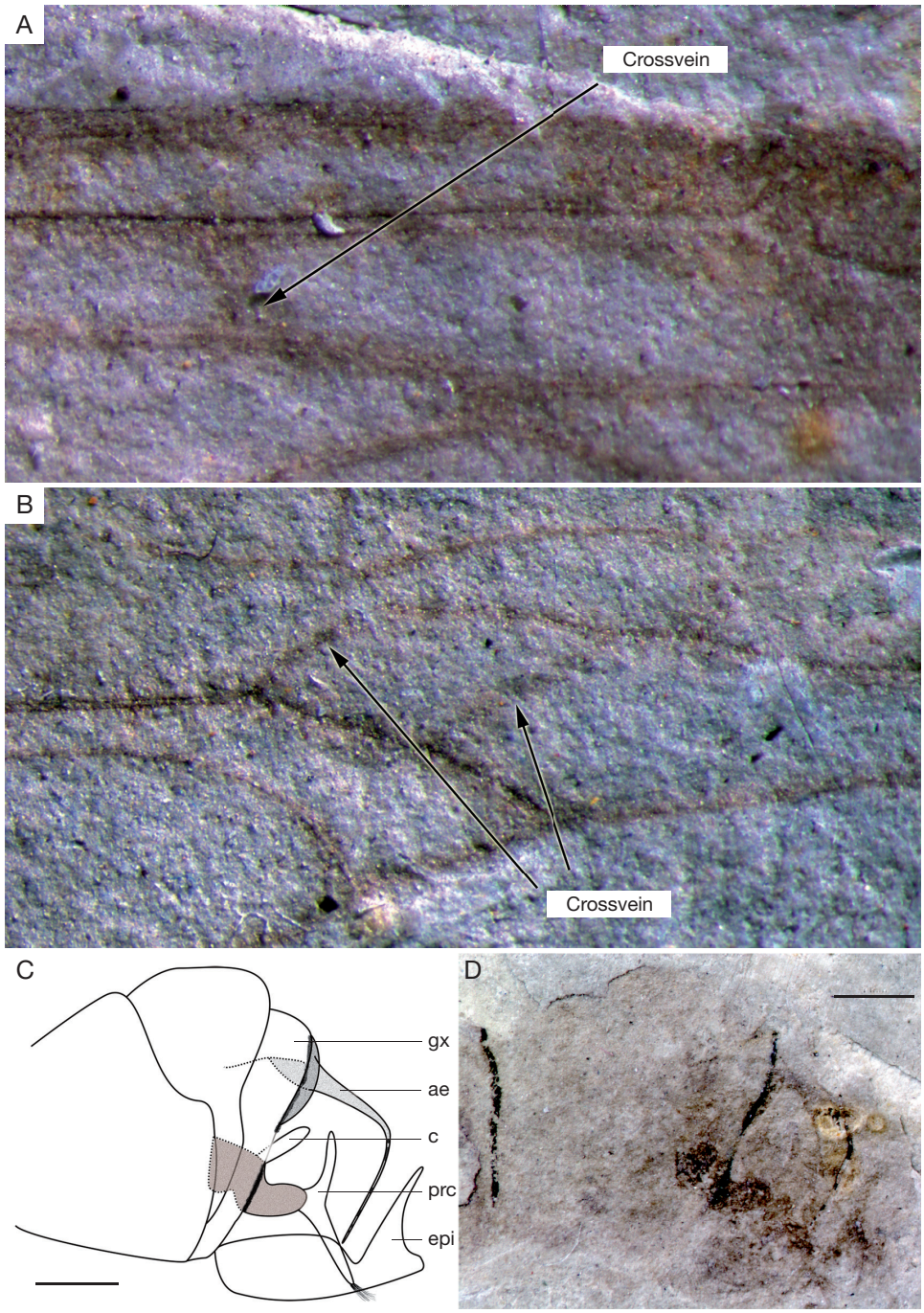

FIG 5. — *Megabittacus spatiosus* n. sp., photographs and line drawing of holotype: **A**, photograph of one inclined crossvein before pterostigma; **B**, photograph of two crossveins between M4 and CuA; **C**, line drawing of genitalia in ventral view; **D**, photograph of genitalia in ventral view. Abbreviations: **gx**, gonocoxite; **ae**, aedeagus; **c**, cercus; **prc**, proctiger; **epi**, epiandrium. Scale bars: C, D, 1 mm.

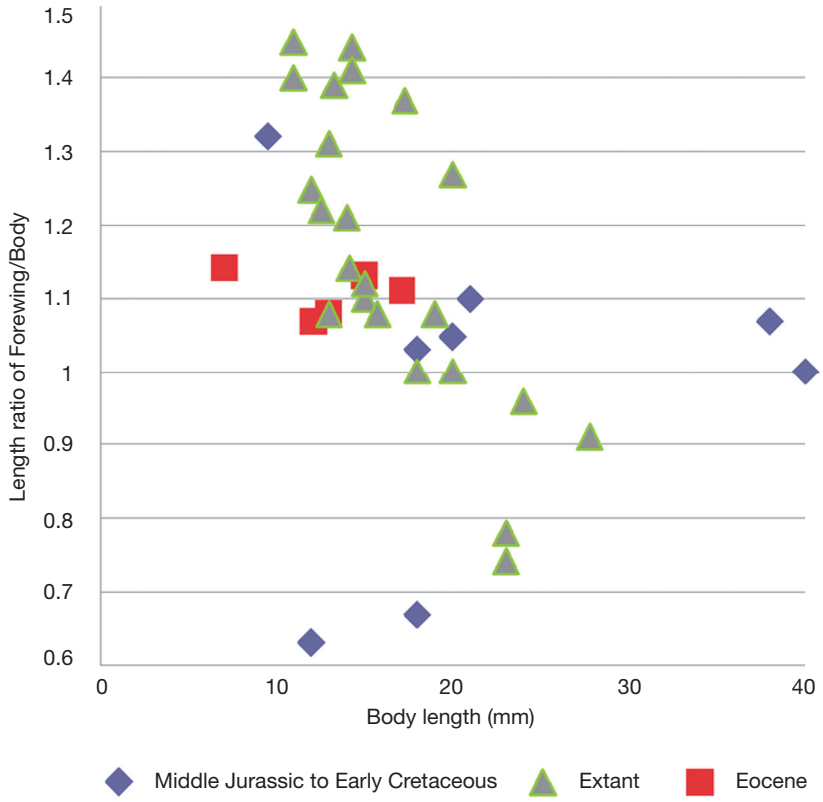

FIG 6. — Length ratios of forewing/body versus body lengths for fossil and extant hangingflies. All data are in mm. Three sets of data are indicated by legends in the Figure.

KEY TO THE KNOWN SPECIES OF *MEGABITTACUS* REN, 1997

1. RP+MA forking before the level of the fork of MP ..... *M. beipiaoensis* Ren, 1997
— RP+MA forking slightly after or at the same level of the fork of MP 2

2. One crossvein between MP4+CuA1+2 and CuA3+4 ..... *M. colosseus* Ren, 1997
— Two crossveins between MP4+CuA1+2 and CuA3+4 ..... *M. spatiosus* n. sp.

Megabittacus spatiosus n. sp.
(Figs 3A, B; 4A-D; 5A-D)

HOLOTYPE. — CNU-MEC-NN2010003, lateral view, preserved completely. Deposited at the Key Lab of Insect Evolution & Environmental Changes, the College of Life Sciences, Capital Normal University (CNU), Beijing, China.

ETYMOLOGY. — The Latin word of "*spatiosus*" means long, indicating elongated body and wing.

LOCALITY AND HORIZON. — Dawangzhangzi in Lingyuan, western Liaoning, China; Yixian Formation, Late Jurassic to Early Cretaceous.

DIAGNOSIS. — One oblique crossvein from RA to RP1+2 before pterostigma; two crossveins between MP4+CuA1+2 and CuA3+4.

DESCRIPTION

Male, large sized (Fig. 3A, B).

Head
Rostrum short; eyes large; antennae not preserved.

Leg
Long and slender, preserved partially.

Wings
Narrow basally, no thyridium, broadening from base towards rounded apex, with broadly convex posterior margin, pterostigma slightly dark. The wings much narrower and longer at the base than those of previously known bittacids, apices rounded; ScP very long, ending not far from the pterostigma, well beyond the fork of RP+MA; RA running through pterostigma, with a short single branch and RA3+4 distally scoop-shaped; RP arising at a distance of about one quarter length of the wing from the base, RP+MA dividing late into four branches. RP1+2 and RP3+4 notably curved, the distance between the RP1+2 and RP3+4 very short and one short crossvein connecting them, MP with four branches, RP3+4+MA forking before MP1+2, slightly after the fork of MP3+MP4+CuA1+2; vein AA3+4 long, extending before the forks of RP+MA and MP, AP1+2 short; in hind wing, AP1+2 coalesced with AA3+4 for a long distance.

Right forewing ScP with two crossveins reaching the wing anterior margin; an oblique basad crossvein from RA to RP1+2 ending before pterostigma; four crossveins between ScP and RA; two crossveins between RP1 and RP2, two crossveins between RP2 and RP3+4, three crossveins between RP3+4 and MA, three crossveins between MA and MP1, three crossveins between MP1 and MP2, three crossveins between MP2 and MP3, two crossveins between MP3 and MP4+CuA1+2 (Fig. 4A).

Left forewing ScP with one crossvein reaching anterior margin; an oblique apicad crossvein from RA to RP1+2 before pterostigma; two crossveins between ScP and RA; two crossveins between RP2 and RP3+4, two crossveins RP3+4 and MA, two crossveins between MP1 and MP2, five crossveins between MP2 and MP3, three crossveins between MP3 and MP4+CuA1+2, four crossveins between CuA3+4 and CuP, two crossveins between AA3+4 and AP1+2 (Fig. 4C).

Right hind wing ScP with one crossvein to anterior margin; an oblique basad crossvein from RA to RP1+2 ending before pterostigma; two crossveins between ScP and RA; no crossveins preserved in RP, MA and MP (Fig. 4B).

Left hind wing ScP with one crossvein reaching anterior margin; five crossveins between ScP and RA; an oblique apicad crossvein from RA to RP1+2 before pterostigma; two crossveins between RP2 and RP3+4, three crossveins between RP3+4 and MA, three crossveins between MA and MP1, two crossveins between MP1 and MP2, one crossvein between MP2 and MP3, five crossveins between CuA3+4 and CuP (Fig. 4D).

Abdomen
Ten segments visible. Genital segment visible, epiandrium long and prong-like, tapering apically with apex curved mesad; upper and low branches of proctiger preserved, upper branch of proctiger with quite long setae; aedeagus of moderate length, recurved (not coiled), with a terminal filamentous extension. (Fig. 5C, D).

Measurement
The entire body nearly 38.0 mm long; forewing 41.0 mm long, 11.5 mm wide; hind wing 37.2 mm long, 11.3 mm wide.

DISCUSSION

As mentioned earlier, *Exilibittacus lii* n. gen., n. sp., has interesting and special venation characters. RP+MA and MP of its left hind wing have only three branches and RP1+2 and MP3+MP4+CuA1+2 not forking, even though RP+MA and MP of its left and right forewings have typical four branches, same as those of most hangingflies. This is the first time that the character of MP with three branches is recorded for the Bittacidae. Intra-species venation variation for radial sector has been reported by Carpenter for *Panorpodes brevicauda* (Hagen): "The additional specimens of *brevicauda* now at hand show that this is not consistently so: the radial sector has six branches in one specimen, five in another, and four in the third; the media has four branches in all specimens" (Carpenter 1954). Since we have collected only a single specimen of *E. lii* n. gen., n. sp., so far, we

don't have comparative information to establish that three branches of RP+MA and MP are indeed stable characters. Therefore, other venation characters were also used to distinguish this new genus from all other known genera. They are: one crossvein between ScP and RA; RA with one pterostigma crossvein to RP1; RP+MA forking before the fork of MP; "Kreuz der Bittaciden" aligned, MP3+MP4+CuA1+2 forking before posterior part of "Kreuz der Bittaciden" (if existing); one crossvein between MP4+CuA1+2 and CuA3+4; and AA3+4 short.

When compared with extant and fossil hangingflies, *E. lii* n. gen., n. sp. (with a body length of 12.0 mm and forewing length of 7.5 mm) seems to be at the low end of the size range; while *M. spatiosus* n. sp. (with a body length of 38.0 mm and forewing length of 41.0 mm), at the high end of the range. As stated before, hangingflies are predacious insects. For hangingflies, larger body size may give them better advantage in catching larger preys, which in turn increasing their opportunity to mate with females and passing on their genes. On the other hand, larger insects are easier targets to be spotted by predators feeding on insects.

We conducted a literature search for described fossil hangingflies which have preserved body and forewing and their respective length data; and surveyed representative extant hangingflies. Their body length, forewing length, hind wing length, length ratio of forewing/body and other pertinent information are summarized in Table 2. We have eight fossils from the Middle Jurassic to the Early Cretaceous of northeastern China, two fossils from the Eocene of Green River, USA, three Baltic amber fossils from the Late Eocene, and twenty-three representative extant species (in ten out of sixteen extant genera). We plotted length ratios of forewing/body versus body lengths in Figure 6.

From Table 2 and Figure 6, we can draw the following observations and conclusions:
1) Eight fossils from the Middle Jurassic to the Early Cretaceous, all from northeastern China, have a very wide range of body lengths from 9.5 to 40.0 mm and a very broad range of length ratios of forewing/body from 0.63 to 1.32. Findings of these wide varieties of hangingfly fossils in northeastern China suggest a high level of diversity for these hangingflies;
2) Five specimens from the Eocene have body lengths from 7.0 mm to 17.1 mm and a very narrow range of length ratio of forewing/body from 1.07 to 1.14. It is probably due to low sample numbers;
3) Twenty three representative extant specimens have a body length range from 11.0 mm to 27.8 mm. This range, which is narrower than that of the Middle Jurassic to the Early Cretaceous, suggests that very large or very small body sizes had less advantages in the long process of evolution for hangingflies. On the ratio, the range is very broad from 0.74 to 1.45, the same as that of the Middle Jurassic to the Early Cretaceous; and 4) For extant species (23 specimens), it seems there is a general trend that larger body-sized species have lower ratio of forewing/body with a correlation coefficient of -0.754. This correlation is not significant for the other two sets of data points as evidenced by very low correlation coefficients, 0.102 (8 specimens) and -0.232 (5 specimens) respectively.

Exilibittacus lii n. gen., n. sp. has the lowest ratio of 0.63, which, in conjunction with its 12.0 mm body length, distinguishes this species from all other species. This further provides support for setting up a new genus of *Exilibittacus* n. gen.

In taxonomy study of hangingflies, especially fossil specimens, length of body and wings and length ratio of wing/body would be important characters to supplement other morphological characters, eg. venation, body and antenna, commonly used. However, these two characters should be used as part of a broad spectrum of other characters with cautious and careful consideration. For example, Table 2 shows that for the same genus, e.g., *Bittacus*, the body lengths are from 7.0 mm to 24.0 mm, and ratios range from 1.08 to 1.45 for 2 fossil and 6 extant species.

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