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Systematic Comparison of Two Species of Genus *Aeropus* Gistel (Orthoptera: Gomphoceridae) from Mongolian Plateau

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SE, HS and R-LT designed and planned the research, identified the specimens, analyzed the data and wrote the manuscript. HM, CB and RH contributed to the collection of specimens and analyzing the data.

Key words
Aeropus* gistel, Mongolian plateau, *Aeropus sibiricus*, *Aeropus

ABSTRACT

The review and summary of research history on *Aeropus* Gistel from Mongolian Plateau were carried out. Simultaneously, the comparative observation was conducted on the male genitalia and forewing veins between *Aeropus sibiricus* (Linnaeus, 1767) and *Aeropus licenti* (Chang, 1939) distributed in the Mongolian Plateau. Mongolian Plateau is the main distribution area for *Aeropus* Gistel, where significant differences exists in the morphological characteristics of Epiphallus and Phallic complex between *Aeropus sibiricus* and *Aeropus licenti*, which is the reliable basis for identifying the two species.

INTRODUCTION

Aeropus Gistel, 1848 is a genus established earlier in Gomphoceridae, Acridoidea, Orthoptera. In the 1930s, the British scholar Uvarov defined the differences between *Aeropus* Gistel, 1848 and *Gomphocerus* Thunberg, 1815. Three species in this genus were recorded, one of which included six subspecies (Uvarov, 1931). However, some scholars recorded the species of this genus into *Gomphocerus* Thunberg, 1815 (Kirby, 1910; Yin *et al*., 1995), and did not categorize *Aeropus*. At present, most scholars followed Uvarov's system (Yin and Xia, 2002), and regarded *Gomphocerus* and *Aeropus* as the parallel genus of Gomphoceridae. *Aeropus* Gistel is a dominant species in alpine, subalpine grassland and forest grassland in Mongolian Plateau and its surrounding areas, especially *Aeropus sibiricus* Linnaeus,1767 being a plateau-sub-plateau indicator species in the Mongolian Plateau and its surrounding areas (He *et al*., 2017; Song *et al*., 2021). Therefore, the comprehensive understanding on the research history and taxonomic characteristics of *Aeropus* Gistel in the Mongolian Plateau has important significance for further and in-depth study on its plateau adaptation mechanism and species differentiation.

There are two species of *Aeropus* Gistel grasshoppers that are distributed in the Mongolian Plateau, including *Aeropus sibiricus* (L., 1767) and *Aeropus licenti* (Chang, 1939) (Supplementary Fig. 1). *A. sibiricus* belongs to *Aeropus* Gistel with its earliest record of existence found in the Mongolian Plateau. In 1925, Tarbinsky collected *A. sibiricus* from the Altai Mountains in Mongolia (Chang, 1939). In 1929, Bey-Bienko recorded distribution of *A. sibiricus* around Mandhe in Yakeshi of Hulunbuir, Inner Mongolia, China (Bey-Bienko, 1929).

In the early 20th century, Paul Emile Licent, a French naturalist and missionary, who was also the founder of the Tianjin Hoang Ho Pai Ho Museum at that time (Now Tianjin Nature Museum), began to collect the insect specimens in the Inner Mongolia and surrounding areas of the Mongolian Plateau from 1919. Chang (1939) from St. John's University who was engaged in research at the Shanghai Zhendan Museum identified the orthopteran specimens collected by Paul Emile Licent. The specimens collected from Hahaye, Shanxi (recorded as Shansi: Hahaye at that time) by Paul Emile Licent in 1933 were regarded as a Holotype, which was identified as a new species and

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named after him as *A. licenti*. Whereas the specimens collected from Wudang Lamasery of Inner Mongolia (recorded as Mongolia: Outangtchao Pl. du Toumet at that time) in 1919 were regarded as Allotype (Chang, 1939). Therefore, Mongolian Plateau was not only the place to be considered as specimen production area of one species in *Aeropus* Gistel, but also the main distribution area of this genus. Until now, The *Aeropus* Gistel in Mongolian Plateau included the above two species (Chen, 2007; Yin and Xia, 2002; Yin *et al*., 1995).

It was found that there was no characteristic map given in the literature published for the new species of *A. licenti,* and the taxonomic characteristics of the two kinds of grasshopper given in various literatures were relatively scattered. In order to clarify the taxonomic characteristics of above both types, the comparative observations on major taxonomic characteristics, male genitalia and forewing veins were conducted in this study.

MATERIALS AND METHODS

In this study, the specimens of *A. sibiricus* were collected from Xiao-jing-gou (111.8ºE, 41.1ºN), Da-qing-shan, Hohhot, Inner Mongolia, China and the specimens of *A. licenti* were collected from Ha-la-wu Bei-gou (105.9ºE, 38.9ºN), He-lan Mountain, Alxa League, Inner Mongolia, China (Fig. 1). All the specimens (male *A. sibiricus*: IMNU-En-Or63103 and male *A. licenti*: IMNU-En-Or63209) were archived in the Biological Herbarium of Inner Mongolia Normal University.

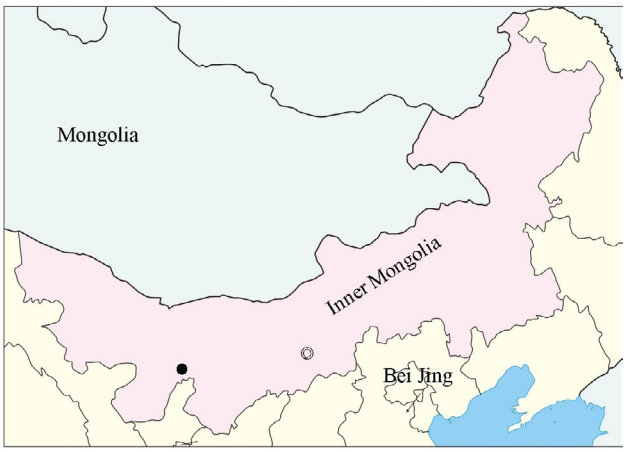

Fig. 1. Map of specimen collection locality. ◎: *A. sibiricus*; ●: *A. licenti*.

Anatomy of male genitalia

The abdominal end of male specimen was cut after softening. This was followed by the removal of the muscle and connective tissue. The epiphallus and phallic complex were isolated and stored in glycerol. Stereomicroscope LEICA S8APO was used to observe and photograph the epiphallus and phallic complex of genitalia. According to the observation results, the characteristic map of epiphallus and phallic complex were drawn. The digital stereomicroscope LEICA S8APO was applied to determine a total of seven measurable traits including the outer distance of apical ancorae in epiphallus, inner distance of basal ancorae, width of the bridge, outer distance of basal ancorae, height of ancorae, inner distance of lophi, outer distance of posterior projection (Zhang, 2009). The unit of length used for measurement was mm.

Characteristics of forewing veins

After softening, the wings of male specimens were spread, and the forewing veins were observed and photographed under stereomicroscope LEICA S8APO. The skeleton map of the forewing veins was drawn according to the observation results, and the length unit was mm.

RESULTS

Male genitalia

The epiphallus in *A. sibiricus* presents bridge shape (Fig. 2A, B), with arched bridge (B). The top of ancorae (An) is sharp and slightly curved inward (Fig. 2B: B:2). The upward protrusion of anterior pro (Ant) is triangular (Fig. 2B, B: 3), and the posterior projection (Pp) has outward acute angle protrusion (Fig. 2, B: 5). The lophi (L) is divided into inner and outer lophi, the inner lophi is kidney shaped and the outer lophi is oval (Fig. 2B, B: 6).

The epiphallus of *A. licenti* presents bridge shape (Fig. 2B: C, D), the bridge (B) is arched. The top of ancorae (An) is sharp and curved inward (Fig. 2B, D: 2). The upward protrusion of anterior pro (Ant) is triangular (Fig. 2B, D: 3), and the protrusion of posterior projection (Pp) is slightly outward (Fig. 2, D: 5), which is not as significant as that of *A. sibiricus*. The lophi (L) is divided into inner and outer lophi, and the inner lophi being kidney shaped and outer lophi is crescent shaped (Fig. 2B, D: 6), while the outer lophi in *A. sibiricus* is oval (Fig. 2B, B: 6).

The detailed indexes of various parts of male genitalia are shown in Table I.

The basal valves of penis (Bp) in phallic complex of *A. sibiricus* (Fig. 3A, B) have been found in two pieces (Fig. 3, B: 1), which are presented in petal shape with sharp angular protrusions at the tip. Zygoma (Zy) are U shaped and reaches 1/2 of the basal valves of penis (Fig. 3, B: 3). The base of valves of cingulum (Vc) has a relatively-wide inverted U-shaped notch (Fig. 3, B: 4). The apical valves

of penis (Ap) present sharp-spine shape, which are curved in the direction of zygoma with hook shape and divided into two valves respectively (Fig. 3, B: 5).

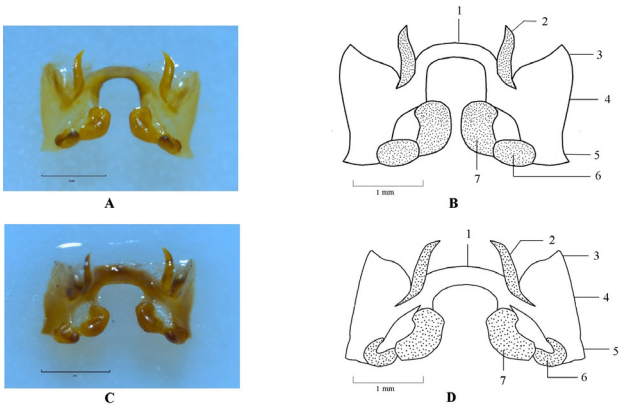

Fig. 2. Epiphallus of *Aeropus sibiricus* and *Aeropus licenti*. A-B: *A. sibiricus*; C-D: *A. licenti*.1: Bridge (B); 2: Ancorae (An); 3: Anterior pro (Ant); 4: Lateral plate (Lp); 5: Posterior projections (Pp); 6: Outer lophi (L); 7: Inner lophi (L).

Table I. Measurement indexes of male genitalia of two species of *Aeropus* Gistel (Length Unit: mm).

Indicator	*A. sibiricus*	*A. licenti*
Width of bridge (Epiphallus)	0.52±0.04	0.58±0.09
Outer distance of apical ancorae (Epiphallus)	1.14±0.06	0.94±0.08
Outer distance of basal ancorae (Epiphallus)	1.26±0.06	1.31±0.05
Inner distance of basal ancorae (Epiphallus)	0.96±0.07	1.00±0.03
Height of ancorae (Epiphallus)	0.63±0.01	0.62±0.09
Inner distance of lophi (Epiphallus)	0.17±0.05	0.50±0.04
Outer distance of posterior projection (Epiphallus)	2.13±0.14	2.28±0.18

Note: Observed and measured specimens, n=4.

The basal valves of penis (Bp) in phallic complex of *A. sibiricus* (Fig. 3, C, D) are two pieces (Fig. 3, D: 1), which are presented as petal shape. Zygoma (Zy) are U shaped and reaches 2/3 of the basal valves of penis (Fig. 3, D: 3), while zygoma in *A. sibiricus* reaches 1/2 of the basal valves of penis. The base of valves of cingulum (Vc) has an inverted U-shaped notch (Fig. 3, D: 4), which is narrower than that of *A. sibiricus* (Fig. 3, B: 4). The apical valves of penis (Ap) are shown as sharp-spine shaped, which are curved in the direction of zygoma with hook shape and divided into two valves, respectively (Fig. 3, D: 5).

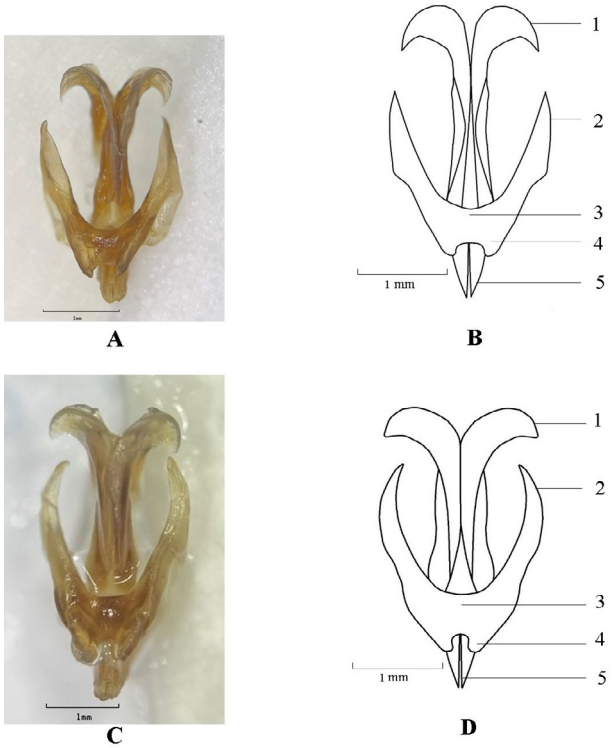

Fig. 3. Phallic complex of *Aeropus sibiricus* and *Aeropus licenti*. A-B: *A. sibiricus*; C-D: *A. licenti*. 1: Basal valves of penis (Bp); 2: Apodemes (Apd); 3: Zygoma (Zy); 4: Valves of cingulum (Vc); 5: Apical valves of penis (Ap).

Characteristics of forewing veins

The fore wings of *A. sibiricus* exceeded the end of meropodium of metapedes. The anterior cubitus (CuA) and posterior cubitus (CuP) were partially or completely merged with each other (Fig. 4: B: 5, 6).

The fore wings of *A. licenti* reached the end of meropodium of metapedes. The base of precostal area in forewings was found to be significantly enlarged and the top was narrow. The full lengths of anterior cubitus (CuA) and posterior cubitus (CuP) were separated and not combined. The cubital area was found to be narrow and significant (Fig. 4, D:5, 6).

The medial areas of both species of grasshoppers were seen to be wide, lacking the intercalary media vein (IM) (Fig. 4: C, D).

DISCUSSION

The precostal area in forewings of *Gomphocerus* Thunberg, 1815 has been found to be particularly long that exceeds the middle of wings, with a cubital area wider than the medial area (Uvarov, 1931). However, the precostal

area in forewings of *Aeropus* Gistel, 1848 has been seen as relatively short and does not reach the middle of wings. The anterior cubitus (CuA) and posterior cubitus (CuP) have been reported to be very close to or overlap, thus making the cubital area extremely narrow (Fig. 4) which even disappears (Uvarov, 1931). In addition, the propodium tibia of male adults of *Aeropus* Gistel was found to expanded (Supplementary Fig. 1), however, *Gomphocerus* Thunberg lacks such characteristics. Therefore, the differences between *Gomphocerus* Thunberg and *Aeropus* Gistel have been found to be extremely significant, and should be identified as two independent genera.

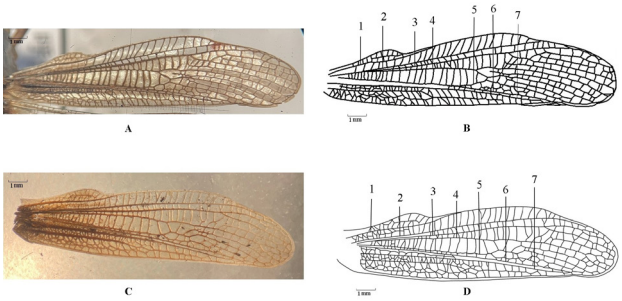

Fig. 4. Veins of fore wings (tegmina) of *Aeropus sibiricus* and *Aeropus licenti*. A-B: *A. sibiricus*; C-D: *A. licenti*. 1: Costa (C); 2: Subcosta (Sc); 3: Radius (R); 4: Media (M); 5: Anterior cubitus (CuA); 6: Posterior cubitus (CuP); 7: Anal (A).

Mongolia Plateau is the general name of the East Asian inland plateau area in Northeast Asia. It starts from the Greater Khingan in the east, ends at the Altai Moutains in the west, is bounded by the Sajan and Yablonovy Khrebet Mountains in the north, and bounded by Moni Mountains in the south. It is located in a vast area within the range of 87°40′-122°15′E and 37°46′-53°08′N with an average altitude of above 1580 m (Chen and Tian, 2001; Zhang, 2009). It includes the whole territory of Mongolia and Inner Mongolia autonomous region of China and its surrounding areas. Such a diverse ecological environment provides a special environment for insect diversity (Tian, 2020). The Mongolian Plateau and its surrounding areas are the main distributing areas for *Aeropus* Gistel.

The differences in the reliable and distinguishing features like phallic complex and epiphallus between *A. sibiricus* and *A. licenti* were found to be most significant (Table I, Fig. 2, 3). Differences have been marked in the characteristics of CuA and CuP in the forewing veins (Fig. 4), which might be more applied in the classification between genera.

Until now there are four species recorded in *Aeropus* Gistel, including *A. kudia* (Caudell, 1927), *A. armeniacus* (Uvarov, 1939), *A. licenti* (Chang, 1939) and *A. sibiricus* (L., 1767) (Yin and Xia, 2002). *A. kudia* is distributed in Siberia and Sakhalin in Russia. *A. armeniacus* is distributed in Armenia of Russia. *A. licenti* is distributed in Inner Mongolia, Shanxi as well as adjacent Ningxia, Gansu, Qinghai, Hebei and Shanxi in China. *A. sibiricus* is also seen as a widely distributed species. In the past, scholars considered that there were seven geographical subspecies according to the differences on the degree of swollen pronotum and distribution areas, including the *A. sibiricus sibiricus* in the western Siberia, *A. sibiricus graecus* (L.) in Greece, *A. sibiricus hispanicus* in central Spain, *A. sibiricus pyrenaicus* in Huesca of northern Spain, *A. sibiricus helveticus* in Switzerland, *A. sibiricus caucasicus* in Western Caucasus, and *A. sibiricus tibetanus* in Southeast Tibet, China (Uvarov, 1931; Chang, 1939; Yin *et al*., 1995). Some recent literatures considered that except for *A. tibetanus* Uvarov, 1935 (Yin and Xia, 2002) as the independent species, the other subspecies were all recorded as *A. sibiricus* (L., 1767). Therefore, there were differences in the morphological characteristics of *A. sibiricus* in different distribution areas. However, whether there are any differences on the physiological characteristics needs to be further studied.

According to the observation results on *A. sibiricus* in Da-qing-shan, Inner Mongolia in the recent years, both the propodium tibia and pronotum in nymph of *A. sibiricus* were not swollen. During the last molt before they become adults, the propodium tibia and pronotum of males were found to be swollen (unpublished data), but the specific reasons for expansion and the biological significance of swollen tibia and pronotum were not clear, which needs to be studied further.

The recorded species in *Aeropus* Gistel were all distributed in the areas above a certain altitude (Uvarov, 1931; Chang, 1939; Yin and Xia, 2002). Therefore, living at a high altitude is a feature of this genus. *A. sibiricus* and *A. licenti* were widely distributed in Mongolian Plateau, which provides indispensable materials for studying the species differentiation mechanism and plateau adaption characteristics in this genus.

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Supplementary material

There is supplementary material associated with

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Statement of conflict of interest

The authors have declared no conflict of interest.

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