New species of *Bipectilus* Chu & Wang (Lepidoptera: Hepialidae) ghost moth from, Meifieng, Taiwan and first record of the genus outside mainland Asia. Contribution to the moths of Taiwan 21*

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Summary

The eastern Asian genus *Bipectilus* is recorded in Taiwan for the first time. A morphological description is presented for two male specimens of *Bipectilus taiwanicus* **sp. n.** collected from Meifeng in May 2011. The genitalia are distinct from all other described species. We have been able to provide ventral and oblique lateral views that provide a three dimensional clarity for the structure of the male genitalia in *Bipectilus taiwanicus* **sp. n.** that may be helpful for interpreting the structure of genitalia illustrated for the other *Bipectilus* species. Distribution of all congeneric species are discussed and male genitalia figured for all species.

Zusammenfassung

Die ostasiatische Gattung *Bipectilus* wird zum ersten Mal in Taiwan nachgewiesen.

Von zwei männlichen Exemplaren wird eine morphologische Beschreibung vorgelegt.

Die Tiere wurden im Mai 2011 in Meifeng gesammelt. Die Genitalien unterscheiden sich von allen anderen beschriebenen Arten dieser Gattung. Wir konnten ventrale und laterale Seitenansichten abbilden, die eine dreidimensionale Klarheit für die Struktur der männlichen Genitalien bei *Bipectilus taiwanicus* **sp. n.** zeigen. Dies kann für die Interpretation der Struktur der Genitalien der anderen Bipectilus-Arten hilfreich sein. Die Verbreitung aller kongenerischen Arten wird besprochen und die männlichen Genitalien aller Arten abgebildet.

Key words: Lepidoptera, Hepialidae, new species, biogeography, description, ecology, morphology, taxonomy, tectonics

Introduction

Meifeng is located at 2100 to 2200 m a. l. s., within the central high mountains of Taiwan, a region covering about 2/3 of the country with 200 peaks above 3000 m a.s.l., the highest being Mount Jade at 3952 m a.s.l. A concerted effort to record and document the high mountain biodiversity has resulted in the discovery of many new Lepidoptera species, especially from Meifeng (e. g. BUCHSBAUM & MILLER 2002, BUCHSBAUM et al. 2006, CHEN & BUCHSBAUM & COUCHSBAUM & CHEN 2013, CHEN et al. 2013). This documentation includes two new species of Hepialidae in the genus *Endoclita* (BUCHSBAUM et al. 2018, BUCHSBAUM et al. 2018, BUCHSBAUM et al. 2019).

With a biota of 12 described species, Taiwan has a diverse range of Hepialidae that includes most of the eastern Asian genera along with the monotypic endemic genus *Parathitardes* Ueda (GREHAN et al. 2023). The other genera represented in Taiwan are all widespread in eastern Asia, and comprise *Endoclita* C. & R. Felder (six species), *Hepialiscus* Hampson (three species), *Palpifer* Hampson and *Thitarodes* Viette (one species each) (UEDA 1988, 1999, GREHAN 2011, HEPPNER & INNOUE 1992, GREHAN et al. 2023). The recent discovery of two large bodied *Endoclita* species (BUCHSBAUM et al. 2018, BUCHSBAUM & GREHAN 2019) indicates that even for this well collected and geographically small region, knowledge of the hepialid fauna may be far from exhaustive.

When *Endoclita meifenga* Buchsbaum & Grehan, 2019 was collected in 2011 from the mountains of central-northern Taiwan, a much smaller moth of nonde-

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script appearance was also found. We have since had the opportunity to examine the specimen in detail and are able to confirm that characteristics of the male genitalia support it being recognized as a new species of the genus *Bipectilus* Chu & Wang, previously known only from mainland Asia. In this paper we provide a description of the new species and discuss aspects of *Bipectilus* ecology and distribution.

Materials & Methods

Two specimens were collected at Meifeng using a 250 W mixed light lamp in front of a white screen between 07:00 pm to about 06:00 am. The moth was collected with KCN poison glasses, field pinned and later mounted on a spreading board. Legs and abdomen were removed for dissection. Genitalia were macerated in 10% KOH. The holotype dissection was slide mounted in Euparal following the methods of Robinson (1976), and the paratype dissection was preserved in 10-% ethylalcohol. Wing venation is recorded as a line diagram drawn over a photo in Inkscape and cross-checked against the specimen. Terminology for principle genitalic structures follows that of MIELKE & CASAGRANDE (2013).

Photos of moths were made with an Olympus Tough TG-5 camera, and holotype genitalia were scanned with a Nikon coolscan 3000 and managed for publication with Adobe Photoshop (personal license). The distribution map was created with mapcreator (personal license). The paratype dissection was photographed with a Canon EOS 6D digital single-lens reflex camera outfitted with a Canon MP-E 65mm f/2.8 1x-5x Macro Photo Lens. The camera was equipped with a Canon Macro Twin Lite MT-24EX Flash Unit, a StackShot 3X Controller and macro rail, and mounted to a Macropod Pro photo-stacking setup. Image series were then stacked together using Zerene Stacker.

Abbreviations

NHMUK	Natural History Museum, London,	
	United Kingdom	
NMNS	National Museum of Nature Science	
	Taichung, Taiwan.	
ZSM	Zoologische Staatssammlung München	

Taxonomic Section

Bipectilus taiwanicus Buchsbaum & Grehan sp. n. Figs. 1a-e, 2a-d, 3b, 4a-b, 5a-e, 7, 8.

Holotype (verbatim labels): ♂ Central TAIWAN near Puli, Nantou Co., Mefeng, ca. 2100 NN. 24°05'19N/121°10'26E LF, 11, Mai 2011, leg. Mei-Yu Chen & U.Buchsbaum / Gen: 2022–001 / Holotypus *Bipectilus taiwanicus* Buchsbaum & Grehan, 2023 des. Holotype in Collection Zoologische Staatssammlung München (ZSM), later deposited in collection of Natural History Museum Taichung (Taiwan, R.O.C.)

Paratype δ : same collection data as holotype, Gen: 2022–004 / Paratypus *Bipectilus taiwanicus* Buchsbaum & Grehan, 2023 des. Paratype in Collection Zoologische Staatssammlung München (ZSM), later to deposited in collection of Natural History Museum Taichung (Taiwan, R.O.C.)

Etymology: Named after the country of Taiwan (R. O. C.). A noun in the nominative singular, standing in apposition to the generic name.

Diagnosis

Morphology of antennal flagellum place this species in *Bipectilus* as the only eastern Asian genus with bipectinate antennae. *Bipectilus taiwanicus* **sp. n.** can be distinguished from all other species of the genus by the subrectangular shape of sternum VIII with shallow concave lateral margins in the male (Fig. 8). The distally broad elbowed valva (Fig. 7) is distinct from other *Bipectilus* species where the elbowed region narrows to the apex (*B. unimacula*, *B. zhejiangensis*, *B. paraunimacula*, *B. omainensis*), is broad and short (subequal to sacculus) throughout (*B. yunnanensis*), or has an anterior basal spine (*B. perfuscus*, *B. tandalei*, *B. latirami*, *B. gracilirami*).

Description

 δ (Fig. 1). Wingspan (n = 2): ~ 27 mm, forewing length 12–13 mm, width 6 mm, hindwing length width 11 mm, width 5 mm.



Fig, 1. Bipectilus taiwanicus sp. n.: (1a, 1b, 1e) holotype, (1c, 1d) paratype. Photos by Mei-Yu Chen.

Head (Fig. 2): Densely covered with short greyish-brown piliform scales. Eyes partially obscured by surrounding by scales. Antenna bipectinate, pale yellowish brown, scape cylindrical, pedicel rounded and slightly barrel shaped, flagellum with 22 segments, rami covered with numerous sensilla trichodea, and scattered sensilla caetica (Fig. 2d), rami narrow, longest for basal 2/3, narrowing distally, lamellar scales present along dorsal surface.

Thorax: Covered with pale reddish-brown to greyish brown piliform scales, scutum III pale brown, anteriorly free of scales, exposed surface covered by mesothoracic scales extending posteriorly (i.e. not visible from above). **Wings** (Fig. 3b): venation 'hepialine' (sensu Dumbleton 1966), Sc1 present on forewing only, hindwing with single A vein; surface scales short, lamellarform, fringing scales well developed along outer and posterior wing margins. Forewing dorsal ground colour greyish brown with scattered reddish-brown shading posteriorly and basally; three diffuse transverse bands of pale whitish-grey from posterior margin to approximately Rs veins. Dorsal hindwing and ventral fore- and hindwings greyish brown. *Legs* (Fig. 4a): covered with piliform pale yellowish brown scales, epiphysis and arolium present.

Pregenital abdomen: Covered with pale greyish brown piliform scales. Tergites and sternites weakly sclerotized (Fig. 4b); tergum II with lateral ridge, anterior margin of tergum II and tergosternal sclerite not recovered, sternum II anteriorly damaged medially, lateral arms broad, anteriorly oriented, sternum VIII sclerotized, subrectangular, lateral edges irregular, slightly concave (Fig. 8a).

Genitalia: (Fig. 5): Pseudotegumen narrow, postero-ventrally forming posterior lobe with two shallow spines, and anterior lobe with single, distal, shallow spine. Tegumen forming a narrow ventro-lateral branch articulating with saccus, and narrow curved branch (teguminal bridge) fused medially as a short, curved hook at articulation with fultura superior. Fultura inferior sub-



Fig. 2. Head of *Bipectilus taiwanicus* sp. n.: (a) paratype, dorsal, (b) paratype, anterior, (c) paratype, lateral, (d) paratype, details of antenna. Photos by Ulf Buchsbaum.



Fig 3. Wing venation: (a) Bipectilus unimacula (from Nielsen 1988), (b) Bipectilus taiwanicus sp. n.

rectangular with longitudinal medial rod-like sclerotization, and shallow concave lateral margins; fultura superior sub-triangular, weakly sclerotized medially, anterior corners narrow, slightly curved. Valva with broad sacculus anteriorly, valva lobe broad, distally curved with apical triangular flange. Saccus U-shaped, broad and longitudinally shallow, anterior margin irregular with medial indentation, lateral edges forming a deep shelf.

Distribution

Known only from the type locality at Meifeng (Hehuan mountains of central Taiwan), Nantou County.

Habitat

The type-series of *Bipectilus taiwanicus* **sp. n.** was collected at The Highland Experimental Farm of the National Taiwan University (NTU), an open area of agricultural crops and dry meadows at an elevation of about 2100 m, surrounded by natural mountain forest of northern Taiwan (Fig. 6). At the time of collection conditions were misty and cloudy with light rain, preceded by dry and warm weather. Evening temperature was about 15°C on the date of collection (11 May), which was few days before a typhoon hit Taiwan (the principal typhoon season usually lasting from about June through October).

Discussion

Following the original designation of Bipectilus for a single species by CHU & WANG (1985), Bipectilus was expanded by NIELSEN (1988) to include an additional seven species, with a combined geographic range across eastern Himalayas, central Thailand, and eastern China (Fig. 9). Whereas the overall range is very broad, it is represented by very few localities, including a single location for five species, and two or three localities for the remaining two species respectively (NIELSEN 1988). We consider this limited geographic representation to be a collecting artefact as the moths may escape attention due to their relatively small size and the lack of bright colours or prominent wing markings. For his revision of the genus, NIELSEN (1988) was able to locate a total of 32 specimens in collections. In this respect, the geographic representation of *Bipectilus* is similar to the small dark and subdued patterned Palpifer, a genus also known by a few scattered localities across southern and eastern Asia (GREHAN & MIELKE 2019).

The prominent bipectinate antennae of *B. taiwanicus* **sp. n.** is a feature shared with all other *Bipectilus* species and distinct in this respect from all other Eurasian genera. In addition, the distal termination of pseudote-guminal processes as conspicuous spines is a feature of



Fig 4. Leg and abdomen of *Bipectilus taiwanicus* sp. n.: (a) foreleg (bottom), midleg (top), (b) tergum II partially folded back over sternum III. Photo of legs by Mei-Yu Chen, abdominal skin by Loren Jones.



Fig. 5. Male genitalia of *Bipectilus taiwanicus* sp. n.: (a-b, d-e) paratype, (c) holotype. Holotype photo by Ulf Buchsbaum, paratype photos by Loren Jones.



Fig. 6. Collecting locality of *Bipectilus taiwanicus* sp. n.: (a) Meifeng Experimental Farm. Location of light trap arrowed, (b) surrounding biotype, (c) habitat immediately around the collection site, (d) Light sheet in early morning with second author. Photos (a-c) by Ulf Buchsbaum, (d) by Mei-Yu Chen.

Bipectilus that is unique within the Hepialidae (NIELSEN 1988). Some species of Bipectilus have a tuft of lamellar scales behind the eyes, a feature found in other Hepialidae such as Druceiella Viette (GREHAN & RAWLINS 2018), but appears to be absent in B. taiwanicus sp. n. The presence of spurs at the distal end of the tibia (a plesiomorphic feature for Hepialidae) in some species of *Bipectilus* is not applicable to *B. taiwanicus* sp. n. The following forewing venation features described by NIELSEN (1988) for *Bipectilus* that are applicable to *B*. taiwanicus sp. n. are: R₃ [Rs2] extending to apex, R₂ [Rs1] and R₂ [Rs2] on a long stalk, R₄ [Rs3] and R₅ [Rs4] on a short to moderate stalk, CuP extending 1/3 distance from wing base to margin, cross vein CuA-CuP meets CuA distal to, and CuP-A cross vein proximal to insertion of M stem, and A not divided at the wing base. The only difference found was that instead of cross vein R₅ [Rs4]-M1 reaching R₅ [Rs4] well before bifurcation R4-R5 [Rs3-Rs4], the intersection occurs at

the bifurcation. This difference may not be phylogenetically distinct as there can be considerable variation in the relative position of wing vein intersections within species (MIELKE et al. 2019).

The sister group affinities of *Bipectilus* was unresolved by NIELSEN (1988) who suggested that the genus may be the sister group of *Palpifer*, or to most or all other Hepialidae sensu stricto.

We have not analysed the sister species relationships of *B. taiwanicus* **sp. n**. However, we note that the subrectangular shape of sternum VIII in *B. taiwanicus* **sp. n.** occurs in *B. omaiensis* Nielsen, 1988, *B. yunnanensis* Chu & Wang, 1985, and to a lesser degree, the posteriorly tapered SVIII of *B. unimacula* Nielsen, 1988 (Fig. 8). The distally curved shape and lobate apex of the valva is a feature shared with *B. unimacula*, *B. paraunimacula* Nielsen, 1988, and *B. zhejiangensis* Wang, 2001 (Fig.7). The bifurcated distal spines of



Fig. 7. Comparison of *Bipectilus taiwanicus* sp. n. male genitalia. Published species reproduced from NIELSEN (1988) and WANG (2000). Orientation of view variable.

the dorsal pseudotegumen lobe is shared with *B. tindalei* Nielsen, 1988, *B. latirami* Nielsen, 1988, and *B. gracili-rami* Nielsen, 1988. The least similar genitalic structure is that of *B. perfuscus* where the ventral spines are strongly curved laterally (Fig. 7). Because the dorsal pseudotegumen lobe is unique to *Bipectilus*, there is no outgroup condition for this feature to identify which shape variations in the spines may be phylogenetically informative.

The distally curved lobate shape of the valva of *B. tai-wanicus* **sp. n.** may indicate a closer affinity with *B. unimacula*, *B. paraunimacula* and *B. zhejiangensis* that have a similarly shaped valva. This similarity may indicate close affinity between these species, as the valva shapes are distinct from those found in other Hepialidae. The latter three species are also geographically closest to *B. taiwanicus* **sp. n.**, particularly *B. unimacula* of central-eastern China (Fig. 9). We note that the diagram of *B. zhejiangensis* genitalia by WANG (2001) presents a structure that appears to be identical to the genitalia of *B. unimacula* (Fig. 7) with which it has broad geographic overlap. It is possible that *B. zhejiangensis* is conspecific with *B. unimacula*.

Habitat and ecology

Taiwan is located in a biogeographically diverse region that is rich in endemic species relative to its geographic size (MYERS et al. 2000, BROOKS et al. 2002, OLSEN & DIRENSTEIN 2002, SCHINTLMEISTER 2003, REICHHOLF

2003, CHEN 2009, KIER et al. 2009, BUCHSBAUM & CHEN 2019, BUCHSBAUM et al. 2020). This localized diversity of Taiwan may be the result of the islands geological history along the western plate boundary and subduction zone of the Pacific plate. At this tectonic boundary, Taiwan could have inherited both 'continental' and Pacific island arc taxa brought together and 'compressed' within a geographically small area through geological shortening where tectonic uplift generates topographic and ecological diversification. In an earlier study on the origins of Endoclita atavala Buchsbaum & Grehan 2018, divergence of this species from its continental relatives was attributed to a widespread eastern Asian ancestor followed by vicariance separating E. atavala from its closest relatives through Cainozoic rifting of a continental island arc that subsequently collided with the oceanic Taiwan island arc (Buchsbaum & Grehan 2018). This same tectonic process may be responsible for other taxa endemic to Taiwan, including that of Bipectilus taiwanicus sp. n.

Habitat and biological characteristics are unknown for most *Bipectilus* species. The surrounding habitat of *B. taiwanicus* **sp. n.** at 2,100 m comprises upland forest interspersed with open areas, including farmland (Fig. 6a), and the habitat of *B. latiramai* is montane-oak-laurel forests at 2,000–2,500 m in Nepal (NIELSEN 1988). Host plant records are documented for two species: *B. zhejiengensis* feeding on the bamboo *Phyllostachys viridis* (Poaceae) (WANG 2001), and *B. yunnanensis* feeding on



Fig. 8. Comparison of Bipectilus taiwanicus sp. n. sternum VIII. Published species reproduced from Nielsen (1988)

Polygonum glacialis (Polygonaceae), *Astragalus multiflora* (Fabaceae), *Rhododendron*, and *Azalea* (Ericaeae) (ZHU et al. 2004). Bamboo forest in Zhejiang and Fujian provinces is identified as a habitat of *B. zhejiengensis*, where larvae occupy the humus layer and feed on roots and subterranean shoots (SHU et al. 2009, DU et al. 2011). Damage from feeding is sufficiently intense for *B. zhejiengensis* to be considered an economic pest (WU et al. 2007, Luo 2009, SHU et al. 2009, DU et al. 2011).

NIELSEN (1988) noted that the elevation of the genus ranges between near sea level to 4,000 m (Table 1). The two highest elevation records are *B. gracilirami* in Nepal (3,300-3,500 m) and B. yunnanensis in southeastern China (4,000 m). The two lowest elevations are B. paraunimacula (900 m in Hunan, China) and B. tindalei (600 m [central Thailand]-900 m [northern Vietnam]). The highest elevation records occur in north of the geographic range rather than in the tropical south, where higher elevation occurrences might be expected because of warmer conditions at high elevations. The higher northern elevations is consistent with the northern high elevation localities being the result of tectonic uplift rather than climate. With tectonic uplift, lowland ancestors are raised to higher elevations during mountain orogeny, and the uplifted populations may become geographically/topographically isolated and diverge (HEADS 2019). Pending further geographic records, this pattern of higher elevation occurrences in the north of the Bipectilus range is a biogeographic characteristic previously documented for monkeys (HEADS 2012), and butterflies (HEADS et al. 2023) in eastern Asia.

Table 1. Elevation records (metres above sea level) for *Bipectilus* species. Data from NIELSEN (1988), WANG (2000), and current study.

B. gracilirami Nielsen, 1988	3300-3500
B. latirami Nielsen, 1988	2000-2500
B. omaiensis Nielsen, 1988	1340
B. paraunimacula Nielsen, 1988	900
B. perfuscus Nielsen, 1988	3350
B. taiwanicus Buchsbaum & Grehan sp. n.	2100
B. tindalei Nielsen, 1988	600-900
B. unimacula Nielsen, 1988	2300
B. yunnanensis Chu & Wang, 1985	4000
B. zhejiangensis Wang, 2001	700-900

The widely scattered records of *Bipectilus*, and the new species record for Taiwan, is an indication that the full extent of the geographic range of *Bipectilus* is poorly known. The occurrence of three species in the eastern Himalayas may indicate further species being present further west along the Himalayas, as recently confirmed for *Thitarodes* (GREHAN et al. 2021). The genus is apparently absent from Japan, and has not been recorded in the Russian Far East. The southern distributional limit of *Palpifer* is currently within Java (GREHAN & MIELKE 2019), but estimation of the southern geographic limits of *Bipectilus* will require detailed collection records from this region.

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Fig. 9. Distribution of *Bipectilus* species: (a) species localities, (b) type locality of *B. taiwanicus* sp. n. Distribution of *B. zhejiangensis* represented as a square symbol under *B. unimacula* (see discussion for explanation).

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