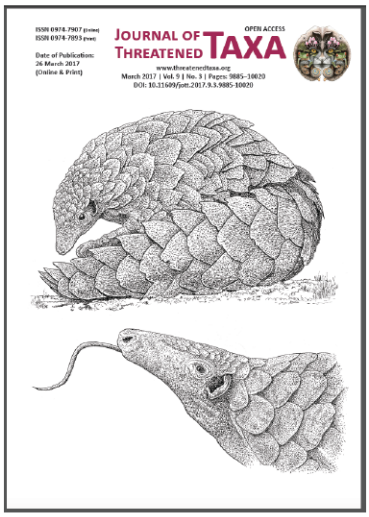

Journal of Threatened Taxa

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ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

COMMUNICATION

FOREST GHOST MOTH FAUNA OF NORTHEASTERN INDIA (LEPIDOPTERA: HEPIALIDAE: *ENDOCLITA*, *PALPIFER*, AND *HEPIALISCUS*)

John R. Grehan & Vijay Anand Ismavel

26 March 2017 | Vol. 9| No. 3 | Pp. 9940–9955
10.11609/jott.3030.9.3.9940-9955

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 March 2017 | 9(3): 9940–9955

Forest ghost moth fauna of northeastern India (Lepidoptera: Hepialidae: *Endoclita*, *Palpifer*, and *Hepialiscus*)

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Abstract: Taxonomic and biological information is reviewed for the forest Hepialidae of northeastern India, a poorly known group of moths in a region known for the global significance of its biodiversity. The taxonomic and biological characteristics are described for genera known from the northeast - *Endoclita*, *Palpifer*, and *Hepialiscus*. A key is provided for distinguishing these genera and the genus *Thitarodes* known from nearby Bhutan, China, and Nepal, which is almost certainly present within the borders of India. Taxonomic characteristics are described for 12 species from the northeast along with illustrations of the species and maps of their known distributions. Information on species distributions is extremely fragmentary and it is considered very likely that most species have more extensive distributions than currently documented. The northeastern Indian region represents a center of hepialid diversity comprising three principal distribution patterns: (i) local endemics, (ii) Himalayan, and (iii) northeastern. Comparison of distribution records and major vegetation types indicate the absence of information on the hepialid fauna for much of the northeast region. The principal challenge for future documentation and assessment of the hepialid fauna for this region, as with any other part of India, is the lack of modern descriptions of type specimens. The inclusion of voucher collections of Hepialidae in future biodiversity surveys of northeastern India is to be strongly encouraged, particularly in the context of current and future environmental impacts affecting the sustainability of forest environments in the region.

Keywords: Biodiversity, Hepialidae, Lepidoptera, northeastern India.

DOI: http://doi.org/10.11609/jott.3030.9.3.9940-9955 | **ZooBank:** urn:lsid:zoobank.org:pub:78E18828-D0B0-46F1-AE31-3C2C1C571914

Editor: Anonymity requested. **Date of publication:** 26 March 2017 (online & print)

Manuscript details: Ms # 3030 | Received 03 September 2016 | Final received 30 January 2017 | Finally accepted 23 February 2017

Citation: Grehan, J.R. & V.A. Ismavel (2017). Forest ghost moth fauna of northeastern India (Lepidoptera: Hepialidae: Endoclita, Palpifer, and Hepialiscus). *Journal of Threatened Taxa* 9(3): 9940–9955; http://doi.org/10.11609/jott.3030.9.3.9940-9955

Funding: None.

Competing interests: The authors declare no competing interests.

Author Details: Dr. John R. Grehan is a research Associate at the Carnegie Museum of Natural History, Pittsburgh, USA, with a specialist interest in the biology and taxonomy of Hepialidae (see http://www.johngrehan.net/index.php/hepialidae/). Dr. Vijay Anand Ismavel is a pediatric surgeon working at the Makunda Christian Hospital in Assam. He is active in biodiversity documentation with over 5000 observations and 10,000 photographs of nearly 2000 species uploaded to iNaturalist. He is the founder of the Makunda Nature Club which documents biodiversity, promotes conservation of wildlife. Observations recorded at http://www.inaturalist.org/observations/ivijayanand

Author Contribution: JRG - provided information content. VAI - provided information details regarding localities, habitats, specimen data and expertise on northeast region.

Acknowledgements: We are very grateful to Alessandro Giusti and David Lees (Natural History Museum, London), Norbert Maczey (Centre for Agriculture and Biosciences International), John Rawlins and Jayne Hyland (Carnegie Museum of Natural History), Peter Hudson (South Australia Museum), Nickolay Ignatyev, and Thomas Witt (Witt Museum München) for specimen photos, and to the staff of the Canadian National Collection for long-term specimen loans. We thank Dayong Xue (Chinese Academy of Sciences) for information on *Hepialiscus*, and to George Matthews for helpful advice, and Chandra Negi (L S M Government Postgraduate College) for information on fungal infected Hepialidae. And we are also grateful to Carlos Mielke (Curitiba, Brazil) and an anonymous reviewer for constructive comments on the manuscript.

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INTRODUCTION

Northeastern India is a geographically and tectonically complex region, a triangular corner of the Indian plate that is topographically edged by the eastern Himalaya to the north, the India-Burma mountains to the east, the Shillong plateau at the center and extending to the south between Bangladesh and Myanmar. Identified by Reddy et al. (2015) as the Northeast Biogeographic Zone, the region is administratively defined by the Ministry of Development of the northeastern Region (DoNER - http://mdoner.gov.in/) as the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. It is both one of the world's globally significant centers of biodiversity and a region that is facing a broad range of environmental threats to its future sustainability (Chatterjee et al. 2006; Chatterjee 2008). This is especially true for the forest ecosystem that is experiencing widespread deforestation or severe ecological degradation. While constituting only 8% of India's geographical area, the northeastern region contributes 25% of the country's total forest cover (Forest Survey of India 2015). As much as 60% of the region still retains some type of forest cover, but the proportion of ecologically intact forest ecosystems is far less. Damage to this ecosystem is seen to represent a loss of future human resources as well as resulting in the extinction or extirpation of the biodiversity necessary for the future stability and sustainability of forest ecosystems (Chatterjee et al. 2006; Chatterjee 2008).

Butterfly surveys have highlighted the importance of the northeast for species biodiversity of this group in forest ecosystems (e.g., Singh & Banyal 2014; Lodh & Agarwala 2015; Sondhi & Kunte 2016) whereas moth biodiversity surveys (e.g., Rose 2002; Chandra & Sambath 2013) are too limited to provide a similar assessment. While the relatively high visibility or abundance of many plants, mammals, birds, and butterflies draw attention to the detailed biodiversity of a region, the great majority of smaller organisms often escape attention, and their very existence often remains unknown or obscure. For the Indian fauna, accurate documentation and identification of many Lepidoptera is challenging because type specimens are housed in other countries, or they are inadequately described in the literature. Shubhalaxmi et al. (2011) identified the lack of sufficient reference literature and expertise as major impediments to the study of moth diversity in India. Less than 50% of all Indian Lepidoptera species are represented in Indian collections, and less than 50 species of moths have been described by Indian researchers (Smetacek 2011).

Ghost moths, a common name for Hepialidae (larger species in eastern Asia are often referred to as 'bat moths'), represent an example of a poorly understood lepidopteran group in northeastern India that is threatened by loss or degradation of forest habitat. In this region the Hepialidae are low in species diversity and probably also relatively low in population density as may be indicated by their relative scarcity in collections. Some species are moderately large as adults, but these nocturnal moths do not appear to be often attracted to light, and the immature stages often escape notice due to their secluded feeding habits (Grehan 1989). The Hepialidae occupy a significant phylogenetic position in the evolutionary history of moths and butterflies as a whole, being the largest of the primitive moth families (Reiger et al. 2015). The biology and ecology of this group is also distinct with respect to host plant relationships that often encompass sequential feeding stages on detritus or fungi before feeding on live plants (Grehan 1989).

We review here the current knowledge on the taxonomy and biology of ghost moths inhabiting the lower elevation tropical moist forests and the higher elevation subtropical and temperature forests of the northeast (as characterized by Reddy et al. 2015: Fig. 6) (Appendix 1). We begin with a brief outline of the principal characteristics of global ghost moth biodiversity followed by descriptions of the taxonomic, biological and distributional characteristics of the forest genera and species. We highlight the taxonomic importance of type specimens and their description as a primary biodiversity resource for accurate species identification. Access to this kind of information is an acute problem for the assessing of the biodiversity of Indian Hepialidae where all the type specimens are housed outside India. This situation has recently been compensated by digital images of many types being made available by the Natural History Museum, London, some of which are included in this article. Detailed descriptions that include illustration and characterization of male and female genitalia will be essential for accurate identification of Indian Hepialidae (Grehan & Mielke 2016).

GLOBAL GHOST MOTH BIODIVERSITY

Ghost moths range in size from small moths with wingspans of about 20mm, to large bodied giants with wingspans of 160mm or more. Females may contain hundreds or thousands of eggs (up to 40,000; Tindale

Image 1. Female *Endoclita signifer* at rest. Bazarichera, Assam.

1932). Moths are generally various shades of brown (including orange and yellow) or green, and sometimes with silver or other pale markings. Adults lack functional mouthparts, and individual moths are usually active for only a single day or night (most being nocturnal). At rest, they fold their wings in a steep tent-like manner, and grasp the substrate with their fore and mid legs while the smaller hind legs are tucked against the abdomen (Image 1). Hepialidae are present in every continent outside Antarctica and comprise 73 genera and about 630 species (for current list, see johngrehan.net/hepialidae). The family is particularly diverse in eastern Asia, Australasia, and Central and South America, while absent from Madagascar, western Africa and Congo basin, and the Caribbean - these patterns are possibly the result of ancestral Mesozoic distributions that were centered on particular regions prior to continental breakup (Grehan 2012). Of this global diversity, three genera and 24 species are recorded from India, of which about 19 are endemic to the country (Table 1).

Ghost moths require moist conditions, either seasonally or throughout the year. Tindale (1942: p. 151) suggested that the distribution of Hepialidae in the Western Ghats of India between Mangaluru and Kochi was strongly influenced by the necessity for high summer rainfall and some rain during emergence in November–December and March–May. But an adequate moisture regime for Hepialidae also appears to be present as far north as Mumbai (e.g. Shubhalaxmi et al. 2011).

Female Hepialidae deposit eggs while at rest or during flight. The eggs develop among ground debris and require near 100% humidity to complete development. Within about 3–4 weeks larvae emerge and feed on decaying plant material, fungi, or immediately locate host plants. It is uncertain at this time whether all larval Hepialidae initially feed on fungi or decaying plant tissue before transferring to plants. Most species are subterranean and excavate tunnels in the soil, roots or both. Some species tunnel in the soil but feed on ground foliage (grasses, herbs). A few species feed and live within mosses such as sphagnum (Grehan 1989). Larvae of several genera bore into stems and feed on callus tissue around the tunnel entrance: *Endoclita* C. & R. Felder, 1874 (India–eastern Asia), *Aenetus* Herrich-Schäffer, 1855 (Australasia), *Zelotypia* Scott, 1894 (Australia), and *Phassus* Walker, 1856, *Schausiana* Viette, 1950 and the 'cibyrine'genera (as defined in Grehan 2012) in America south of the United States. Larvae of *Leto* Hübner, [1820] (South Africa) and the North American *Phymatopus* Wallengren, 1869 consume woody tissue while tunneling in the host roots and stems (Wagner 1985; Maron 2001). Larvae of North American *Sthenopis* Packard, [1865] initially tunnel into roots before entering the lower stem from which the moths emerge (Grehan 1989). Some stem-boring species are considered pests of commercial forestry (Tobi et al. 1993).

GHOST MOTH GENERA OF NORTHEASTERN INDIA

Three genera are recorded from India—*Endoclita* C. & F. Felder, 1874, *Palpifer* Hampson, 1893, and *Hepialiscus* Hampson, 1893 (Table 1). Only *Endoclita* has attracted regular intermittent attention due to the impact of stem boring on commercial forestry (Nair 2007). *Endoclita* includes about 18 species within India, of which four are also recorded from outside the country (Table 1). The five Indian species of *Palpifer* are so poorly known that their level of endemism cannot be estimated. The single species of Indian *Hepialiscus* is limited to the Himalayan region (Ueda 1988). A fourth genus, *Thitarodes* Viette, 1961, has not been documented from within India although its presence is almost certain because it is known from adjacent Bhutan, China, and Nepal. *Thitarodes* is diverse and widespread across eastern-central China (Xizang) and further species are recorded from northern Thailand, Taiwan, southern Japan, and the Russian far-east (Grehan 2011). The central Asian species are largely from higher elevation grass and shrublands where larvae infected by the fungus *Ophiocordyceps sinensis* (Berk.) Sacc. are highly sought after for medicinal purposes (Li et al. 2006). Unidentified hepialid larvae infected by *O. sinensis* have been recorded from Uttarakhand in alpine meadows (Negi et al. 2016) and forest habitats between 2,200–2,400 m (Chandra Negi 2017 pers. comm.).

The following section summarizes the taxonomic status and known biological characteristics of the forest inhabiting genera - *Endoclita*, *Palpifer*, and *Hepialiscus*. As this section will show, details of biological information are known principally for only a few species of *Endoclita* in China, India, Indonesia, Malaysia, and Myanmar.

Table 1. Species of Hepialidae recorded from India

1. *Endoclita aboe* (Moore, [1860]) northeastern India
2. *Endoclita albofasciatus* (Moore, [1879]) southwestern India
3. *Endoclita albosignata* (Moore, 1879) northeastern India
4. *Endoclita auratus* (Hampson [1893]) northeastern India/Myanmar
5. *Endoclita chalybeatus* (Moore, 1879) northeastern India, Bangladesh, Myanmar
6. *Endoclita chrysoptera* Tindale, 1941 northeastern India (Darjeeling)
7. *Endoclita damor* (Moore, [1860]) Himalayan India/Nepal
8. *Endoclita magnus* (Tindale, 1942) southwestern India
9. *Endoclita malabaricus* (Moore, 1879) southwestern India, Karnataka
10. *Endoclita metallica* (Tindale, 1941) northeastern India (Darjeeling)
11. *Endoclita microscripta* Tindale, 1941 southwestern India
12. *Endoclita punctimargo* (Swinhoe, 1892) northeastern India (Darjeeling)
13. *Endoclita rustica* Tindale, 1941 northeastern India
14. *Endoclita salsettensis* (Moore, 1897) southwestern India
15. *Endoclita signifer* (Walker, 1856) northeastern India
16. *Endoclita strobilanthes* (Tindale, 1942) southwestern India
17. *Endoclita undulifer* (Walker, 1869) northeastern India, Myanmar
18. *Endoclita viridis* (Swinhoe, 1892) southwestern India
19. *Palpifer minutus* Hampson, 1896 northeastern India
20. *Palpifer murinus* (Moore, 1879) Himalayan India
21. *Palpifer pellicia* (Swinhoe, 1905) northeastern India
22. *Palpifer sexnotatus* (Moore, 1879) Himalayan/northeastern India
23. *Palpifer umbrinus* (Moore, 1879) northeastern India (Darjeeling)
24. *Hepialiscus nepalensis* (Walker, 1856) Himalayan India, Nepal/China

(a) *Endoclita*

This genus was first established by Felder & Felder (1874) but its member species were for a long time widely referred to as *Phassus* Walker, 1856 (the name also including Mexican and central American species). Tindale (1941, 1942) substantiated the priority of *Endoclita* for Asian species while *Phassus* was restricted to the New World species (a group that may yet prove to be closely related). Some Indian species have also been referred to as *Sahyadrassus* as proposed by Tindale (1941) for those species lacking the forewing vein Sc1, but this feature also applies to other genera. There is currently no clear evidence of monophyly for *Sahyadrassus* which was subsumed under *Endoclita* by Nielsen et al. (2000).

Most Indian *Endoclita* species are recorded from northeastern India or the southern states of Karnataka, Kerala, Tamil Nadu, and Andhra Pradesh. Larvae are yellowish-brown with darker or lighter sclerotized plates. Moths are generally various shades of brown with more or less developed transverse markings, with the exception of *E. viridis* (Swinhoe, 1892) of southern India, which is unique in having featureless pale yellowish-green forewings. Although the generic limits of *Endoclita* are not well defined, it is probable that it represents a monophyletic group as the described external female genitalia all have a prominent dorsal extension to the central lobe of the lamella antevaginalis (Grehan & Mielke 2016). Individual species are critically in need of further taxonomic work and it is probable that there remain undescribed species within and beyond India. The males have enlarged scent scales (androconia) on the metatibia, a feature present in just a few other ghost moth genera (Grehan & Rawlins 2016). Tindale (1941: p. 23) reported metatibial scales to be absent from the male of *E. undulifer* (Walker, 1869) but corroboration is required.

Of the 18 *Endoclita* species reported from India, 12 were described in the 19th century and the remainder were described by Tindale (1941, 1942). Most descriptions refer only to externally visible structures of the genitalia and they are often inadequate for confident species identification. Particularly problematic are the species *E. signifer* (Walker, 1856) and *E. sinensis* (Moore, 1877) where these names have been applied to similar looking moths from India to Asia without detailed reference to type specimens.

The stem boring habit of Indian *Endoclita* was perhaps first recorded by Hampson (1893). The first detailed biological account is probably by Atkinson (1931) for *E. signifer* in teak. Larvae were described as yellowish-white with chitinized abdominal plates, a heavily sclerotized chestnut colored thorax, and an almost circular shiny black head. The caterpillar was known to be able to rapidly move forward or backwards (a common hepialid characteristic) and to bore a tunnel that is open to the surface where the entrance is covered by a web of silk and debris about four inches (100mm) in diameter. Beneath the web is a deep funnel-like depression in the back and sapwood ending in a circular tunnel into the heartwood. The larva obtained at least a portion of its nourishment by browsing callus tissue formed at the exposed cambium. The entrance tunnel is excavated at a slight incline before extending downwards often up to 50cm. The larva pupates in the tunnel and the shed larval skin is left at the bottom of the tunnel.

A review of the ecology and control of Indian forest insects by Beeson (1941) noted that almost all Indian forest Hepialidae are borers of stems of woody plants, usually saplings of trees or shrubs, and have habits similar to those of *E. malabaricus* (Moore, 1879). This species was known to fly at dusk and females were believed to scatter eggs while in flight. Stems are usually inhabited by a single larva which bores an entry tunnel into the center and then it curves to extend down as far as the roots. In older stems the tunnel is relatively short, extending up to ~20cm. Larvae bore tunnels ~8–90 cm above ground into stems up to ~13cm in diameter, and feed on sapwood and callus under a silk/debris web over the tunnel entrance. The feeding web may encompass an area as large as the palm of the hand. At

pupation the larva blocks the tunnel with a thick plug of brownish silk. Beeson (1941) noted that the pupa has ridges and tooth-like projections that provide traction enabling it to move up tunnel and push out through the web where the pupal shell often remains after adult emergence. Pupation begins in April and lasts about three weeks, with moths emerging in May–June. Host plants represented many genera and species, including commercial plantations of teak (*Tectona grandis*) and *Eucalyptus*. Host plants of *E. auratus* (Hampson, 1893) of Himalayan Bengal included young saplings of *Alnus nepalensis*, *Eucalyptus* sp., and *Cryptomeria japonica*, while *E. punctimargo* (Swinhoe, 1892) was recorded as a borer in tea plantations. In Assam and Burma, *E. signifer* was characterized by Beeson (1941) as having a similar life cycle to *E. malabaricus* and recognized as a borer of teak and other commercial forest trees such as *Clerodendron infotunatum* and *Gmelina arborea*.

An extended study on the seasonal incidence, host range and control of *E. malabaricus* by Nair (1982, 1987) recorded the insect in over 40 species of woody shrubs and trees belonging to 22 families, of which Ulmaceae, Verbenaceae, Mimosaceae, and Myrtaceae were most prominent. Among forest plantation species, hosts included saplings of teak, *Eucalyptus* spp., *G. arborea*, *Anthocephalus chinensis*, *Sterculia companulata*, *Albizia falcataria*, and *Calliandra callothyrsus*. In some teak plantations the proportion of infested 2–4 year old saplings ranged between 6–61 % and medium-sized *Trema* trees sometimes supported up to 30 larvae per tree. But the insect was not considered a serious forest pest because callus feeding had a negligible impact and only in rare instances did ring-barking or girdling result in host mortality. Damage to coffee plantations was documented by Tintumol et al. (2014), and an indirect agricultural impact was described by Devasahayam et al. (1987) where *E. malabaricus* girdled *Gliricidia maculata* trees used to train the growth of black pepper vine in Kerala

The field observations of *E. malabaricus* by Nair (1982, 1987) established that moths generally emerge by mid-May whereas larvae of the next generation were not seen until three months later in mid-August when they were 1.5–2.0 cm in length. The earlier stages could not be located, and initial development in weedy ground vegetation was considered a possibility. Nair (2007) suggested that the early instars fed on detritus, fungi or fungus-infested wood before moving to living saplings as documented for some other Hepialidae (Grehan 1987; Tobi et al. 1993). Nair (2007) also drew attention to Kalshoven's (1951, 1965) discovery of young *E. sericeus* (Swinhoe, 1901) larvae (7–10 mm long and 1mm diameter) living in small tunnels in dead, more or less rotten twigs among the litter near the forest edge. These larvae later transferred to living plants where they tunneled into 1–6 cm diameter stems and stalks near the collar and fed under a silk web.

Dhanarajan (1976) reported an annual life cycle for the teak collar ring borer *E. gmelina* Tindale, 1941 in northwestern Malaysia. The possibility of initial detritus feeding by young larvae was recognized, but not confirmed. Larvae entered stems in June–July, and adults emerged in the evening from mid-March to May. Larvae fed on callus and sapwood near the tunnel entrance under a silk web. Most tunnels were located less than 25cm above ground and in stem diameters of less than 73cm (and most less than 25cm). Feeding sometimes resulted in stem breakage. Host plants included *Lantana* and *Eupatorium*. A survey of four sites found that the highest incidence occurred in a locality with the lowest annual rainfall and two dry seasons.

Larvae of *E. sinensis* in Taiwan were found in only two species of Euphorbiaceae in a forest of 206 species and six plant families (Liang & Lee 2011). Larvae tunneled 10–200 cm above ground into stems of 6–24 cm diameter and fed on callus beneath a web at the entrance of a tunnel that initially inclined upwards before curving down to follow the wood grain for 30–50 cm. In southern China, moths identified as *E. signifer* have a host range of 31 species in 16 families and 24 genera, and it has recently become a pest of *Eucalyptus* plantations. The species has an annual life cycle with eggs hatching between April and May followed by a detritus feeding stage of 1–2 months before third and fourth instar larvae transfer to live stems where development is completed over the next 10 months. Larvae pupate in February and adults emerge in April between late afternoon and evening (Yang et al. 2013a,b, 2015). Damage to teak and other forest trees was described by Zeya (1980, 1985) for an unidentified species of *Endoclita* in Myanmar.

(b) *Palpifer*

A widespread, but poorly documented genus of 11 species scattered across parts of India and eastern Asia. The five Indian species are all from northern India. The moths have a dark brown body and forewings that are rounded at the apex. The male has an oval shaped scent gland at the base of the forewing (illustrated for *P. sexnotatus* (Moore, 1879) by Tindale 1942) although its presence in all species has not yet been confirmed. The only record of *Palpifer* larval biology is for *P. sordida*

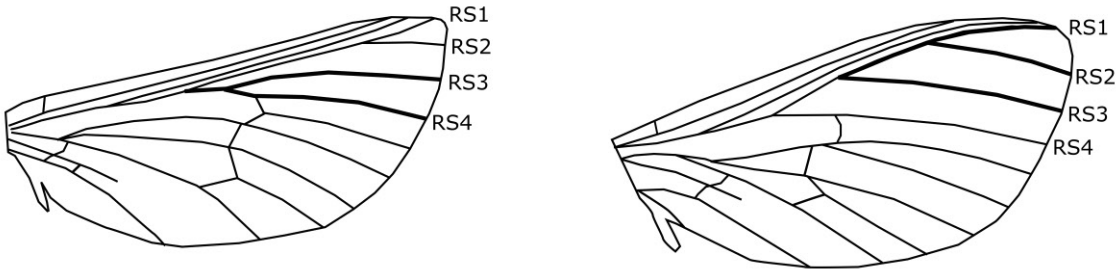

Figure 1. Generalized patterns of forewing radial sector veins in Hepialidae: (a) 'hepialine'venation where RS3 has a common stalk with RS4; (b) 'oxycanine'venation where RS3 joins the common stalk of RS1 and RS2.

Snellen, 1900 from Java that was characterized by Kalshoven (1965) as a root borer 'at some depth' in tubers of *Dioscorea*, *Alocasia*, and *Amosphophallus*. Moths were reared in January-February and July-October, and two moths were observed to emerge at 16:00hr. A mated female produced eggs at the end of October that hatched 30 days later. Thirty-five larvae placed directly on *Dioscorea* tubers developed over 6–8 weeks resulted in one adult. Larval tunnels encircle the tubers and stems of *Dioscorea* and *Alocasia*. Kalshoven (1965) also referred to root feeding on *Colocasia antiquorum* by larvae of *P. 'sexnotatus'*(= *P. hopponis* Matsumura, 1931) in Taiwan causing host mortality and suggested that monocots were the principal hosts of *Palpifer*.

(c) *Hepialiscus*

A small genus of six species, with *H. nepalensis* (Walker, 1856) distributed along the Himalaya, *H. htayaungi* in southern Myanmar (Grehan & Mielke 2016), an unnamed species in northern Myanmar and Thailand (C. Mielke, pers. comm. 2016), and three species in Taiwan (Ueda 1988). The taxon *H. nepalensis* subsumes four other names from the Himalayan region (Tindale 1942; Nielsen et al. 2000), but because the type specimen was never dissected before the abdomen was lost the precise identification of specimens from this region remains problematic. The only reference to larval biology is a brief note by Hampson (1893: p. 317) that the larvae feed on the roots of grasses and other plants.

Identification of genera

Distinguishing the genera *Endoclita, Palpifer, Hepialiscus*, and *Thitarodes* can be made correctly with reference to illustrations of identified species. Defining differences between all of the genera cannot be made with full confidence as the generic limits have not been definitively identified. *Endoclita* is highly variable in external appearance and may be distinguished principally in the way that its species do not resemble the other genera. Palpifer appears to be externally uniform in some respects that appear to be distinct. A unique genitalic structure described for two species and a basal forewing gland reported for some species (Tindale 1942) may also characterize the genus. *Thitarodes* comprises about 79 species, many of which are poorly described. There is no resolved character or characters to define the monophyly of *Thitarodes* and there are insufficient illustrations of the moths to fully characterize external appearance, although the species from Nepal and Buhtan have been described in some detail (Viette 1961; Ueda 2000; Maczey et al. 2011). Although *Hepialiscus* is not yet clearly distinguished from closely related genera (Mielke & Grehan 2016), forewing venation distinguishes it from other Indian Hepialidae. With these considerations in mind, the following preliminary and generalized generic key to the external features to assist with initial identification:

1a. Forewings with 'hepialine'venation (Fig. 1a) 2

1b. Forewings with 'oxycanine'venation (Fig. 1b) .... *Hepialiscus*

2a. Wingspan small to medium <~30–40 mm.....3

2b. Wingspan medium to large >~50mm, brown or olive green, plain or with irregular transverse markings on outer HW ..... *Endoclita*

3a. Wings and body pale to dark chocolate brown, hindwings orange-brown at base and/or hindwings with orange or cream patch on outer margin .... *Palpifer*

3b. Wings brown with extensive mottling and/or pale transverse and longitudinal markings, hindwing margins often with alternating pale and dark markings (Image 2) ..... *Thitarodes*

Image 2. Examples of Himalayan *Thitarodes* species: (a) Male of *Thitarodes eberti* Viette, 1968 from Nepal (Canadian National Collection). Photo by Jayne Hyland; (b) Male of *Thitarodes caligophilus* Maczey, 2010 from Bhutan. Photo by Norbert Maczey.

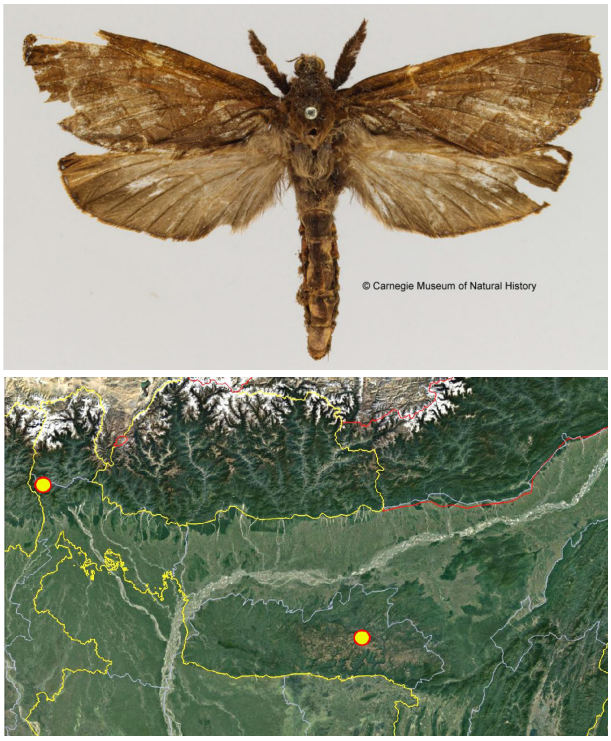

Image 3. *Endoclita aboe*: (a) Female, northern India. Carnegie Museum of Natural History. Photo by Jane Hyland; (b) distribution records.

GHOST MOTH SPECIES OF NORTHEASTERN INDIA

(1) *Endoclita aboe* (Moore, 1859). Male type at the Natural History Museum, London. Wingspan of type 71 mm (Tindale 1941: 40). The moths are dull chocolate brown and wings are covered with indistinct transverse lines between veins that form two irregular transverse lines in the outer wing (Image 3a). Indian localities are Darjeeling (West Bengal) and Khasi Hills (Meghalaya) (Image 3b). Tindale (1941) also referred to the southwestern species *E. salsettensis* (Moore, 1879) of Mumbai (Maharastra) and specimens from Kodaikanal (Tamil Nadu) as *E. aboe*, but this was based only on their general similarity and Tindale (1941) suggested that future examination of a better series may indicate differences.

(2) *Endoclita albosignata* (Tindale, 1941). Male type at the Natural History Museum, London. Wingspan 68mm (Tindale 1941). The moth has a dull, inconspicuous appearance, but it is readily distinguished from all other species by the presence of a pale white 'Y'shaped mark edged with brown, a proximal dark brown bar in the central forewing, and a dark brown hook-like spot near the base of the forewing (Image 4a). When first

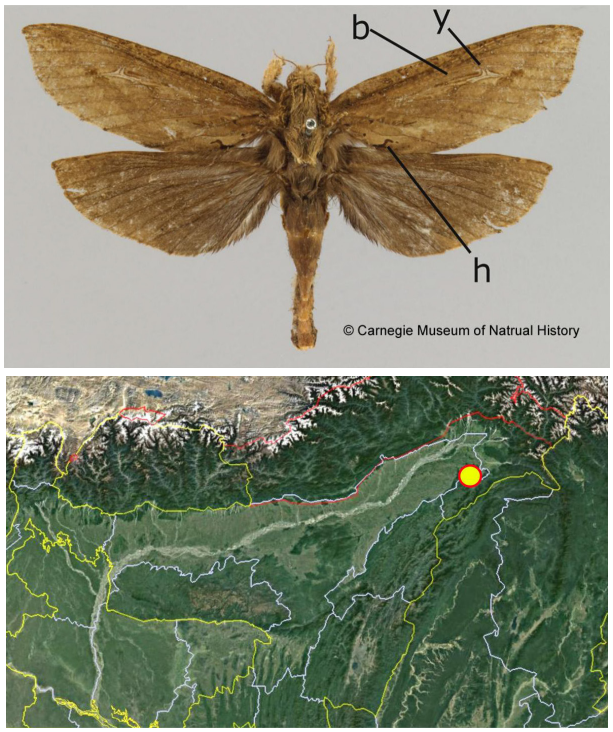

Image 4. *Endoclita albosignata*: (a) male dorsal (y - y-shaped mark, b - brown bar, h - hook mark); Photo by Jane Hyland; (b) distribution record (Magherita).

Image 5. *Endoclita auratus*: (a) type male, dorsal. Natural History Museum. Photo by Alessandro Giusti; (b) distribution records.

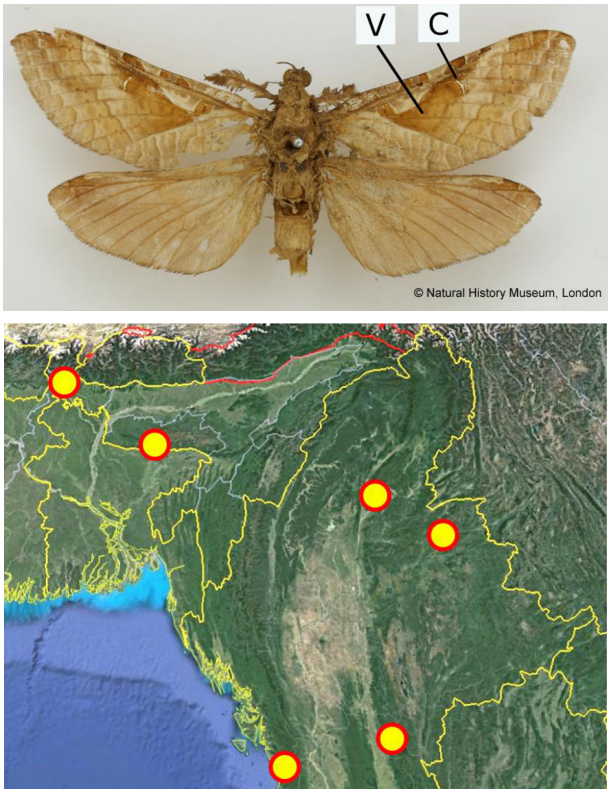

Image 6. *Endoclita chalybeatus*: (a) male type. Natural History Museum, London. Photo courtesy of Thomas Witt. v - shaped patch, c - crescent; (b) distribution records.

described by Tindale (1941: 32), the species was known from only a single unique specimen recorded from 'Assam'but without any locality or date information. The only other specimens known to the authors at this time is a pair of mating moths at the Carnegie Museum of Natural History, Pittsburgh, collected in 1888 from Margherita (Assam) (Image 4b).

(3) *Endoclita auratus* (Hampson, 1892). Male type at the Natural History Museum, London. Wingspan 39–42 mm (Tindale 1941). Forewings grayish brown with sub-metallic golden yellow over anterior-basal region and near apex (Image 5a). Known only from two localities: Bernardmyo, Myanmar at 1,700–2,100 m (type specimen), and the Khasi Hills, Meghalaya (Image 5b).

(4) *Endoclita chalybeatus* (Moore, 1879). Female type at the Natural History Museum, London. Wingspan 82mm (Tindale 1941). The forewing has a yellowish-brown shallow 'V'shaped patch with a narrow crescent shaped white mark at the outer edge (Image 6a). The V-shaped pattern is also found in *E. signifer* with which it may be confused, but the outer white mark is broader and a basal white mark is also present (see below for *E. signifer*). The posterior margin of the eighth sternite of the male has a central peak or tooth which is absent in *E. signifer*. Moths have been reared from *Tectona grandis* and *Gmelina arborea* (Tindale 1941). The species was first described by Moore (1879: 412) for specimens from Darjeeling (West Bengal). When Tindale (1941: 24) examined the type he found the abdomen was missing and therefore used another female specimen from Darjeeling to characterize the genitalia. For the male he used a specimen from Assam [Meghalaya] that he felt could confidently be associated with the type. In addition to the type locality, Tindale (1941) reported *E. chalybeatus* from the Khasi Hills (Meghalaya), northern Bangladesh (Sylhet), and Myanmar (Namtu, Sandoway, Katha, south Toungoo) (Image 6b).

(5) *Endoclita damor* (Moore, 1859). Female type at the Natural History Museum, London. Wingspan 68mm (Tindale 1941: 21). Body and wings are predominantly pale brown with faint crescent-shaped transverse markings, a region of darker oblique banding in the basal region, and a longitudinal, finger-like band extending from near the central costal margin towards, but not meeting, the outer margin (Image 7a). This latter feature is distinctive for the species. Distribution localities for India are Darjeeling (West Bengal),

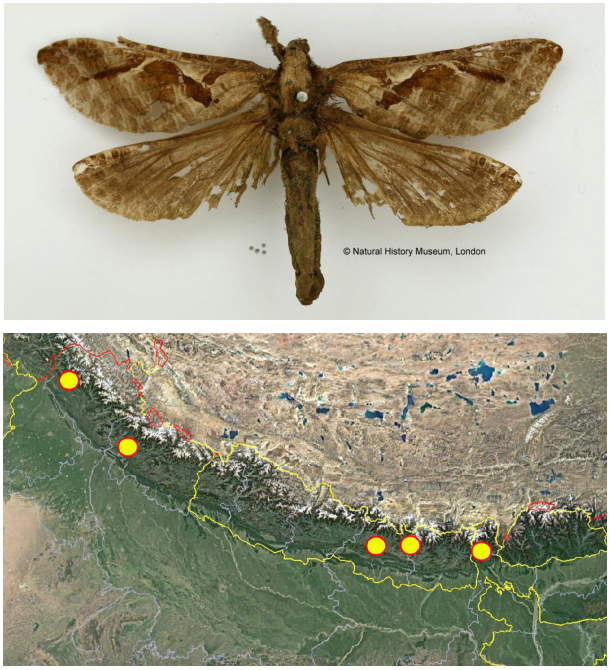

Image 7. *Endoclita damor*: (a) male type, Natural History Museum. Photo courtesy of Thomas Witt; (b) distribution records.

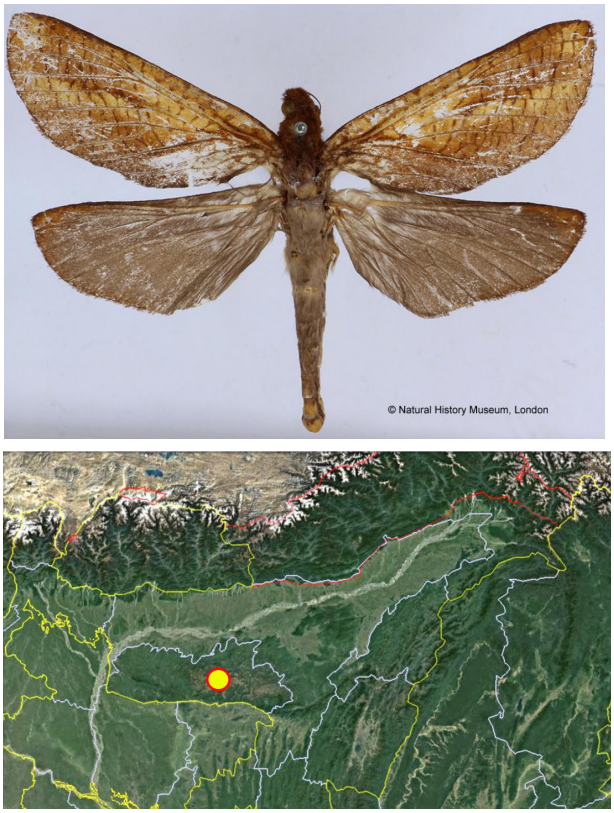

Image 8. *Endoclita rustica*: male type, Natural History Museum. Photo by David Lees; (b) distribution record.

Mussoorie (Uttarakhand), and Kangra Valley (specimen cited as Punjab [Himachal Pradesh]). Localities in Nepal are Kathamandu, Janakpur, and Godawari [Godavari Forest] (Image 7b) (Ueda 2000).

(6) *Endoclita rustica* Tindale, 1941. Male type at the Natural History Museum, London. Wingspan 56 mm (Tindale 1941: 33). The species is distinctive for its golden yellowish-brown shading marked with short transverse brown lines on the forewings, and dull grey hindwings (Image 8a). The eighth sternite has a concave posterior margin that is slightly notched in the middle. This species is known only from two male specimens from Shillong (type specimen) and the Khasi Hills (Image 8b).

(7) *Endoclita signifer* (Walker, 1856). Female type at the Natural History Museum, London. Wingspan 100–120 mm (Tindale 1941). As with *E. chalybeatus* (and various other *Endoclita* species beyond Assam and Meghalaya), the forewing has a prominent yellowish-brown, shallow 'V'shaped patch with a basal and distal white spot (Image 9a,b). An external difference between *E. signifer* and *E. chalybeatus* is the presence of a slight convex inflation of the forewing costal margin. Otherwise the two species have a very similar appearance and may be impossible to distinguish accurately without comparing structures of the genitalia. Tindale (1941: 30) assigned to *E. signifer* nine male and eleven female specimens from the Cherrapunji and Jaintia Hills (Meghalaya) to this species (Image 9c). The female type was collected from 'Silhet'(Sylhet, Bangladesh). A female specimen (Image 1) from Bazaricherra (Karimganj District of Assam 24^{0}26'N & 92^{0}18'E) found by the second author appears to conform to this species based on wing pattern and external genitalia (cf. Grehan & Mielke 2016). As there has always been considerable doubt and confusion about the identity of E. signifer, and at one time or another the name has been applied to eastern Asian specimens, Tindale (1941) concluded that the species does not occur beyond Assam. Future detailed description of male and female genitalia will be necessary to accurately identify the applicability of the name *E. signifer* to specimens beyond northeastern India.

(8) *Endoclita undulifer* (Walker, 1869). Female type at the Natural History Museum, London. Wingspan 54-92 mm (Tindale 1941, Image 10b). Although the condition of the type specimen is poor, there is sufficient detail present to show that the species is distinct from other *Endoclita* species in the region by the presence of an oblique, partly broken, dark brown band that extends into the cubital region (Image 10a). This feature is visible on a complete specimen that also exhibits scattered golden yellowish-brown over much of

Image 9. *Endoclita signifer*: (a) female type, bs - basal stigma, ci - costal inflation. Natural History Museum, London. Photo by Thomas Witt; (b) male, South Australian Museum. Photo by Peter Hudson; (c) distribution records.

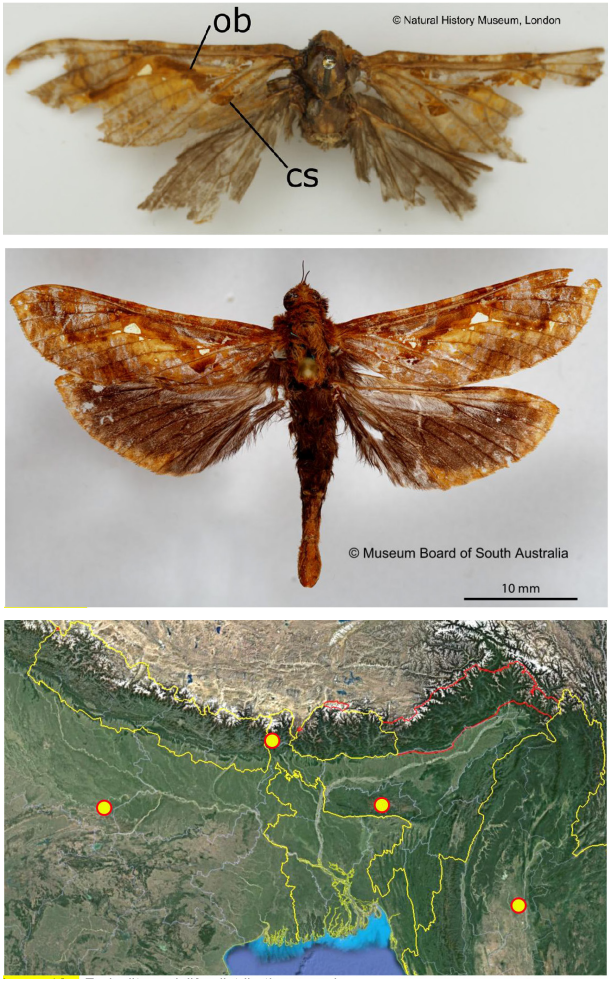

Image 10. *Endoclita undulifer*: (a) male type specimen, ob - oblique band, cs - cubital spot. Natural History Museum, London. Photo by David Lees; (b) Khasi Hills. Natural History Museum, London. Photo by Thomas Witt; (c) distribution records.

the central and outer forewing and the outer margins of the hind wing (Image 10b). Tindale (1941: 23) reported the type locality as Benares, (= Varanasi also known as Benares, Banaras or Kashi), Uttar Pradesh. Other specimens assigned to this species were reported from Darjeeling and Senchal Range (West Bengal); Khasi Hills (Meghalaya), and Shwebo [Nauhlaing reserve] (Myanmar) (Image 10c). Moths reared by the Forest Research Institute, Dehra Dun, emerged between August and October from *Alnus nepalensis* at Darjeeling, and *Buettneria pilosa* and *Callicarpia arborea* at Shwebo

(9) *Palpifer minutus* Hampson, 1896. Type in the Natural History Museum, London, but not located. Wingspan 18mm (Hampson 1896). Known only for the type from Khasi Hills, this species is described as having a yellowish-brown head and thorax and reddish-brown abdomen. Forewings are yellowish-brown with dark brown shading and black and white spots centrally, and an oblique series of five black and white spots from apex to near the middle of the posterior margin (Hampson 1896). This species was not included in Tindale's (1942) revision of *Palpifer* (although he did cite Hampson's 1896 work), or the global species catalogue of Hepialidae by Nielsen et al. (2000). Precise identification of this species will only be possible when the type specimen is found.

(10) *Palpifer murinus* (Moore, 1879). Male type in the Natural History Museum, London. Wingspan 29mm (Tindale 1942: 163). This species is known from 20 specimens from Jalandhar (Punjab), Dharmsala [type specimen] (Himachal Pradesh), and Cherrapunjee and Khasi Hills (Meghalaya). A single emergence record was for the month of May. The forewings are dark brown

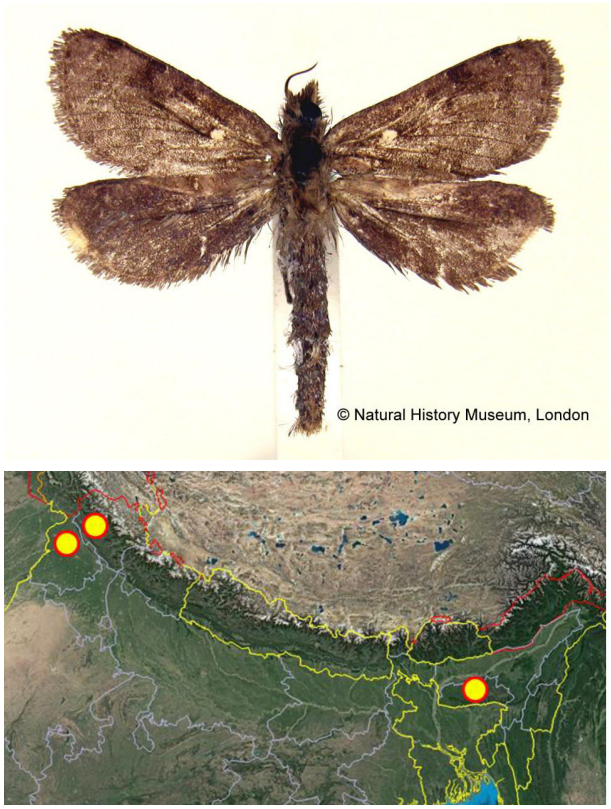

Image 11. *Palpifer murinus*: (a) type of junior synonym *P. caerulescens* Swinhoe, 1894. Natural History Museum, London. Photo by Carlos Mielke; (b) distribution records.

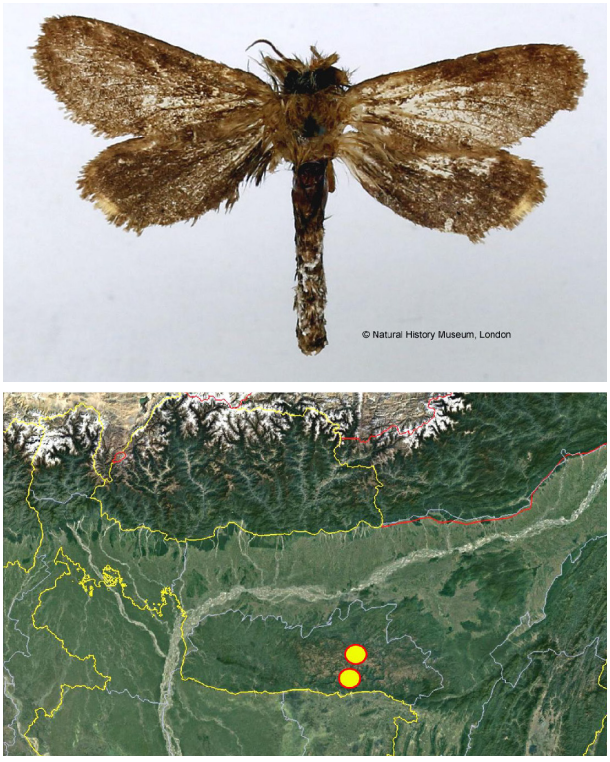

Image 12. *Palpifer pellicia*: (a) male type specimen. Natural History Museum, London. Photo by David Lees; (b) distribution records.

with a central creamy white spot near the base of the forewing. Hindwings are also dark brown with a creamy white patch near the wing apex on the posterior outer margin (Image 11a). The valves of the male genitalia have a short spine on the interior edge (Tindale 1942). The few locality records suggest a broad distribution along the lower Himalayas (Image 11b). A specimen from West Pahang, Malaysia that was assigned to this species by Robinson et al. (1995) requires verification.

(11) *Palpifer pellicia* (Swinhoe, 1905). Male type in the Natural History Museum, London. Wingspan 22–28 mm (Tindale 1942). The species is dull uniform brown with a small white spot on the forewings that is sometimes absent, and a sub-rectangular marginal yellow spot on the outer margin (Image 12a). The genitalia have not been described. Tindale (1942: 163) considered the species close to *P. murinus* from which it can be distinguished by its smaller size and obscure markings. *P. pellicia* also has narrower wings than *P. murinus* (length: width ratio of 3.0: 1 and 2.6: 1 respectively). The type and female allotype are recorded from the Khasi Hills, while a further six specimens are from Cherrapunjee (Meghalaya) (Image 12b).

(12) *Palpifer sexnotatus* (Moore, 1879). Female type at the Natural History Museum, London. Wingspan 25–38 mm (Tindale 1942). Forewings are pale brown with a basal white spot, and a dark chocolate brown spot at the posterior margin of the forewing (similar to *P. murinus*). Hindwings are also dark brown with yellowish-white base and outer and posterior margins (Image 13a). Specimens assigned to this species by Tindale (1842: 153) are from Darjeeling (type locality), Gopaldhara, and Mirik (West Bengal), and the Khasi Hills (Meghalaya). A further specimen in the Natural History Museum collection conforming to this species is from Simla, Himachal Pradesh, and Smetacek (2008) records the species from Bhimtal Valley, Uttarakhand (Image 13b). The correct identity of specimens from eastern Asia named as *P. sexnotatus* requires future verification.

(13) *Hepialiscus nepalensis* (Walker, 1856). Female type at the Natural History Museum, London. Wingspan 40–56 mm (Tindale 1942). The abdomen is missing from the type specimen (Image 14a) so it is not possible to characterize the genitalia of the species. Several other names have been subsumed under *H. nepalensis* (Tindale 1942; Ueda 1988), but their correct status needs to be verified. A specimen conforming to, or very near *H. nepalensis* from Surke Danda, Nepal (Image 14b)

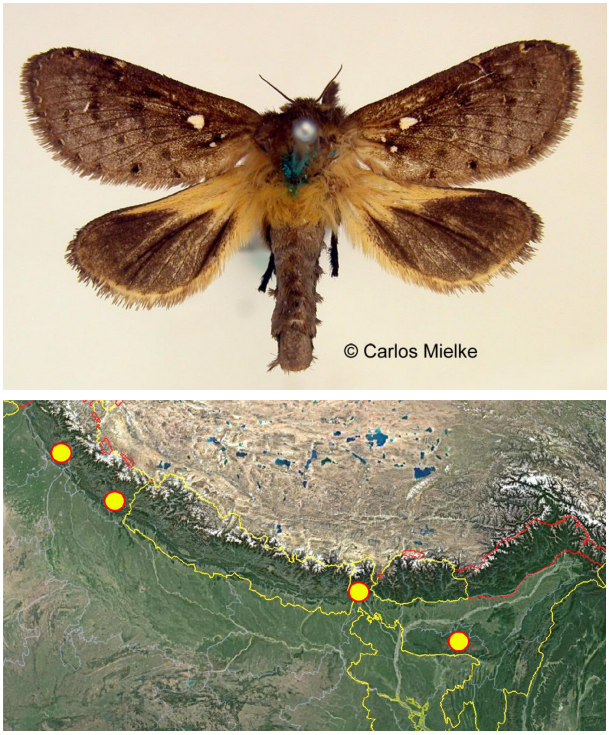

Image 13. *Palpifer sexnotatus*: (a) male, Simla, Himchal Pradesh. Natural History Museum, London. Photo by Carlos Mielke; (b) distribution records.

has a background forewing color ranging from shades of pale orange-brown to dark grayish brown with scattered pale silver-white spots edged with gray (see also Ueda 2000 for pattern variation). Moths referred to *H. nepalensis* are recorded from Simla - 7,000'(~2000m) and Subathu (both in Himachal Pradesh), Nepal, Darjeeling (West Bengal), Khasi Hills (Meghalaya), and Bhimtal (Uttarakhand) (Image 14c) (Tindale 1942: 165; Ueda 1988). The species *Hepialiscus flavus* Chu & Wang, 1985 from Nilamo in (China, Xizang) described by Chu & Wang (1985: 129) was synonymized under *H. nepalensis* by Nielsen et al. (2000) but this taxonomic reassignment requires verification.

CONCLUSIONS

The forest Hepialidae of northeastern India represents a taxonomically and ecologically poorly known group of Lepidoptera. In addition to the 13 species presented here, the species *Endoclita chrysoptera E. metallica, E. punctimargo* and *Palpifer umbrinus* are also very likely to be present in the northeast as they are recorded from Darjeeling and nearby Senchal very close to the border of Sikkim (Tindale, 1941, 1942). An overlay of Northeast

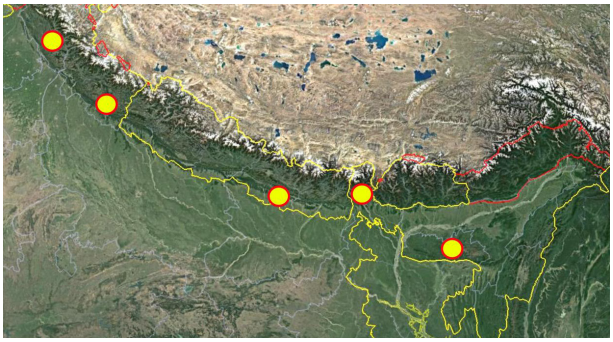

Image 14. *Hepialiscus nepalensis*: (a) female type specimen. Natural History Museum, London. Photo by David Lees; (b) *H. nepalensis,* male, Surke Danda, East Nepal, Witt Museum, München. Photo by Nickolay Ignatyev and Thomas Witt; (c) distribution records

hepialid locality records (including the Darjeeling/ Senchal records) with a regional vegetation map (Image 15) illustrates the very limited sampling of forest habitats in the northeast, particularly for those states with large areas of tropical evergreen forest - Arunachal Pradesh, Meghalaya, and Sikkim. Forest Hepialidae may also be expected to occur within the states of Manipur, Mizoram and central Assam where evergreen forest is interspersed among large areas of deciduous forest. The record of *Endoclita* at Bazarichera shows that this genus may continue to survive in smaller forest fragments. While *Hepialiscus nepalensis* appears to be confined to the Himalayan region, recent discovery of *H. htayaungi* in central-western Myanmar (Mielke & Grehan 2016)

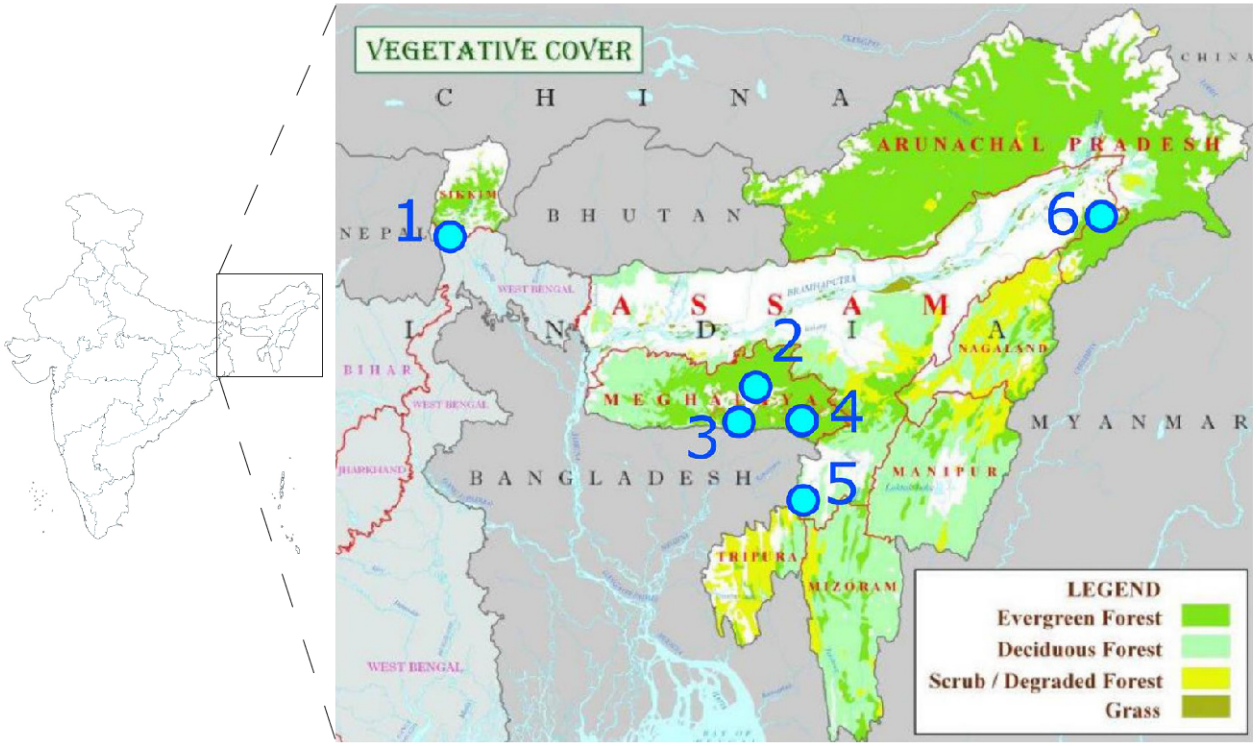

Image 15. Collection localities of Hepialidae and major vegetation types of northeastern India: (1) Darjeeling/Senchal Range, (2) Khasi Hills/ Schillong, (3) Cherrupanji, (4) Juanita Hills, (5) Bazarichera, (6) Magherita. Vegetation map from Ministry of northeastern Region (http:// mdoner.gov.in/node/224) in compliance with Ministry terms and conditions of use.

raises the possibility that this species is also present in eastern parts of Mizoram, Manipur, Nagaland and Arunachal Pradesh.

Even with the current taxonomic constraints on precise identification and the limited geographic scope of sampling, three broad distributional categories may be recognized for ghost moth biodiversity in the northeastern region.

(1) Potential Endemics: Five species - *E. albosignata, E. rustica, E. signifer, P. minutus, P. pellicia - are* known from only within the boundaries of northeastern India. Since this region is a geopolitical rather than biogeographic entity there is no necessary ecological or biogeographic reason why these species may not be found to have broader distributions. This is most likely true of *E. albosignata* given its proximity to Myanmar. The species *E. rustica*, *P. minutus*, and *P. pellicia* known from only the Shillong Plateau may also be more broadly distributed as may be inferred from the Bazaricherra record of a specimen conforming to *E. signifer*.

(2) Northeastern: This distribution range applies to *E. auratus, E. chalybeatus, and E. undulifer*. These distributions are likely include at least areas of nearby Bangladesh, and China. The distribution of *E. undulifer* includes a record from the lowlands of eastern Uttar Pradesh (Varanasi) that requires future verification as it is the only hepialid recorded from that area.

(3) Himalayan: Four species have distributions closely associated with the Himalaya. *E. damor, P. murinus*, and *P. sexnotatus* appear to be distributed along the southern foothills of the Himalaya while *H. nepalensis* may also be present in higher elevations over the same range.

The two species possibly endemic to the Shillong Plateau represent a potentially interesting geomorphological correlation. Uplift of the plateau began 15-9 Ma or possibly earlier (Biswas et al. 2007) and this process may have contributed to local differentiation of Hepialidae and other organisms such as the 1,173 endemic plant species of Meghalaya (cf. Lakadong & Barik 2006). The geographic overlap between Himalayan and Indo-Myanmar distributions in the Northeast highlights the region as a biogeographic boundary affecting divergence of ancestral Hepialidae formerly distributed across India and adjacent regions. Some of this differentiation may be correlated with the tectonic upheaval that occurred when the Indian continent merged with south Asia. At present there

is insufficient taxonomic and systematic resolution to allow a more detailed historical inference. The distribution of *Palpifer* is also of regional biogeographic interest because there are no records from sub-Himalayan India even though the genus is present in Sri Lanka and widespread (with very scattered records) across southeastern Asia south to Java.

Our review of the northeastern Hepialidae illustrates the critical need for taxonomic revision of the Indian hepialid fauna. This need is highlighted by the lack of detailed type descriptions necessary to verify the status of *Endoclita* nr. *malabaricus* from Kodaikanal in southwestern India (Grehan & Mielke 2017). Future taxonomic work will also require locating outstanding type specimens such as that of *P. minutus*, and establishing adequate descriptions of species types to corroborate or refute current synonymies and resolve other taxonomic uncertainties. The inclusion of Hepialidae in biodiversity surveys should be a high priority given the specialized host plant relationships represented by this group of moths. Meeting that goal will require attention to species that often have a dull or drab appearance and that may be hard to notice when there is an abundance of other Lepidoptera at light traps. Such factors may have contributed to the absence or lack of Hepialidae from some short-term surveys of Indian Lepidoptera (e.g., Shubhalaxmi et al. 2011 [one species of *Endoclita*], Chandra & Sambath 2013, Gurule & Nikam 2013) while a three-decade compilation of Lepidoptera in the Nainital District of Uttarakhand recovered three hepialid species (Smetacek 2008). The collection of voucher specimens, enhanced by live specimen imaging (e.g. http://www.inaturalist.org/observations/ivijayanand) represents a vital need not only for the Hepialidae, but also for the Indian insect fauna in general (cf. Smetacek 2011).

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Appendix 1. Summary of distribution records of Hepialidae species in Northeast India. Map references are estimated or approximated for most localities; source https://www.distancesto.com

Endoclita aboe (Moore, 1860)	Darjeeling (West Bengal) 27°2'N & 88°15'E [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E
Endoclita albosignata (Moore, 1879)	Margherita (Assam) 27°17'N & 95°40'E
Endoclita chalybeatus (Moore, 1879)	[West] Khasi Hills (Meghalaya, India) 25°34'N & 91°37'E Sylhet (Bangladesh) 24°54'N & 91°51'E Katha (Myanmar) 24°10'N & 96°19'E Namtu (Myanmar) 23°5'N & 97°23'E Sandoway [Thandwe] (Myanmar) 18°28'N & 94°20'E South Toungoo [Taungoo] (Myanmar) 18°56'N & 96°26'E
Endoclita damor (Moore, [1860])	Darjeeling (West Bengal) 27°2'N & 88°15''E Godawari Forest (Nepal) 27°36'N & 85°21'E Janakpur (Nepal) 26°43'N & 85°56'E Kathamandu (Nepal) 27°42'N & 85°19'E Mussoorie (Uttarakhand) 30°27'N & 78°3'E Kangra Valley (Himachal Pradesh) 32°10'N & 76°30'E
Endoclita rustica Tindale, 1941	[West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E Shillong (Meghalaya) 25°34' N & 91°52' E Bazaricherra (Assam) 24°26'N & 92°18'E
Endoclita signifer (Walker, 1856)	Cherrapunjee (Meghalaya) 25°16'N & 91°43'E [West] Jaintia Hills (Meghalaya) 25°30'7 N & 92°20'E Sylhet (Bangladesh) 24°54'N & 91°51'E
Endoclita undulifer (Walker, 1869)	Darjeeling (West Bengal) 27°2'N & 88°15''E [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E Senchal Range (West Bengal) 27°2'N & 88°15''E Shwebo (Myanmar) 22°34'N & 95°41'E Varanasi (Uttar Pradesh) 25°19'N & 82°58'E
Hepialiscus nepalensis (Walker, 1856)	Bhimtal (Uttarakahnd) 29°20'N & 79°33'E Darjeeling (West Bengal) 27°2'N & 88°15''E East Nepal [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E Nilamo (Xizang, China) Simla (Himachal Pradesh) 31°6'N & 77°10'E Subathu (Himachal Pradesh) 30°58'N & 76°59'E
Palpifer minutus Hampson, 1896	[West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E
Palpifer murinus (Moore, 1879)	Jalandhar (Punjab) 31°19'N & 75°34'E Dharmshala (Himachal Pradesh) 32°13'N & 76°19'E Cherrapunjee (Meghalaya) 25°16'N & 91°43'E [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E
Palpifer pellicia (Swinhoe, 1905)	Cherrapunjee (Meghalaya) 25°16'N & 91°43'E [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E
Palpifer sexnotatus (Moore, 1879)	Bhimtal Valley (Uttarakahnd) 29°20'N & 79°33'E Darjeeling (West Bengal) 27°2'N & 88°15''E Gopaldhara (West Bengal) 26°55'N & 88°10'20.23'E [West] Khasi Hills (Meghalaya) 25°34'N & 91°37'E Mirik (West Bengal) 26°53'N & 88°10'E Simla (Himachal Pradesh) 31°6'N & 77°10'E

Journal of Threatened Taxa

OPEN ACCESS

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

March 2017 | Vol. 9 | No. 3 | Pages: 9885–10020
Date of Publication: 26 March 2017 (Online & Print)
DOI: 10.11609/jott.2017.9.3.9885-10020
www.threatenedtaxa.org

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