

Phylogeny and nomenclature of the box tree moth, *Cydalima perspectalis* (Walker, 1859) comb. n., which was recently introduced into Europe (Lepidoptera: Pyraloidea: Crambidae: Spilomelinae)

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Abstract. The box tree moth, *Cydalima perspectalis* (Walker, 1859) comb. n., is native to India, China, Korea, Japan and the Russian Far East. Its larvae are a serious pest of different species of *Buxus*. Recently, *C. perspectalis* was introduced into Europe and first recorded from Germany in 2006. This species has been placed in various spilomeline genera including *Palpita* Hübner, 1808, *Diaphania* Hübner, 1818, *Glyphodes* Guenée, 1854 and the monotypic *Neoglyphodes* Streltsov, 2008. In order to solve this nomenclatural confusion and to find a reasonable and verifiable generic placement for the box tree moth, the morphology of the above mentioned and some additional spilomeline taxa was investigated and their phylogeny analysed. The results show that *C. perspectalis* belongs to a monophylum that includes three of the genera in which it was previously placed: *Glyphodes*, *Diaphania* and *Palpita*. Within this monophylum, it is closely related to the Asian *Cydalima* Lederer, 1863. As a result of this analysis, *Sisyrophora* Lederer, 1863 syn. rev. and *Neoglyphodes* Streltsov, 2008 syn. n. are synonymised with *Cydalima* Lederer, 1863, and five species are transferred to this genus: *Cydalima caprinodes* (Hampson, 1912) (*Glyphodes*) comb. n., *Cydalima decipiens* (Hampson, 1912) (*Glyphodes*) comb. n., *Cydalima joiceyi* (Janse, 1924) (*Margaronia*) comb. n., *Cydalima perspectalis* (Walker, 1859) (*Phakellura*) comb. n. and *Cydalima pfeifferae* (Lederer, 1863) (*Sisyrophora*) comb. rev.

INTRODUCTION

The natural range of the box tree moth (Fig. 3A, B) is the humid subtropical regions of East Asia, in India (Hampson, 1896), China (Walker, 1859), Japan (Inoue, 1982), Korea (Park, 2008) and Russian Far East (Kirpichnikova, 2005). Its larvae feed on the leaves of *Buxus microphylla* Siebold & Zucc., but also accept other *Buxus* species (Maruyama, 1993), seriously damaging these ornamental plants in Asian gardens. Therefore, the ecology of the box tree moth has been well studied in Japan (Maruyama, 1992, 1993; Maruyama & Shinkaji, 1987, 1991, 1993; Tominaga 1998), China (Tang et al., 1990; Zhou et al., 2005) and Korea (Park, 2008). Due to its economic importance in East Asia, there is information on its chemical control (Zhou et al., 2005), biological control using nematodes (Choo et al., 1991; Lee et al., 1996) and its pheromones (Kawazu et al., 2007).

In 2006, the box tree moth was introduced into south-western Germany (Krüger, 2008). In 2007, it was also found in Switzerland (Käppeli, 2008; Sigg, 2009) and in the Netherlands (Muus et al., 2009). In 2008, it was first reported in Britain (Mitchell, 2009), France (Feldtrauer et al., 2009) and Austria (Rodeland, 2009). Rodeland (2009) provides an overview of its colonization of central Europe. It is assumed that the box tree moth was imported by man into Europe and since then transported within Europe on *Buxus*-plants distributed by tree nurseries (Krüger, 2008; Käppeli, 2008; Muus et al., 2009; Sigg, 2009). In addition, it is also capable of hibernating and

spreading naturally in Europe (Krüger, 2008; Feldtrauer et al., 2009; Muus et al., 2009; Sigg, 2009). In Central Europe, larvae of the box tree moth are usually found in high numbers, which defoliate and subsequently kill this evergreen shrub (Krüger, 2008; Käppeli, 2008; Sigg, 2009). Thus, the box tree moth is becoming a serious threat for the West-Palaeartic *Buxus sempervirens* L.

The box tree moth, originally described as *Phakellura perspectalis* Walker, 1859 has been variously placed in the spilomeline genera *Palpita* Hübner, 1808 (= *Phakellura* Guilding, 1830) (Muus et al., 2009), *Diaphania* Hübner, 1818 (Zhou et al., 2005; Feldtrauer et al., 2009; Mitchell, 2009) and *Glyphodes* Guenée, 1854 (Maruyama, 1992, 1993; Maruyama & Shinkaji, 1987, 1991, 1993; Tominaga, 1998; Kawazu et al., 2007; Krüger, 2008; Park, 2008). Unfortunately, there are no good reasons cited in the literature for placing *perspectalis* in any of these genera. In 2008, Streltsov, comparing *perspectalis* with *Diaphania* and *Glyphodes*, pointed to morphological differences between these three taxa and established a new, monotypic genus *Neoglyphodes* for *perspectalis*. This systematic action is uninformative as the new genus was not put into context within the Spilomelinae, with the exception that Streltsov refers to a second, still undescribed species of *Neoglyphodes*. Moreover, the establishment of this new genus makes the systematics of the Spilomelinae even more confusing, as this subfamily currently comprises 277 genera (plus 246 synonyms) with more than 3,700 species (Nuss et al., 2010) and needs to be more extensively taxonomically

and phylogenetically revised. The only phylogenetic studies available are those by Sutrisno (2002a, b, 2005, 2006) and Sutrisno et al. (2006) on *Glyphodes* and allied genera.

Against this background, the morphology of the above mentioned genera and some additional spilomeline taxa were investigated and their phylogeny analysed in order to obtain a reasonable and verifiable generic placement for the box tree moth.

MATERIAL AND METHODS

For the cladistic analysis, taxa of all genera in which *perspectalis* has been placed so far (*Diaphania*, *Glyphodes*, *Palpita*), taxa similar to *perspectalis* identified by screening the collections (*Sisyrophora* and *Cydalima*) and six additional taxa from different spilomeline genus-groups sensu Munroe (1995), were investigated. Altogether, 16 species belonging to 14 different genera were included as in-groups and *Evergestis forficalis* (Crambidae: Evergestinae) as the out-group. Details of the specimens studied are given below:

Evergestis forficalis (Linnaeus, 1758): 1♂, 1♀ Germany, Saxony, Moritzburg, 5.vi.1967; 18.viii.1965, Bembenek & Krause leg., SMTD.

Agrioglypta eurytusalis (Walker, 1859): 1♂, 1♀ Cambodia, Cardamom Mts, Tumpor area, 12°22'N, 103°02'E, 1,250 m, 27.ii.–5.iii.2000, Nuss leg., SMTD.

Agrotera nemoralis (Scopoli, 1763): 1♂, France, Department Lot, Douelle, 9.viii.1931, Lhomme leg.; 1♀, NE-Turkey, Rize province, Karadeniz, Dağları, Iyidere valley, above İkizdere, 840 m, 7.vi.2002, Ochse leg.; SMTD.

Bradina diagonalis (Guenée, 1854): 1♂, 1♀ Vietnam, Province Lao Cai, Mt. Fan Si Pan, Nui Se, 22°21.168'N, 103°46.477'E, 1,927 m, 19.–20.x.2001, Löffler leg., SMTD.

Cydalima laticostalis (Guenée, 1854), Syntype: ♀, with labels “Type”, “Laticostalis | Gn. Sil”, “Assam | Silhet | ex coll. Gn.”, “Paravicini Coll. | B.M. 1937-383.”, BMNH. – 1♂, Cambodia, Cardamom Mts, Tumpor area, 12°22'N, 103°02'E, 1,250 m, 27.ii.–5.iii.2000, Nuss leg.; 1♀, Philippines, South Luzon, Los Baños, Mt. Makiling, 14°08'N, 121°14'E, 815 m, 30.iii.2000, Nuss leg.; SMTD.

The following three names are synonyms of *C. laticostalis* and their types were investigated:

Margarodes conchylalis Guenée, 1854, Syntype: ♀ [abdomen and right antenna missing], with labels “Type”, “Conchylalis | Gn Corom”, “Madras | Coromandel | ex coll. Gn.”, “Paravicini Coll. | B. M. 1937-383.”, BMNH.

Margarodes nitidicostalis Guenée, 1854, Syntypes: 1♀, with labels “Co- | type”, “Nitidicostalis | Gn Silhet”, “Assam | Silhet | ex coll. Gn.”, “Paravicini Coll. | B.M. 1937-383”, BMNH. 1♀ [abdomen missing], same labels, except the identification label, BMNH.

Margaronia leodicealis Walker, 1859, Syntype: ♀, with labels “E Ind” [back] “61 | 83.”, BMNH.

Diaphania indica (Saunders, 1851): 1♂, Kenya, Tana River, Primate N.P., 01°52'34"S, 40°08'25"E, 8.–9.vi.2005, Errolat, Muli, Nuss & Okuku leg.; 1♀, Kenya, Tsavo-West N.P., 2°27'06"S, 38°03'54"E, 1.–2.vi.2005, Errolat, Muli, Nuss & Okuku leg.; SMTD.

Glyphodes caprinoides Hampson, 1912, Syntype: ♂, with labels “Type”, “Bombay”, “Moore Coll. | 94-106.”, “Glyphodes. | caprinoides | type ♂ Hmpsn.”, BMNH.

Glyphodes decipiens Hampson, 1912 Holotype (by monotypy): ♂, with labels “Type”, “Ceram [back] 62 | 18”,

“Glyphodes | decipiens | type ♂. Hmpsn.”, “Pyrilidae | Brit. Mus. | Slide No. | 2138 ♂”, BMNH.

Glyphodes stolalis Guenée, 1854: 1♂, 1♀ Philippines, South Luzon, Los Baños, Mt. Makiling, 14°08'N, 121°14'E, 815 m 16.iii.2000, Nuss leg., SMTD.

Glyphodes onychinalis (Guenée, 1854): 1♂, 1♀ Cambodia, Cardamom Mts, Tumpor area, 12°22'N, 103°02'E, 1,250 m 27.ii.–5.iii.2000, Nuss leg., SMTD.

Glyphodes sp.: 1♂, Cardamom Mts, Tumpor area, 12°22'N, 103°02'E, 1,250 m, 27.ii.–5.iii.2000, Nuss leg.; 1♀, India, Andaman Is., Middle Andaman, Tagapure, 12°50'72"N, 92°49'29"E, 22.–26.xi.2000, J.-P. Rudloff leg.; SMTD.

Margaronia joiceyi Janse, 1924, Paratypes: 2♂, 2♀, Central Ceram, Manusela, x.–xii.1919, C.F. & J. Pratt, BMNH.

Mecyna lutealis (Duponchel, 1833): 1♂, Italy, Malcesine, Lake Garda, 2.vi.1948, Möbius leg.; 1♀, Switzerland, Wallis, Stalden, 20.iv.1918, Möbius leg.; SMTD.

Nomophila noctuella (Denis & Schiffermüller, 1775): 1♂, Germany, Saxony, Oberfrohna, 16.viii.1946, Ernst leg.; 1♀, Italy, Campania, Napoli, Posillipo, 26.viii.2006, Vegliante leg.; SMTD.

Palpita vitrealis (Rossi, 1794): 1♂, Italy, Abruzzo, Riserva Naturale Lago Penne, Giardino farfalle, 260 m, 24.–25.x.1999, Bellini & Dell'Agata leg.; 1♀, Italy, Province of Rome, Monterotondo, vii.1894, “MR” leg.; SMTD.

Phakellura advenalis Lederer, 1863, Lectotype, with labels “Lectotype”, “Felder | colln”, “Shanghai”, “Phacellura [sic] | advenalis m”, “Lectotype | Phacellura [sic] | advenalis Lederer | E.G. Munroe. 1958”, BMNH.

Glyphodes albifuscalis Hampson, 1899, Syntype, with labels “Type”, “Ichang | 91 45.”, “Glyphodes | albifuscalis | type ♂. Hmpsn.”, BMNH.

Phakellura perspectalis Walker, 1859, Holotype (by monotypy): ♀, “Type”, “N. China | 54.8.”; with a handwritten bottom label “perspectalis | Walk”, BMNH. – 1♂, Germany, Weil am Rhein, ex larva, 2007, Walter leg.; 1♂, Tokio, Nippon, no date given, Staudinger & Bang-Haas; 1♂, China, Tianjin, Nankai University, 15.vii.2009, Nuss & Tränkner leg.; 1♂, China, Zhejiang, Shanghai, Mount Mogao, 29.vi.1931, Höne leg.; 1♂, China, Jiangsu Province, Shanghai, 30.v.1937, Höne leg.; 1♀, China, Zi-Ka-Wey, no date given, Staudinger & Bang-Haas; SMTD.

Pleuroptya ruralis (Scopoli, 1763): 1♂, 1♀ Germany, Saxony, Dresden, Heller, Augustusweg, 17.vii.2008, Tränkner leg., SMTD.

Sisyrophora pfeifferae Lederer, 1863, Holotype (by monotypy): with labels “Ida | Pfeiffer. | Singap. | 1858”, “Sisyrophora | Pfeifferae m”, NHMW. – 1♂, Cambodia, Cardamom Mts, near Cham Kar Chhrey, 12°20'N, 103°01'E, 350 m, 6.iii.2000, Nuss leg.; 1♀, Cambodia, Cardamom Mts, Tumpor area, 12°22'N, 103°02'E, 1,250 m, 27.ii.–5.iii.2000, Nuss leg.; SMTD.

Stemorrhages sericea (Drury, 1773): 1♂, Madagascar, Brickaville, no date given, Staudinger & Bang-Haas; 1♀, Sierra Leone, no date given, Staudinger & Bang-Haas; SMTD.

Udea ferrugalis (Hübner, 1796): 1♂, Italy, S-Tyrol, Bozen, 11.ix.1912, Möbius leg.; 1♀, Italy, Arco, Lake Garda, 27.ix.1930, Möbius leg., SMTD.

For the morphological analysis, dried museum specimens and adults were used. Dissections of abdomens and preparation of genitalia were performed according to Robinson (1976). Photographic documentation of genitalia was done using a Nikon Eclipse E600 Microscope in combination with a Zeiss AxioCam MRc5 camera and AxioVision programme (Version 4.4) on a Windows PC. Morphological characters are coded with respect

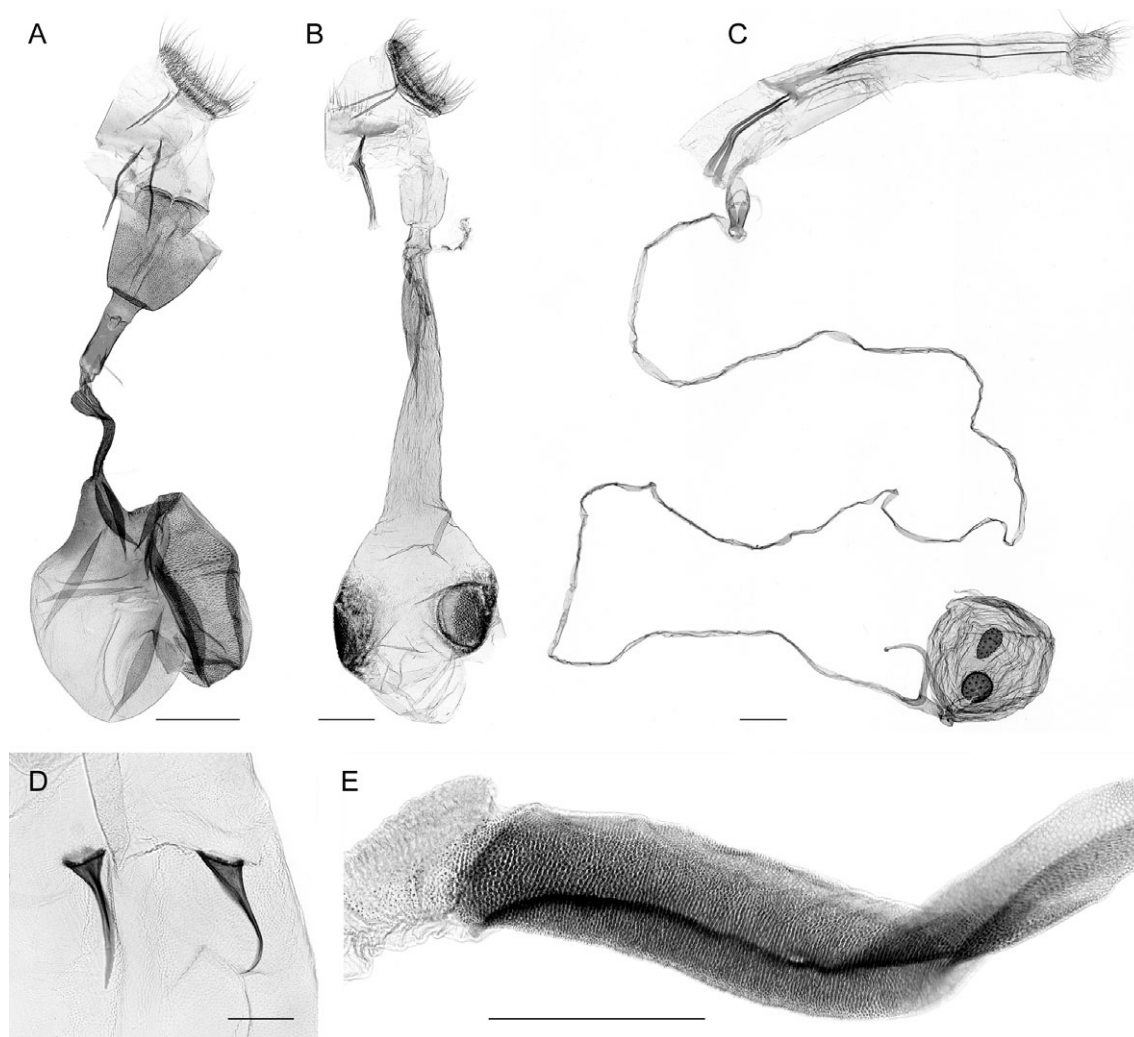


Fig. 1. Female genitalia. A – *Udea ferrugalis*; B – *Evergestis forficalis*; C – *Glyphodes* sp.; D – *Palpita vitrealis*, detail of corpus bursae, showing the signa; E – *Cydalima perspectalis*, detail of ductus bursae, showing sclerotization anterior to ductus seminalis. Scale bars: 500 μ m.

Palpita + *Stemorrhages*. Synapormophy: Corpus bursae with a pair of thorn-shaped signa (2:1).

Agrioglypta + *Glyphodes* + *Diaphania* + *Cydalima* + *Sisyrophora* + *perspectalis* + *Palpita* + *Stemorrhages*. Synapormorphies: Coremata pads present and with a distinct, sclerotised margin (7:2); sacculus with an elevated, sclerotised ridge (8:1); ductus ejaculatorius leaving the phallus apodeme anteriorly (9:1) [uncertain (“?”) in *Agrioglypta* + *Glyphodes* sp.].

Agrioglypta + *Glyphodes* + *Diaphania* + *Cydalima* + *Sisyrophora* + *perspectalis* + *Palpita* + *Stemorrhages* + *Bradina*. Synapormorphies: Uncus distally with bulbous thickening (5:1); tergite 8 with Y-shaped sclerotisation (13:1); violet iridescence of white ground colour present (19:0).

Agrioglypta + *Glyphodes* + *Diaphania* + *Cydalima* + *Sisyrophora* + *perspectalis* + *Palpita* + *Stemorrhages* + *Bradina* + *Nomophila*. Synapormophy: Ventrally sclerotised groin of phallus apodeme present (11:1).

DISCUSSION

The results indicate that *perspectalis* belongs to a monophylum to which also belong the three genera in which it was previously placed: *Glyphodes*, *Diaphania* and *Palpita*. Munroe (1995) treated these genera in a *Diaphania*-group of 18 spilomeline genera centred on the Neotropical region, but did not mention which character(s) supported this group. In the analysis presented here, this monophylum is supported by the three synapomorphies 7:2, 8:1 and 9:1, and in addition contains the Old World taxa *Agrioglypta*, *Cydalima*, *Sisyrophora* and *Stemorrhages*.

First, the possible close relationships of *perspectalis* with the three genera in which it was previously placed are discussed below.

Diaphania contains 89 described species occurring in the Neotropical region, including *D. indica* Saunders, 1851 (Munroe, 1995). The latter species also occurs abundantly in the tropics of the Old World. Its larvae are pests of different cultivated plants, particularly Cucurbitaceae, but also Malvaceae, Amaranthaceae, Leguminosae

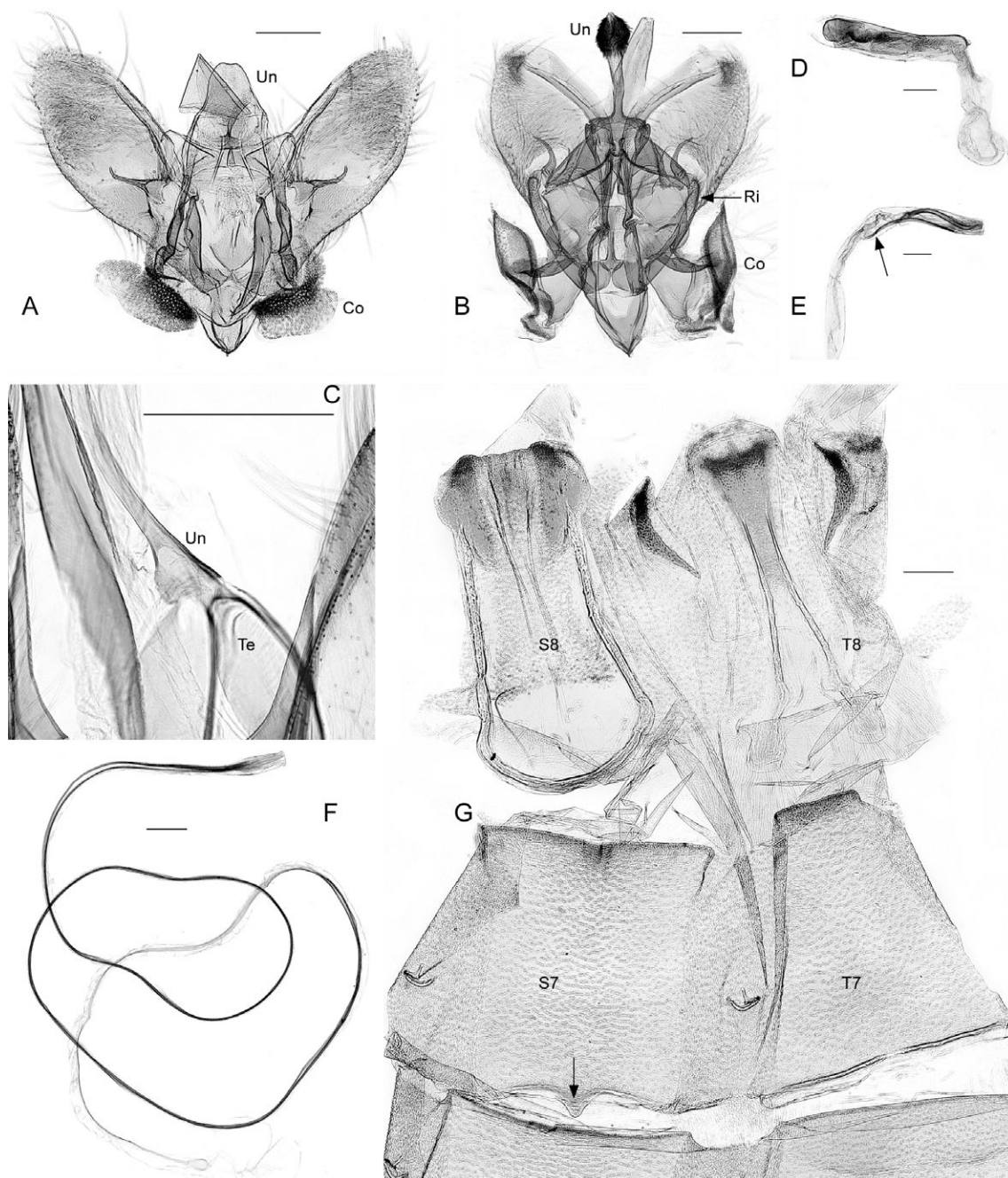


Fig. 2. Male genitalia. A – *Pleuroptya ruralis*, caudal view; B – *Cydalima laticostalis*, caudal view; C – *Glyphodes* sp., uncus base, caudal view; D – *Pleuroptya ruralis*, lateral view, phallus; E – *Cydalima perspectalis*, phallus, lateral view; arrow indicates ventrally sclerotised groin; F – *Glyphodes* sp., phallus, lateral view; G – *Cydalima perspectalis*, 7th to 8th abdominal segments; arrow indicates anterior median extension of sternite 7. Co – Coremata; Ri – Ridge of Sacculus; S – Sternite; Te – Tegumen; T – Tergite; Un – Uncus. Scale bars: 500 μ m.

and Solanaceae. Thus, it might be assumed that *D. indica* was introduced by man into the Old World. There is a second species of *Diaphania* in the Old World, *D. holophaealis* (Hampson, 1900) on Christmas Island, which might be a melanic form of *D. indica* (J. Shaffer & Munroe, 2007). Thus, it is highly probable that *Diaphania* is a neotropical taxon. Apart from characteristic wing patterns and features of their genitalia, J. Shaffer & Munroe (2007) recognize species of *Diaphania* by the presence of anal tufts of spatulate scales in both sexes. This character

is unique for *Diaphania* in our matrix, and therefore was omitted from the analysis because it is parsimony-uninformative. On the basis of these arguments, there is no evidence for placing *perspectalis* in *Diaphania*.

Glyphodes is pantropical in distribution, comprising more than 120 species and in need of revision (Robinson et al., 1994). Similar to Sutrisno (2002a, b) the morphological analysis presented here does not support the monophyly of *Glyphodes* (= *Dysallacta* Lederer, 1863, as synonymised by Inoue 1982). In this analysis, all

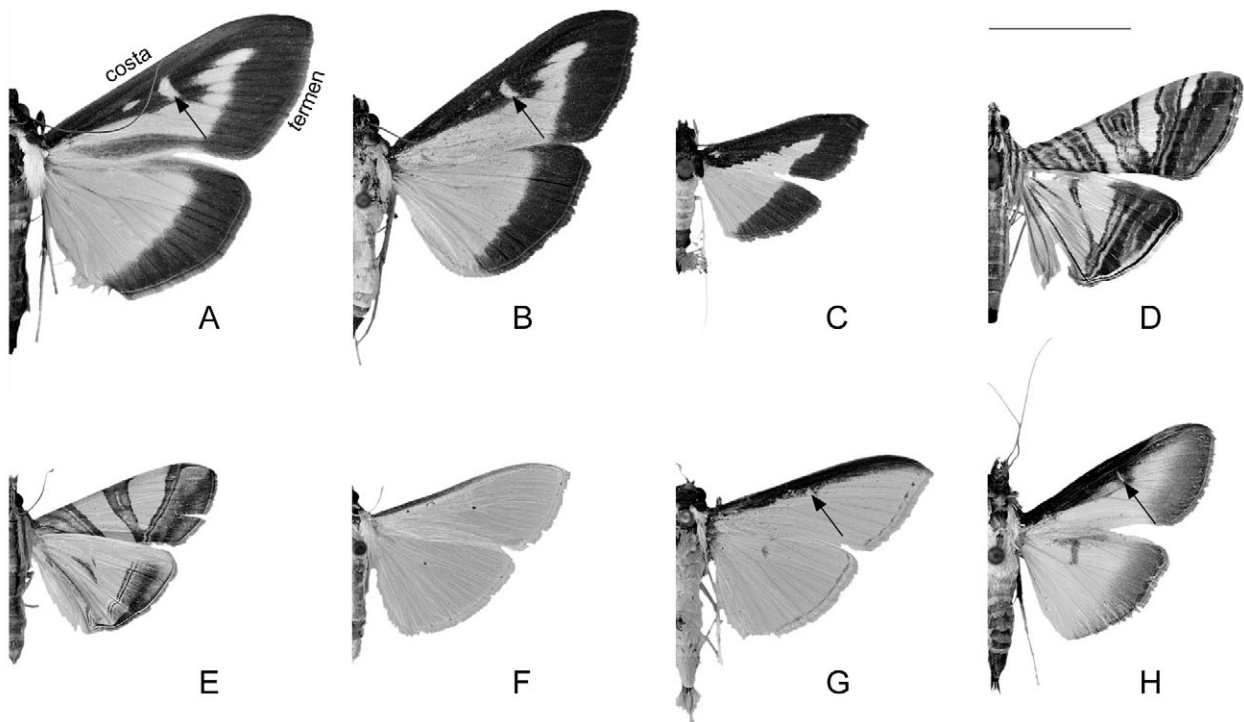


Fig. 3. Wing pattern. A – *Cydalima perspectalis* with brown anal margin on forewing; B – *Cydalima perspectalis* with white anal margin on forewing; C – *Diaphania indica*; D – *Glyphodes stolalis*; E – *Glyphodes* sp.; F – *Palpita vitrealis*; G – *Cydalima laticostalis*; H – *Sisyrophora pfeifferae*. Arrows indicate white spot in discoidal cell. Scale bar: 10 mm.

Glyphodes-species, together with *Agrioglypta* and *Diaphania* are characterized by character 6:1, uncus very narrowly attached to the tegumen. In contrast, the base of uncus in *perspectalis* is broadly attached to the tegumen. Externally, species of *Glyphodes* characteristically have colourful wings, which are easily distinguished from the white, brown edged wings of *perspectalis*. On the basis of these arguments, there is no evidence for placing *perspectalis* in *Glyphodes*.

Palpita comprises 146 described species mainly in the Neotropical, Afrotropical, Oriental and Australian regions (Nuss et al., 2010). The taxonomic revisions of the Asian and Australian species by Inoue (1996, 1997, 1999) indicate that these species and *Stemorrhages sericea* all have a pair of thorn-shaped signa in the corpus bursae (character 2:1), which unambiguously supports the monophyly of this group. On the basis of these arguments, there is no evidence for placing *perspectalis* in *Palpita*.

The above indicates that *perspectalis* is not closely related to *Diaphania*, *Glyphodes* or *Palpita*. A fourth generic name, *Neoglyphodes*, was proposed for *perspectalis* in 2008 by Streltsov. This genus is monotypic and Streltsov does not provide any hypothesis for its relationship. He lists eight diagnostic characters for this genus: (1) “In colouration – forewings with broad black or dark grey band along outer margin, continuing in narrower bands along costal and anal margins”. This character complex is also present in other genera, e.g. the costal band in *Diaphania*, *Cydalima*, *Palpita* and *Sisyrophora*; the terminal band in *Diaphania* and *Glyphodes*, while the anal band in *perspectalis* can be present or absent. (2) “Triangular central field white with violet glistening”. In

the analysis presented here, this character state is 19:0 and supports the monophyly of *Agrioglypta* + *Glyphodes* + *Diaphania* + *Cydalima* + *Sisyrophora* + *perspectalis* + *Palpita* + *Stemorrhages* + *Bradina*. (3) “Hindwings white with the same band at outer margin as in forewings”. This character is also present in *Diaphania*. (4) “In wing venation – discal cells are open.” This character was investigated here and there are only closed discal cells in *perspectalis*, a character state that is also visible in the photograph of *perspectalis*, but not in the drawing of its wing venation in Streltsov (2008). (5) “In male genitalia – uncus bifurcate”. This character is homoplastic in Spilomelinae, as it is also present in *Pycnarmon* Lederer, 1863 and *Nacoleia* Walker, 1859. (6) “Valva apex with three processes” is present only in an undescribed species mentioned by Streltsov (2008), but not in *perspectalis*. (7) “Aedeagus [phallus] long and narrow” is a description, which is valid for most Lepidoptera. (8) “In female genitalia – ductus short and strongly sclerotized.” Here, Streltsov (2008) probably refers to the sclerotization of the ductus bursae anterior to the ductus seminalis that is identical to the character state 4:1 in the present study, which is shared by *Cydalima laticostalis* and *Sisyrophora pfeifferae*. It is the only diagnostic character given by Streltsov (2008), which, according to the analysis presented here supports relationships of *perspectalis* with other taxa, but none of these characters are autapomorphic for *Neoglyphodes*.

In contrast, the analysis presented indicates a close relationship of *perspectalis* with *Cydalima laticostalis* and *Sisyrophora pfeifferae*. The taxon formed by these three species is supported as monophyletic by the character

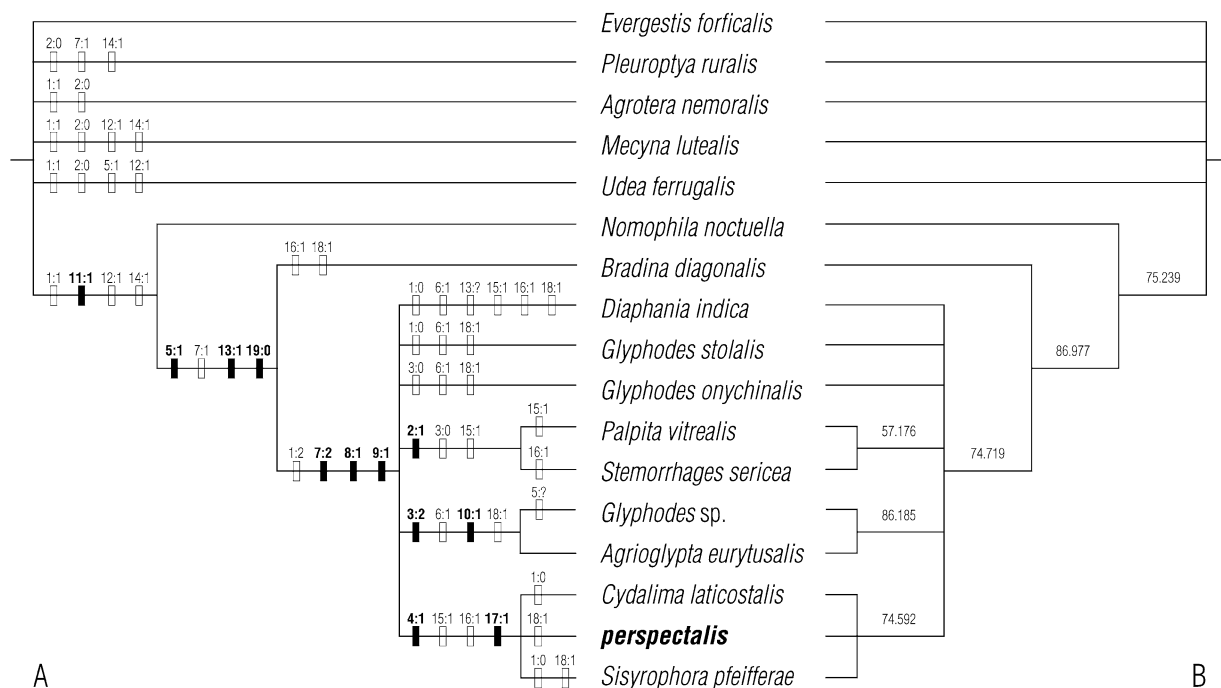


Fig. 4. A – Strict consensus tree of the 136 most parsimonious trees. Black rectangles: synapomorphies; white rectangles: homoplasies. B – 50% majority-rule consensus tree with bootstrap values.

states 4:1, sclerotisation of ductus bursae anterior of ductus seminalis developed and 17:1, a white spot in the discoidal cell of forewing, partly located on the brown costal margin.

Based on this phylogenetic analysis and the above discussion, the following taxonomic changes are proposed:

(1) The box tree moth be transferred to *Cydalima* Lederer, 1863 (type species: *Margarodes conchylalis* Guenée, 1854, a junior subjective synonym of *Cydalima laticostalis* (Guenée, 1854), in the combination *Cydalima perspectalis* (Walker, 1859) comb. n. Since *perspectalis* is the type-species of *Neoglyphodes* Streltsov, 2008 syn. n., this genus name be synonymised with *Cydalima* Lederer, 1863.

(2) Following Hering (1901), *Sisyrophora* Lederer, 1863 syn. rev. be regarded as a synonym of *Cydalima* Lederer, 1863 and its type species *Cydalima pfeifferae* (Lederer, 1863) (*Sisyrophora*) comb. rev. and *Cydalima joiceyi* (Janse, 1924) [*Margaronia* (*Sisyrophora*)] comb. n. be placed in this genus.

(3) Based on the investigation of type specimens, *Cydalima caprinodes* (Hampson, 1912) (*Glyphodes*) comb. n. and *Cydalima decipiens* (Hampson, 1912) (*Glyphodes*) comb. n. be transferred to *Cydalima*.

Based on these nomenclatural changes and the published data, there are currently 9 species (+ 9 synonyms) of *Cydalima*, all occurring in Asia and some also in Australia (Nuss et al., 2010). A taxonomic revision is still required to verify the status of available species group names and new species might be discovered as indicated by Streltsov (2008). Regarding the box tree moth *C. perspectalis* Walker, 1859, the type-specimen from China coincides with the specimens collected in Europe. Species group names currently treated in *Cydalima* and older than

C. perspectalis Walker, 1859, exclusively belong to *C. laticostalis* (Guenée, 1854) and its synonyms *Margarodes conchylalis* Guenée, 1854, *Margarodes nitidicostalis* Guenée, 1854, and *Margaronia leodicalis* Walker, 1859. The type specimens of these four taxa were also investigated. They are all easily recognized as specifically distinct from *C. perspectalis*. Thus, it is very unlikely that a taxonomic revision of *Cydalima* will affect the species-group name *perspectalis*.

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