Parasitoids (Hymenoptera: Chalcidoidea) of the Cabbage Seedpod Weevil (Coleoptera: Curculionidae) in Georgia, USA

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Abstract.—Five families and 13 species of Chalcidoidea (Hymenoptera) were obtained from mass-reared seedpods of *Brassica napus* L. (Brassicaceae) as putative parasitoids of the cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), in Georgia, USA. The species are *Conura torvina* (Cresson) (Chalcididae), *Euderus glaucus* Yoshimoto and *Necremnus tidius* (Walker) (Eulophidae), *Brasema allynii* (French) **n. comb.** (from *Eupelmus* Dalman) and *Eupelmus cyaniceps* Ashmead (Eupelmidae), *Eurytoma tylodermatis* Ashmead (Eurytomidae), and *Lyrcus incertus* (Ashmead), *L. maculatus* (Gahan), *L. perdubius* (Girault), *Mesopolobus moryoides* Gibson, *Neocatolaccus tylodermae* (Ashmead), *Pteromalus cerealellae* (Ashmead) and *Pteromalus* sp. (Pteromalidae). An illustrated key is provided to differentiate the taxa. *Lyrcus maculatus* constituted about 96% of all reared Pteromalidae and 86% of the total parasitoid fauna. The associations of *B. allynii*, *E. glaucus*, *E. cyaniceps*, *E. tylodermatis*, *L. incertus*, *N. tylodermae*, *Pteromalus* sp. and *P. cerealellae* with *C. obstrictus* are new, but some of these species likely are hyperparasitoids or emerged from insect contaminants of the mass-reared seedpods. The only previous report of a parasitoid of *C. obstrictus* in eastern North America, *Trichomalus perfectus* (Walker) (Pteromalidae), is a misidentification. The parasitoid fauna of *C. obstrictus* in Georgia is discussed relative to that known for western North America.

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), was introduced from Europe to western North America about 70 years ago. Since then it has become the most important insect pest of canola and rape, *Brassica napus* L. and *B. rapa* L. (Brassicaceae), in most areas of the continent where these crops are grown (Cárcamo et al. 2001, Kuhlmann et al. 2002). It was first reported from eastern North America in North Carolina, USA (USDA 1960), and is now known to extend from Georgia to Quebec and Ontario, Canada (Brodeur et al. 2001, Mason et al. 2004). There have been several surveys of the introduced and native chalcid (Hymenop-tera: Chalcidoidea) parasitoids of the cabbage seedpod weevil in western North America, including Breakey et al. (1944), Doucette (1944, 1948), Hanson et al. (1948), Carlson et al. (1951), McLeod (1953), Walz (1957), and Dosdall et al. (in press). Murchie and Williams (1998) listed 7 identified and 4 unidentified species in 9 genera and 5 families of Chalcidoidea as parasitoids of *C. obstrictus* in North America, but almost all of the species names either represent misidentifications or are now recognized as junior synonyms of older names (Gibson et al. 2005). Dosdall et al. (in press) reported another six chalcid species as reared from *B. napus* and *B. rapa* seedpods in Alberta. Consequently, the

Table 1. Chalcid parasitoids associated with the cabbage seedpod weevil in North America, including for Georgia the number of specimens and percentage (in parenthesis) of total parasitoids reared by Buntin (1998).

Taxon	Western North America	Georgia
Chalcididae		
Conura albifrons (Walsh)	+	–
? Conura side (Walker)[1]	+	–
Conura torvina (Cresson)	+	9 (0.8)
Eulophidae		
Euderus albitarsis (Zetterstedt)	+	–
Euderus glaucus Yoshimoto	–	2 (0.2)
Necremnus tidius (Walker)	+	6 (0.5)
Eupelmidae		
Brasema allynii (French)	–	5 (0.5)
Eupelmus cyaniceps Ashmead	–	4 (0.4)
Eupelmus vesicularis (Retzius)	+	–
Eurytomidae		
Eurytoma tylodermatis Ashmead	+	25 (2.2)
Pteromalidae		
Chlorocytus sp.	+	–
Lyrcus incertus (Ashmead)	–	6 (0.5)
Lyrcus maculatus (Gahan)	+	967 (86.0)
Lyrcus perdubius (Girault)	+	60 (5.3)
Mesopolobus bruchophagi (Gahan)	+	–
Mesopolobus mayetiolae (Gahan)	+	–
Mesopolobus moryoides Gibson	+	2 (0.2)
Neocatolaccus tylodermae (Ashmead)	–	33 (2.9)
Pteromalus cerealellae (Ashmead)	–	1 (0.1)
Pteromalus spp.[2]	+	4 (0.4)
Trichomalus lucidus (Walker)	+	–

[1] Single record, likely a misidentification of C. torvina (see text).
[2] Females in the two regions represent different species (see text).

chalcid fauna purportedly parasitizing C. obstrictus in western North America includes at least 14 species (Table 1). In contrast, there is only a single published report of parasitoids of C. obstrictus in eastern North America. Buntin (1998) stated that greater than 96% of the parasitoids recovered from seedpods of B. napus in Georgia were Trichomalus perfectus (Walker) (Pteromalidae). This species is the most common biological control agent of C. obstrictus in Europe (Murchie and Williams 1998) and was long thought to have been introduced to North America along with the seedpod weevil. However, Gibson et al. (2005) showed that all previous reports of T. perfectus in western North America were misidentifications of Trichomalus lucidus (Walker), another European species.

Accurate identification of parasitoid species is a prerequisite for successful classical biological control and integrated pest management. The senior author examined the parasitoids reared by Buntin (1998) as part of a larger study to document the diversity and identity of the chalcid parasitoids of C. obstrictus in North America. The primary purpose of Buntin (1998) had been to examine the effect of trap cropping on the number of seedpod weevils and its parasitoids in canola crops in Georgia. The species identities of the parasitoids had therefore never been thoroughly investigated. The purpose of this paper is to provide the first comprehensive information on the diversity of the chalcid parasitoids reared from canola seedpods in southeastern USA in order to facilitate future studies of the parasitoid fauna associated with C. obstrictus throughout North America.

MATERIALS AND METHODS

The chalcid parasitoids identified in this study were obtained from mass-reared seedpods of B. napus collected from the Bledsoe Research Farm (33°10.635'N 84°24.354'W) located near Griffin, Georgia, from 1994–1996, as per "Material and methods" in Buntin (1998). Although not stated, the pods were screened for insect contaminants prior to rearing. Contaminants mainly included aphids (Hemiptera:

Aphididae) and larvae and pupae of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). The reared parasitoids had been stored in ethanol, but were critical-point dried, point-mounted, and identified to genus by the senior author using the relevant family keys in Gibson et al. (1997). The senior author is responsible for all species identifications except *Eurytoma tylodermatis* Ashmead (Eurytomidae), which was identified by MWG. Information concerning the method of species identification within each genus is provided under the relevant species discussion. Voucher specimens are deposited in the Canadian National Collection of Insects and Arachnids (CNC), Ottawa, Ontario, the University of Georgia Museum of Natural History (UGCA), Athens, Georgia, and the United States National Museum of Natural History (USNM), Washington, District of Columbia. Terms used for parasitoid structure follow Gibson (1997). Photographs are composite serial images that were combined using Auto-Montage™. These images and the scanning electron microphotographs were digitally retouched using Adobe Photoshop™ to enhance clarity.

RESULTS

A total of 1,127 specimens of Chalcidoidea were sufficiently intact that they could be identified accurately. Of these, there was a single male *Pachyneuron aphidis* (Bouché) and a female and male *Asaphes suspensus* (Nees) (Pteromalidae). Members of *Pachyneuron* and *Asaphes* are obligate hyperparasitoids of aphids (Gibson et al. 1997) and are not dealt with further. The remaining 1,124 specimens included 5 families, 10 genera, and 13 species of Chalcidoidea that are possible parasitoids of *C. obstrictus*. These taxa are keyed below and subsequently treated by family in alphabetical order. The key also segregates *Trichomalus* Thomson and *Chlorocytus* Graham, the only two genera reared from *C. obstrictus* in western North America (Dosdall et al. in press) that were not recovered by Buntin (1998) (Table 1). The two taxa are included in the key because species of both genera occur in eastern North America and may eventually be reared as part of the regional *C. obstrictus* parasitoid fauna.

KEY TO CHALCIDOIDEA PUTATIVELY PARASITIZING *C. OBSTRICTUS* IN GEORGIA

1   Hind leg with elongate coxa of similar length to conspicuously swollen and ventrally
         toothed femur, and with curved tibia (Fig. 1) ... *Conura torvina* (Cresson) (Chalcididae)
-        Hind leg with comparatively short coxa, slender femur, and straight tibia (Figs 3–8) ... 2
2(1)   Tarsi 4-segmented; flagellum with 3 or 4 funicular segments, the segments sometimes
         branched (Figs 9, 10) .... (Eulophidae) 3
-        Tarsi 5-segmented; flagellum with 5 or 6 unbranched funicular segments (Figs 11–18) ... 4
3(2)   Meso- and metatarsi with basal 4 segments white; forewing membrane bare dorsally
         behind marginal vein, but with clearly visible row of long admarginal setae
         (Fig. 42, ams) on ventral surface near marginal vein; flagellum of both sexes with 4
         unmodified funicular segments .... *Euderus glaucus* Yoshimoto
-        Meso- and metatarsi with basal 1 or 2 segments white; forewing membrane uniformly
         setose dorsally behind marginal vein, the setae largely obscuring admarginal setae
         on ventral surface (Fig. 41); flagellum branched in male (Fig. 10) and with only 3
         funicular segments in female (Fig. 9) .... *Necremnus tidius* (Walker)
4(2)   Head and mesosoma with coarse piliferous punctures and non-metallic, dark brown
         to black (Figs 3, 4); pronotal collar quadrangular in dorsal view, only slightly
         shorter than mesoscutum; male with elongate petiole and flagellar segments having
         whorls of conspicuously long setae (Fig. 4)........................

   . . . .   *Eurytoma tylodermatis* Ashmead (Eurytomidae)

\-   Head and mesosoma with finer mesh-like sculpture and often with metallic green to bluish luster; pronotum strongly transverse in dorsal view, conspicuously shorter than mesoscutum; male with short petiole and flagellar segments having short, inconspicuous setae 5

5(4)   Mesopleuron elongate, convex or cushion-like, and uniformly finely sculptured (Figs 5, 7); middle leg with strong black spines at apex of tibia and on ventral surface of tarsal segments (Figs 5, 7, sp), the colour of spines contrasting distinctly with mostly yellowish leg . . . . (Eupelmidae: Eupelminae female) 6

\-   Mesopleuron about as high as long, usually with a smooth region dorsally below base of wings and often with an oblique femoral depression or groove, but at least not convex or uniformly sculptured (Figs 23–25); middle leg with slender spines at apex of tibia and on ventral surface of tarsal segments, the colour of spines not contrasting with leg 7

6(5)   Ovipositor sheaths projecting only slightly beyond apex of gaster and uniformly coloured (Fig. 5); forewing completely setose behind parastigma and marginal vein (Fig. 5) . . . . *Brasema allynii* (French)

\-   Ovipositor sheaths projecting beyond apex of gaster by about one-third its length and medially whitish between darker basal and apical bands (Fig. 7); forewing with slender, oblique bare band (Fig. 7, bb) below parastigma and base of marginal vein . . . . *Eupelmus cyaniceps* Ashmead

7(5)   Flagellum with only basal segment conspicuously differentiated as strongly transverse ring segment and with 7 or 8 distinct funicular segments; head in frontal view with inner margin of eyes distinctly divergent over about ventral half; mesotibial spur much longer and thicker than metatibial spurs, as long as basal tarsal segment and about one-third length of tarsus . . . . (Eupelmidae: Eupelminae male) 8

\-   Flagellum with 2 or 3 basal segments conspicuously differentiated as ring segments and then with 6 or 5 tubular funicular segments, respectively (Figs 11–18); head in frontal view with inner margin of eyes subparallel or slightly but uniformly incurved; mesotibial spur somewhat longer than, but otherwise similar to, metatibial spurs, the spur obviously shorter than basal tarsal segment and only about one-quarter length of tarsus . . . . (Pteromalidae) 9

8(7)   Forewing completely setose behind parastigma and base of marginal vein (Fig. 6); hind leg with femur yellowish-white and tibia usually more or less distinctly brown (Fig. 6); flagellum clavate, the segments widening distinctly to clava and apical funicular segments transverse (Fig. 6) . . . . *Brasema allynii* (French)

\-   Forewing with large, oblique bare region (Fig. 8, bb) behind parastigma and base of marginal vein; hind leg with femur and tibia dark (Fig. 8); flagellum robust-filiform, the segments all about the same width and apical funicular segments quadrate (Fig. 8) . . . . *Eupelmus cyaniceps* Ashmead

9(7)   Flagellum with 5 tubular funicular segments and 3 strongly transverse ring segments (Figs 11, 13, 14) 10

\-   Flagellum with 6 tubular funicular segments and 2 ring segments (Figs 12, 15–18) . . . 14

10(9)   *Female only*: head and mesosoma dark with conspicuous, white, lanceolate setae (Figs 19, 20, 24, 25); costal cell ventrally with setae only within about apical half of cell (Figs 43, 46) 11

\-   *Female or male*: head and mesosoma variable in colour, but with inconspicuous hairlike setae (Figs 21–23); costal cell ventrally with line of setae extending almost entire length of cell or at least setae present both basally and apically if line more or less interrupted medially (Figs 44, 45) 13

11(10)   Forewing dorsally setose behind marginal vein over about apical half of vein, the setae partly obscuring at least 3 rows of ventral admarginal setae apically (Fig. 43); propodeum with transverse ridge or carina within anterior half dividing it into anterior and posterior sections on either side of median carina (Fig. 30);

metapleuron completely sculptured and with anterior margin on same plane as and
abutting mesopleuron (Fig. 25, am) . . . .   *Neocatolaccus tylodermae* (Ashmead)

- Forewing dorsally bare behind marginal vein to level at least equal with middle of
stigmal vein, completely exposing 1 or sometimes 2 partial rows of ventral
admarginal setae (Fig. 46, ams); propodeum sometimes with transverse furrow
near middle, but without transverse ridge (Figs 27, 29); metapleuron partly smooth
anteriorly and with anterior margin either curved outward (Figs 24, 29) or
extending anteriorly above and over posterior margin of mesopleuron (Figs 27, 28)   12

12(11)   Propodeum with nucha (Fig. 29, nuc) delineated laterally by longitudinal carina
within furrow along posterior margin; metapleuron with anterior margin (Figs 24,
29, am) curved outwards, extending as thin brown flange almost at right angle to
posterior margin of mesopleuron; lower face without evident malar depression,
evenly convex along oral margin between malar sulcus and clypeus . . . .
. . . . *Lyrcus perdubius* (Girault)

- Propodeum with nucha not delineated laterally by carina, the furrow along posterior
margin of callus continued uninterrupted mesally and anteriorly so as to delineate,
more or less conspicuously, anterior limit of nucha (Fig. 27); metapleuron with
anterior margin (Figs 27, 28, am) raised above and extending over posterior margin
of mesopleuron; lower face with short but distinct, concave malar depression
(Fig. 20, md) between malar sulcus and clypeus . . . . *Lyrcus incertus* (Ashmead)

13(10)   *Both sexes*: mesonotum usually dark with conspicuous pattern of bluish-green spots,
the spots usually most distinct on mesoscutum paramedially behind pronotum and
laterally on lateral lobe adjacent to notaulus, though small specimens sometimes
brown. *Female*: gaster lanceolate (Fig. 22); forewing dorsally bare behind marginal
vein to level at least equal with middle of stigmal vein (Fig. 45). *Male*: flagellum
brown with first funicular segment oblong and much longer than combined length
of the 3 ring segments (Fig. 14); marginal vein strong, but only as thick as width of
stigma and with posterior margin straight, parallel with anterior margin. . . . . . .
. . . . *Lyrcus maculatus* (Gahan)

- *Both sexes*: mesonotum metallic green. *Female*: gaster subcircular (Fig. 21); forewing
dorsally bare behind marginal vein, but apically the setae extending to base of
stigmal vein (Fig. 44). *Male*: flagellum yellowish with first funicular segment
quadrate to slightly wider than long and at most as long as combined length of the
3 ring segments (Gibson et al. 2005, fig. 8); marginal vein conspicuously thickened
relative to slender stigma and with posterior margin slightly convex (Gibson *et al.*
2005, fig. 31) . . . . *Mesopolobus moryoides* Gibson

14(9)   *Male only*: forewing with bare band behind marginal vein extending to level about
equal with middle of stigmal vein, and with 1 or at most 2 partial rows of
admarginal setae (Fig. 46, ams) that are obviously longer than setae on dorsal
surface of disc; metapleuron partly smooth and with anterior margin (Figs 24, 28,
am) curved outward or raised above mesopleuron   15

- *Male or female*: forewing with bare region behind marginal vein less extensive, the
discal setae extending to or almost to base of stigmal vein, and with more than 2
rows of admarginal setae of about same length as setae on dorsal surface of disc
(Figs 43, 47–50); metapleuron completely sculptured and with anterior margin
(Fig. 25, am) on same plane as and abutting mesopleuron   16

15(14)   Propodeum with nucha (Fig. 29, nuc) delineated laterally by longitudinal carina
within furrow along posterior margin; flagellum with most funicular segments only
slightly longer than wide, the first segment subquadrate and shorter than pedicel
(Fig. 15); metapleuron with anterior margin (Figs 24, 29, am) curved outwards,
extending as thin brown flange almost at right angle to posterior margin of
mesopleuron . . . . *Lyrcus perdubius* (Girault)

-           Propodeum with nucha not delineated laterally by carina, the furrow along posterior margin of callus extending uninterrupted mesally and anteriorly so as to delineate, more or less conspicuously, anterior limit of nucha (Fig. 27); flagellum with all funicular segments clearly oblong, the first segment as long as pedicel (Fig. 16); metapleuron with anterior margin (Figs 27, 28, am) raised above and extending anteriorly over posterior margin of mesopleuron . . . . . . *Lyrcus incertus* (Ashmead)

16(14)   *Male only*: head and body dark with conspicuous, long, slightly lanceolate white setae (Fig. 25); propodeum with transverse ridge or carina within anterior half dividing it into anterior and posterior sections on either side of median carina (Fig. 30) . . . . *Neocatolaccus tylodermae* (Ashmead)

-           *Male or female*: head and body metallic green with inconspicuous hairlike setae (Fig. 26); propodeum with or without median carina but without transverse ridge (Figs 35–38) 17

17(16)   Pronotum anteriorly with collar rounded into neck, the reticulations extending uninterrupted from dorsal to inclined surface (*cf.* Figs 23, 24); forewing with marginal vein comparatively short, less than 1.5 times as long as stigmal vein (Figs 49, 50); propodeum with convex, reticulate nucha (Figs 31, 32, nuc), reticulate panels (Figs 31, 32, pnl), and often without distinct median carina 18

-           Pronotum anteriorly with shiny, transverse carina differentiating collar from neck (Fig. 26); forewing with marginal vein obviously (at least 1.5 times) longer than stigmal vein (Figs 47, 48); propodeum with flat or slightly concave, lunate or triangular adpetiolar strip (Fig. 35, aps) delineated by inverted Y-shaped median carina anterior to petiolar foramen or, if with reticulate nucha (Fig. 37, nuc), then with panels (Fig. 37, pnl) partly strigose (having oblique, irregular, fine carinae or striae) 19

18(17)   *Female*: costal cell with line of setae on ventral surface interrupted medially (Fig. 49); scutellum anterior to frenum with reticulations distinctly smaller medially than laterally (Fig. 33); propodeum with plical carina (Fig. 31, pc) directed obliquely toward inner margin of spiracle . . . . *Pteromalus cerealellae* (Ashmead)

-           *Female*: costal cell with entire line of setae ventrally (Fig. 50); scutellum anterior to frenum with almost uniform meshlike reticulations (Fig. 34); propodeum with plical carina (Fig. 32, pc) less strongly angled, directed distinctly mesal of inner margin of spiracle toward outer margin of basal fovea (Fig. 32, bf) . . . *Pteromalus* sp.

19(17)   Metacoxa setose dorsally only over about apical half; forewing of female without setae on basal fold (Fig. 48); propodeum with inverted Y-shaped median carina delimiting adpetiolar strip (Fig. 35, aps); propodeum in male without complete plical carina (Fig. 36, pc) and in female largely bare posterior to spiracle, setose only from callus to postspiracular sulcus (Fig. 35, pss) . . . . *Chlorocytus* Graham[3]

-           Metacoxa setose dorsally over at least apical two-thirds and often completely setose to base; forewing of female with at least a couple of setae on basal fold (Fig. 47, bf) differentiating basal cell from speculum; propodeum with or without median carina but with convex, reticulate nucha (Fig. 37, nuc); propodeum in male with complete plical carina (Fig. 38, pc) and in female extensively setose posterior to spiracle, from callus to complete, strong plical carina (Fig. 37) . . . .
            . . . . *Trichomalus* Thomson[3]

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[3] Genus not yet reported parasitizing *C. obstrictus* in eastern North America.

SPECIES NOTES, ARRANGED BY FAMILY

Chalcididae

One species of Chalcididae was reared—*Conura torvina* (Cresson), which comprised nine specimens (7 ♀♀, 2 ♂♂) or 0.8% of the parasitoid fauna. Delvare (1992) keyed the species-groups of *Conura* and differentiated *C. torvina* as one of eight species of the *side*-group in a key to the "common species" of that group in North America north of Mexico. Prior to Delvare (1992), *C. torvina* was consistently misidentified as *Conura side* (Walker). Carlson et al. (1951) reported that a specimen of *C. side* was reared from *C. obstrictus* in California. We were unable to locate this specimen to confirm the identification, but it is possible that it is conspecific with the Georgia species because *C. torvina* is transcontinental in North America (Delvare 1992, Noyes 2002). Because of the confusion in names prior to Delvare (1992), the list of published distribution and host records given for *C. side* by Noyes (2002) certainly contains many records that actually refer to *C. torvina*. Based on previous name usage, of those Curculionidae listed as hosts of *C. side* by Noyes (2002), the record of the cotton boll weevil, *Anthonomus grandis* (Boheman), probably does refer to *C. side*, whereas the records of *Rhynchaenus pallicornis* (Say) and *Hypera* spp. likely refer to *C. torvina*. Because of variability in the colour pattern features given by Delvare (1992), females of *C. torvina* can be easily misidentified as *Conura albifrons* (Walsh), another transcontinental species that Dosdall et al. (in press) reported parasitizing *C. obstrictus* in Alberta. Females of both species have paramedial yellow marks on the first gastral tergum, but in female *C. torvina* the distance between the marks is, at most, only about equal to the length of a mark (Fig. 2). In female *C. albifrons* the separation between the marks is at least similar to the width of a mark, if not conspicuously greater. Males of the two species are more easily differentiated. Males of *C. torvina* have the interantennal region and lower face yellow, whereas males of *C. albifrons* have the clypeus dark so that they have a conspicuous, angulate (∧-like), yellow band extending dorsally between the antennal scrobes.

Eulophidae

Two genera and species of Eulophidae were reared—*Euderus glaucus* Yoshimoto (2 ♀♀; 0.2% of the parasitoid fauna) and *Necremnus tidius* (Walker) (1 ♀, 5 ♂♂; 0.5% of the parasitoid fauna). Although *E. glaucus* was known from Florida and Texas (Noyes 2002), its association with *C. obstrictus* in Georgia represents a new state distribution record and a possible new host record. The only other reported host for *E. glaucus* is *Epiblema obfuscana* (Dyar) (Lepidoptera: Tortricidae) (Yoshimoto 1971). Dosdall et al. (in press) reported a second *Euderus* species, *E. albitarsis* (Zetterstedt), as an incidental parasitoid of *C. obstrictus* in Alberta, but this association was also obtained by mass-rearing seedpods. *Euderus glaucus* and *E. albitarsis* are differentiated in Yoshimoto (1971), though problems remain in species recognition within the genus.

Necremnus tidius is a comparatively common parasitoid of *C. obstrictus* in western North America, but it was misidentified as *N. duplicatus* Gahan prior to Gibson et al. (2005), who differentiated and illustrated the species. The specimens from Georgia represent the first record of the species in eastern North America.

Eupelmidae

Two genera and species of Eupelmidae were reared—*Eupelmus* (*Eupelmus*) *cyaniceps* Ashmead (2 ♀♀, 2 ♂♂; 0.4% of the parasitoid fauna) and *Brasema allynii* (French) **n. comb.** (from *Eupelmus* Dalman) (1 ♀, 4 ♂♂; 0.5% of the parasitoid fauna). *Brasema* Cameron is unrevised for the region, but there are about 25 described species in North America north of Mexico.

Most of the species are currently misclassified in *Eupelmus* (Gibson 1995). Gahan (1933) described and partly illustrated both sexes of *B. allynii* as a parasitoid of the Hessian fly, *Mayetiola destructor* (Say) (Diptera: Cecidomyiidae). Phillips and Poos (1921) also provided both a dorsal and lateral habitus of the female, and for both sexes illustrated the colour pattern of the legs, important species-recognition features, when they described the immature stages of *B. allynii* as a parasitoid of the wheat jointworm, *Tetramesia tritici* (Fitch) (Hymenoptera: Eurytomidae). The sexes of Eupelminae are strongly dimorphic (Gibson 1995), but the more important diagnostic features of *B. allynii* females include: head and mesosoma variably brown or dark with metallic green luster, scrobal depression finely coriaceous and quite shiny, lower face with relatively sparse and only inconspicuously lanceolate white setae, mesonotum finely coriaceous, and middle legs entirely or largely yellow beyond coxae (mesofemur and tibia often with some light brown infusion but mesofemur not extensively dark). Males of *B. allynii* are in part diagnosed within *Brasema* by a clavate flagellum with very short and inconspicuous setae (Fig. 6), head and mesosoma metallic green, head with only very slightly lanceolate and comparatively sparse white setae, and legs with all femora yellow (Fig. 6). *Brasema allynii* is transcontinental in North America and a polyphagous primary or facultative hyperparasitoid of hosts in concealed situations. Noyes (2002) listed 58 host species in 22 families of Coleoptera, Diptera, Hemiptera, Hymenoptera, and Lepidoptera, though the putative host record of *C. obstrictus* is the first for Curculionidae.

Gibson (1995) recognized three subgenera in *Eupelmus*, including *E.* (*Episolindelia*) Girault and *E.* (*Macroneura*) Walker in addition to the nominate subgenus. Noyes (2002) listed 45 valid species of *Eupelmus* in the Nearctic region, but this includes all three subgenera and several species in-

correctly classified to genus. *Eupelmus* is unrevised for the region, but there are about 15 described species of *E.* (*Eupelmus*) in North America north of Mexico. *Eupelmus cyaniceps* belongs to the *urozonus* species-group *sensu* Gibson (1995). Hunter and Pierce (1912, pl. XVIII, f) provided a dorsal habitus drawing of the female when they recorded the species as a parasitoid of *A. grandis*. A species revision of *E.* (*Eupelmus*) that includes evaluation of size-correlated and host-induced variation is necessary to confidently characterize species limits within the subgenus. However, females of *E. cyaniceps* are differentiated from most other regional species of the subgenus by the following combination of features: macropterous, the forewing hyaline and with a linea calva (Fig. 7, bb), scape dark, mesosoma dark with metallic green luster, and ovipositor sheaths extending for a distance at least equal to two-thirds length of the metatibia and with a medial white band (Fig. 7). Because of extreme sexual dimorphism (*cf.* Figs 7, 8), species recognition in *Eupelmus* is based almost entirely on females; males are not characterized for most species. The features provided in the key for males of *E. cyaniceps* are of family and generic level. *Eupelmus cyaniceps* is a primary or facultative hyperparasitoid of hosts in concealed situations. The rearing from *C. obstrictus* represents a new putative host record, but Noyes (2002) listed 17 other species in 11 different genera of Curculionidae as part of 65 host records in 20 families of Coleoptera, Diptera, Hymenoptera and Lepidoptera.

The only eupelmid previously reported as a parasitoid of *C. obstrictus* is *Eupelmus* (*Macroneura*) *vesicularis* (Retzius) from Washington state (Hanson et al. 1948) and British Columbia (McLeod 1953). This species likely represents one of the earliest accidental introductions from Europe to North America; only females are known in North America and they are brachypterous (Gibson 1990).

Eurytomidae

One species of Eurytomidae was reared —*Eurytoma tylodermatis* Ashmead, which comprised 25 specimens (8 ♀♀, 17 ♂♂) or 2.2% of the parasitoid fauna. The Georgia rearing represents a new host record for *E. tylodermatis*, but a previously unidentified species of *Eurytoma* was also reared in most surveys of the parasitoid complex of *C. obstrictus* in western North America (Doucette 1948, Hanson et al. 1948, McLeod 1953, Dosdall et al. in press). Examination of voucher and additional reared material from Alberta, British Columbia, Idaho, Oregon, and Washington indicates the western species is also *E. tylodermatis*. Noyes (2002) listed 19 other curculionid species in 11 genera as part of 46 reported host species in 14 families of Coleoptera, Diptera, Hymenoptera and Lepidoptera.

Over 90 nominal species of *Eurytoma* are known from the Nearctic region (Noyes 2002). Bugbee (1967) revised the North American species, but species recognition remains extremely difficult because of variability of the morphological features he used to differentiate species, and because sexual dimorphism (*cf.* Figs 3, 4) presents difficulties in recognizing conspecific sexes. Rearing is necessary to make the association, and one sex of several species of *Eurytoma* remains undescribed. Bugbee (1967) examined over 4,000 specimens originally identified as *E. tylodermatis* in the USNM and stated that "even this number was not enough to give an adequate picture of the geographical distribution, or the range of variation of several species in the complex" (Bugbee 1967, p. 492). He keyed *E. tylodermatis* as one of 48 species of his "*tylodermatis* complex" and considered the species to be most closely related to *E. bolteri* Riley, *E. diastrophi* Walsh, and *E. pini* Bugbee. He also stated that the four species were probably associated with the larvae of weevils and small moths that live in stems of various plants, either as primary parasitoids or as hyperparasitoids. It is beyond the scope of this study to assess the monophyly of species-groups or species limits in *Eurytoma*, but at least the four *Eurytoma* species listed above have the propodeum densely setose lateral to the propodeal foramen, and the petiole (Fig. 40, ptl) has one dorsomedial and two anterolateral processes. Furthermore, the anterior margin of the first gastral tergum (Fig. 40, Gt1) is emarginate and depressed medially, and the tergum is deeply depressed anterolaterally, to accommodate the processes of the petiole when the gaster is raised. Bugbee's (1967) key to species differentiates *E. tylodermatis*, in part, by stating the sculpturing of the fourth gastral tergum extends over the dorsal surface at least narrowly along the anterior margin (couplet 20). The species description, however, states that the sculpture of the fourth tergum is heavy ventrolaterally, continues dorsally for about one-half to two-thirds of the surface, and then fades out so that the dorsal surface is smooth and shiny. The extent of sculpturing on the fourth gastral tergum appears to be variable in species of *Eurytoma*, and the appearance is partly affected by telescoping of the terga. Features that can be used in combination to differentiate *E. tylodermatis* from similar species include the malar space lacking an alveolate boss (a slightly raised area), the ventrolateral margin of the scrobes (Fig. 39, vls) being produced anteriorly and reflexed posteriorly, and the median channel of the propodeum being distinct and defined laterally by carinae formed by longitudinally aligned crenulae (Fig. 40).

A single species of *Eurytoma*, *E. curculionum* Mayr, has also been reported as reared from *C. obstrictus* in Europe (Dmoch 1975). Individuals of *E. curculionum* have a mesocoxal lamella according to Claridge and Askew (1960, fig. 2), which is absent from the North American specimens identified as *E. tylodermatis*.

Pteromalidae

Three species of *Lyrcus* Walker, one species of *Mesopolobus* Westwood, one species of *Neocatolaccus* Ashmead, and what likely are two species of *Pteromalus* Swederus comprised about 96% of the reared parasitoids (Table 1).

Lyrcus is restricted to the New World. The genus is unrevised for the Nearctic, but Noyes (2002) listed 16 species from the region. Species identifications in this study are based on examination of type material of the North American species contained in the USNM, which excludes the four oldest names assigned to *Lyrcus* from the Nearctic. Walker (1847) described four species collected in Florida that are now classified in *Lyrcus* (Noyes 2002) and type material of these species is in The Natural History Museum, London. Although Burks (1975) examined the types, the names have yet to be placed adequately within a species concept of *Lyrcus*. Until this is done within a comprehensive taxonomic revision, it is possible that one or more of the four Walker names represents a senior synonym of a name used in this paper.

Lyrcus maculatus (Gahan) was the most commonly reared species of all the parasitoids, comprising 967 specimens (515 ♀♀, 452 ♂♂) or 86% of the parasitoid fauna. The distribution record is the first east of Illinois and Texas (Noyes 2002), but in western North America *L. maculatus* has often been reported as an incidental parasitoid of *C. obstrictus*. In the older literature it was identified as a species of *Trimeromicrus* Gahan or *Zatropis* Crawford. Gahan (1914) originally described *L. maculatus* as a parasitoid of the clover seed chalcid, *Bruchophagus platypterus* (Walker) (Hymenoptera: Eurytomidae). In addition to other species of *Bruchophagus*, it has also been reported as a parasitoid of the clover seed weevil, *Tychius picirostris* (Fabricius) (Yunus and Johansen 1967), the sunflower seed weevil, *Smicronyx fulvus* LeConte (Bigger 1933), the thistle seedhead weevil,

Rhinocyllus conicus (Frölich) (Wilson and Andres 1986) (Coleoptera: Curculionidae) and, as a hyperparasitoid, of the alfalfa gall midge, *Asphondylia websteri* Felt (Diptera: Cecidomyiidae) (Gahan 1919). Among known species of *Lyrcus*, *L. maculatus* is usually distinguished by its distinctive mesoscutal colour pattern, as described in the key. Urbahns (1919, pl. 23A) provided a dorsal habitus of the female that illustrates this colour pattern. Included in the material we have identified as *L. maculatus* are about 25 unusually small, more or less brown specimens that either have quite obscure blue spots or that lack the spots entirely. The abnormally coloured individuals also have much finer, coriaceous mesonotal sculpture rather than the reticulate sculpture of typical specimens. However, some individuals are intermediate in both colour pattern and sculpture so that a very fine mesonotal sculpture and brown body colour without blue regions likely is correlated with small body size.

Lyrcus perdubius (Girault) was the second most commonly reared parasitoid, comprising 60 specimens (39 ♀♀, 21 ♂♂) or 5.3% of the parasitoid fauna. Georgia represents a new state distribution record for the species. Dosdall et al. (in press) first reared *L. perdubius* from canola seedpods in Alberta, putatively as a parasitoid of *C. obstrictus*, and Noyes (2002) listed *Anthonomus grandis*, *A. rutilus* (Boheman), *A. signatus* (Say), *Lixus musculus* Say, and *Smicronyx tychoides* Le Conte (Coleoptera: Curculionidae) as other hosts.

Six specimens (3 ♀♀, 3 ♂♂; 0.5% of the parasitoid fauna) of *Lyrcus incertus* (Ashmead) were also reared. This species is widespread throughout southern and eastern USA. Although *C. obstrictus* represents a new host association, Noyes (2002) listed several other genera and species of Curculionidae as hosts, including *A. grandis* and a single report of a *Ceutorhynchus* sp. (Pierce et al. 1912).

Only one female and male of *Mesopolobus moryoides* Gibson were reared, which rep-

resent 0.2% of the parasitoid fauna and the first distribution record for Georgia and eastern North America. This species is a common parasitoid of *C. obstrictus*, its only known host, in western USA (Gibson et al. 2005). Two other species of *Mesopolobus* have also been reported as putative parasites of *C. obstrictus* in western North America, *M. mayetiolae* (Gahan) in California (Carlson et al. 1951) and *M. bruchophagi* (Gahan) in Alberta (Dosdall et al. in press). *Mesopolobus moryoides* was misidentified as *Mesopolobus morys* (Walker) in North America until Gibson et al. (2005) correctly identified it and provided features to differentiate the two species from each other and from other regional species. *Mesopolobus* is yet another unrevised, speciose genus in North America, with Noyes (2002) listing 20 valid species for the region.

A total of 33 *Neocatolaccus tylodermae* (Ashmead) (13 ♀♀, 20 ♂♂) were reared, which represent 2.9% of the parasitoid fauna. Although Georgia is a new state distribution record, the species was known from Florida and is transcontinental in the USA (Noyes 2002). *Ceutorhynchus obstrictus* also represents a new putative host association, though Noyes (2002) listed 15 other curculionid species in 10 genera as hosts. Pierce (1909) reared it along with *E. cyaniceps* from *Lixus musculus*, Wilson and Andres (1986) reared it along with *L. maculatus* from *Rhinocyllus conicus*, and there is a single published association with *Anthonomus grandis* (Pierce 1909). Bouček (1993) provided a key to the three described North American species of *Neocatolaccus*. He differentiated *N. tylodermae* from *N. moneilemae* Gahan on the basis of a rounded rather than medially carinate pronotum and truncate rather than medially narrowly emarginate clypeus. Forewing setal differences also help to differentiate the species. In *N. tylodermae* the ventral surface of the costal cell has setae only over about its apical half and dorsally the forewing is bare behind about the basal

half of the marginal vein so that three or four rows of ventral admarginal setae are visible within a distinct speculum (Fig. 43), whereas individuals of *N. moneilemae* have a line of setae along the length of the costal cell and the forewing is setose behind the marginal vein more or less to its base so that a distinct speculum is lacking and the admarginal setae are covered by dorsal setae.

Five individuals (2 ♀♀, 3 ♂♂; 0.5% of the parasitoid fauna) of *Pteromalus* were reared. One female was identified as *Pteromalus cerealellae* (Ashmead) based on examination of type material in the USNM, but the other specimens remain unidentified to species (see below). Girault (1917) provided a key to several species of *Pteromalus* (as *Habrocytus* Thomson) in North America, but there is no modern revision and Noyes (2002) listed 46 valid species names in the Nearctic region. In western North America, unidentified species of *Pteromalus* have been reported from surveys in Idaho (Walz 1957), Washington (Hanson et al. 1948), British Columbia (McLeod 1953), and Alberta (Dosdall et al. in press). Examination of voucher specimens from these studies by the senior author revealed at least one unidentified species common to the four areas as well as a single rearing of *Pteromalus puparum* (L.) from the surveys reported by McLeod (1953) in British Columbia (Gibson et al. 2006). The unidentified species from western North America and *P. cerealellae* belong to a comparatively small group of Nearctic species whose females have the line of setae on the ventral surface of the costal cell interrupted medially and the bare band behind the marginal vein extending the length of the vein (sometimes with one or two setae apically within an otherwise distinct bare band, Fig. 49). Females of the two species differ from each other most conspicuously in propodeal features. In *P. cerealellae* the setae on the callus extend mesal of the postspiracular sulcus posteriorly, almost to the

plical carina (Fig. 31), whereas females of the species from western North America have the region between the postspiracular sulcus and plical carina bare. The propodeal structure of *P. cerealellae* is very similar to that of the European species *Pteromalus semotus* (Walker) (Graham 1969, fig. 385), which was reported as reared from *C. obstrictus* in England and Poland (Murchie and Williams 1998). Bouček (1977) once considered the two names conspecific, but subsequently (Bouček 1988) re-established *P. cerealellae*. Among other features, *P. semotus* has an entire costal setal line (*cf.* Fig. 50). *Pteromalus cerealellae* was described from, and until recently was thought to be a monophagous parasitoid of, the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Noble 1932). Flanders (1932) stated that it would also oviposit into the tuberworm moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). However, Brower (1991) showed that it effectively parasitized 12 different species in 4 families of Coleoptera (including 3 species of Curculionidae) that are pests of stored products. He concluded that although the species probably prefers *S. cerealella*, it is more habitat specific than host specific.

The second *Pteromalus* female reared and that of *P. cerealellae* are similar in having the forewing dorsally bare behind the entire length of the marginal vein (Figs 49, 50), but differ in those features given in the key. A comprehensive generic revision is necessary to establish the correct species name of the unidentified female. The three unidentified males may represent the opposite sex of the unnamed female, based on the presence of a continuous line of setae on the costal cell, but species characteristics of male *Pteromalus* remain largely unknown and the males are not included in the key.

DISCUSSION

The parasitoid fauna reared from *B. napus* seedpods in Georgia, 1994 through 1996, revealed the same five chalcid families that have been reported as reared from *C. obstrictus* in western North America, including six species apparently shared in common (Table 1). Of the shared species, *L. maculatus* was by far the most commonly reared parasitoid in Georgia, comprising about 86% of the fauna. This contrasts to western North America where it appears to be only an incidental parasitoid of *C. obstrictus*. Furthermore, two common parasitoids of *C. obstrictus* in at least some parts of western North America, *N. tidius* and *M. moryoides*, were reared as only incidental parasitoids in Georgia. The latter rearings represent the first distribution records of the respective species in eastern North America. If *C. obstrictus* was introduced to Georgia from western North America, the two parasitoid species may have been introduced accidentally at the same time. The most common parasitoid of *C. obstrictus* throughout most of western North America, *T. lucidus*, was not reared in Georgia despite the statement of Buntin (1998) that most of the reared specimens consisted of *T. perfectus* (a misidentification of *T. lucidus* prior to Gibson et al. 2005). The second and third most commonly reared species in Georgia were *L. perdubius* and *N. tylodermae*, respectively. Because of their relative abundance and because neither has been reported from hosts other than Curculionidae (Noyes 2002), both species very likely are parasitoids of *C. obstrictus*. However, it remains to be determined whether they are primary or hyperparasitoids. At least some of the other incidental species, such as *C. torvina*, *B. allynii* and *E. cyaniceps*, likely are hyperparasitoids rather than primary parasitoids. The rearing of *E. glaucus*, *B. allynii*, *E. cyaniceps*, *L. incertus*, *P. cerealellae* and the unidentified species of *Pteromalus* from *B. napus* seedpods in Georgia represent new rearing records, but these are at most incidental parasitoids, if *C. obstrictus* was the actual host for all the species. Buntin (1998) obtained the parasitoids from mass-reared seedpods. The

very few *Asaphes* and *Pachyneuron* that were reared, along with several Aphidiinae (Braconidae) also preserved with the material, show that some aphid mummies contaminated the seedpods even though an attempt was made to remove these prior to rearing. Likewise, one or more of the uncommon parasitoid taxa may have emerged from other undetected insects within or on the pods. For example, the only other host record for *E. glaucus* is a lepidopteran. Individual rearing of parasitoids dissected from seedpods is necessary to definitively prove the host associations listed in Table 1, which at present are only inferred.

Both *L. incertus* and *L. perdubius* have been reported previously as parasitoids of the cotton boll weevil, as has also *E. cyaniceps*, *E. tylodermatis*, and *N. tylodermae*, though not the most commonly reared parasitoid of *C. obstrictus* in Georgia, *L. maculatus*. These results suggest that the chalcid parasitoid fauna acquired by *C. obstrictus* in any area where it is introduced is partly influenced by what other curculionid species occur in the region. If so, the parasitoid fauna from eastern Canada and the southeastern USA might be expected to differ as substantially as between eastern and western North America.

ACKNOWLEDGMENTS

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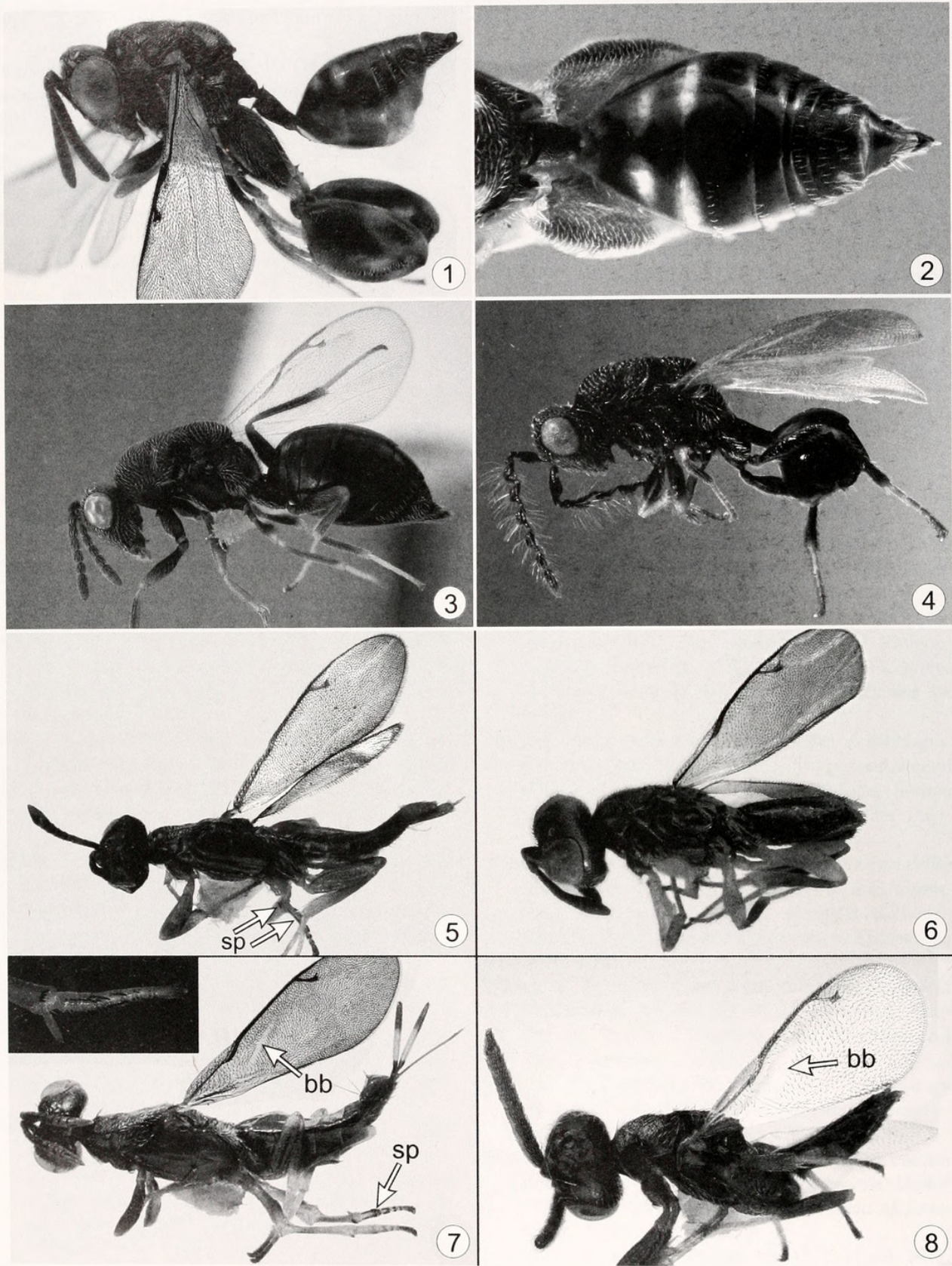
Figs 1–8.   1 and 2, *Conura torvina*, female: 1, lateral habitus; 2, metasoma, dorsal. 3 and 4, *Eurytoma tylodermatis*, lateral habitus: 3, female; 4, male. 5 and 6, *Brasema allynii*, lateral habitus: 5, female; 6, male. 7 and 8, *Eupelmus cyaniceps*, lateral habitus: 7, female (insert: mesotarsus and apex of mesotibia showing spines); 8, male. (Abbreviations: bb = bare band, sp = spines.)
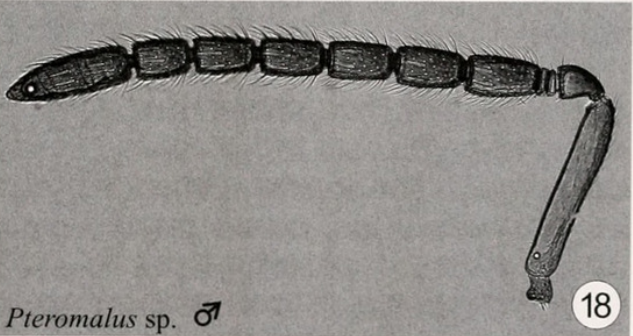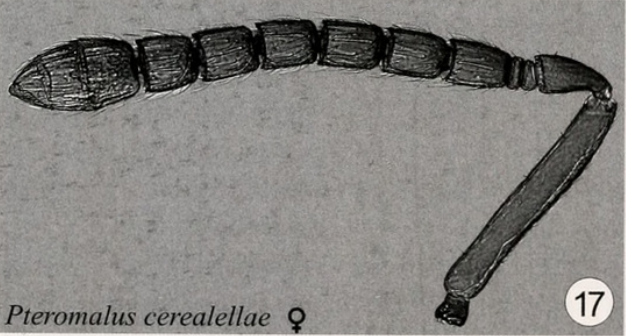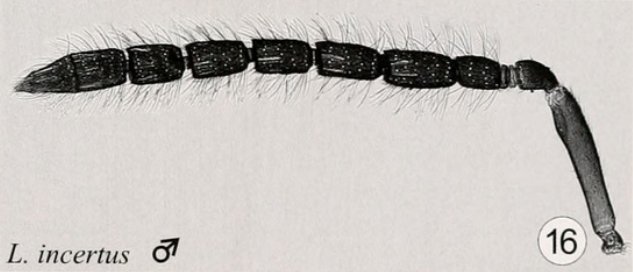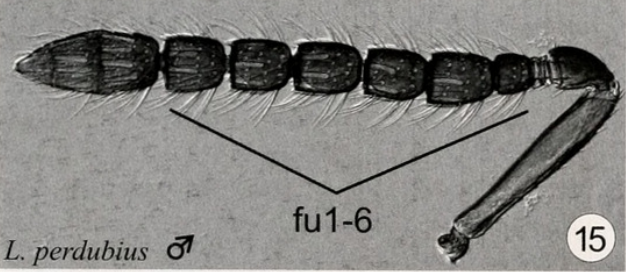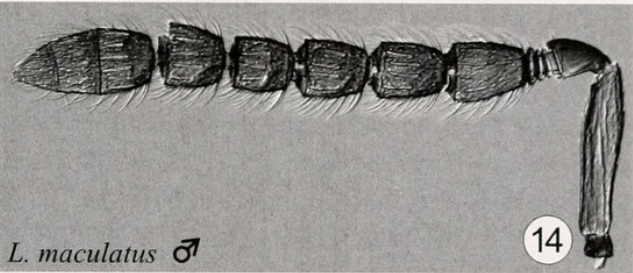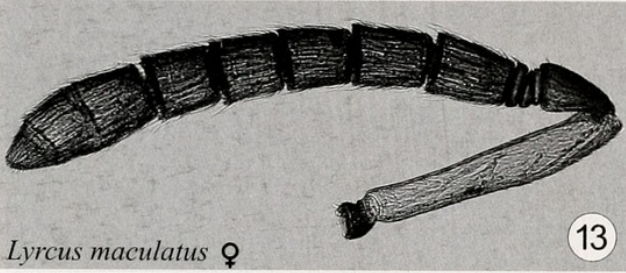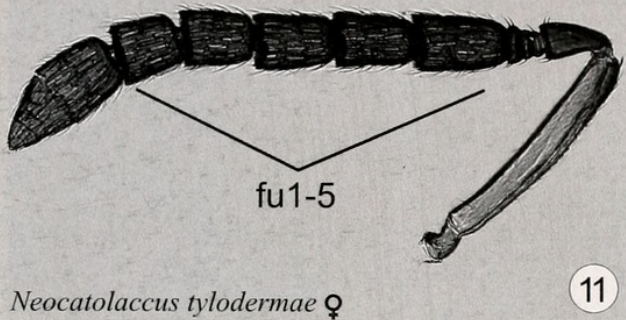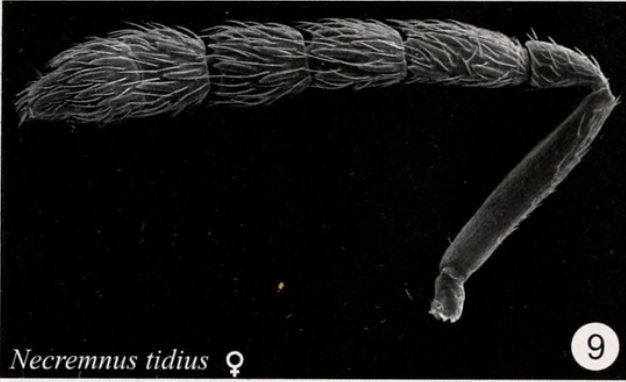
Figs 9–18.   Antenna, male and female. (Abbreviations: fu = funicular segment.)
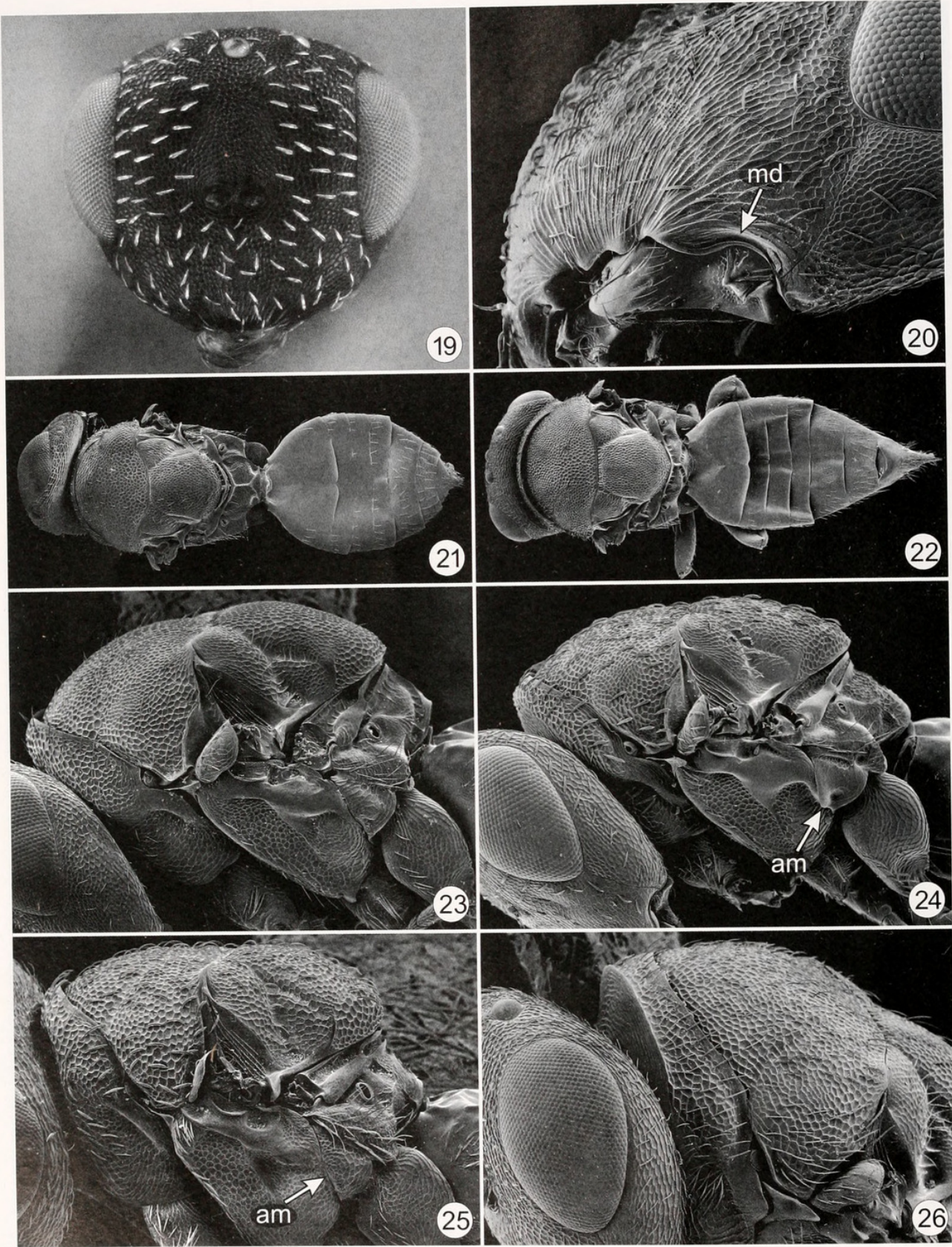
Figs 19–26.   19, *Lyrcus perdubius*, head. 20, *L. incertus*, malar space. 21 and 22, dorsal habitus, female: 21, *Mesopolobus moryoides*, 22, *L. maculatus*. 23–25, mesosoma, lateral: 23, *L. maculatus*; 24, *L. perdubius*; 25, *Neocatolaccus tylodermae*. 26, *Trichomalus perfectus*, pronotum and mesoscutum. (Abbreviations: am = anterior margin of metapleuron, md = malar depression.)
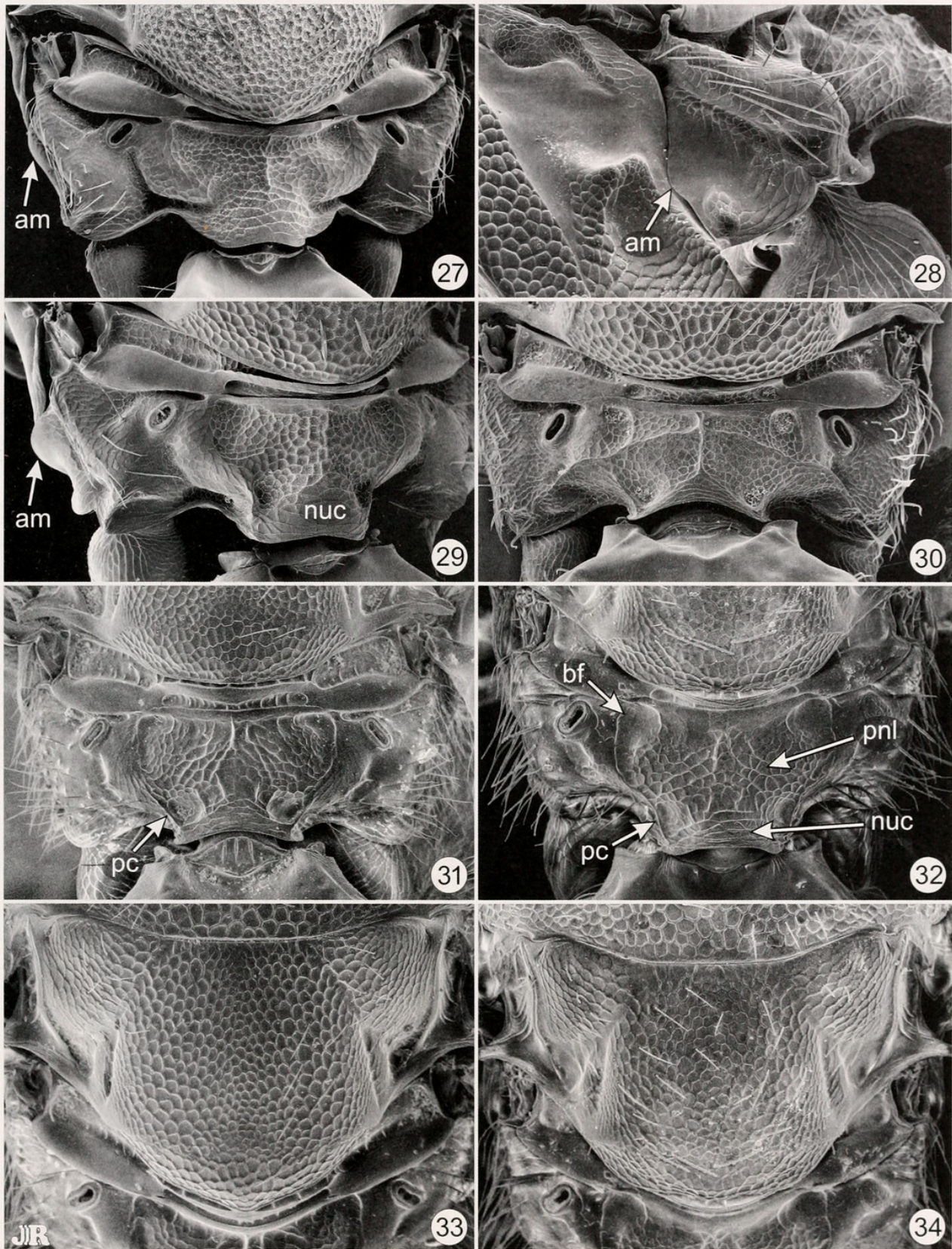
Figs 27–34.   27 and 28, *Lyrcus incertus*: 27, propodeum; 28, metapleuron. 29–32, propodeum: 29, *L. perdubius*; 30, *Neocatolaccus tylodermae*; 31, *Pteromalus cerealellae*; 32, *Pteromalus* sp. 33 and 34, scutellar-axillar complex: 33, *P. cerealellae*; 34, *Pteromalus* sp. (Abbreviations: am = anterior margin of metapleuron, bf = basal fovea, nuc = nucha, pc = plical carina, pnl = propodeal panel.)
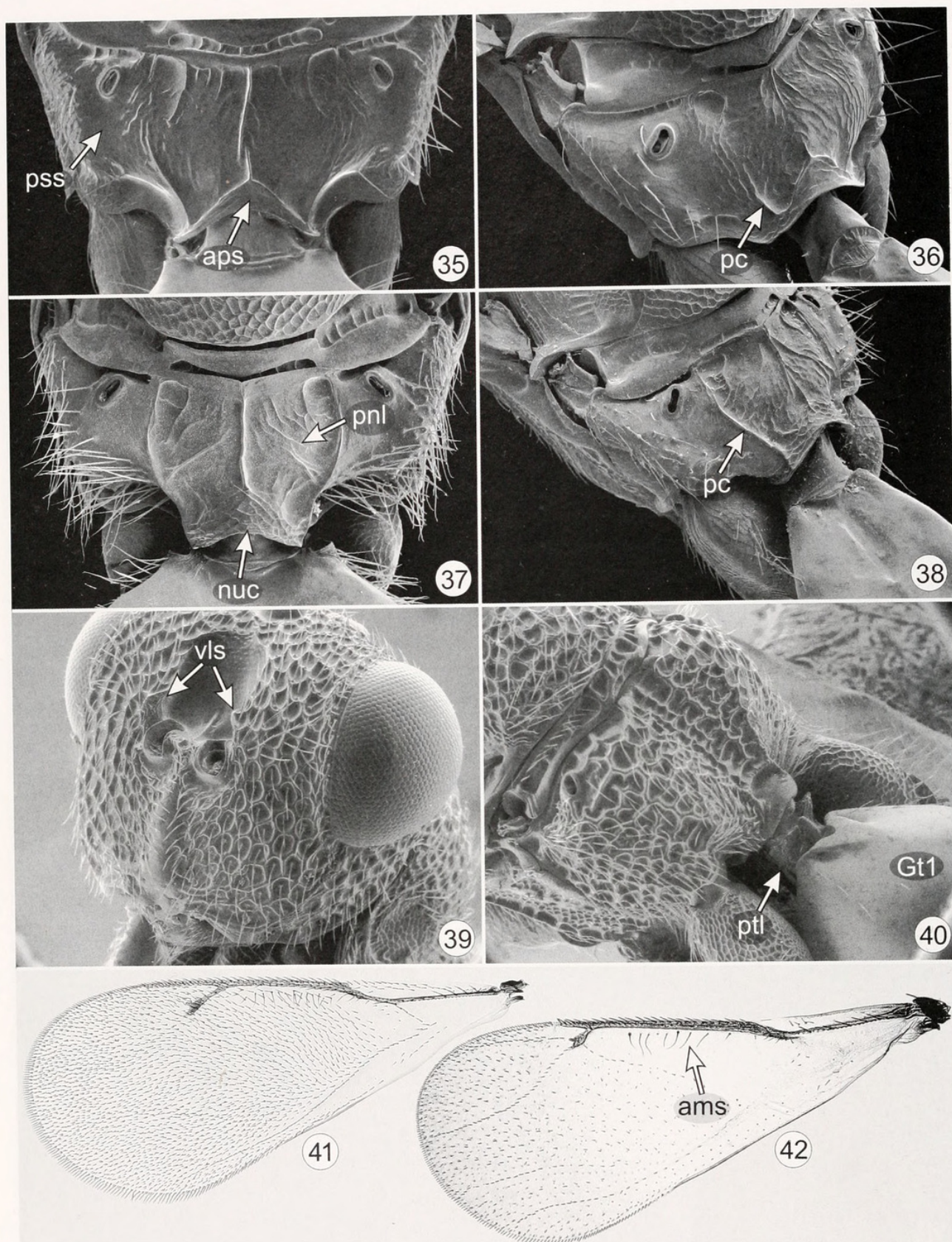
Figs 35–42.   35 and 36, *Chlorocytus* sp., propodeum: 35, female, posterior; 36 male; posterolateral. 37 and 38, *Trichomalus lucidus*, propodeum: 37, female, posterior; 38, male, posterolateral. 39 and 40, *Eurytoma tylodermatis* female: 39, head, frontolateral; 40, propodeum and base of metasoma, dorsolateral. 41 and 42, forewing: 41, *Necremnus tidius*; 42, *Euderus glaucus*. (Abbreviations: ams = admarginal setae, aps = adpetiolar strip, Gt1 = first gastral tergite, nuc = nucha, pc = plical carina, pnl = propodeal panel, pss = postspiracular sulcus, ptl = petiole, vls = ventrolateral margin of scrobes.)
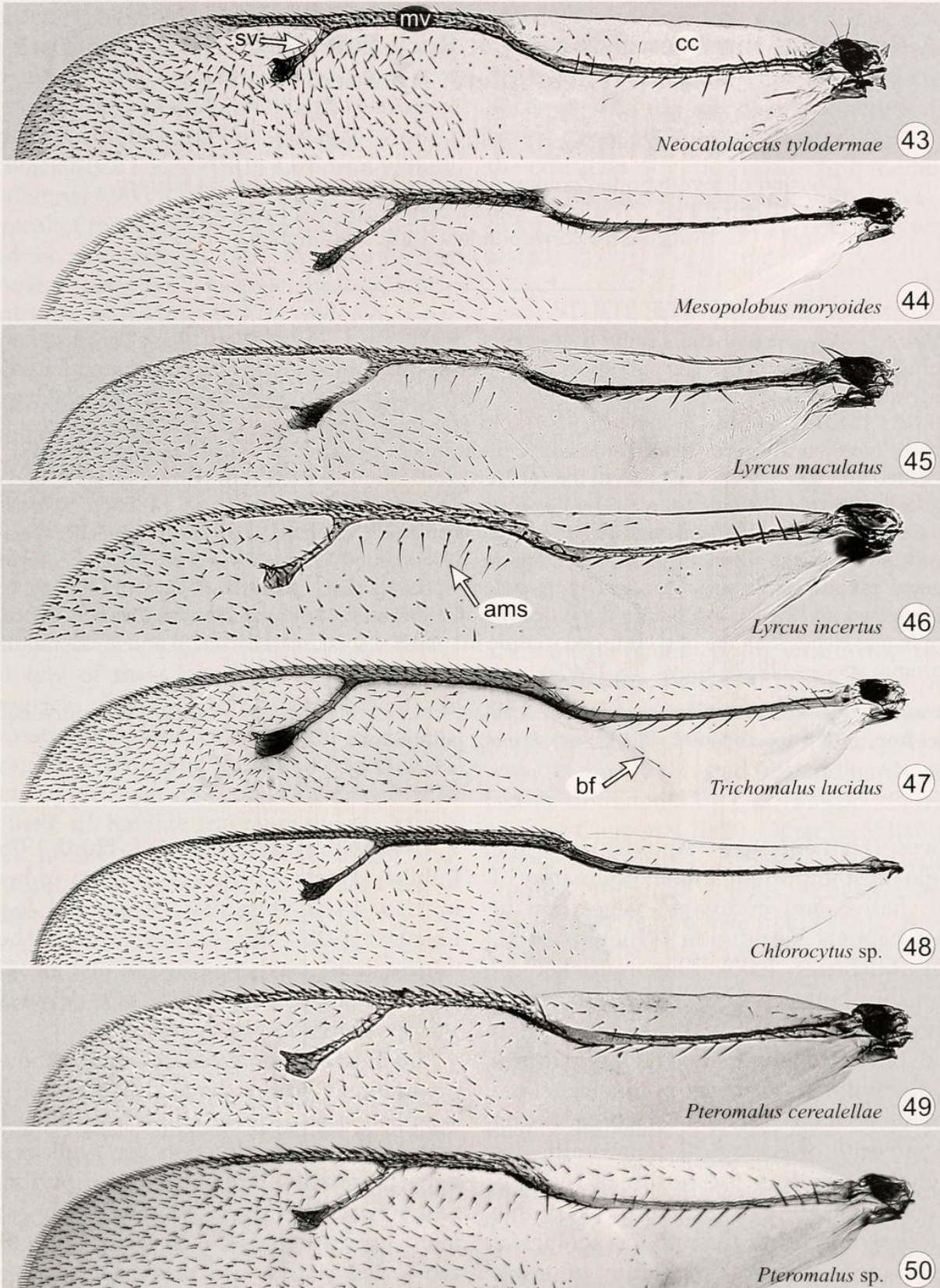
Figs 43–50. Forewing, female. (Abbreviations: ams = admarginal setae, bf = basal fold, cc = costal cell, mv = marginal vein, sv = stigmal vein.)