© Entomologica Fennica. 19 April 2002

Taxonomical characters of *Selidosema plumarium* and *S. brunnearium* (Lepidoptera: Geometridae: Ennominae) and the function of the internal genitalia during copulation

Pasi Sihvonen & Kauri Mikkola

Sihvonen, P. & Mikkola, K. 2002: Taxonomical characters of *Selidosema plumarium* and *S. brunnearium* (Lepidoptera: Geometridae: Ennominae) and the function of the internal genitalia during copulation. — Entomol. Fennica 13: 13–19.

The genitalia of the Palaearctic species pair, *Selidosema plumarium* (Denis & Schiffermüller, 1775) and *S. brunnearium* (Villers, 1789), are described and illustrated. Keys to the species, based on male and female genitalia, particularly on the internal parts, are presented. Based on indirect evidence, an hypothesis of the functional anatomy of the internal genitalia, i.e. the disappearance of a distinctive ventral angle at the anterior end of the female ductus bursae during copulation, is presented and discussed. The hypothesized functions are compared to the geometrid genus *Eupithecia* Curtis. Contrary to the earlier held view, it is confirmed that only *Selidosema brunnearium* is recorded from Finland, from the years 1969 (one specimen) and 1999 (two specimens).

Pasi Sihvonen & Kauri Mikkola, Finnish Museum of Natural History, P.O. Box 17, FIN-00014 University of Helsinki, Finland; *E-mail: pasi_sihvonen@hotmail.com*

Received 17 August 2000, accepted 2 November 2001

1. Introduction

Compared to the long tradition of using characters of the external genitalia in species taxonomy, the use of internal genitalia (i.e. the male aedeagus and vesica and the female bursa copulatrix) is a new branch in lepidopterology, providing an improvement in taxonomical resolution. Despite early pioneering work (Janse 1932, Hardwick 1950), the method for eversion of the vesica has not become a common practise except in a few groups of Lepidoptera, such as Noctuoidea (e.g. Lafontaine & Mikkola 1987) and Sphingidae (McCabe 1984). In Geometridae, the vesica has been everted for taxonomical purposes in a few genera only: for instance *Eupithecia* (Bolte 1990, Mikkola 1993), *Operophtera* (Troubridge & Fitzpatrick 1993), *Rhodostrophia* (Kaila *et al.* 1996), *Entephria* (Troubridge 1997) and in the tribe Cidariini (Choi 1997).

Largely as a result of morphological taxonomy, the functional anatomy of the genitalia, especially the internal genitalia, has remained overlooked. *In situ* studies of copulation are few (e.g. Callahan & Chapin 1960, Takeuchi & Miyashita 1975), as are *ex situ* studies based on indirect evidence (e.g. Mikkola 1994). Knowledge of these mechanisms may help in species-level taxonomy, as well as in understanding the processes behind the species-specific genitalia, or even

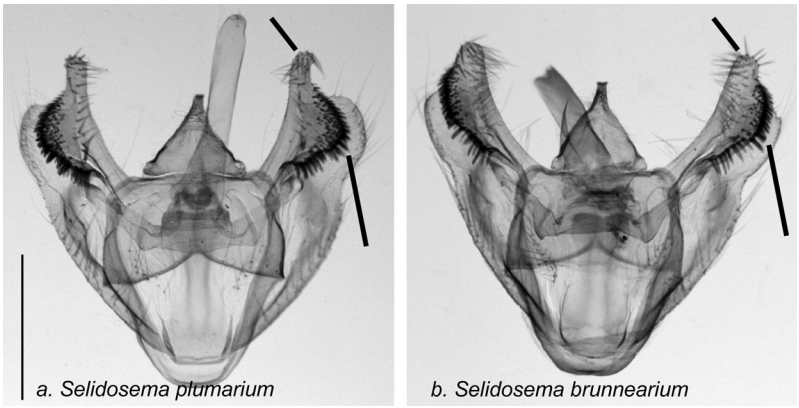

Fig. 1. Ventral aspect of the male genitalia of *Selidosema* species, showing the valval characters used previously to separate the taxa. — a. *S. plumarium*, apex of valvula narrow, ventral margin enlarged, forming a slightly angular lobe. — b. *S. brunnearium*, apex of valvula wide, ventral margin rounded. Scale bar = 1 mm.

speciation (e.g. Eberhard 1986, Arnqvist 1997).

The taxonomy of the ennomine geometrid species pair, *Selidosema plumarium* (Denis & Schiffermüller, 1775) and *S. brunnearium* (Villers, 1789), has been confusing, although the species status of these is well established. Krampl & Marek (1981) deserve credit for having shown the taxonomical differences of the eggs, larvae, pupae and imagos of these taxa. The habitus character, the straightness of the costal part of the median fascia in *Selidosema plumarium*, but with inward arch in *S. brunnearium*, is usually reliable but is sometimes obscured by the variability of both species (Rezbanyai 1983). Krampl and Marek (1981) gave a distinctive external genitalia character by means of which to distinguish the males according to the shape of the valva. This character is, however, relative and susceptible to incorrect interpretation: the lateral and medial sides of the valvae may create different impressions (Fig. 1). These authors also mention some characters of the internal genitalia that are visible without eversion.

The aim of this study was to check whether the internal genitalia of *Selidosema plumarium* and *S. brunnearium* could offer any precise, distinctive features to separate these species from each other. Furthermore, we wanted to study the functional anatomy of these species, because it seemed that the pre- and postcopulation females had differently shaped genitalia.

2. Material and Methods

The studied specimens originate from the Finnish Museum of Natural History, Zoological Museum (ZMH). The specimens were initially separated into two groups, based on external characters (Rezbanyai 1983), and furthermore, males were checked for the valvae character (Fig. 1) (Krampl & Marek 1981).

To decide whether the female specimens had been copulated, we checked for the absence (not mated)/presence (mated) of a spermatophore in the corpus bursae. Use of the character for this purpose was not unambiguous, because prolonged KOH-treatment tended to dissolve the spermatophores.

The genitalia of specimens were prepared using routine techniques, the male vesicae were everted and expanded, and the female corpus bursae were expanded (Hardwick 1950, Lafontaine & Mikkola 1987) with the following modifications: the caecum of the aedeagus was excised using small secondary cataract scissors, the vesica was pushed towards the posterior end of the aedeagus, using a hair via the caecum, and the vesica was everted and expanded with the aid of a hypodermic needle via the caecum. The corpus bursae was expanded through the ostium bursae.

The genitalia were stained with chlorazol black and they were kept in absolute alcohol during the study and measurements. After that, the genitalia were mounted in euparal, so that it was possible to reconstruct the copulation posture. The slides were turned so that the ventral side of the female was towards the observer and the ovipositor pointed upwards, and the male such that the aedeagus was also with its ventral side towards the observer, that is, with the opening of the ductus ejaculatorius away from the observer and the caecum end upwards (Lafontaine & Mikkola 1987).

The inferences regarding the anatomical functions of the internal genitalia are based on detailed examination and

measurements (measuring accuracy 0.02 mm). Drawings of Fig. 2 were made with the aid of a mirror and correspond to real specimens.

Dissected material (additional information is placed in square brackets): *Selidosema plumarium*: Czech Republic, S Moravia, Palava Mts., 1 ♂ 2.9.1994 (slide PS 194); Russia, Sarepta 1 ♂ 3/9 [18] 98, (PS 197); Russia, Sarepta 1 ♂ (PS 193); Bulgaria, Nos Kaliakra, 2 ♀ 10.9.1976 (PS 195, PS 198); no label 1 ♀ (PS 199). *Selidosema brunnearium*: Sverige, Öland, 1 ♀ VIII. [19] 67 (PS 192); Estonia, Saaremaa, Kuressaare, 3 ♂ 28.7.1999 (PS 190, PS 191, PS 196); Sverige, Gotland, 1 ♀ (PS 200); Finland, U: Tvärminne, 1 ♂ 31.7.1969 (vesica missing after an earlier preparation). All specimens and slides are in the collections of ZMH.

3. Taxonomic characters of *Selidosema plumarium* and *S. brunnearium*

Medium-sized ennomine species; wingspan 29–36 mm, females lighter and smaller; ground colour light brown-gray, markings darker; median fascia often distinct; discal spot conspicuous. Male valvae widest medially, tapering towards apex, spined; vesica simple, without cornutus; female lamella postvaginalis large, corpus bursae with signum. On dry, warm fields and heaths in the Western Palaearctic.

Key to the species of *Selidosema plumarium* and *S. brunnearium* (male genitalia):

1. Aedeagus sclerotized ventro-laterally near apex, rounded ..... *plumarium* (Fig. 3a)
2. Aedeagus sclerotized ventro-laterally near apex, with pyramid-like projection ..... *brunnearium* (Fig. 3b)

Key to the species of *Selidosema plumarium* and *S. brunnearium* (female genitalia):

1. Anterior end of ductus bursae slightly expanded laterally ..... *plumarium* (Fig. 3c)
2. Anterior end of ductus bursae with distinct lateral projection ..... *brunnearium* (Fig. 3d)

The shape and size of the membranous corpus bursae and lamella postvaginalis (= *lamella antevaginalis* of Krampl & Marek 1981) was found to be variable in both species. These characters cannot be used to separate these taxa, although they are illustrated as such elsewhere (Urbahn & Urbahn 1978, Forster & Wohlfahrt 1980, Skou 1984).

It was found that the male aedeagus (max. width 0.2 mm) and the female ductus bursae (min. width 0.27 mm) of *Selidosema plumarium* (n = 6) appear to be narrower than those of *S. brunnearium* (max. width of aedeagus 0.3 mm, min. width of ductus bursae 0.3 mm) (n = 5), but the material is too limited for reliable statistical testing.

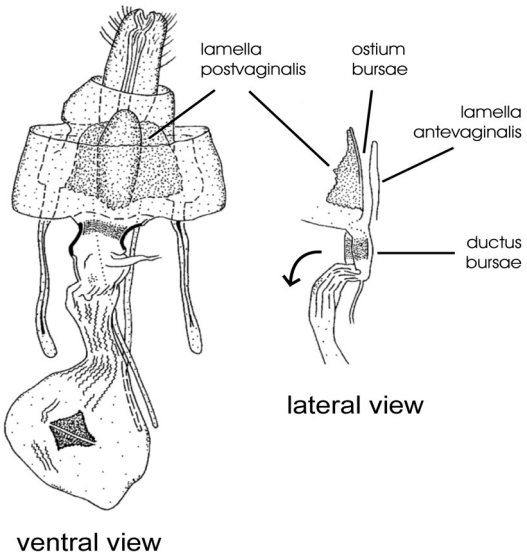

Fig. 2. The female bursa copulatrix of *Selidosema brunnearium* from ventral and lateral view. It is hypothesized that the dorsal angle at the anterior end of the ductus bursae straightens as the aedegus penetrates the bursa copulatrix (lateral view). See text for details.

4. Discussion

4.1. Earlier identity confusions

In the case of *Selidosema plumarium* and *S. brunnearium*, detailed information for identification was not presented until the revision of Krampl and Marek (1981) and Rezbanyai (1981). Earlier illustrations, including the female genitalia, have been quite confusing (e.g. Urbahn & Urbahn 1978). As a result, the old literature records are not reliable, neither are the distribution areas of these species known in detail (Rezbanyai 1983, Skou 1984); the most reliable distribution map to date is that presented by Mikkola (1987, figure 3).

As an example of this confusion, the first *Selidosema* record from Finland dates back to 31

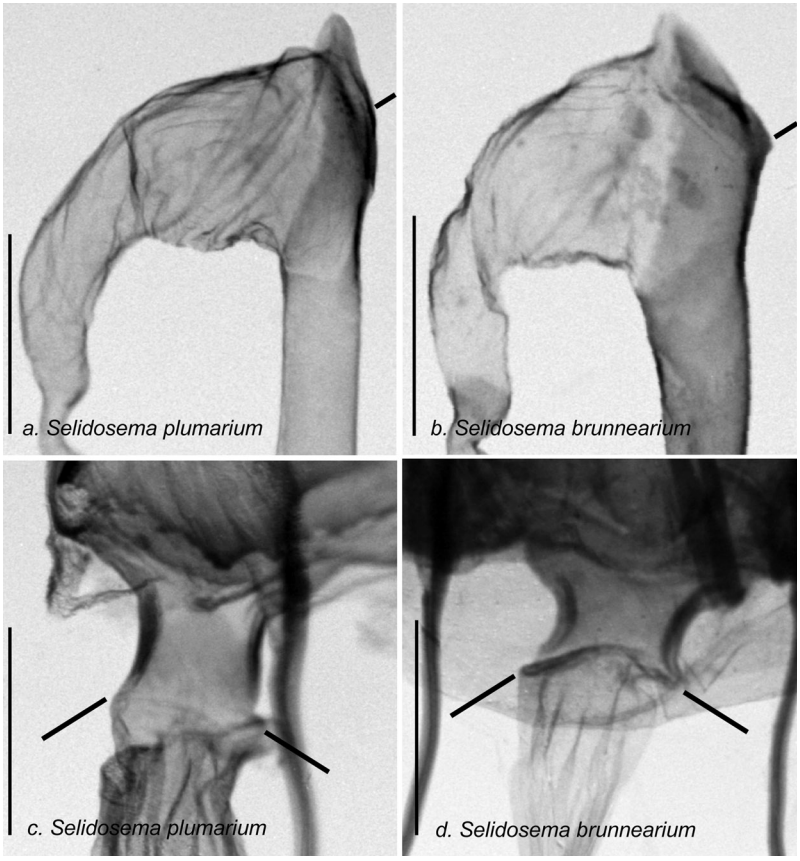

Fig. 3. Taxonomic characters of the male aedeagus and the female ductus bursae. — a. *Selidosema plumarium*, aedeagus laterally round. — b. *S. brunnearium*, aedeagus with pyramid-like lateral sclerotization. — c. *S. plumarium*, ductus bursae with small lateral extentions distally. — d. *S. brunnearium*, ductus bursae with distinct lateral extentions distally. Scale bar = 0.5 mm.

July 1969, which was first reported as *S. plumarium* by Keynäs (1969) and subsequently changed to *S. brunnearium* by Suomalainen (1971). In the recent literature, it is referred to as *S. plumarium* (Mikkola 1987, Mikkola *et al.* 1989, Varis *et al.* 1995). The identity of this specimen was recently checked from the external genitalia (Krampl pers. comm.) and, in the present study, from the internal genitalia. By both means it is confirmed to be *S. brunnearium*.

Mikkola (1987) interpreted that the specimen had been carried by a warm air current from what is now Slovakia, where *Selidosema plumarium* occurs, but the same air current later passed the Swedish Baltic islands, Gotland and Öland, as well as Saaremaa in Estonia (cf. Mikkola 1987: figure 2), where *S. brunnearium* is now known to be common. Since then, two additional *Selidosema brunnearium* specimens have been caught on the southwestern coast of Finland: U: Tammisaari 664:29 1 ♂ 18.–28.7.1999 (J. Huusko, J. Ketonen, S. Korpela & A. Virtanen leg.) and U:Hanko 664:27 1 ♂ 21.7.1999 (K. Männistö leg.).

The nomenclature of these two species has been confused too (for a revision, see Fletcher 1949). *Selidosema brunnearium* is referred to as *S. plumarium* in the handbook of Polish Geometridae (Bleszynski 1966), and elsewhere (e.g. Busse & Ockruck 1991). In the Hungarian Geometridae, the opposite is the case, as *Selidosema plumarium* is referred to as *S. brunnearium* (Vojnits 1980, Rezbanyai 1983). According to Müller (1996), both species have been recorded recently from Hungary. These nomenclatorial errors have been corrected in recent works (e.g. Fajcik & Slamka 1996, Nestorova 1998).

4.2. Function of the genitalia

Based on the studied material, the female ductus bursae is in both of the studied *Selidosema* spe-

cies concave before copulation and the colliculum is on the ventral side (Fig. 2). The dorsal wall of the ductus bursae is membranous and the distal part of the ductus bursae makes an acute dorsal turn near the proximal part of the corpus bursae. The apex of the aedeagus, on the other hand, is sclerotized and another sclerotized area is found on the distal third of the aedeagus. Based on this, we present the following hypothesis that is based on indirect evidence, not on actual copulation experiments, which would be necessary to confirm our hypothesis. Due to the nature of our findings, and to promote interest in the functional anatomy of the genitalia the discussion is warranted.

As the aedeagus penetrates the ductus bursae of the female, the whole ductus becomes rounded. This may force the dorsal arch in the distal part of the ductus bursae to disappear, allowing the male vesica to enter the proximal part of the female corpus bursae, which is necessary for successful spermatophore deposition. A similar structure is found in the female genitalia of *Cyclophora maderensis* Bethune-Baker (Geometridae, Sterrhinae) (P. Sihvonen unpubl.).

As described above, the shape of the female bursa copulatrix may change drastically during copulation, because the dorsal turn at the distal end of the ductus bursae disappears. Our material indicates that the posture of the ductus remains quite unchanged afterwards. As a result, there is a possibility that a lepidopterologist may encounter female specimens of *Selidosema* with differently shaped genitalia: the ones that have not mated, with an angled ductus bursae, and the ones that have mated, with a straight ductus bursae. Without proper understanding of the functional anatomy of the genitalia, one may be misled to consider these even as separate taxa.

4.3. Geometrids *Selidosema* and *Eupithecia* compared

When the functional anatomy of the genitalia of the genus *Selidosema* (Ennominae) is compared to the genus *Eupithecia* Curtis (Larentiinae) (cf. Mikkola 1993, 1994), the following basic differences are found (characters of *Eupithecia* in parantheses): 1. In *Selidosema* the colliculum is on the ventral side of the ductus bursae (dorsally). 2. The distal end of the ductus bursae is angled before copulation (rather straight). 3. The valvae are strongly sclerotized with strong lateral spines (rather membranous). 4. There exist no cornuti on the vesica, only a small sclerotization, and a single signum in corpus bursae (the tip of the vesica usually has at least double, apically rounded cornuti and the corpus bursae is often internally covered by numerous spines).

It seems from the above that, in *Selidosema*, the critical point in successful sperm transfer is the ability to open the colliculum and the related angle at the distal end of ductus bursae. The strongly sclerotized rounded area at the tip of aedeagus, seems to be a special device to open the colliculum and straighten the angle of the ductus bursae. In *Eupithecia*, on the other hand, successful sperm transfer requires the ability to open the colliculum, as well as to handle the ductus seminalis with a special structure which is present in the male vesica. These apically rounded cornuti, "the ductus openers", serve to deposit the distal end of the spermatophore into the appendix bursae in such a way that the frenum end of it is placed against the opening of the ductus seminalis (Mikkola 1993).

It is assumed from 3 and 4 that, in *Selidosema*, the male external genitalia, the valvae, with the assistance of the uncus, serve to grasp the female during the early phase of copulation. In *Eupithecia*, this function is similarly carried out by the valvae and the uncus, although here the valvae are less sclerotized and less species-specific. These organs hold the female in such a position that the insertion of the aedeagus becomes possible. Subsequently, they do not have such a function. P. Sihvonen (unpubl.) has dissected a pair of *Eupithecia pygmaeata* Hb. (Geometridae, Larentiinae) *in copula* and, even after both valvae of the male had been removed, the *copula* remained fixed together. Similarly, in many photographs, e.g. of *Lycaena phlaeas* (L.) (Lycaenidae, Lycaeninae) (Mikkola & Tanner 2001, p. 34), it can be seen that it is the chitinous or membranous internal genitalia which hold the *copula* together, not the valvae.

Acknowledgements. We are grateful to Stephen Venn for revising our English.

References

Arnqvist, G. 1997: The evolution of animal genitalia: distinguishing between hypotheses by single species studies. — Biological Journal of the Linnean Society 60: 365–379.

Bleszynski, S. 1966: Geometridae. — In: Riedel, A. (ed.), Klucze do oznaczania owadow Polski XXVII (Lepidoptera), 46a: 1–149. Panstwowe Wydawnictwo Naukowe, Warsaw. 149 pp. [In Polish].

Bolte, K. B. 1990: Guide to the Geometridae of Canada (Lepidoptera) VI. Subfamily Larentiinae. 1. Revision of the genus *Eupithecia*. — Memoirs of the Entomological Society of Canada 151: 1–253.

Busse, R. & Ockruck, F. 1991: Ein Beitrag zur Kenntnis der Schmetterlingsfauna des Pirin-Gebirges in südwesten Bulgariens (Lepidoptera). — Phegea 19: 5–20.

Callahan, P. S. & Chapin, J. B. 1960: Morphology of the reproductive system and mating in two representative members of the family Noctuidae, *Pseudaletia unipuncta* and *Peridroma margaritosa*, with comparison to *Heliothis zea*. — Annals of the Entomological Society of America 53: 763–782.

Choi, S.-W. 1997: A phylogenetic study on the genera of Cidariini from the Holarctic and the Indo-Australian areas (Lepidoptera: Geometridae: Larentiinae). — Systematic entomology 22: 287–312.

Eberhard, W. G. 1986: Sexual selection and animal genitalia. — Harvard University Press, Cambridge, Massachusetts. 244 pp.

Fajcik, J. & Slamka, F. 1996: Die Schmetterlinge Mitteleuropas, I. Band: Drepanidae, Geometridae, Lasiocampidae, Endromidae, Lemoniidae, Saturniidae, Sphingidae, Notodontidae, Lymantriidae, Arctiidae. — Bratislava. 113 pp.

Fletcher, D. S. 1949: Notes on some European species of *Selidosema* (Lep., Geometridae). — Entomologist 82: 217–222.

Forster, W. & Wohlfahrt, T. A. 1981: Die Schmetterlinge Mitteleuropas, band 5: Spanner (Geometridae). — Franckh, Stuttgart. 312 pp.

Hardwick, D. F. 1950: Preparation of slide mounts of Lepidopterous genitalia. — Canadian Entomologist 82: 231–235.

Janse, A. J. T. 1932: The moths of South Africa, vol. 1. Sematuridae and Geometridae. — E. P. & Commercial Printing Co., Durban. 376 pp.

Kaila, L., Viidalepp, J., Mikkola, K. & Mironov, V. 1996: Geometridae (Lepidoptera) from the Tian-Shan Mountains in Kazakhstan and Kyrgyzstan, with descriptions of three new species and one new subspecies. — Acta Zoologica Fennica 200: 57–82.

Keynäs, K. 1969: *Selidosema plumaria*. — Circular of the Finnish Lepidopterists Society 7/1969:1.

Krampl, F. & Marek, J. 1981: *Selidosema plumaria* and *S. brunnearia* in Czechoslovakia and their developmental stages (Lepidoptera, Geometridae). — Acta Entomologica Bohemoslovaca 78: 397–411.

Lafontaine, J. D. & Mikkola, K. 1987: Lås-och-nyckel systemen i de inre genitalierna av Noctuidae (Lepidoptera) som taxonomiska kännetecken. — Entomologiske Meddelelser 55: 161–167.

McCabe, T. L. 1984: A new *Cautethia* from the Bahamas (Lepidoptera: Sphingidae). — Proceedings of the Entomological Society of Washington 86: 614–618.

Mikkola, K. 1987: *Selidosema plumarium* new to northern Europe (Lepidoptera, Geometridae). — Notulae Entomologicae 67: 147–150.

Mikkola, K. 1993: The lock-and-key mechanisms of the internal genitalia of the noctuid and geometrid moths (Lepidoptera) in relation to the speciation concepts. — Folia Baeriana 6: 149–157.

Mikkola, K. 1994: Inferences about the function of genitalia in the genus *Eupithecia*, with description of a new organ (Lepidoptera, Geometridae). — Nota Lepidopterologica, Supplement 5: 73–78.

Mikkola, K., Jalas, I. & Peltonen, O. 1989: Finnish Lepidoptera, Geometroidea 2. — Hangon Kirjapaino, Finland. 280 pp. [In Finnish].

Mikkola, K. & Tanner, H. 2001: Perhospuutarha. — Gummerus, Jyväskylä. 240 pp. [In Finnish].

Müller, B. 1996: Geometridae. — In: Karsholt, O. & Razowski, J. (eds.), The Lepidoptera of Europe, a distributional checklist: 218–249. Apollo Books, Stenstrup. 380 pp.

Nestorova, E. 1998: Catalogus Faunae Bulgaricae 2. Lepidoptera, Geometridae. — Pensoft Publishers, Sofia. 193 pp.

Rezbanyai, L. 1981: Erste sichere Nachweise beider *Selidosema*-Arten: *plumaria* D. & Sch. 1775 und *brunnearia* Vill. 1789 in der Schweiz (Lep., Geometridae). — Mitteilungen der Schweizerischen Entomologischen Gesellschaft 54: 271–279.

Rezbanyai, L. 1983: Ein weiterer Beitrag zur Morphologie und Verbreitung von *Selidosema plumaria* ([Denis & Schiffermüller], 1775) und *Selidosema brunnearia* (deVillers, 1789). — Entomofauna 4: 435–442.

Skou, P. 1984: Nordens målere. Håndbog over de danske og fennoskandiske arter af Drepanidae og Geometridae (Lepidoptera). Danmarks dyreliv, bind 2. — Fauna Bøger & Apollo Bøger, Københavns. 332 pp.

Suomalainen, E. 1971: *Selidosema brunnearia*. — Circular of the Finnish Lepidopterists Society 7/1971: 1.

Takeuchi, F. S. & Miyashita, K. 1975: The process of spermatophore transfer during the mating of *Spodoptera litura* F. — Japanese Journal of Applied Entomology and Zoology 19: 41–46.

Troubridge, J. T. 1997: Revision of the nearctic species of the genus *Entephria* Hübner (Lepidoptera: Geometridae, Larentiinae). — Entomologica Scandinavica 28: 121–139.

Troubridge, J. T. & Fitzpatrick, S. M. 1993: A revision of the North American *Operophtera* (Lepidoptera: Geometridae). — Canadian Entomologist 125: 379–397.

Urbahn, E. & Urbahn, H. 1978: *Selidosema plumaria* Schiff. (1775) und *S. brunnearia* Vill. (1789) (Lep., Geom). — Entomologische Nachrichten, Dresden 22: 113–118.

Varis, V., Ahola, M., Albrecht, A., Jalava, J., Kaila, L., Kerppola, S. & Kullberg, J. 1995: Check-list of Finnish Lepidoptera. — Sahlbergia 2: 1–80.

Vojnits, A. 1980: Geometridae I. — In Akos, U. (ed.), Fauna Hungariae 137. XVI. kötet (Lepidoptera), 8: 1–157. Füzet, Hungary. 157 pp.