Identification of *Delia* pest species (Diptera: Anthomyiidae) in cultivated crucifers and other vegetable crops in Canada

Jade Savage[1*], Anne-Marie Fortier[2], François Fournier[3], Véronique Bellavance[1]

[1]Biological Sciences, Bishop's University, 2600 College Street, Sherbrooke, QC, J1M 1Z7, Canada (jsavage@ubishops.ca, vbelleav@ubishops.ca)

[2]Compagnie de Recherche Phytodata Inc., 291 rue de la Coopérative, Sherrington, QC, J0L 2N0, Canada (afortier@phytodata.ca)

[3]Collège Montmorency, 475 boulevard de l'Avenir, Laval, QC, H7N 5H9, Canada (Francois.Fournier@cmontmorency.qc.ca)

* Corresponding Author

Abstract

A number of root maggot fly species from the large genus *Delia* Robineau-Desvoidy (Diptera: Anthomyiidae) are important pests of cultivated crucifers and many other field and vegetable crops. The present work provides identification keys in English and French to the adults, third instar larvae, puparia, and eggs of all pests of cultivated crucifers and other vegetable crops in Canada, namely *Delia antiqua* (Meigen), *D. floralis* (Fallén), *D. florilega* (Zetterstedt), *D. planipalpis* (Stein), *D. platura* (Meigen) and *D. radicum* (Linnaeus). DNA barcodes are provided for all species except *D. planipalpis* and new data on larval host associations in southern Québec are presented.

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Introduction

Feeding damage by root maggot flies (*Delia* Robineau-Desvoidy spp. (Diptera: Anthomyiidae)) can result in important crop losses in Canada, being especially detrimental to vegetable crops (Griffiths 1986, 1991, 1993; Howard *et al*. 1994) and, more recently, to the production of a variety of canola cultivars (*Brassica rapa* Linnaeus and *Brassica napus* Linnaeus (Brassicaceae)) (Broatch 1993; Soroka *et al.* 2004; Soroka and Dosdall 2011). As their common names indicate, certain phytophagous *Delia* species such as the onion maggot, *Delia antiqua* (Meigen) and the cabbage maggot *Delia radicum* (Linnaeus), have a relatively narrow range of hosts, in this case feeding exclusively on *Allium* Linnaeus (Amaryllidaceae) or Brassicaceous species, respectively. However, other primarily saprophagous taxa such as the seedcorn maggot, *Delia platura* (Meigen), and the bean seed maggot *Delia florilega* (Zetterstedt) have a much wider range of larval plant food, including decomposing (and sometimes fresh) cultivated crucifers and *Allium* species as well as many other types such as legumes, cucurbits, a wide variety of garden crops and even certain cereals (Griffiths 1993; Howard *et al*. 1994).

Because most crops can be infested by more than one species of root-maggot flies, the correct identification of species involved in plant damage is important for the adequate development and assessment of pest-control strategies, as each may respond differently to treatments. This is especially relevant to targeted control methods such as the mass release of sterile insects, a strategy currently used for the control of the onion maggot in southern Québec (Fournier 2014). Much can be learned about the ecology and population dynamics of *Delia* flies by studying adults (Broatch 1993; Broatch *et al*. 2006; Ellis and Scatcherd 2007; Soroka and Dosdall 2011); however, using adults as a proxy for the abundance and species composition of the taxa actually causing the damage can be misleading. Different trap designs will capture different proportions of each species (Finch 1989; Broatch and Vernon 1997); some species can be very abundant as adults but rarely involved in damage, and the relative contribution of different species to plant damage can be over or underestimated (see DNA barcoding and larval host associations section).

Specimen identification of even the most common *Delia* pest species can be difficult for anyone without extensive training and this challenge is more pronounced when dealing with females or immature specimens which may lack obvious diagnostic features. While excellent, the keys to adult *Delia* flies published by Griffiths (1993) in his monumental revision of Nearctic Anthomyiidae rely heavily on genitalic characters and include over 150 couplets for each sex, being therefore virtually incomprehensible to non-specialists. The key to third instar larvae by Dahlem and Thompson (1991) remains a good resource for *Delia* species of economic importance but it contains some inaccuracies (see key to larvae for additional details). The work of Brooks (1951) offers identification keys to the different life stages of *Delia* pests of cruciferous crops in Canada and remains the

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most comprehensive taxonomic tool currently available for the group. However, Brooks (1951) includes pests of crucifers only, is poorly illustrated, does not discuss intraspecific variability for certain key structures, and uses obsolete name combinations for most taxa.

The main objective of this work is, therefore, to provide a simple and comprehensive taxonomic resource (identification keys to the different life stages and reference DNA barcodes) for economically important species of *Delia* flies in cultivated crucifers and other vegetable crops in Canada. New host association data for various crops grown in southern Québec are also presented.

More than 5000 adults and 3500 immatures from dozens of Nearctic and Palaearctic localities were examined to document intraspecific variability and host associations; however, all specimens photographed in the keys except for those belonging to *Delia planipalpis* (Stein) were reared from laboratory cultures to ensure the correct association of the various life stages. Live puparia of *Delia floralis* (Fallén) (cultured from wild Norwegian stocks) were provided by R. Meadows (Norwegian University of Life Sciences, Ås, Norway) and K. Hillier (Acadia University, Wolfville, Nova Scotia, Canada), while laboratory cultures of *D. platura*, *D. florilega*, *D. antiqua* and *D. radicum* descending from wild Québec populations were maintained by F. Fournier (Collège Montmorency, Laval, Québec, Canada). All wild larvae collected in the province of Québec are housed at the Bishop's University Insect Collection, Sherbrooke, Québec, Canada (BUIC). Additional adult and/or immature specimens from BUIC, the Canadian National Collection of Insects, Ottawa, Ontario, Canada (CNC), the National Museum of Natural History, Smithsonian Institution, Washington DC, United States (NMNH) and the E.H. Strickland Museum, Edmonton, Alberta, Canada (UASM) were also examined. Provincial acronyms used in the distribution section of each species are based on Canadian provincial and territorial postal abbreviations.

Adults and their external structures were photographed with a Canon DSLR camera equipped with a Canon MP-E65 lens and a Canon MT24EX flash. Male genitalia and immature specimens and structures were photographed using a Luminera 1 digital camera mounted on a Leica M125 dissection microscope. Multiple images taken at different focal points were stacked using Helicon Focus 6.3.0 (Helicon Soft Ltd., Kharkov, Ukraine) and final image editing was completed in GIMP (v.2.8; http://www.*gimp*.org). All larvae were immersed in near-boiling water for a minute before they were measured and photographed.

DNA barcoding

DNA barcodes (Folmer region of COI gene) were sequenced for multiple adult specimens of all species except *D. planipalpis* (lack of recently collected material) as well as for the eggs and larvae (1^{st} and 3^{rd} instars) of most other species included in this work. A neighbor joining tree including a subset of high quality sequences from various life stages is presented in Fig. 1. Images, collection details and individual COI sequences for a subset of barcoded specimens can be retrieved from the Barcode of Life Data System (BOLD) (www.barcodinglife.org) in the public dataset: *Delia* pests of Canada (dx.doi.org/10.5883/DS-DPOC). All vouchers were deposited in the BUIC.

The DNA barcodes for *D. radicum*, *D. floralis*, *D. antiqua* and *D. florilega* all clustered in single, well-defined Barcode Index Numbers (BIN, Ratnasingham and Hebert 2013) (Fig. 1). *Delia platura* sequences, however, formed two distinct BINs (AAA3453 and AAG2511) separated by a minimum distance of 4.45% (Fig. 1). More than 100 adults (both sexes) and 50 third instar larvae from each of these two *D. platura* BINs were examined but no morphological differences was found. There is, however, a distinctive pattern in the geographical distributions of these BINs based on thousands of records found in the Barcode of Life Data System (BOLD, Ratnasingham and Hebert, 2007): AAA3453 is almost entirely restricted to the New World (transcontinental distribution in Canada and the United States, Costa Rica) with a single record from South Africa whereas AAG2511 is found throughout Europe, Asia, Greenland, eastern Canada (NB, NS, NL, ON, PEI, QC), with a single record from Alaska. *Delia platura* is found on all continents except Antarctica (Griffiths 1993) and little is known of the origins of the North American fauna. The global distribution pattern reported here for the two BINs suggests, however, that the New World fauna includes at least two distinct populations, one possibly native (AAA3453) and one introduced (AAG2511). The phylogeography of these two groups of *D. platura* will be further investigated in a separate project as it will require additional data beyond the scope of the present work.

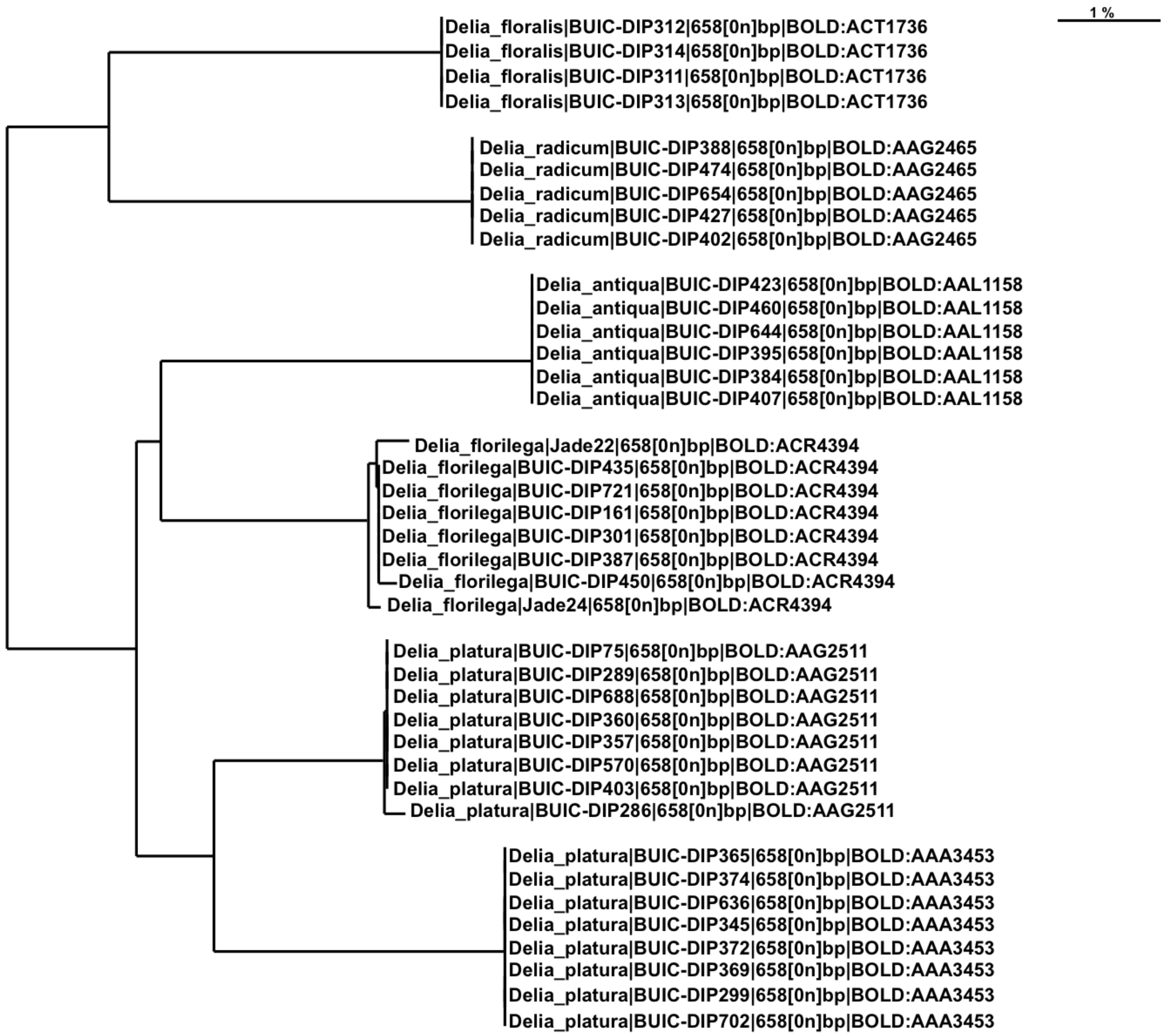


Fig. 1. Neighbor-joining tree based on Kimura 2-parameter distances (K2P, Kimura 1980) for representative sequences from each species. Each line includes species name, BOLD sample ID, read length, number of ambiguities and Barcode Index Number.

Larval host associations

The abundance of different *Delia* species in canola and/or vegetable crops is often monitored using passive traps (yellow and/or blue sticky cards, cone traps, water traps, etc.) to capture adults (Finch 1989). While *D. radicum* and *D. antiqua* are often assumed to be the main contributors to crop damage in crucifers and *Allium*, respectively, adults of *D. platura* and/or *D. florilega* can be much more abundant in passive traps than primary pests (Broatch and Vernon 1997; Villegas *et al.* 2009), as they are attracted to organic matter and fresh crop residues (Hammond 1990) and can breed in previously damaged and/or healthy cultivated plants. Little is known, however, of their actual involvement in plant damage. To determine the species composition of *Delia* species feeding on vegetable crops in southern Québec, more than 3500 third instar larvae were collected from 85 vegetable fields distributed in 21 farms in the Montérégie region (Fig. 2) between 15 May 2015 and 23 September 2015. Each field was sampled at least once and sampling protocol varied according to crop type. In crucifers (Brassicaceae), 150 seedlings each of broccoli (*Brassica oleracea* Linnaeus var. *italica* Plenk), cauliflower (*B. oleracea* var. *botrytis* Linnaeus) and Napa cabbage (*Brassica napus* Linnaeus subsp. *pekinensis* (Lour.) Hanelt) were examined, and 300 seedlings of radishes (*Raphanus sativus* Linnaeus) were collected. Regarding onions, all yellow onion (*Allium cepa* Linnaeus) seedlings along 30 lines of 1 meter each were examined, and all green onion (*Allium fistulosum* Linnaeus) seedlings along 15 lines of 1 meter each were examined. Broccoli and cauliflower were grown in mineral soils while Napa cabbages, radishes and all onions were grown in muck soils. The larvae were identified morphologically and those of *D. platura* and *D. florilega* were grouped together since they can't be distinguished morphologically (see identification key to larvae for details). The abundance of species in samples where at least one larva was collected was compared in each crop using a two-tailed Wilcoxon-signed rank test on paired data. Green and yellow onion samples were divided into two groups according to the presence or absence of mass release (since 2012) of sterile *D. antiqua* on the farms where they were collected (Fournier 2014). The statistical analysis was computed using the R package "stats" 3.2.4 (R Development Core Team, 2016) and statistical significance was assessed using an alpha-level of $P < 0.05$ and 0.95 confidence intervals.

As expected, the diversity of collected larvae was low: *Delia platura*/*D. florilega* was collected in all crops, *D. radicum* was found only in crucifers and *D. antiqua* only in onions (Table 1). In crucifers, most larvae were collected from broccoli (n=2089) and Napa cabbage (n=858). The larval abundance of each species was quite variable but *Delia radicum* was significantly more abundant than *Delia platura*/*D. florilega* only in Napa cabbage ($V = 108.0$, $P = 0.007$) and radishes ($V = 242.5$, $P = 0.001$) (Table 1), even if *D. platura* and *D. florilega* adults were always much more abundant than *D. radicum* on both sticky cards and emergence traps placed in the fields (A.-M. Fortier and J. Savage, unpublished). Liu and Sparks (1999) reported substantial damage to Napa cabbage by *D. florilega* in Texas based on rearing data but our results suggest that the pattern may not apply to more northern localities, and that the attribution of feeding damage to Napa cabbage by *D. florilega* and *D. platura* in southern Québec based on the high abundance of adults observed laying eggs in the field by Lafontaine *et al.* (2008) may have been incorrect.

In spite of intensive sampling efforts in onions, infestation rates were low in 2015, with damages averaging 0.7% and 1.6% in yellow and green onions respectively, independently of the control method used (F. Fournier, unpublished) and relatively few *Delia* larvae were collected, both in fields where sterile *D. antiqua* had been released and those where they had not (Table 1). Overall, we collected more larvae of *Delia platura*/*D. florilega* (n=360) than of *D. antiqua* (n=213), but found no significant differences in species abundance (Table 1). In onions, *D. platura* is often reported in joint infestations with *D. antiqua* (Merrill 1951; Merrill and Hutson 1953; Finlayson 1956). However, in the present work, *D. platura*/*D. florilega* larvae were collected alone in 38 of 72 yellow onion samples (53%) and in 17 of 37 green onion samples (46%), suggesting primary infestations.

Since the larvae of *D. florilega* are identical to those of *D. platura* and because of the presence of two distinct BINs for *D. platura* (see DNA Barcoding section), we used DNA barcodes to determine larval host associations of 288 randomly selected *D. platura*/*D. florilega* larvae collected in various vegetable crops in southern Québec (Table 2). Both BINs of *D. platura* were recorded from all hosts – broccoli, cauliflower, Napa cabbage, radish, green and yellow onions. In crucifers, the larvae from BIN AAG2511 (n=139) were more than 2.5x as abundant as those from BIN AAA3453 (n=52) but the trend was reversed in onions, where 49 out of 64 sequenced individuals belonged to BIN AAA3453 (Table 2). *Delia florilega* was always less abundant than *D. platura* (BINs combined) but recorded from all sampled hosts with the exception of cauliflower (Table 2).

The host association data presented here is based on a large number of sampled plants and localities throughout the season, but it was all collected over a single year (2015) in southern Québec. It should therefore be used as baseline data to further document host preference (and its variability) in *Delia* flies found in vegetable crops in Canada.

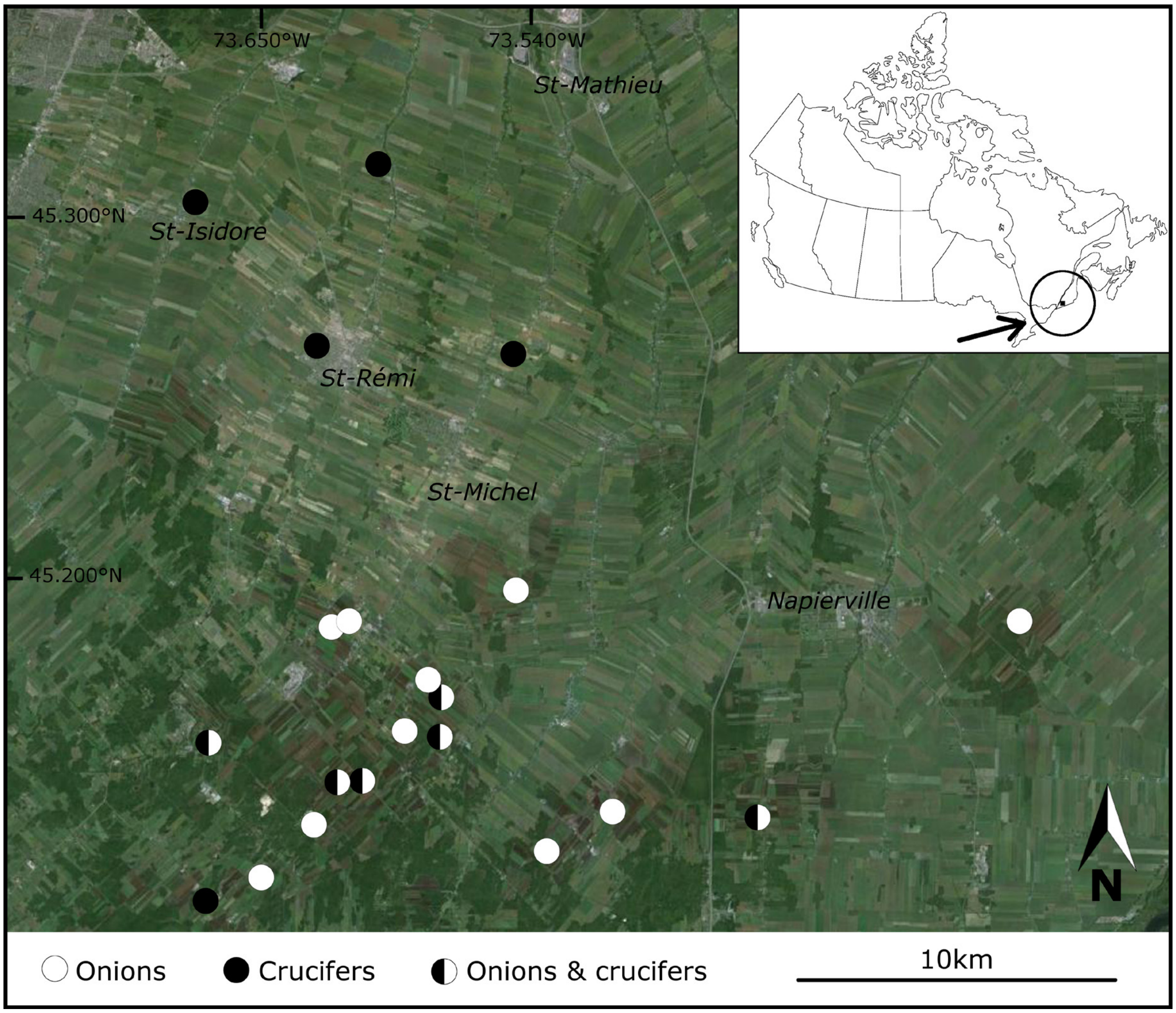


Fig. 2. Location of farms from Montérégie, southern Québec, Canada, where *Delia* larvae were collected in 2015.

Table 1. Mean, standard deviation (SD) and range of *Delia* species abundance per sample (n) of larvae collected in crucifers and onions in 2015 in Montérégie, southern Québec, Canada, with a comparison of mean species abundance for each crop type. S = samples collected in fields where sterile males of *D. antiqua* were released, NS = samples collected in fields where no sterile males of *D. antiqua* were released

	D. radicum		*D. platura/D. florilega**			
Crucifers	Mean ± SD	range	Mean ± SD	range	V[α]	p-value
Broccoli (n=37)	23.8 ± 34.2	(0-135)	32.7 ± 94.5	(0-417)	409.0	0.39
Napa cabbage (n=15)	48.9 ± 75.5	(0-281)	8.3 ± 17.0	(0-64)	108.0	0.007
Radish (n=24)	5.0 ± 5.0	(0-17)	2.2 ± 5.3	(0-20)	242.5	0.001
Cauliflower (n=10)	5.8 ± 9.5	(0-29)	2.6 ± 4.5	(0-12)	34.0	0.54
	D. antiqua		*D. platura/D. florilega**			
Onions	Mean ± SD	range	Mean ± SD	range	V[α]	p-value
Yellow onion S (n=35)	2.3 ± 5.6	(0-31)	3.3 ± 4.5	(0-17)	205.5	0.18
Green onion S (n=30)	1.8 ± 2.9	(0-10)	2.9 ± 4.1	(0-17)	165.5	0.26
Yellow onion NS (n=30)	2.4 ± 5.0	(0-22)	4.7 ± 8.0	(0-42)	139.5	0.09
Green onion NS (n=6)	1.2 ± 1.5	(0-4)	3.0 ± 3.6	(0-8)	6.0	0.40

* The larvae of these two species cannot be distinguished morphologically.

[α]V value from two tailed Wilcoxon-signed rank test on paired data with confidence interval of 0.95.

Table 2. Number of *Delia platura* and *D. florilega* larvae per species (based on DNA barcodes) and Barcode Index Number (BIN) for a selected subset of the larvae collected in 2015 in Montérégie, southern Québec, Canada (n = number of farms from which at least one larva was sequenced).

Crop type	*D. platura* (BIN AAG2511)	*D. platura* (BIN AAA3453)	*D. florilega* (BIN ACR4394)
Broccoli (n=4)	98	34	9
Cauliflower (n=2)	21	3	0
Napa cabbage (n=3)	12	11	11
Radish (n=2)	8	4	1
Green onions (n=2)	7	28	9
Yellow onions (n=8)	8	21	3

Checklist

The species included in this work and listed below were selected based on published records of crop damage in Canada (Brooks 1951; Griffiths 1991, 1993; Broatch 1993; Howard *et al*. 1994; Soroka and Dosdall 2011) and the identification of over 3500 larvae collected in damaged crucifers and onions in southern Québec. While *Delia echinata* (Séguy) has been reported as a pest of spinach in the Palaearctic Region (Miles 1953; Suwa 1974) it was excluded from the present work as damage caused by this species in the Nearctic Region is restricted to carnations (Griffiths 1991). Due to numerous nomenclatural changes and the large number of publications focused on some of the most important pest species, a list of most commonly used synonyms and combinations found in the literature as well as the French and English common names recognized by the Entomological Society of America (http://www.entsoc.org/pubs/common_names) and/or the Entomological Society of Canada (http://www.esc-sec.ca/d13/CNDBHome.php) are provided below.

***Delia antiqua* (Meigen, 1826)**

English common name: onion maggot; French common name: Mouche de l'oignon.

Commonly used synonyms or combinations: *Hylemyia antiqua*, *Hylemya antiqua*.

***Delia floralis* (Fallén, 1924)**

English common name: turnip maggot; French common name: Mouche du navet.

Commonly used synonyms or combinations: *Hylemyia crucifera* Huckett, *Hylemya crucifera*, *Hylemya floralis*.

***Delia florilega* (Zetterstedt, 1845)**

English common name: bean seed maggot; French common name: none.

Commonly used synonyms or combinations: *Hylemya trichodactyla* (Rondani), *Hylemyia trichodactyla*, *Delia liturata* (Meigen), *Hylemya liturata*.

***Delia planipalpis* (Stein, 1898)**

Common name: none.

Commonly used synonyms or combinations: *Hylemya planipalpis*, *Hylemyia planipalpis*.

***Delia platura* (Meigen, 1826)**

English common name: seedcorn maggot; French common name: Mouche des semis.

Commonly used synonyms or combinations: *Hylemya platura*, *Chortophila cilicrura* Rondani, *Hylemya cilicrura*, *Hylemyia cilicrura*.

***Delia radicum* (Linnaeus, 1758)**

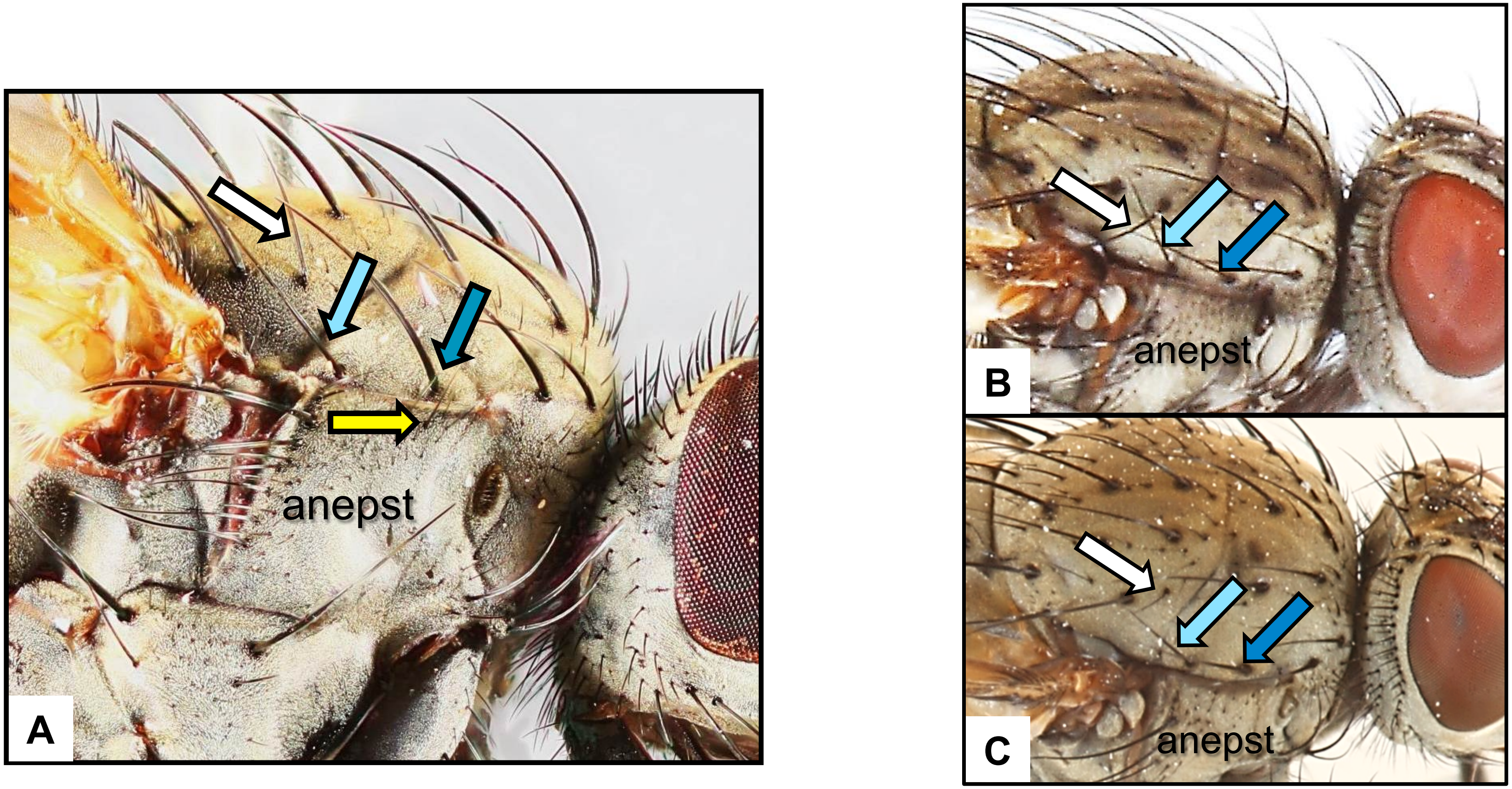
English common name: cabbage maggot; French common name: Mouche du chou.

Commonly used synonyms or combinations: *Hylemya brassicae* (Bouché), *Hylemyia brassicae*, *Erioischa brassicae*.

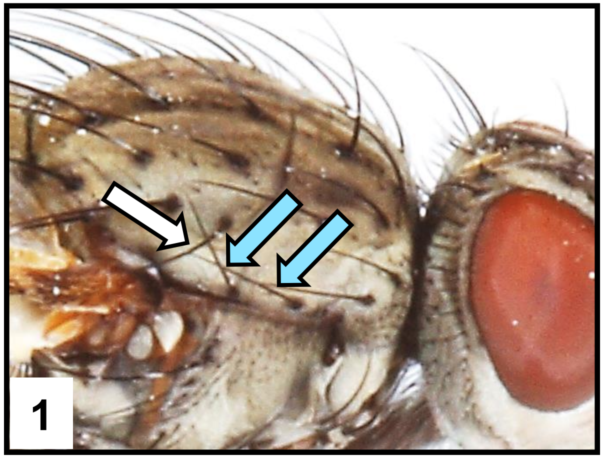
Keys to *Delia* pests of cultivated crucifers and other vegetable crops in Canada

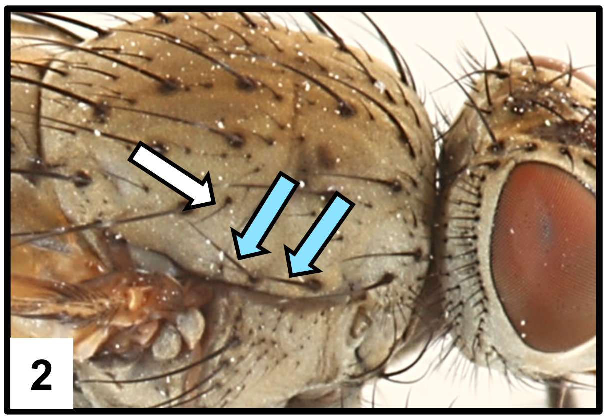
Botanophila fugax (Meigen) is an anthomyiid species associated with decaying plant matter (Ferrar 1987, p. 72 as *Pegohylemyia fugax*) whose immature stages are quite distinctive from those of *Delia* species included in the present work (see Brooks 1951 and Miles 1952 for descriptions of immature stages (as *Pegohylemyia fugax*)). However, the adults (and especially the females) are remarkably similar to those of certain *Delia* species. According to Brooks (1951), *B. fugax* is only occasionally encountered on cruciferous crops in Canada. The examination of 3220 adults caught by conical traps and sticky traps and more than 3500 larvae collected in various *Allium* (green and yellow onions) and cruciferous crops (radish, Napa cabbage, broccoli, cauliflower) in southern Québec, Canada, in the summer of 2015 (Fig. 2) yielded only 15 adults of *B. fugax* (0.5%) and no larvae. *Botanophila fugax* is therefore distinguished from *Delia* spp. only in the key to adults in the present work.

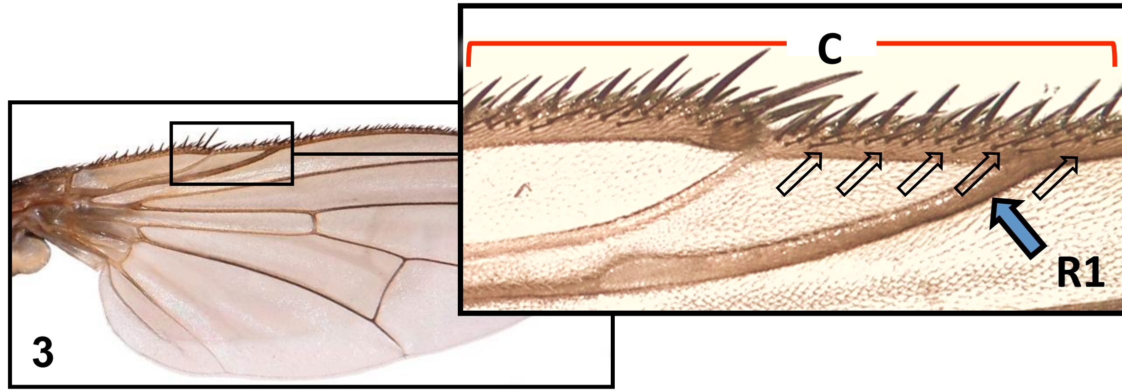
Separating *Botanophila fugax* from *Delia* pests of crucifers and other vegetable crops in Canada

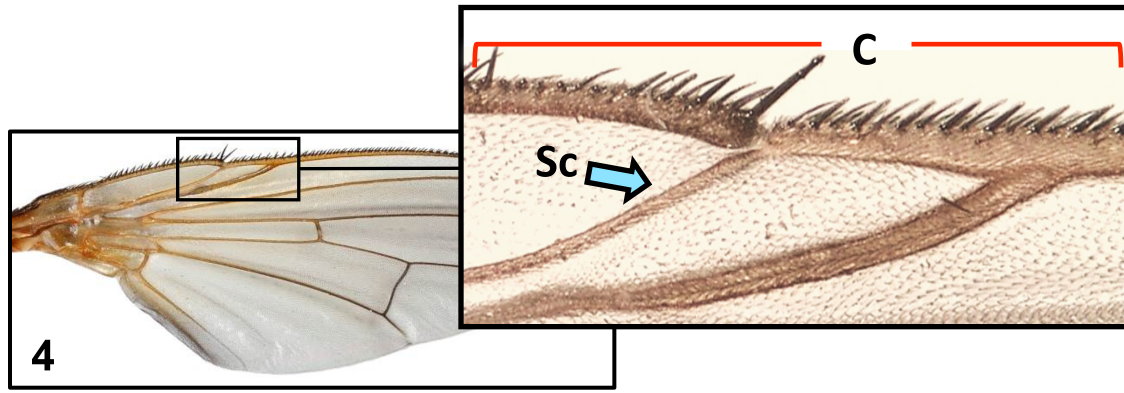


A	Prealar bristle (white arrow) well-developed but always shorter than posterior notopleural bristle (pale blue arrow) (Fig. A); anepisternum (anepst) with a fine, short, but well-developed hair (yellow arrow) on upper margin just below anterior notopleural bristle (dark blue arrow) (Fig. A).	*Botanophila fugax* (Meigen)
A'	Prealar bristle (white arrow) either longer than posterior notopleural bristle (pale blue arrow) (Fig. B) or absent/hair-like (Fig. C); anepisternum usually without a fine, short, but well-developed hair below anterior notopleural bristle (dark blue arrow) (Figs. B and C); if such a hair visible (some specimens of *D. radicum*), then prealar bristle always longer than posterior notopleural bristle (pale blue arrow).	*Delia* pests of crucifers and vegetable crops in Canada

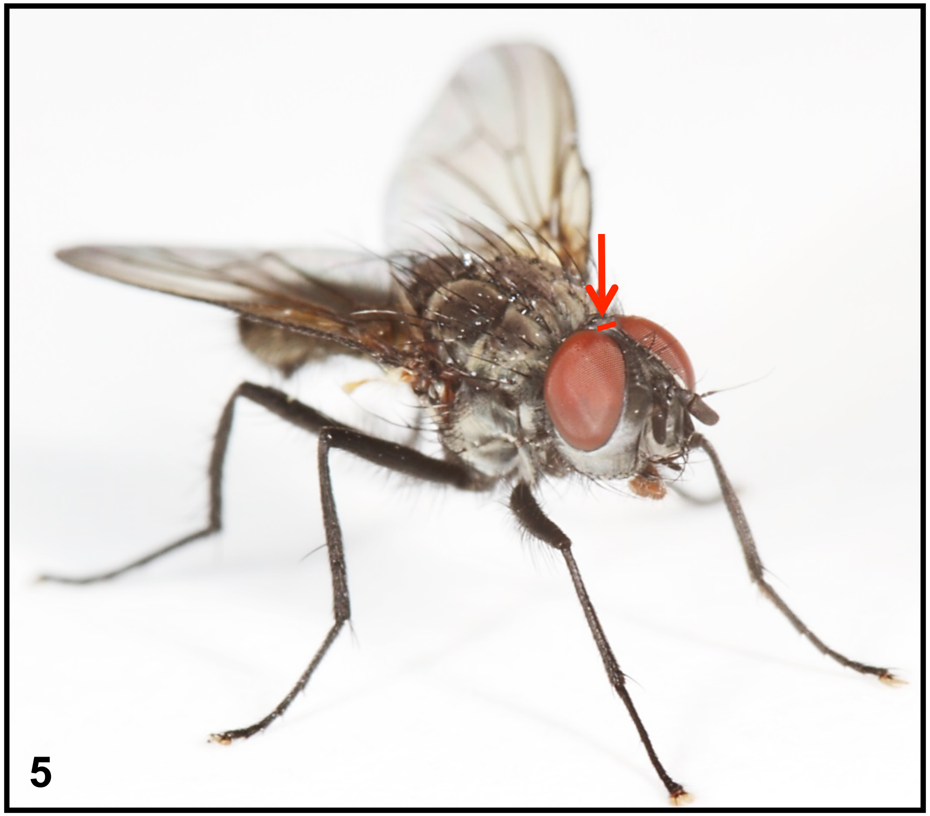


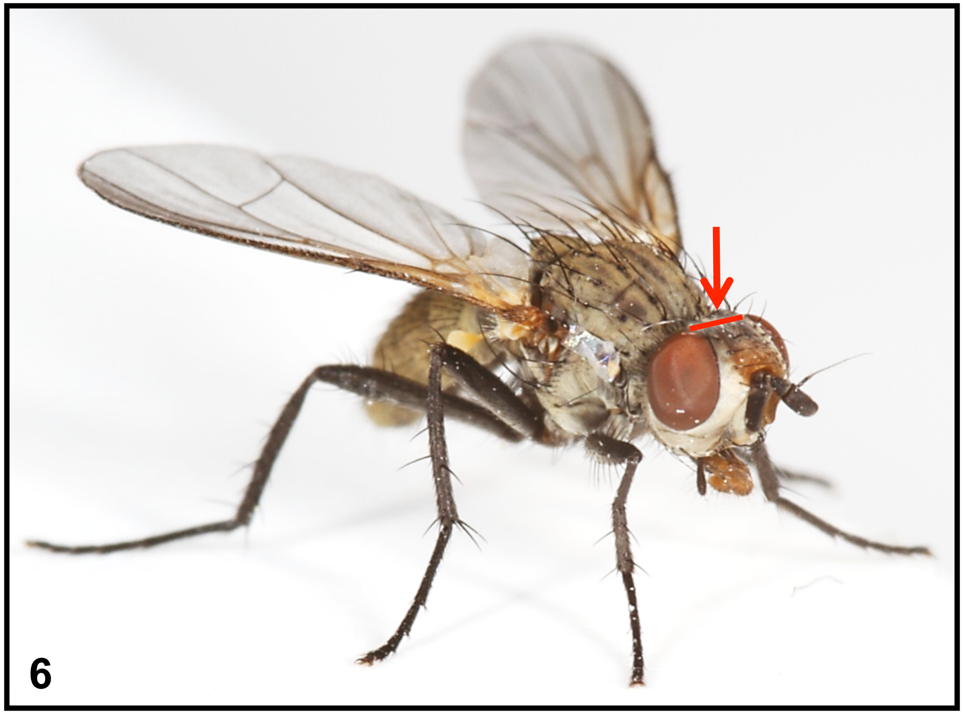






1	Prealar bristle (white arrow) present, at least as long as notopleural bristles (blue arrows) (Fig. 1); ventral surface of costal vein (C) setulose, with hairs (transparent arrows) reaching at least as far as (and often beyond) the insertion point of vein R1 (Fig. 3).	2
1'	Prealar bristle (white arrow) absent or very short, never as long as notopleural bristles (blue arrows) (Fig. 2); ventral surface of costal vein (C) naked or with a few spare hairs distally from the insertion point of the subcostal vein (Sc) (Fig. 4).	7

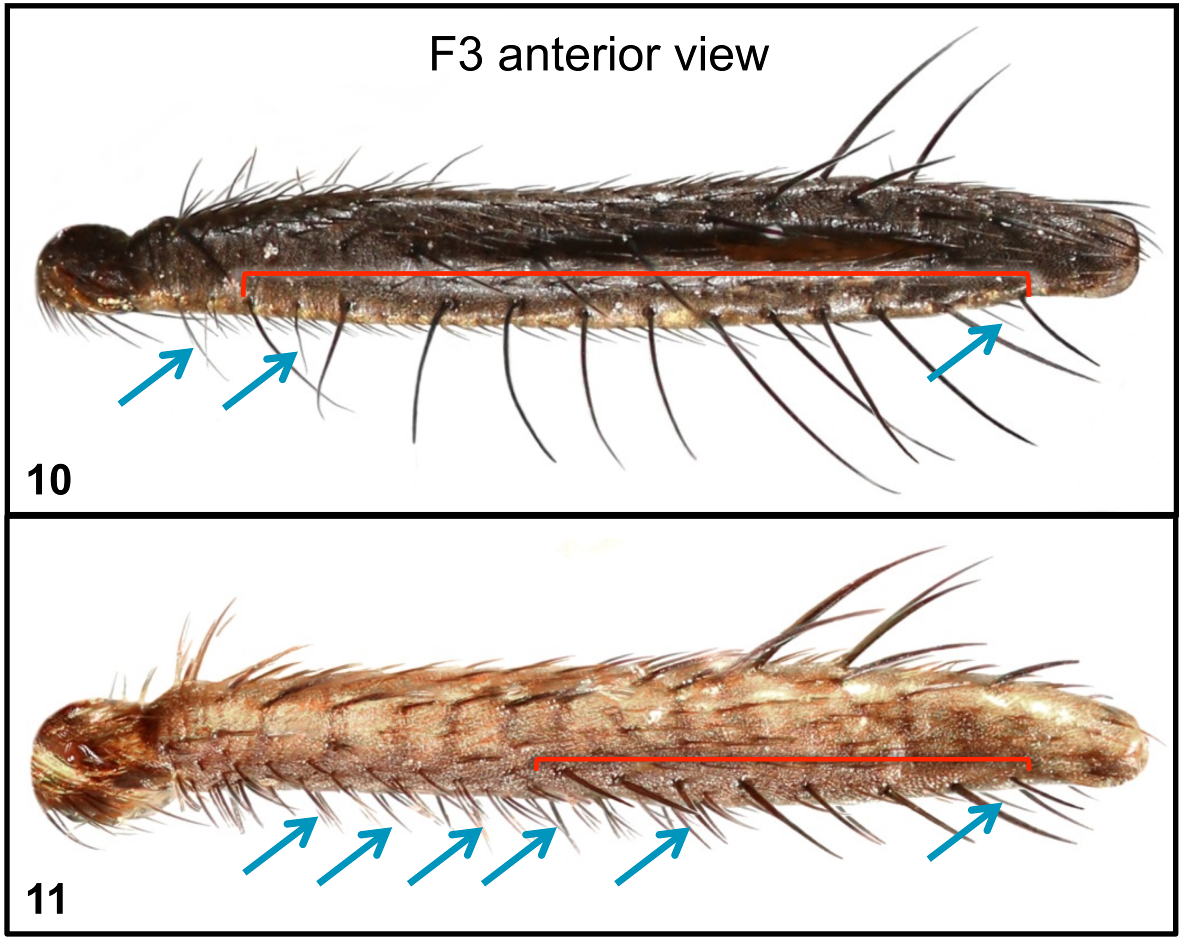




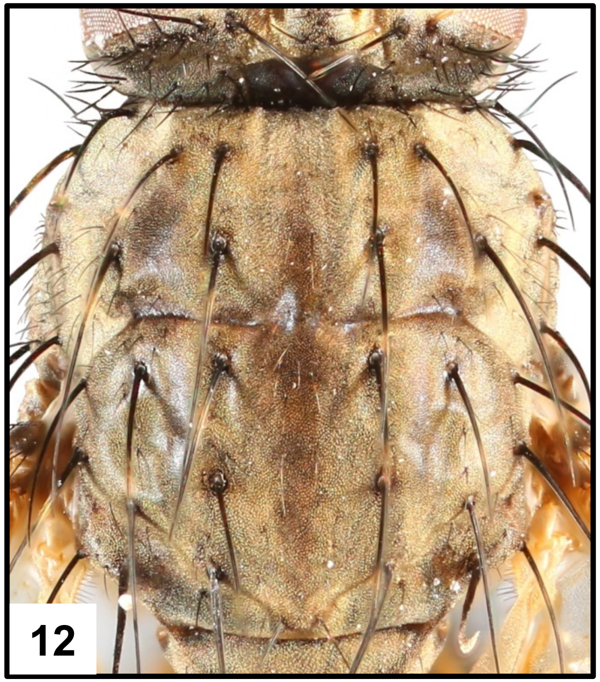
2(1)	Male head holoptic (Fig. 5), eyes closely approximated dorsally.	3
2’	Female head dichoptic (Fig. 6), eyes widely separated dorsally.	5

F3 anterior view

3(2)	Hind femur (F3) with a dense brush of long anteroventral and ventral bristles and hairs on basal third (Fig. 7).	*Delia radicum* (L.)
3’	Hind femur without a dense brush of long bristles and hairs on basal third (Figs. 8 and 9).	4



4(3)	Hind femur (F3, Fig. 10) with a complete and regular row of long anteroventral bristles (red bracket) and with posteroventral bristles (blue arrows) delicate, restricted to base and preapex. Transcontinental, but more common at higher latitudes.	*Delia floralis* (Fallén)
4’	Hind femur (F3, Fig. 11) with anteroventral bristles irregular but stronger on distal half to two-thirds (red bracket), and with posteroventral bristles (blue arrows) delicate, but spread out over basal half to two-thirds. Western Canada (+ a single record from ON).	*Delia planipalpis* (Stein)



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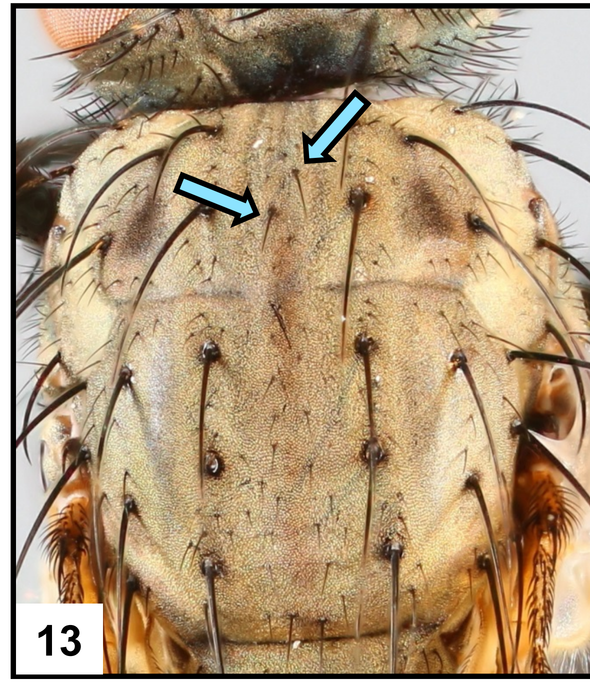

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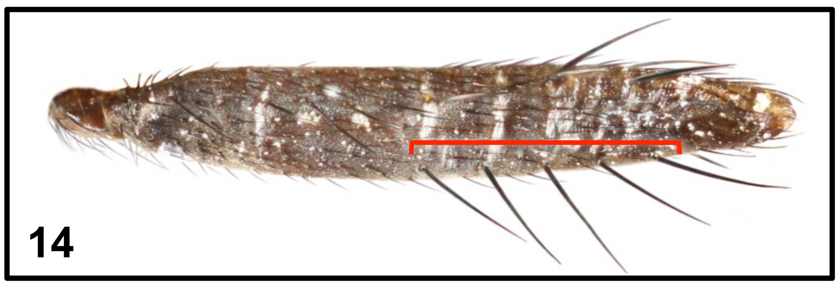

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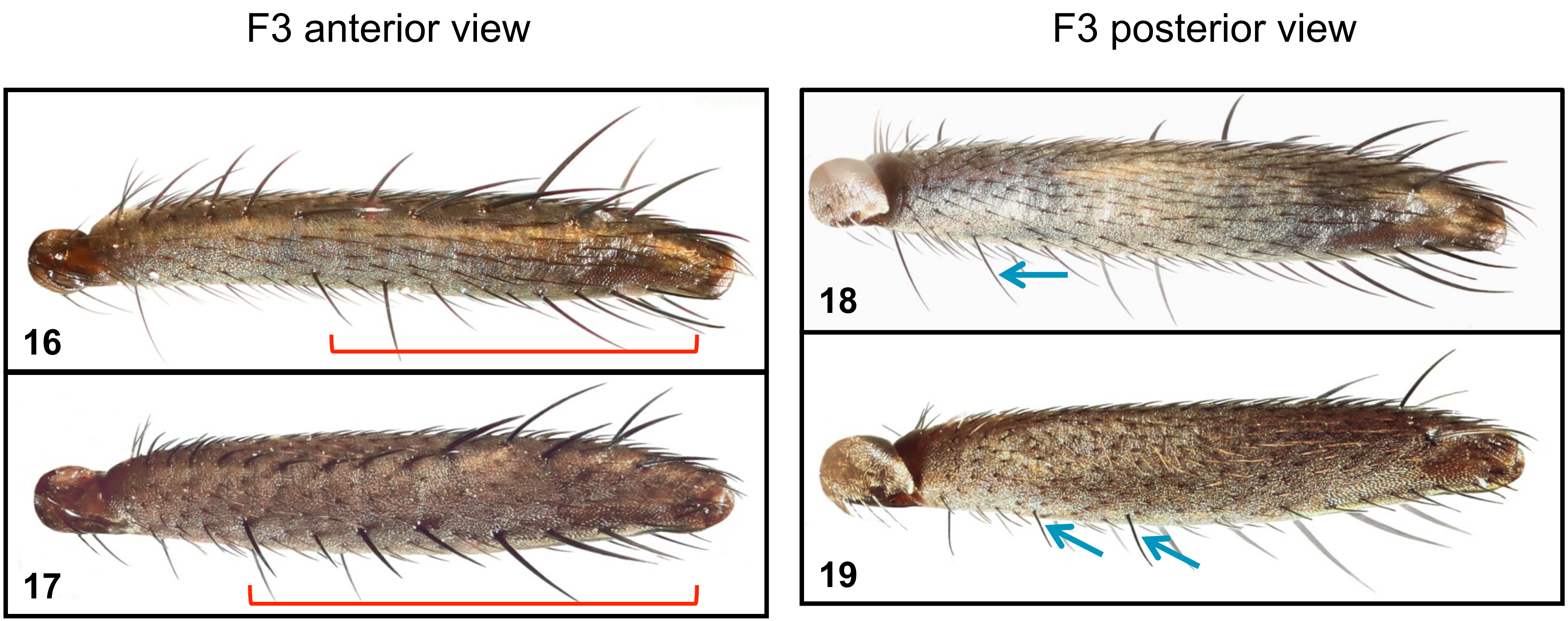
5(2)	Presutural acrostical bristles usually reduced (Fig. 12), but occasionally with a slightly stronger pair; hind femur in anterior view (Fig. 14) with anteroventral bristles restricted to apical half and no basal ventral bristle. Transcontinental, but more common at higher latitudes.	*Delia floralis* (Fallén)
5’	At least a few presutural acrostical bristles distinct (Fig. 13); hind femur in anterior view with anteroventral row irregular but spread over apical two-thirds and with 1 delicate basal ventral bristle (blue arrow) (Fig. 15).	6



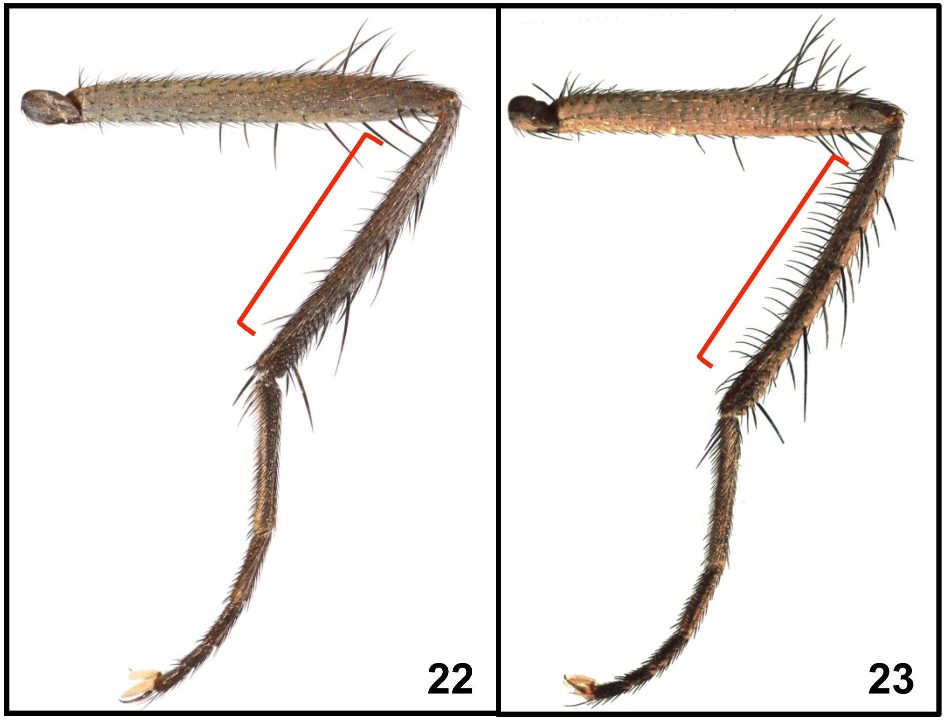
6(5)	Hind femur (F3) with anteroventral row sparse, restricted to apical two-thirds (Fig. 16), and with 0-1 posteroventral setae on basal half (blue arrow) (Fig. 18). Widespread in Canada.	*Delia radicum* (Fallén)
6’	Hind femur (F3) with anteroventral row more regular than above, starting on basal third (Fig. 17), and with 2-3 posteroventral setae on basal half (blue arrows) (Fig. 19). Western Canada (+ a single record from ON).	*Delia planipalpis* (Stein)

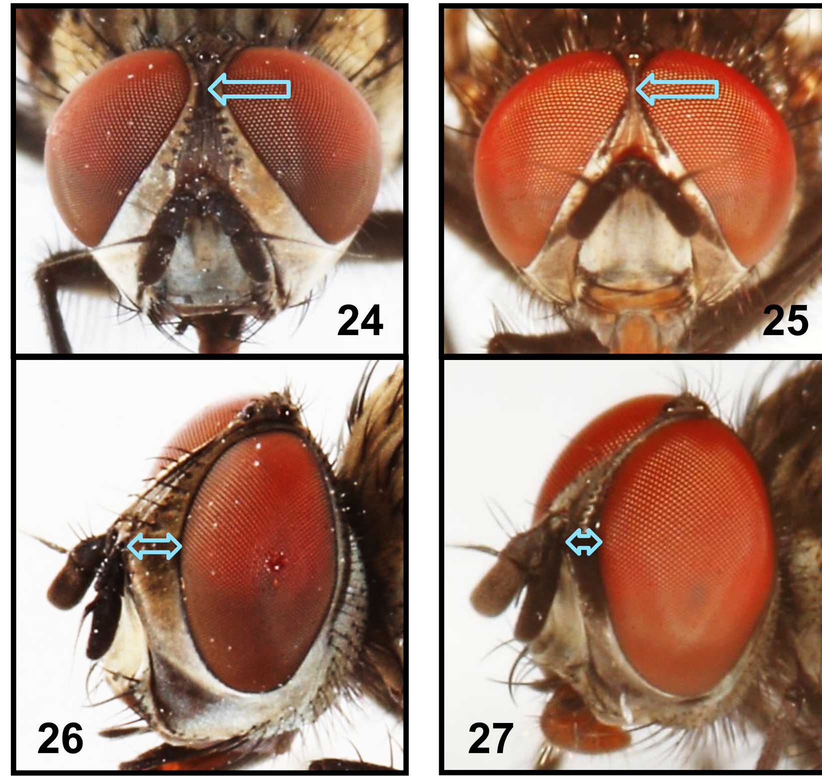

20


21

7(1)	Male head holoptic (Fig. 20), eyes closely approximated dorsally.	8
7’	Female head dichoptic (Fig. 21), eyes widely separated dorsally.	10

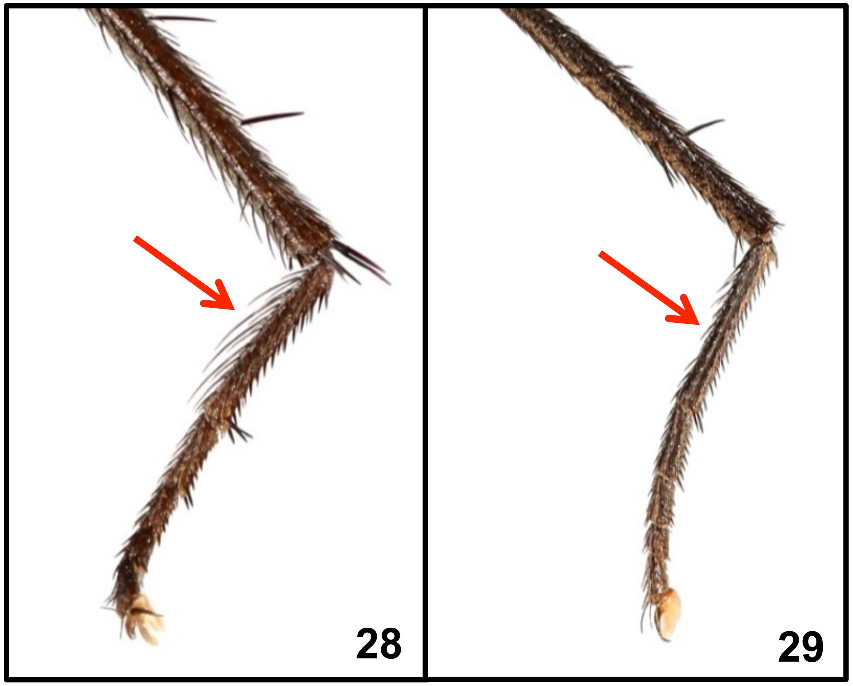
Hind leg posterior view



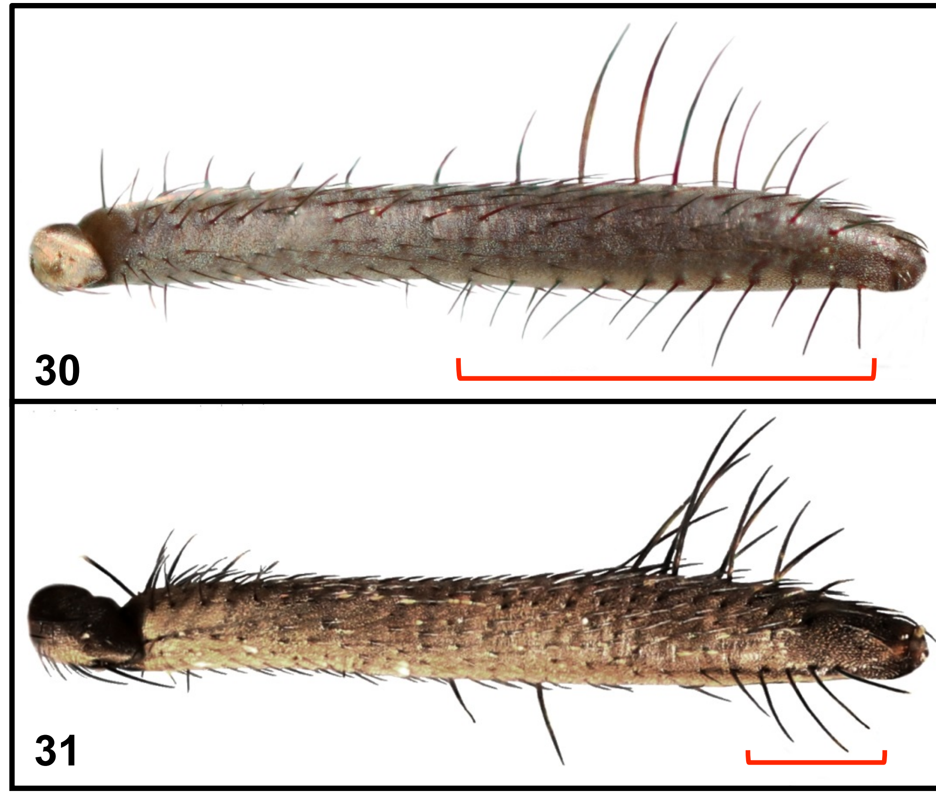


8(7)	Hind tibia with 7-15 short erect posteroventral bristles (Fig. 22); frontal vitta visible at narrowest point of frons (Fig. 24); parafacial broad in lateral view (Fig. 26).	*Delia antiqua* (Meigen)
8'	Hind tibia with >18 short erect bristles (Fig. 23); frontal vitta usually obliterated at narrowest point of frons (Fig. 25); parafacial narrow in lateral view (Fig. 27).	9

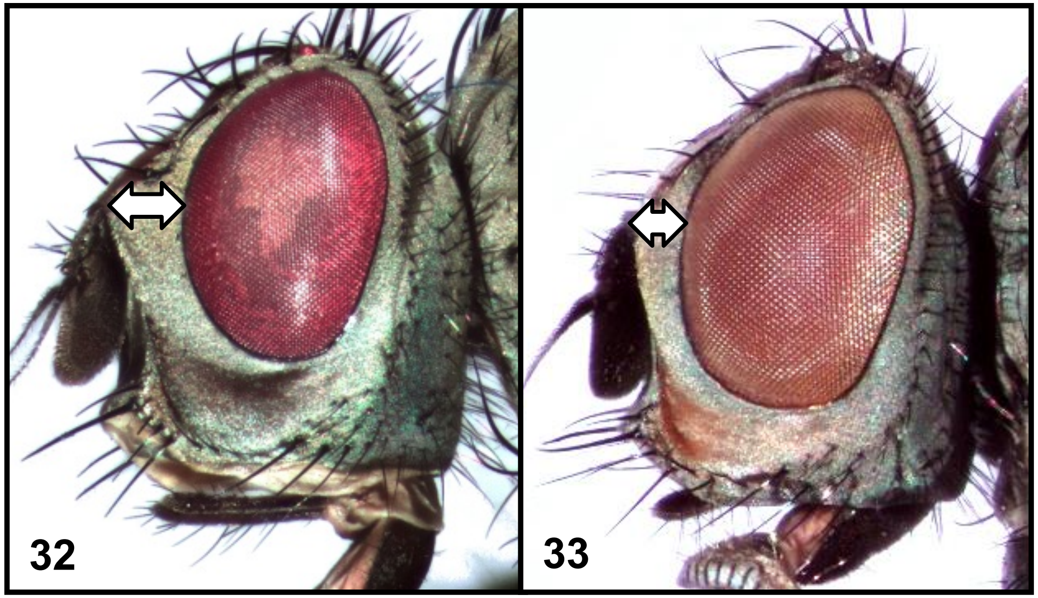
Apex of midleg, anterior view



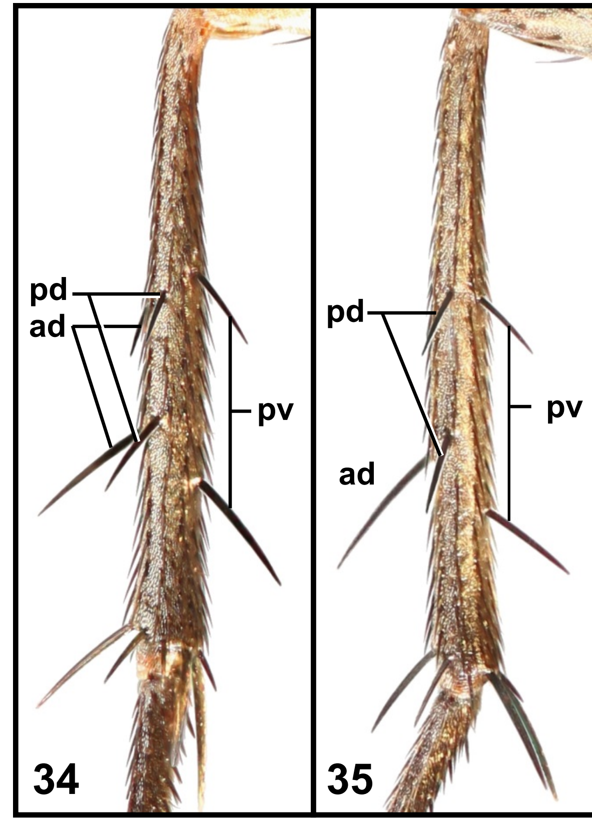
F3 posterior view



9(8)	First tarsomere of midleg with a brush of long dorsal bristles (Fig. 28); hind femur (F3) with numerous preapical posteroventral bristles forming a line on apical half (Fig. 30).	*Delia florilega* (Zetterstedt)
9’	First tarsomere of midleg without a brush of long dorsal bristles, only with regular setae (Fig. 29); hind femur with no more than 6 preapical posteroventral bristles restricted to the apical fifth of the surface (Fig. 31).	*Delia platura* (Meigen)

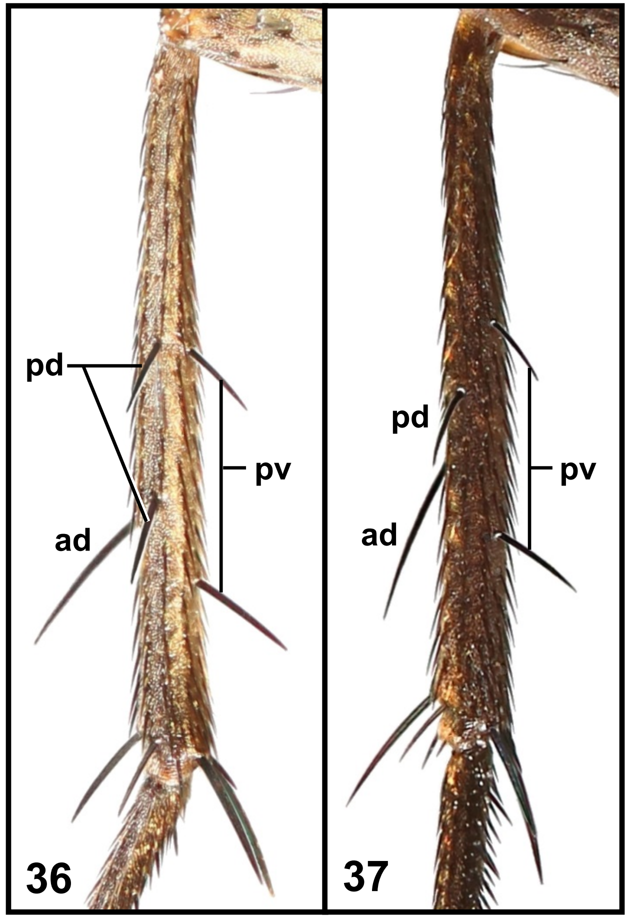


T2 posterior view

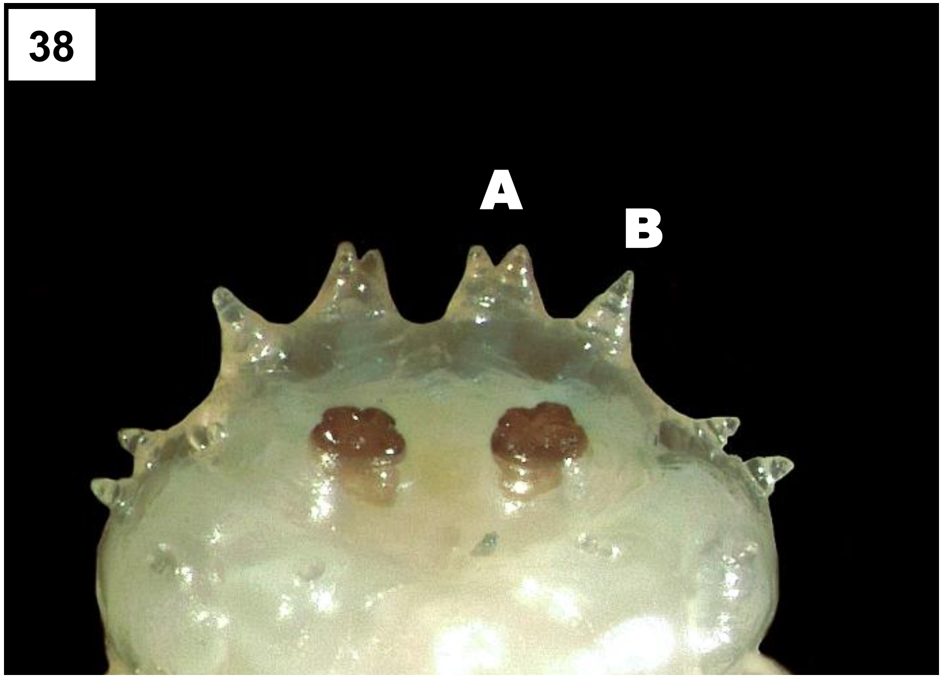


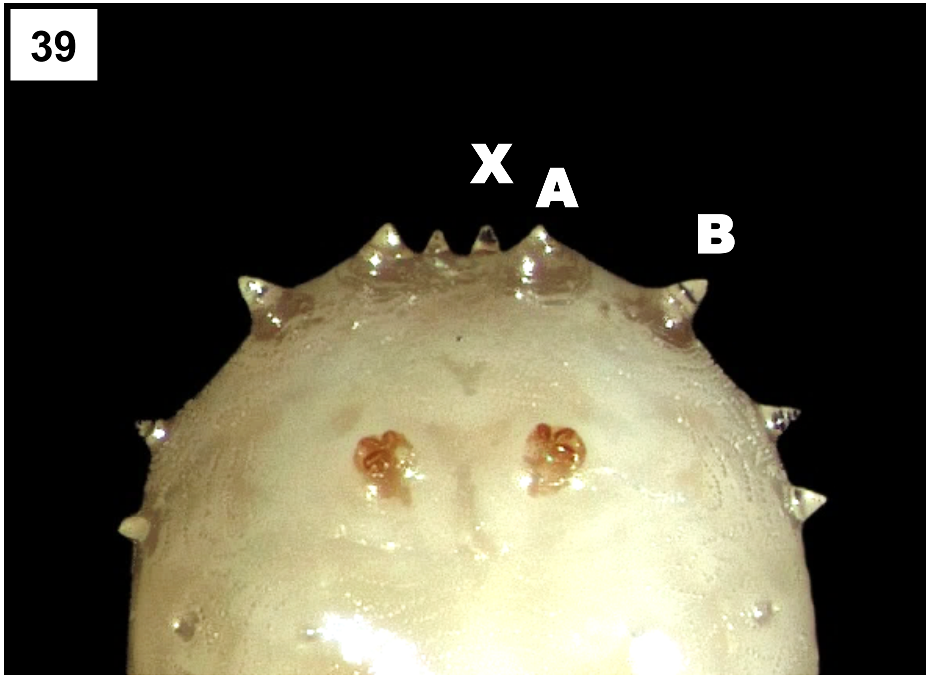
10(7)	Relatively large species, ranging from 5.0 up to 7.2 mm; thoracic pollinosity silvery grey, paler on the pleuron, notopleuron and postpronotum; parafacial broad in lateral view (Fig. 32); fore tibia usually with 3 or more bristles (1-2 ad, 0-2 pd, 1-2 pv); mid tibia (T2) with 6 or more bristles (2-3 ad, 2 pd, 2-3 pv) (Fig. 34).	*Delia antiqua* (Meigen)
10’	Size variable, rarely reaching more than 5.8 mm; thoracic pollinosity brownish grey, usually not as pale as in *D. antiqua*; parafacial narrow in lateral view (Fig. 33); fore tibia usually with 2 and rarely 3 bristles (1 ad, 1 pv, 0-1 pd); mid tibia (T2) usually with less than 5 bristles, rarely 6 (1-2 ad, 1-2 pd, 2-3 pv) (Fig. 35).	11

T2 posterior view

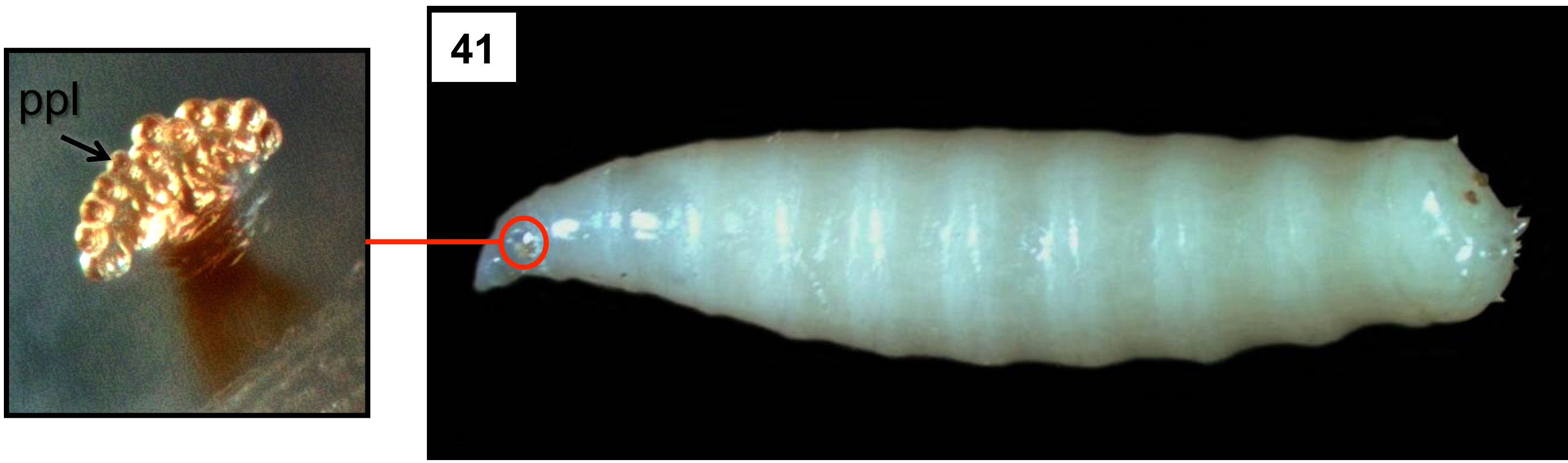


11(10)	Generally larger species (2.9-5.8 mm); mid tibia (T2) usually with 1 (rarely 2) ad, 1-2 pd and 2-3 pv (Fig. 36). *Some specimens of *D. platura* (approximately 15% of material examined) have fewer bristles on T2 and are indistinguishable from *D. florilega*.	*Delia platura* (Meigen)*
11’	Generally smaller species (2.8-4.8 mm); mid tibia (T2) usually with 1 ad, 1 pd and 2 pv (Fig. 37).	*Delia florilega* (Zetterstedt)

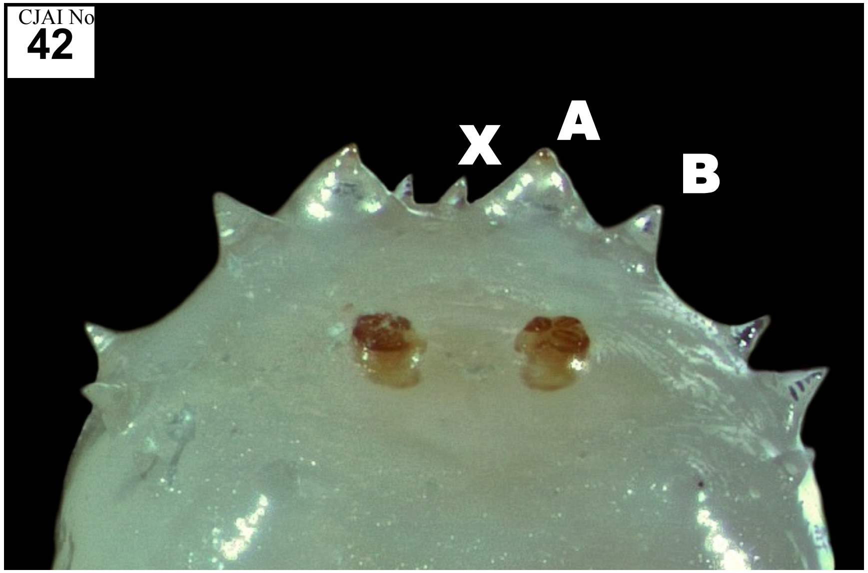


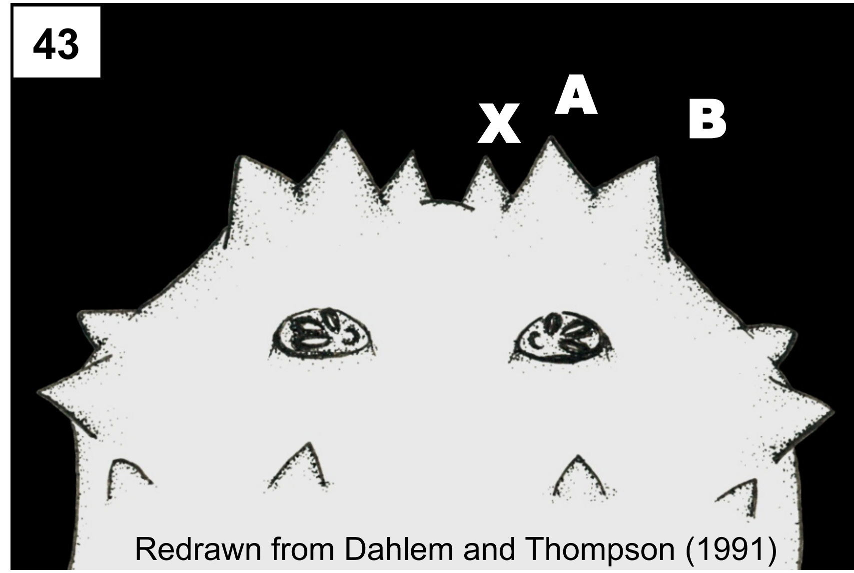


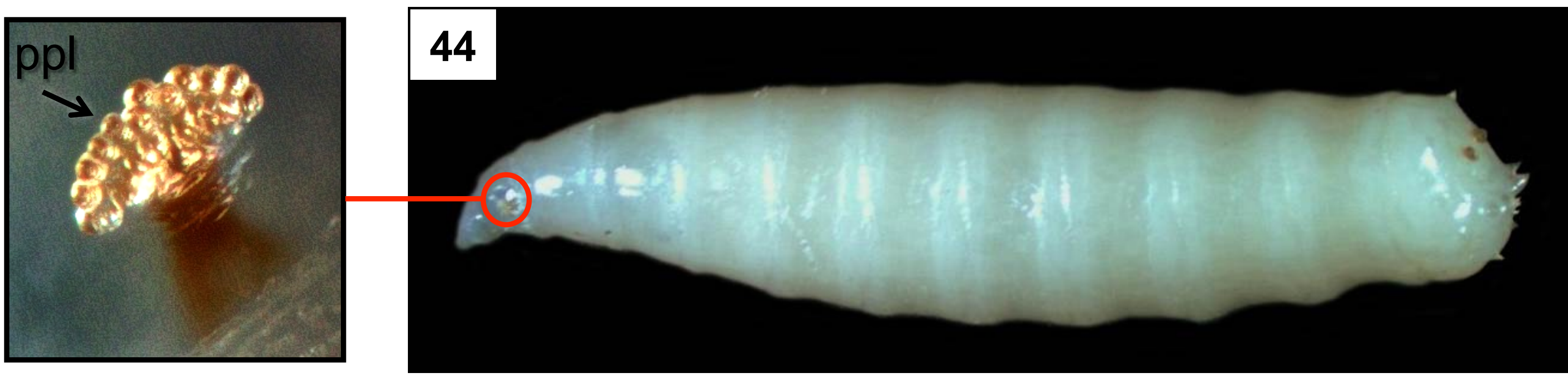
1	Tubercle X absent (Fig. 38); tubercle A notched/forked apically (Fig. 38). In cruciferous hosts.	*Delia radicum* (L.), *Delia planipalpis* (Stein) [click here for details]
1’	Tubercle X present (Fig. 39); tubercle A simple apically (Fig. 39). Hosts variable.	2



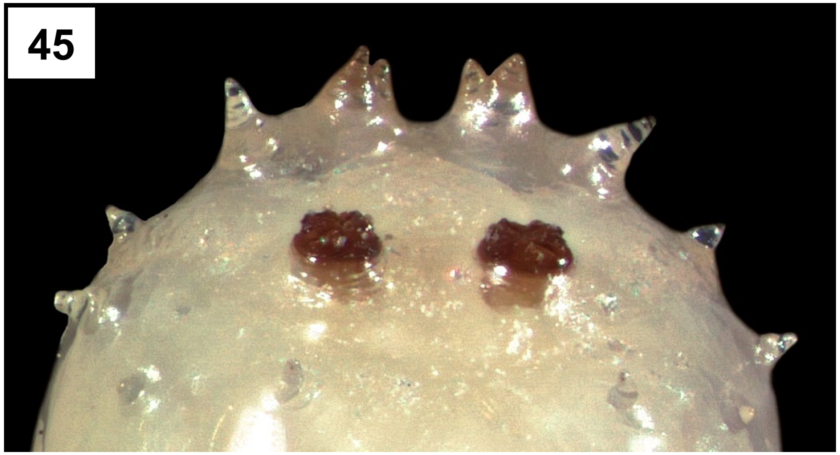
2(1)	Anterior spiracle (Fig. 40) with 6-8 (rarely 9) papillae (ppl); generally smaller larvae, 5.9-6.8 mm long.	*Delia platura* (Meigen), *Delia florilega* (Zetterstedt) [click here for details]
2’	Anterior spiracle (Fig. 41) with 9-16 (rarely 8) papillae (ppl); generally larger larvae, 7.5-12.0 mm long.	3

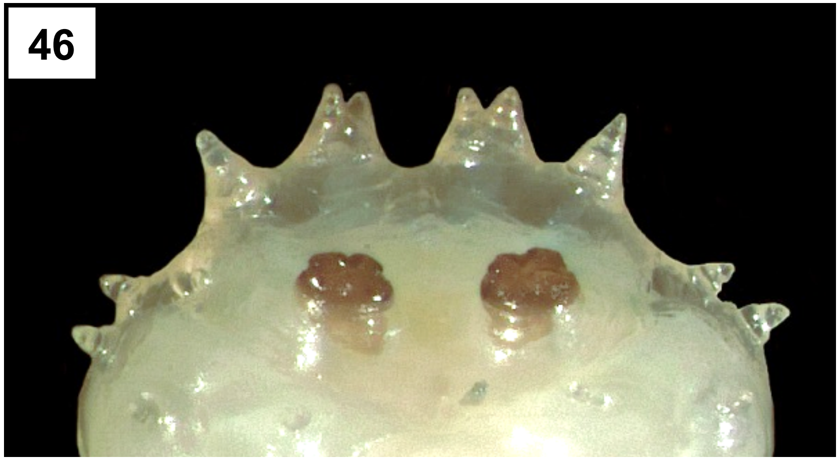


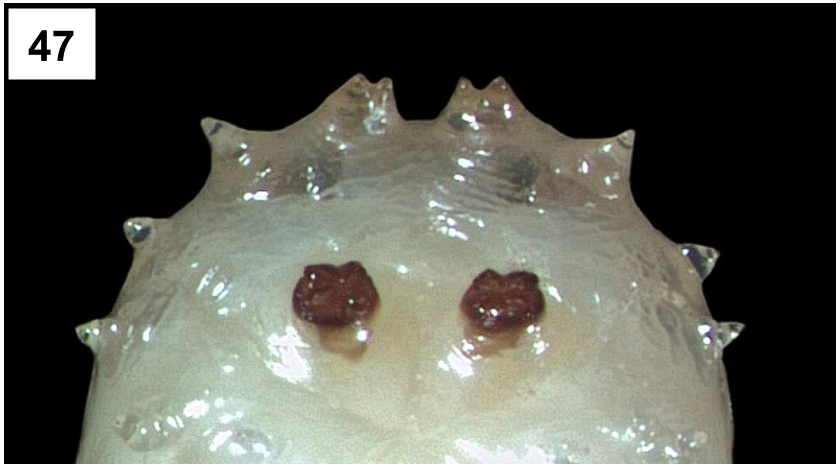




3 (2)	Tubercle X small and located ventrally to tubercles A and B (Fig. 42); tubercle A usually wider near base than tubercle B (Fig. 42); anterior spiracle (Fig. 44) with 9-12 (rarely 13) papillae (ppl). In *Allium* hosts.	*Delia antiqua* (Meigen)
3’	Tubercle X large and located nearly on the same plane as tubercles A and B (Fig. 43); tubercle A and B subequal (Fig. 43). In cruciferous hosts. **Note**: Miles (1952) states that the anterior spiracle of *D. floralis* has 14-16 papillae but no specimens or published illustrations were available to confirm this character.	*Delia floralis* (Fallén)

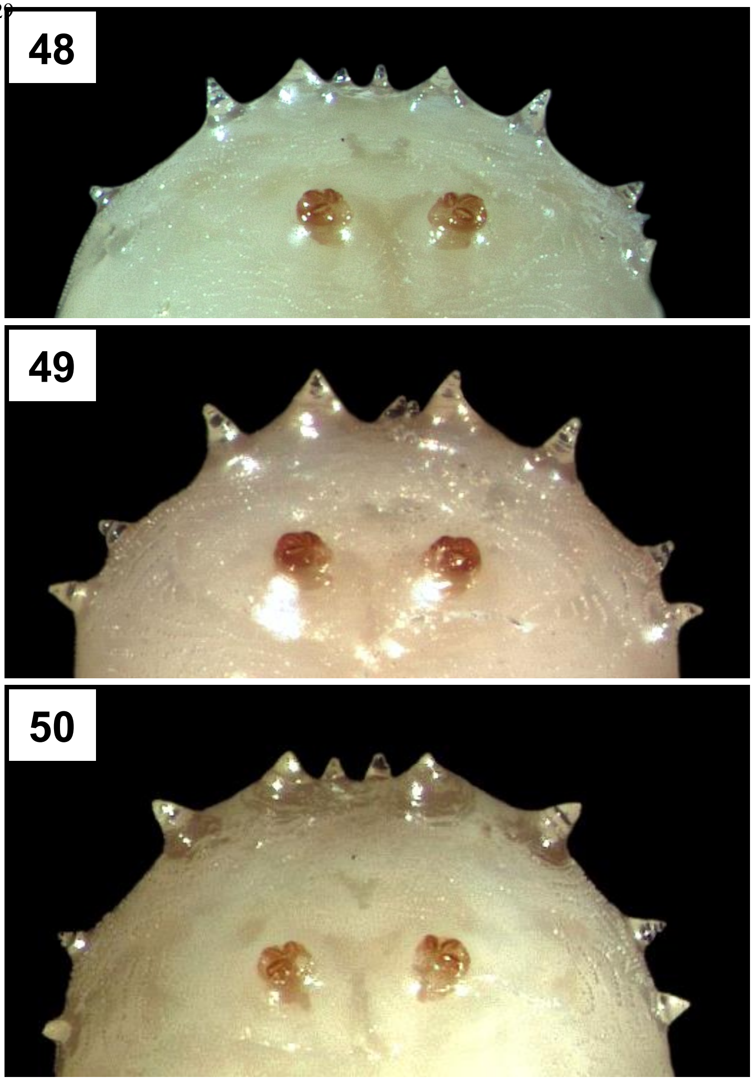




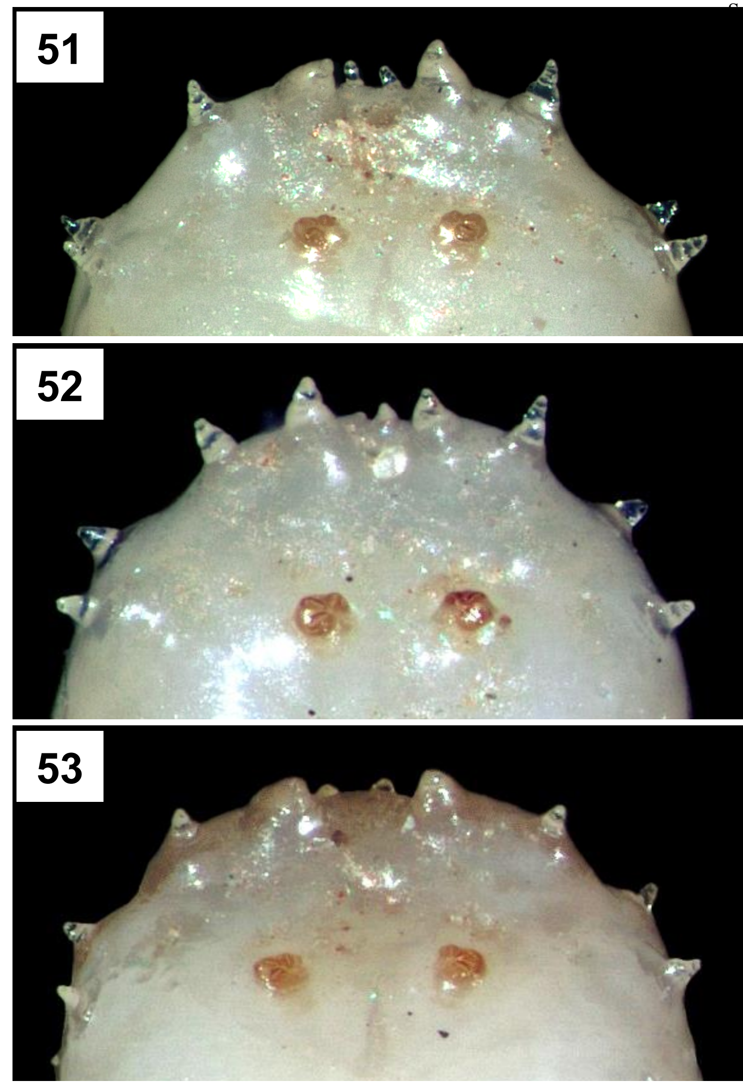


Delia radicum

There is little published about the larva and puparium of *D. planipalpis* and while Brooks (1951), de Vos-de Wilde (1935), Griffiths (1991), and Dahlem and Thompson (1991) all mention that *D. planipalpis* larvae are similar to those of *D. radicum*, this remains to be confirmed as no specimens were available for examination. A reference by Griffiths (1991, p. 978) to the fact that the tubercle A of *D. planipalpis* is not as prominently notched as the one of *D. radicum* remains to be tested as this character appears to be variable in *D. radicum* (see Figs. 45-47).

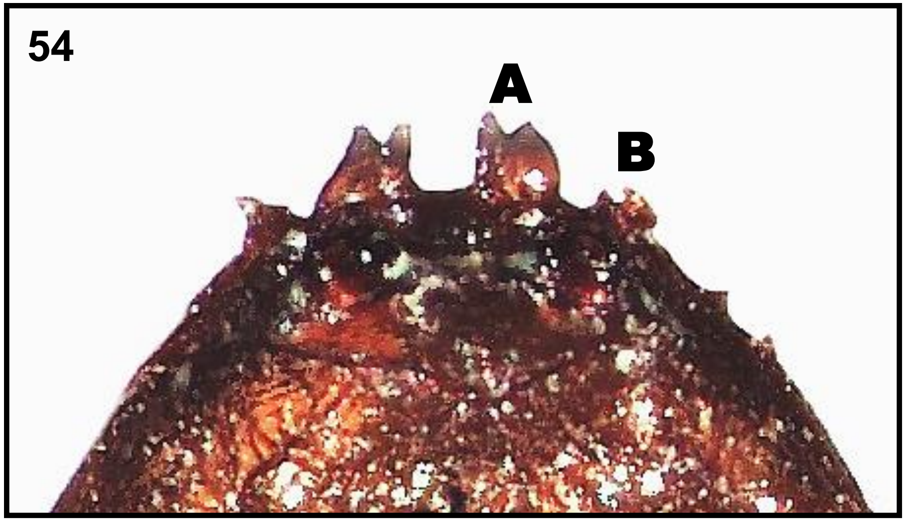


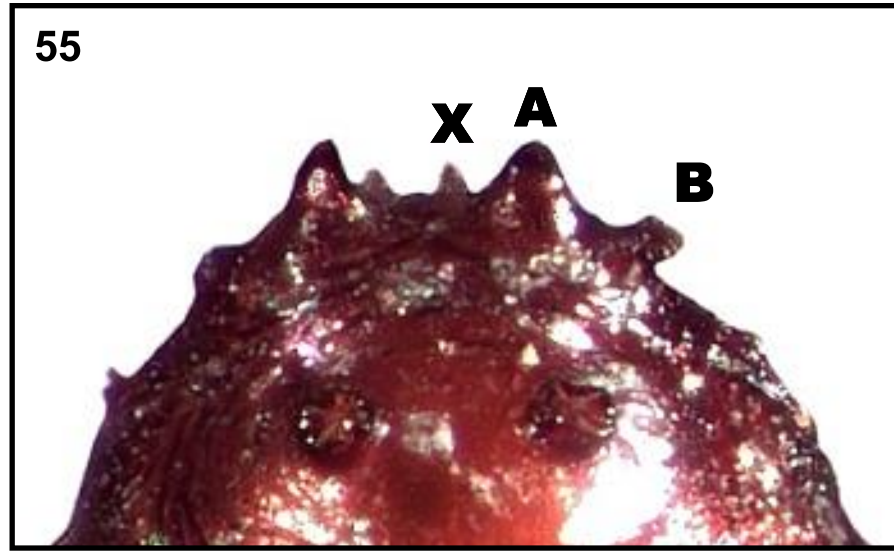
Delia platura



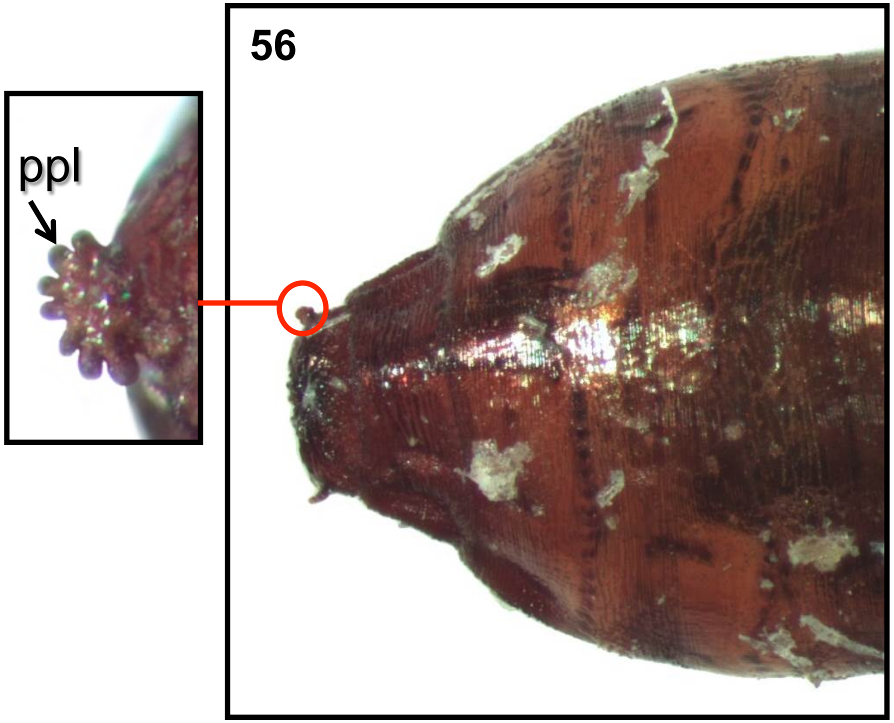
Delia florilega

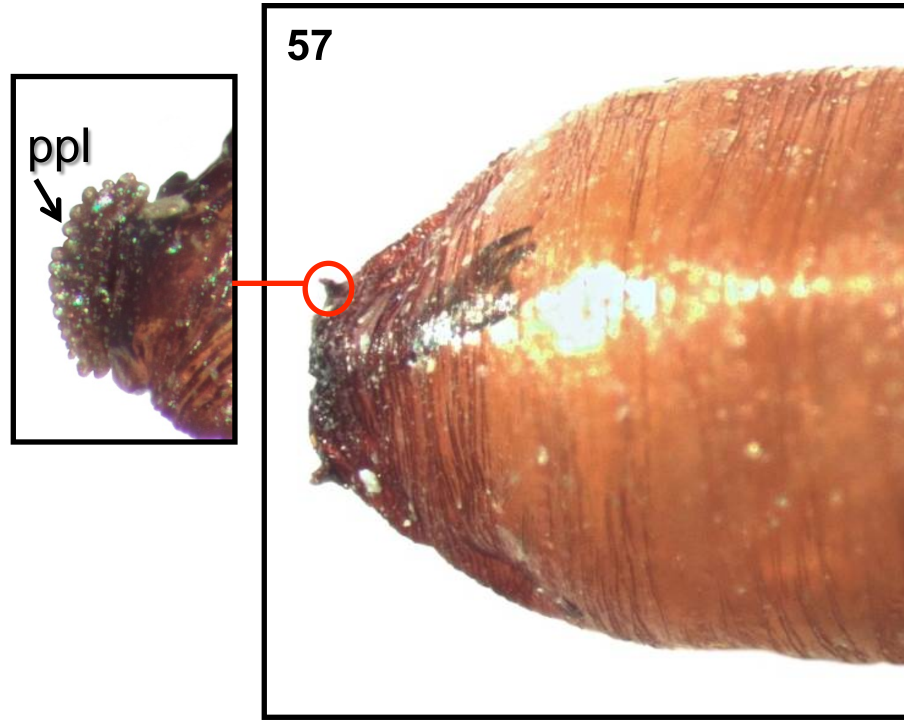
Brooks (1951) and Dahlem and Thompson (1991) list some differences between tubercles A and B of *D. platura* and *D. florilega* larvae. Based on the examination of > 80 specimens (reared from cultures or identified with DNA barcodes), their larvae (and pupae) could not be reliably distinguished morphologically (see Figs. 48-53). Tubercles X are present in *D. platura* (Figs. 48-50) even if these were omitted in Dahlem and Thompson (1991, p. 856, Fig. L).



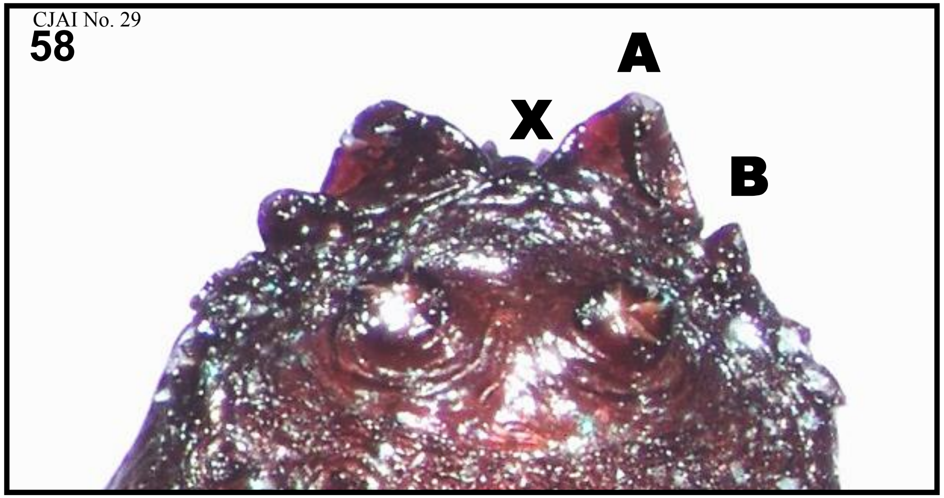


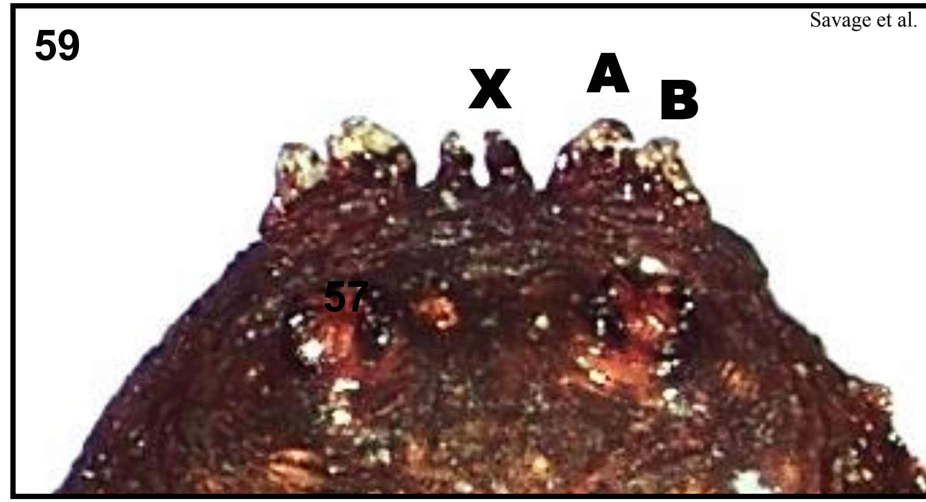
1	Tubercle X absent (Fig. 54); tubercle A notched/forked apically (Fig. 54). Associated with cruciferous hosts. * No morphological differences are found between the puparia of these species.	*Delia radicum* (L.), *Delia planipalpis* (Stein)*
1’	Tubercle X present (Fig. 55); tubercle A simple apically (Fig. 55). Associated with a wide range of hosts.	2

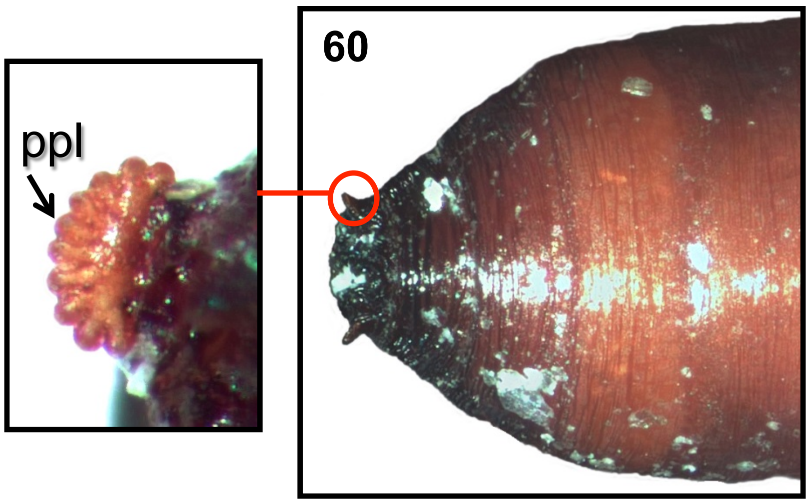


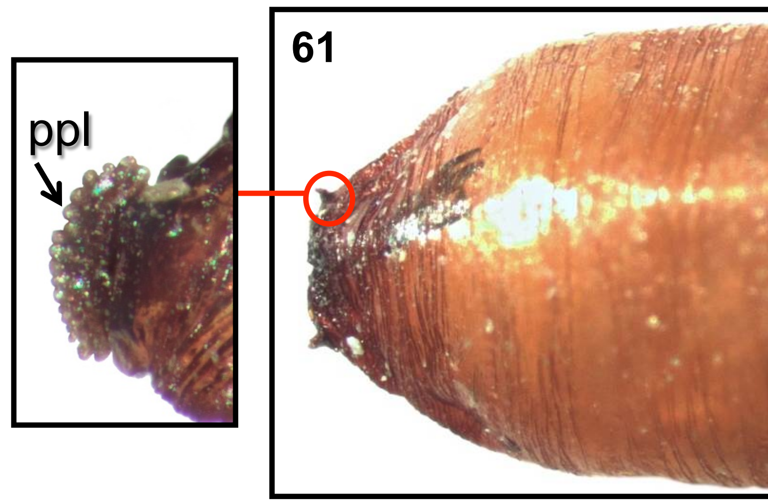


2(1)	Anterior spiracle with 6-8 papillae (Fig. 56); generally smaller puparia, 4.3-5.1 mm long. * No morphological differences are found between the puparia of these species.	*Delia platura* (Meigen), *Delia florilega* (Zetterstedt)*
2'	Anterior spiracle with at least 9 papillae (Fig. 57); generally larger puparia, 5.2-7.0 mm long.	3



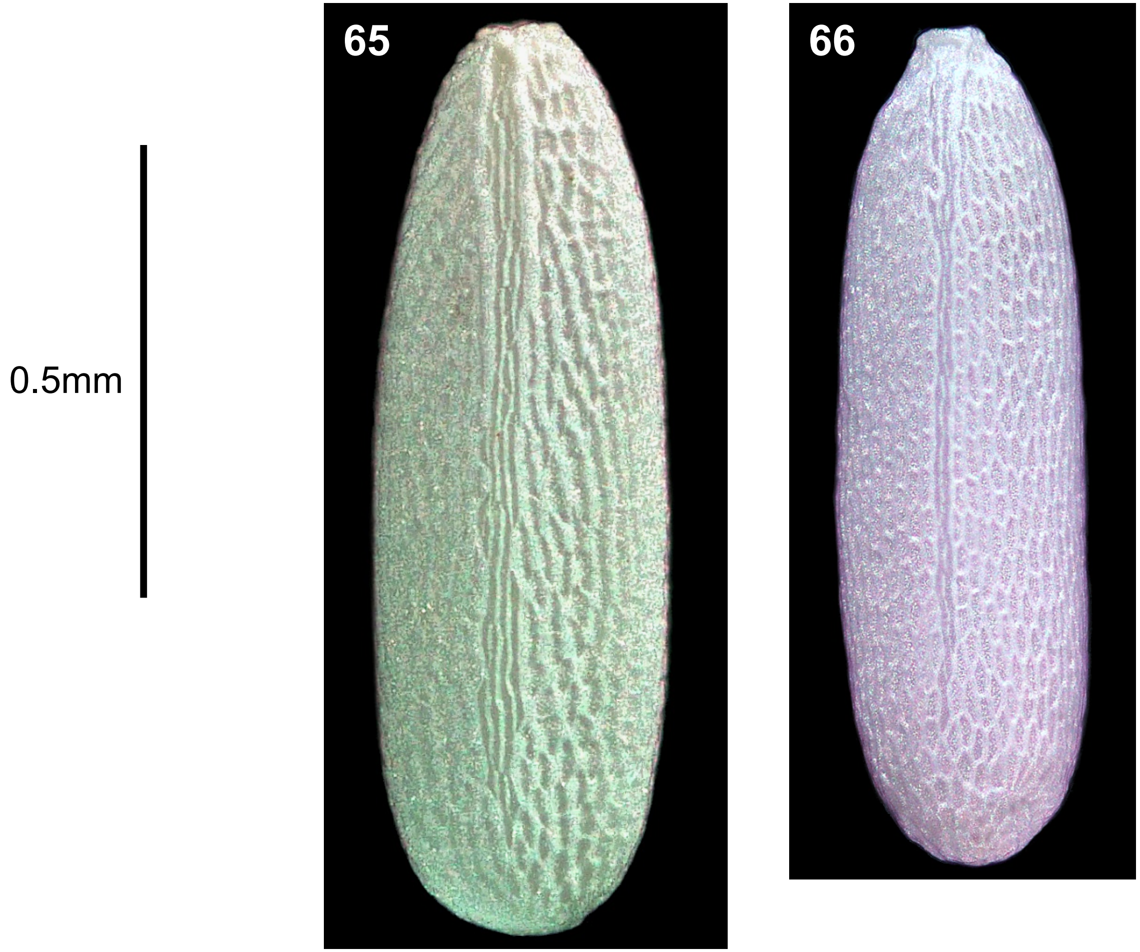






3(2)	Tubercle X much smaller than A or B (Fig. 58); tubercle A and B distinctly separated near base, with tubercle A larger and wider near base than tubercle B (Fig. 58); anterior spiracle with 9-12 papillae (Fig. 60). Associated with *Allium* hosts.	*Delia antiqua* (Meigen)
3'	Tubercle X large (Fig. 59); tubercle A and B subequal and merged near base (Fig. 59); anterior spiracle with more than 12 papillae (Fig. 61). Associated with cruciferous hosts.	*Delia floralis* (Fallén)

1	Hatching pleat (red arrow) of variable length, wide, and with very prominent and well-defined edges (Fig. 62); egg surface near hatching pleat forming longitudinal ribbing with very few struts (Fig. 62). Associated with cruciferous hosts.	*Delia radicum* (L.), *Delia planipalpis* (Stein), *Delia floralis* (Fallén) [click here for details]
1’	Hatching pleat (red arrow) relatively narrow with poorly defined edges (Figs. 63-64); egg surface near hatching pleat reticulated, forming a mesh of irregular-shaped depressions (Figs. 63-64). Associated with a wide range of hosts.	2



2(1)	Generally larger egg (1.12-1.28 mm); reticulation pattern somewhat coarse, with deep depressions divided by relatively thick edges (Fig. 65). Associated with *Allium* hosts.	*Delia antiqua* (Meigen)
2'	Generally smaller egg (0.97-1.05 mm); reticulation pattern delicate, with shallow depressions divided by narrower edges (Fig. 66). Associated with a wide range of hosts. * No morphological differences were found between the eggs of these species.	*Delia platura* (Meigen), *Delia florilega* (Zetterstedt)*

The eggs of *D. radicum* are quite variable in the length of the hatching pleat (Fig. 67-68) as well as in the dorsal chorionic pattern, which is usually striated (Fig. 69) but can also occasionally appear reticulated (Fig. 70); it is therefore better to compare chorionic patterns between different species of *Delia* near the hatching pleat.

No eggs of *D. floralis* and *D. planipalpis* were available for examination. However, those of *D. floralis* are well illustrated in Biron *et al.* (2003), who distinguish *D. floralis* from *D. radicum* based on chorionic ultrastructures; these features were not included here since their examination requires a scanning electron microscope.

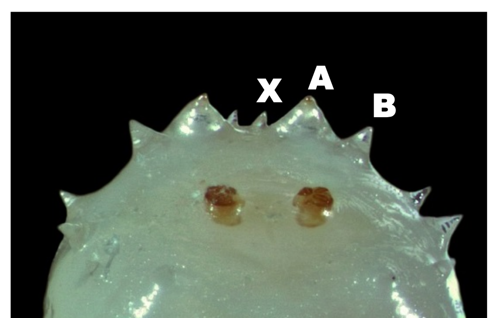
To our knowledge, no illustrations have been published of the eggs of *D. planipalpis*. They are grouped here along with those of *D. radicum* and *D. floralis*, following Brooks (1951), who also stated that, unlike the other two species, *D. planipalpis* does not lay its eggs in a clump but rather singly or in groups of 2 or 3.

Delia antiqua (Meigen)

Vegetable crop hosts: A primary invader and well-known pest of most cultivated *Allium* spp. and the most important insect pest of onions in temperate regions (Howard *et al.* 1994). Crop damage usually most significant in the spring when host plants are young (Howard *et al*. 1994; Nault *et al.* 2011).

Other hosts: Under laboratory conditions, *D. antiqua* will lay eggs on wild *Allium* spp. (Howard *et al.* 1994) and records from remote areas in western Canada suggest that it may be able to complete its development in wild hosts (Griffiths 1993).

Canadian distribution: Widespread wherever *Allium* species (especially onions) are cultivated. Found in all Canadian provinces and territories except NU and NT (Griffiths 1993).



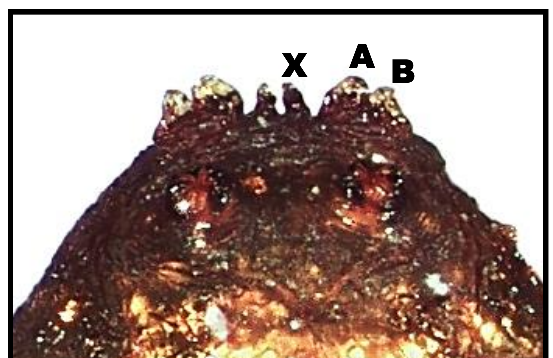
Male Genitalia (Appendix 1)

Delia floralis (Fallén)

Vegetable crop hosts: Host range similar to that of *D. radicum*, including most cultivated vegetable crucifers. While often less abundant than *D. radicum* in the south, *Delia floralis* can be an important pest of cultivated edible crucifers (especially rutabaga) at higher latitudes (Griffiths 1991).

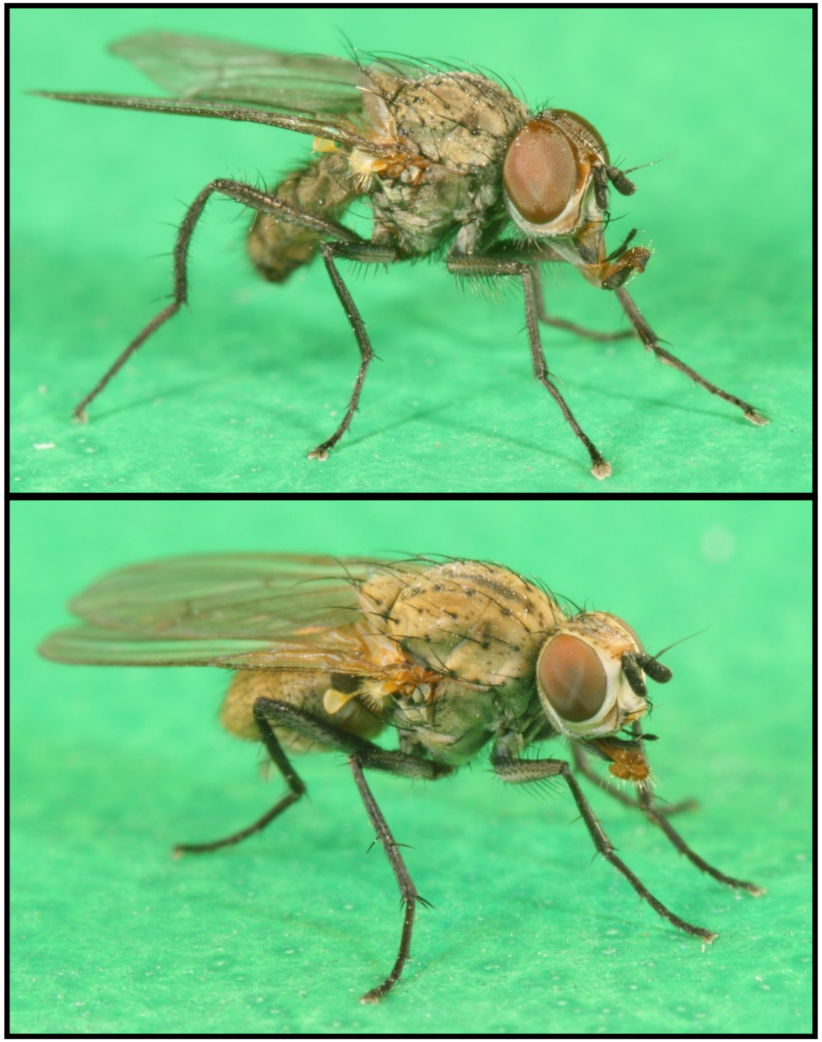
Other hosts: *Delia floralis* is a pest of canola in the most northern growing areas of the Canadian Prairies (Griffiths 1986; Broatch 1993), but it appears to be much less abundant than either *D. radicum* or *D. platura* in more southern localities (Hummel *et al.* 2009; Soroka and Dosdall 2011). Wild cruciferous hosts such as stinkweed (*Thlaspi arvense* L.) have also been reported (Strickland 1938).

Canadian distribution: AB, BC, MB, NL, ON, QC, SK, (Griffiths 1991).



Male Genitalia (Appendix 1)

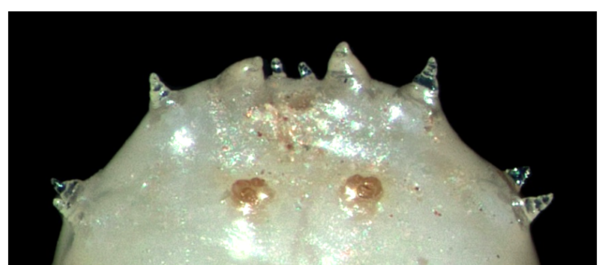
Delia florilega (Zetterstedt)



Vegetable crop hosts: *Delia florilega* has been reported as a primary invader of various large germinating seeds such as beans and squash, and as a primary or, more commonly, secondary invader of various cruciferous crops such as rutabagas and radishes (see Griffiths 1993 for details). This species is often found in mixed infestations with *D. platura* (where it is usually less abundant than the seedcorn maggot), but since the larvae of these two species are indistinguishable morphologically, their identity must be confirmed by rearing or DNA barcoding.

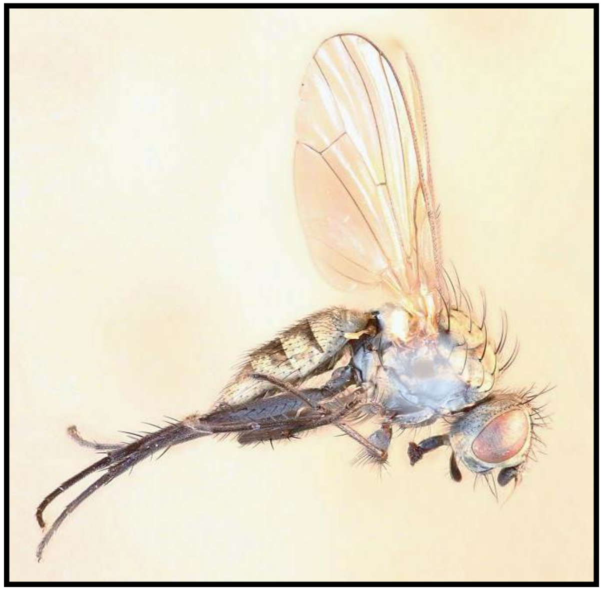
Other hosts: Reported to develop on corn (Kim and Eckenrode 1987), tobacco (Begg 1961) and canola (Liu and Butts 1982).

Canadian distribution: Found in all Canadian provinces and territories (Griffiths 1993; SK record from Soroka and Dosdall 2011).



Male Genitalia (Appendix 2)

Delia planipalpis (Stein)



Vegetable crop hosts: Infestations have been reported from radishes (Brooks 1951) and Napa cabbage (Kelleher 1958) in western Canada as well as from various cultivated vegetable crucifers in the United States (Griffiths 1991). Since the larvae of *D. planipalpis* are identical to those of *D. radicum*, the role of this species in infestations may be underreported in the literature.

Other hosts: Notable infestations of *D. planipalpis,* mostly in polish canola (*Brassica rapa* L.), have been reported from the Peace River region of Alberta (Griffiths 1986; Broatch 1993). While still present on the Canadian Prairies, this species appears much less abundant than *D. radicum* (Hummel *et al.* 2009; Soroka and Dosdall 2011).

Canadian distribution: Mostly western and northern, found in AB, BC, MB, NT, SK, YT, with a single record from ON (Griffiths 1991).

Male Genitalia (Appendix 1)

Delia platura (Meigen)

Vegetable crop hosts: Larval diet extremely broad, including both plant and animal material. Cultivated vegetable hosts in Canada include various crucifers, onions, legumes, soybeans, potatoes, carrots, cucurbits and many others (as either primary and/or secondary invader) (see Griffiths 1993 for detailed list). *Delia platura* is often found in mixed infestations with other *Delia* species depending on the plant host, but will often be found together with *Delia florilega*.

Other hosts: *Delia platura* can complete its development in canola (Liu and Butts 1982) and adults can be very abundant in canola fields from the Canadian Prairies (Broatch *et al.* 2006; Hummel *et al.* 2009; Soroka and Dosdall 2011). It can also develop in a wide range of other substrates including cereals such as corn, fungi, grasshopper egg-pods, human faecal material, and many others (see Griffiths 1993 for complete list).

Canadian distribution: Found in all Canadian provinces and territories (Griffiths 1993).

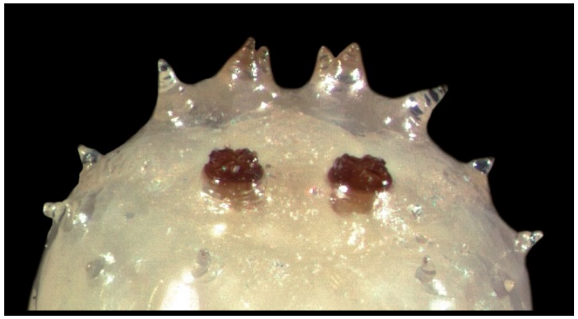
Male Genitalia
(Appendix 2)

Delia radicum (Linnaeus)

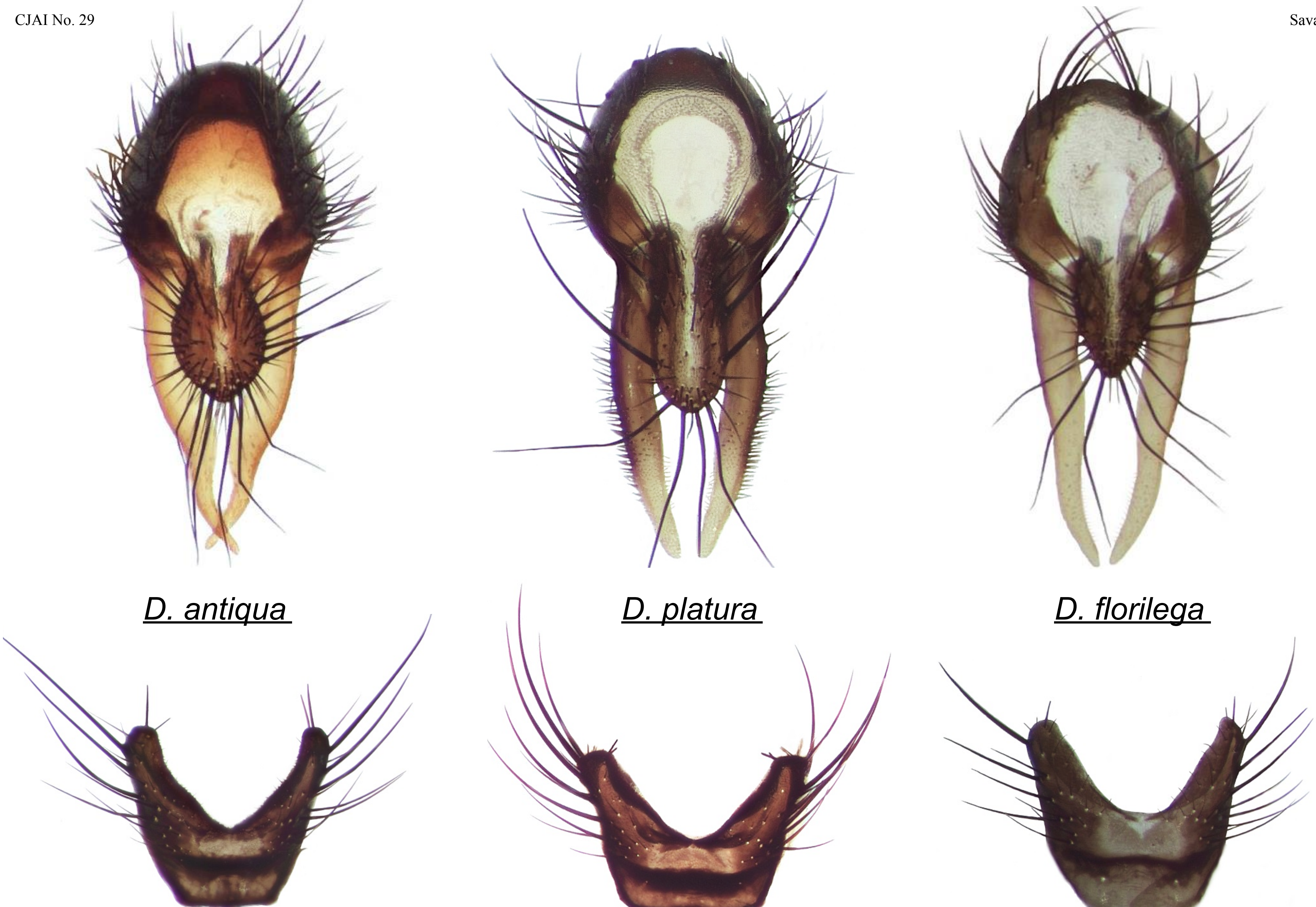
Vegetable crop hosts: A primary phytophagous invader (Doane and Chapman 1964; Griffiths 1991) of a wide range of crucifers. Common (and often most abundant) pest of all vegetable cruciferous crops cultivated in Canada (see Griffiths 1991; Howard *et al*. 1994).

Other hosts: An important pest of canola in central Canada (Griffiths 1986, 1991; Broatch 1993; Soroka *et al.* 2004, Soroka and Dosdall 2011). It can also infest and complete its development in a wide range of wild cruciferous weeds (Griffiths 1991).

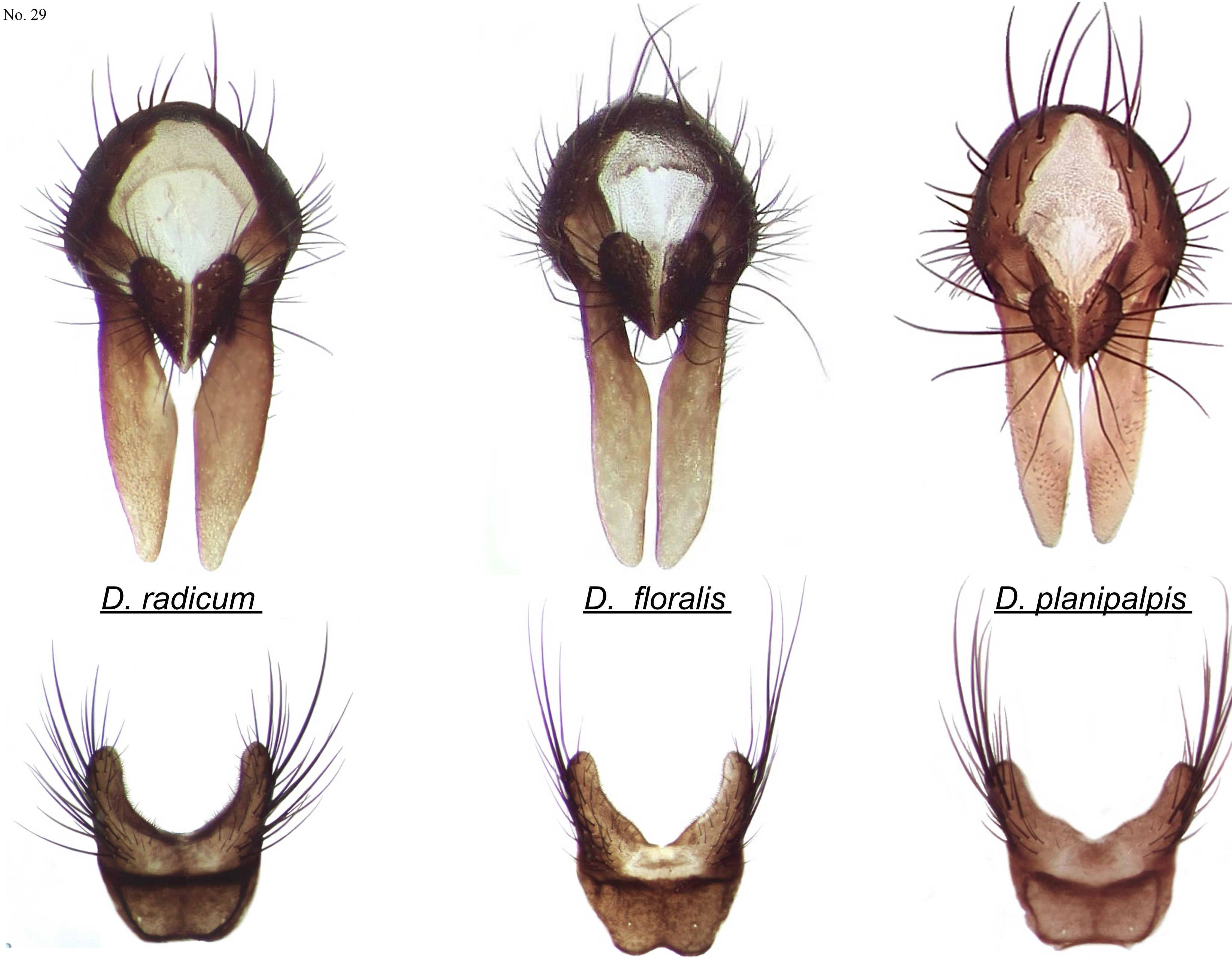
Canadian distribution: Widespread, found in all ten Canadian provinces but in none of the three territories (NT, NU and YT), all located in the north of the country (Griffiths 1991).



Male Genitalia (Appendix 1)



Appendix 1: Posterior view of male terminalia and ventral view of sternite 5 of *D. antiqua*, *D. platura*, and *D. florilega*.



Appendix 2: Posterior view of male terminalia and ventral view of sternite 5 of *D. radicum*, *D. floralis*, and *D. planipalpis*.

Acknowledgements

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