The parasitoid communities associated with an invasive canola pest, *Ceutorhynchus obstrictus* (Coleoptera: Curculionidae), in Ontario and Quebec, Canada

P.G. Mason, J.H. Miall, P. Bouchard, D.R. Gillespie, A.B. Broadbent, G.A.P. Gibson

Abstract—Surveys were conducted to determine the parasitoid communities associated with the cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham), an important invasive pest of canola in Ontario and Quebec, Canada. More than 18 species of Chalcidoidea (Hymenoptera) were associated with this pest through mass rearings from canola siliques. In southwestern Ontario, the most abundant species were a species of *Chlorocytus* Graham (23.6%–48.6%), *Lyrcus perdubius* (Girault) (0%–53%), *L. maculatus* (Gahan) (2.8%–14.7%), and species of *Pteromalus* Swederus (0.6%–23.1%) (Pteromalidae). In contrast, the most abundant species in Quebec were *Trichomalus lucidus* (Walker) (Pteromalidae) (33.3%–56.4%), unidentified Eulophidae (2.1%–39.1%), *Mesopolobus gemellus* Baur and Muller (Pteromalidae) (1.3%–21.4%), and *Necremnus tidius* (Walker) (Eulophidae) (11.5%–19.3%). In the Ottawa, Ontario, area, parasitoids were first recovered in 2008, and *Trichomalus perfectus* (Walker) (Pteromalidae), *M. gemellus*, and species of *Pteromalus* were most prevalent. *Mesopolobus gemellus* and *T. perfectus* are reported in North America for the first time. Although existing communities appear to provide substantial parasitism (*e.g.*, 6.3%–26.3% in 2006), species composition varies among years and differs from that in other regions in North America. Thus, parasitism levels and parasitoid communities of the cabbage seedpod weevil should be monitored to assess whether these will increase or there is a need to introduce more host-specific species from Europe that could provide greater mortality.

Résumé—On a entrepris cette étude dans le but d'identifier la communauté de parasitoïdes associée au charançon de la graine du chou, *Ceutorhynchus obstrictus* (Marsham), important ravageur envahissant du colza en Ontario et au Québec, Canada. On a recensé plus de 18 espèces de la superfamille des Chalcidoidea (Hymenoptera) en faisant l'élevage de masse à partir de siliques du colza. Les espèces les plus abondantes dans le sud-ouest de l'Ontario étaient une espèce de *Chlorocytus* Graham (23.6 %–48.6 %), *Lyrcus perdubius* (Girault) (0 %–53 %), *L. maculatus* (Gahan) (2.8 %–14.7 %), et des espèces du genre *Pteromalus* Swederus (0.6 %–23.1 %) (Pteromalidae). Par contre, les espèces les plus abondantes au Québec étaient *Trichomalus lucidus* (Walker) (Pteromalidae) (33.3 %–56.4 %), une espèce de la famille des Eulophidae non identifiée (2.1 %–39.1 %), *Mesopolobus gemellus* Baur et Muller (Pteromalidae) (1.3 %–21.4 %) et *Necremnus tidius* (Walker) (Eulophidae) (11.5 %–19.3 %). *Trichomalus perfectus* (Walker) (Pteromalidae), *M. gemellus*, et une espèce de *Pteromalus* sont les parasitoïdes qui ont été recensés en plus grand nombre en 2008 dans la région d'Ottawa, Ontario. On rapporte pour la première fois la présence de *Mesopolobus gemellus* et *T. perfectus* en Amérique du Nord. Bien que le taux de parasitisme soit significatif (par exemple entre 6.3 %

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P.G. Mason,[1] J.H. Miall, P. Bouchard, G.A.P. Gibson, Research Centre, Agriculture and Agri-Food Canada, K.W. Neatby Building, 960 Carling Avenue, Ottawa, Ontario, Canada K1A 0C6
D.R. Gillespie, Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1000, Agassiz, British Columbia, Canada V0M 1A0
A.B. Broadbent, Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford Street, London, Ontario, Canada N5V 4T3

[1]Corresponding author (e-mail: peter.mason@agr.gc.ca).
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et 26.3 % en 2006), la composition de la communauté de parasitoïdes diffère d'année en année et par rapport à des communautés d'autres régions de l'Amérique du Nord. En conséquence, on recommande d'effectuer un suivi des taux de parasitisme et des communautés de parasitoïdes s'attaquant au charançon de la graine du chou afin de démontrer si il est nécessaire d'introduire d'autres espèces d'Europe présentant une plus grande spécificité à l'égard de l'hôte pour augmenter les taux de mortalité.

[Traduit par la Rédaction]

Introduction

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), is an invasive alien species of European origin. It has established in North America at least twice in the last century (Laffin *et al.* 2005) and is an important pest of canola, *Brassica napus* L. and *B. rapa* L. (Brassicaceae), in western and eastern Canada (Dosdall and Mason 2010). It is estimated to cost Canadian canola producers in excess of $300 million in losses annually (Colautti *et al.* 2006). An attempt in the 1940s to introduce chalcidoid parasitoids (Hymenoptera: Chalcidoidea) for biological control of *C. obstrictus* in British Columbia, Canada, was unsuccessful except for the establishment of *Stenomalina gracilis* (Walker) (Pteromalidae) (Gibson *et al.* 2005, 2006*b*; Gillespie *et al.* 2006). Two additional European parasitoids, *Trichomalus perfectus* (Walker) and *Mesopolobus morys* (Walker) (Pteromalidae), are currently being reassessed for reintroduction (Kuhlmann *et al.* 2002; Gillespie *et al.* 2006). Earlier studies documented the parasitoid communities in western Canada (Dosdall *et al.* 2006*b*, 2009; Gillespie *et al.* 2006) and Georgia, United States of America (Gibson *et al.* 2006*a*), which, except for *S. gracilis*, consisted of native or putatively Holarctic species such as *Necremnus tidius* (Walker) (Eulophidae) and *Trichomalus lucidus* (Walker). No studies have yet documented the parasitoid communities associated with *C. obstrictus* in the most recently invaded regions of Quebec and Ontario, Canada (Brodeur *et al.* 2001; Mason *et al.* 2004).

The objectives of this study were to (*i*) determine the parasitoid complexes associated with *C. obstrictus* infesting canola in Ontario and Quebec and (*ii*) assess the impact of the parasitoids on this important pest.

Materials and methods

Surveys were conducted in 2003–2009 in canola fields in southern Ontario and southern Quebec where *C. obstrictus* was present (Mason *et al.* 2004) or could potentially occur (Fig. 1). Sites were visited when the crop was in the silique stage of development (stages 73–79 of Lancashire *et al.* 1991) — in early July for winter canola and in late July to early August for spring varieties. Densities of adult *C. obstrictus* were estimated in 2006 and 2007 with a standard sweep net when the canola was flowering (stages 61–65). Samples were taken by sweeping 100 times in a 180° arc while walking from the edge toward the centre of a field. Samples were placed in 70% ethanol and processed in the laboratory. Data were reported as number of adult weevils per sweep to allow comparison with the economic threshold of three or four weevils per sweep, used for insecticidal control (Dosdall *et al.* 2001; Cárcamo *et al.* 2005).

To determine parasitism, 50 (2003–2004) or 100–1000 (2006–2009) canola siliques were harvested from racemes on the lower half of randomly selected plants in each field. In 2003, 2004, 2008, and 2009, samples of siliques were collected at only a few locations with a history of *C. obstrictus* infestation. In 2006 and 2007, larger surveys were conducted to provide semiquantitative data. Because in earlier surveys, *C. obstrictus* was recovered from wild radish, *Raphanus raphanistrum* L. (Brassicaceae), in and around canola fields (Mason *et al.* 2004), siliques were also collected from this non-native host plant. Siliques of another non-native plant, wild mustard, *Sinapis arvensis* L. (Brassicaceae),

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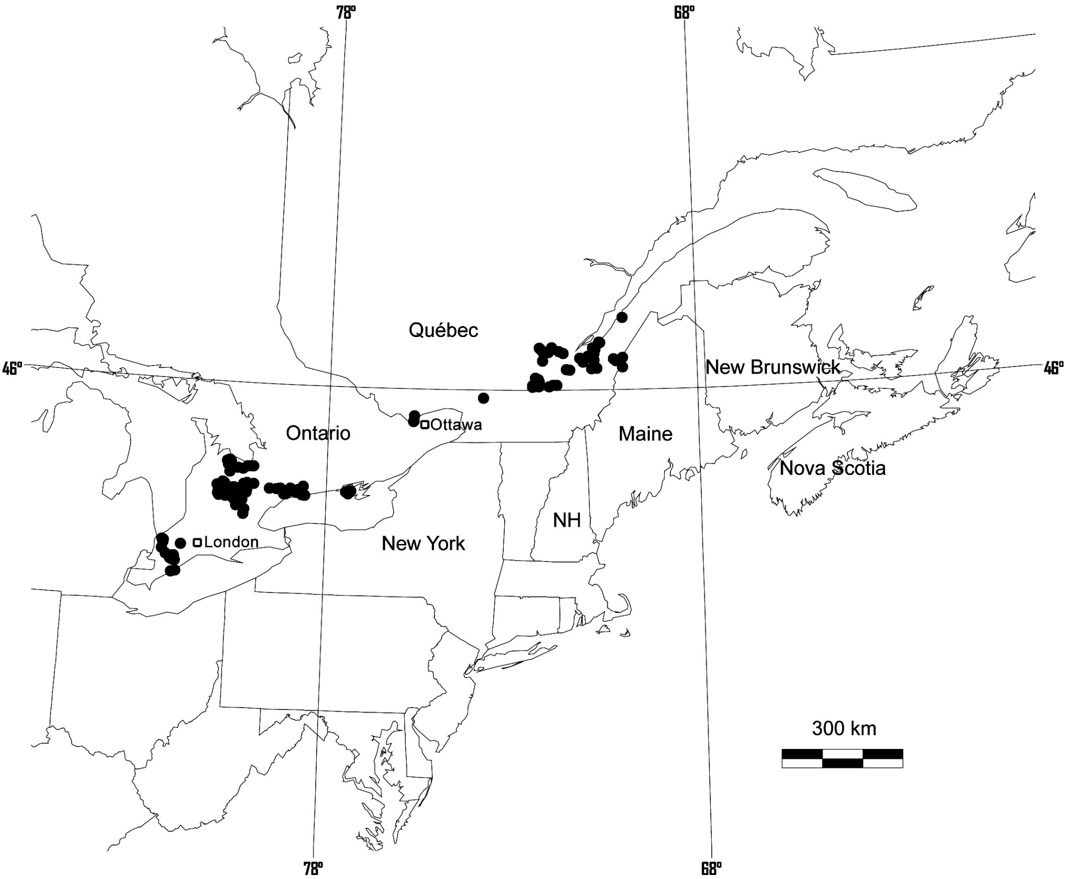
Fig. 1. Localities surveyed for *Ceutorhynchus obstrictus* and parasitoids in Ontario and Quebec, Canada, from 2003 to 2009.



were also collected because this species has been implicated as a host of *C. obstrictus* (Doucett 1947). In 2003 and 2004, samples of 50 siliques were placed in 1 L paper buckets, whereas in each of 2006–2009, samples of approximately 1000 siliques were placed in 30 cm × 30 cm × 30 cm cardboard emergence boxes containing moistened fine vermiculite as a pupation substrate. A 2 cm diameter hole in one side of the bucket or box allowed insects to exit into plastic containers. The emergence buckets/boxes were placed in a lighted room at 22 ± 1 °C. Collection containers were inspected every 1 or 2 days until no insects had emerged from the boxes for 30 consecutive days. Emerged insects were placed in vials containing 70% ethanol, and weevils and parasitoids were sorted and counted. In 2006, percent parasitism was estimated on the basis of numbers of weevil larvae and parasitoid pupae found in the vermiculite substrate and of emerged adult weevils and adult parasitoids. Because of the large numbers of pods collected, it was impractical to dissect each pod to determine whether weevil remains or parasitoid pupae were present. Thus, estimates of parasitism may be slightly lower than actual levels. In 2009, parasitoid data from an ongoing life-table study of *C. obstrictus* in southwestern Ontario (A.B. Broadbent, G.A.P. Gibson, D.R. Gillespie, and P.G. Mason, unpublished data) were included for comparison with data from the Ottawa area. Parasitoids were critical-point dried and identified by G.A.P. Gibson; weevils were identified by P. Bouchard. Voucher specimens of weevils and parasitoids are deposited in the Canadian National Collection of Insects, Arachnids and Nematodes in Ottawa, Ontario. Specimen labels include site codes.

Means and standard errors were calculated using PROC Means of the SAS statistical software (SAS Institute Inc. 2008).

Results

Ceutorhynchus obstrictus

The surveys in 2006 and 2007 demonstrated that *C. obstrictus* was widespread in canola-growing areas south of Québec City and in southwestern Ontario, although weevils were not present at all sites surveyed (Table 1). *Ceutorhynchus obstrictus* was found in the Ottawa area for the first time in 2007 in spring canola on the Agriculture and Agri-Food Canada Central Experimental Farm (CEF). Individuals were subsequently reared in 2008 and 2009 from siliques of spring canola at the same location, indicating that a population had established.

In 2006, numbers of adult *C. obstrictus* per sweep ranged from <0.1 to 15.2 in winter canola and from <0.1 to 1.2 in spring canola in southwestern Ontario, and from 0.1 to 10.2 in spring canola in Quebec (Table 2). The numbers of weevil larvae per 100 siliques were also highly variable, but high numbers of adults collected at flowering were not indicative of high numbers of larvae in siliques. Mean numbers of *C. obstrictus* per 100 *B. napus* siliques were higher in winter canola (6.8 ± 3.0) than in spring canola (1.0 ± 0.1) in southwestern Ontario. In Quebec, mean numbers of *C. obstrictus* per 100 *B. napus* siliques in spring canola were similar to those in spring canola in southwestern Ontario crops but lower than in volunteer *B. napus* (26.7), though only two locations were sampled. Other species of Ceutorhynchinae were collected as adults on flowers during the project, but only *C. obstrictus* emerged from the siliques of *B. napus*.

Parasitoids associated with *C. obstrictus* in *B. napus*

In 2003 and 2004, very few parasitoids were reared from siliques of *B. napus*. A total of three specimens of *Lyrcus perdubius* (Girault) (Hymenoptera: Pteromalidae) were reared from siliques in southwestern Ontario. In southern Quebec, one specimen each of *Euderus glaucus* Yoshimoto (Hymenoptera: Eulophidae) and an unidentified species of *Trichomalus* Thomson (Hymenoptera: Pteromalidae) were reared. In 2006–2009, at least 18 parasitoid species from five families of Chalcidoidea were reared, including at least 17 species from southwestern Ontario (Table 3) and 13 species from Quebec (Table 4). Parasitoids were not present at all sites, and some sites yielded parasitoids but no *C. obstrictus* (Table 1). Furthermore, not all parasitoid species were present at all sites surveyed, and because of the mass rearing method it is possible that some of the species recovered in low numbers (*e.g.*, a single specimen of *Chlorocytus* "sp. 2" in Ontario) were actually associated with other host species contaminating the siliques. Some specimens of other chalcidoid genera and families as well as the superfamilies Ceraphronoidea, Cynipoidea, Ichneumonoidea, and Platygastroidea were reared but are not included in Tables 3 and 4 because known host relationships indicate that they were associated with such contaminants as the diamondback moth, *Plutella xylostella* L., (Lepidoptera: Plutellidae), aphids (Hemiptera: Aphididae), plant bugs (Hemiptera: Miridae), and miscellaneous plant-mining Diptera, which also emerged from our samples.

Two parasitoid species, *Mesopolobus gemellus* Baur and Muller and *T. perfectus*, previously reared in Europe from *Ceutorhynchus typhae* (Herbst) (Baur *et al.* 2007; Muller *et al.* 2011) and *C. obstrictus* (Haye *et al.* 2010), respectively, were reared from siliques of canola and are reported for the first time in North America. Prior to 2009, *T. perfectus* had not been reared from siliques of canola

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Table 1. Numbers of localities in Ontario and Quebec, Canada, surveyed in 2003 and 2004 and 2006–2009 where *Ceutorhynchus obstrictus* was present at flowering and parasitoids of *C. obstrictus* were present in siliques of *Brassica napus*.

	Ontario						Quebec					
	2003	2004	2006	2007	2008	2009	2003	2004	2006	2007	2008	2009
Number of localities surveyed	53	39	29	26	2	1	12	16	20	11	2	1
No. of localities with *C. obstrictus* present	45	25	27	20	2	1	10	13	12	6	2	1
No. of localities with parasitoids present	1	1	19	20	2	1	0	2	15	8	2	1
No. of localities with *C. obstrictus* and parasitoids present	1	1	18	16	2	1	—	2	7	5	2	1

Table 2. Incidence and parasitism of *Ceutorhynchus obstrictus* (CSW) during winter and spring and in volunteer *Brassica napus* plantings in Ontario and Quebec, Canada, in 2006.

Location	*Brassica napus* plant type	CSW/ sweep*	Pod-collection date	No. of CSW/ 100 siliques	Percent parasitism†	No. of parasitoid species
Ontario						
42°32.052′N, 81°55.352′W	Winter	—‡	22 June	4.7	8.6 (8)	2
42°32.053′N, 81°57.415′W	Winter	—	22 June	0.5	33.3 (3)	2
43°38.835′N, 80°24.177′W	Winter	15.18	21 June	4.6	0	—
42°37.052′N, 81°57.781′W	Winter	—	22 June	10.2	7.4 (15)	4
42°37.391′N, 81°59.675′W	Winter	—	22 June	2.3	8.7 (4)	1
42°45.013′N, 82°17.002′W	Winter	—	22 June	13.4	0.4 (1)	1
42°51.594′N, 82°14.902′W	Winter	—	22 June	0.2	0	—
44°00.705′N, 77°23.664′W	Winter	0.02	13 July§	0.5	100.0 (9)	3
44°29.619′N, 80°41.016′W	Winter	—	21 June	30.8	7.4 (49)	5
44°30.852′N, 80°36.799′W	Winter	0.01	21 June	0.5	30.0 (3)	2
Average (±SE)				6.8 (±3.0)		
43°54.038′N, 78°38.900′W	Spring	—	14 July	1.3	0	—
43°57.122′N, 78°47.777′W	Spring	0.62	14 July	0.8	12.5 (2)	1
43°58.111′N, 78°53.664′W	Spring	—	26 July	0.8	12.5 (2)	2
43°58.465′N, 78°50.265′W	Spring	0.25	14 July	1.2	0	—
Average (±SE)				1.0 (±0.1)		

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Table 2 (*concluded*).

Location	*Brassica napus* plant type	CSW/ sweep*	Pod-collection date	No. of CSW/ 100 siliques	Percent parasitism†	No. of parasitoid species
Quebec						
46°32.520′N, 72°13.694′W	Volunteer	0.82	1 August	45.6	16.1 (55)	4
46°40.957′N, 71°40.112′W	Volunteer	3.28	1 August	7.8	36.4 (28)	2
Average				26.7		
46°33.768′N, 70°50.010′W	Spring	10.22	2 August	6.8	19.1 (13)	1
46°35.577′N, 70°50.976′W	Spring	3.05	2 August	1.4	21.4 (3)	1
46°36.645′N, 70°59.252′W	Spring	—	2 August	3.4	29.4 (10)	1
46°37.336′N, 70°59.606′W	Spring	1.53	2 August	0.7	28.6 (2)	1
Average (±SE)				3.1 (±1.4)		

*Sweep samples were taken during flowering, approximately 4 weeks before pod collections.
†Numbers in parentheses show the sample size.
‡Samples were not taken, owing to rain.
§Pod samples were taken very late (therefore parasitoid numbers were normal but weevil numbers decreased).

Table 3. Species composition (%) of Chalcidoidea parasitoids reared from collections of approximately 1000 siliques of *Brassica napus* in 2006–2009 in southern Ontario, Canada, and putatively associated with *Ceutorhynchus obstrictus*.

			2008		2009	
Parasitoid species	2006	2007	Southwestern Ontario*	Ottawa*	London†	Ottawa*
Chalcididae						
Conura albifrons (Walsh)	—	—	—	—	—	—
Eulophidae						
Euderus albitarsis (Zetterstedt)	0.6	—	—		—	—
Euderus glaucus Yoshimoto	—	0.4	7.0	69.4	—	—
Euderus sp.					3.8	
Necremnus tidius (Walker)	5.1	2.7		2.8	4.8	—
Unidentified taxa	—	8.8	12.7	—	3.9	—
Eupelmidae						
Eupelmus vesicularis (Retzius)	0.6	0.2	—	—	—	—
Eurytomidae						
Eurytoma sp. (probably *E. tylodermatis* Ashmead)	—	0.6	1.4	—	—	—
Pteromalidae						
Chlorocytus sp.	48.6	23.6	29.6	—	63.5	—
Chlorocytus sp. 2	—	—	—	—	1.0	—
Lyrcus incertus (Ashmead)	—	1.9	—	—	—	—
Lyrcus maculatus (Gahan)	14.7	3.6	4.2	—	—	—

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Table 3 (*concluded*).

Parasitoid species	2006	2007	2008 Southwestern Ontario*	2008 Ottawa*	2009 London†	2009 Ottawa*
Lyrcus perdubius (Girault)	13.0	53.0	—	—	1.0	—
Mesopolobus gemellus Baur and Muller	1.1	0.4	—	25.0	1.9	—
Mesopolobus moryoides Gibson	3.4	0.8	9.9	—	2.9	—
Neocatolaccus tylodermae (Ashmead)	0.6	—	—	—	—	—
Pteromalus spp.	4.1	0.6	33.8	2.8	10.6	56.3
Trichomalus lucidus (Walker)	8.5	3.6	1.4	—	6.7	—
Trichomalus perfectus (Walker)	—	—	—	—	—	46.7
Number of specimens	177	525	71	36	104	16

*Pod collections are from a single location.
†Pod collections were made weekly from two locations in the London area.

Table 4. Species composition (%) of Chalcidoidea parasitoids reared from collections of approximately 1000 siliques of *Brassica napus* in 2006–2009 in southern Quebec, Canada, and putatively associated with *Ceutorhynchus obstrictus.*

Parasitoid species	2006	2007	2008	2009
Chalcididae				
Conura albifrons (Walsh)	—	1.3	—	—
Eulophidae				
Euderus albitarsis (Zetterstedt)	1.4	—	—	—
Euderus glaucus Yoshimoto	—	0.6	—	—
Euderus sp.	—	—	—	—
Necremnus tidius (Walker)	19.3	11.5	13.0	—
Unidentified taxa	2.1	23.7	39.1	—
Eupelmidae				
Eupelmus vesicularis (Retzius)	—	—	—	—
Eurytomidae				
Eurytoma sp. (probably *E. tylodermatis* Ashmead)	—	0.6	—	—
Pteromalidae				
Chlorocytus sp.	0.7	0.6	8.7	—
Chlorocytus sp. 2	—	—	—	—
Lyrcus incertus (Ashmead)	—	—	—	—
Lyrcus maculatus (Gahan)	—	—	—	—
Lyrcus perdubius (Girault)	—	1.3	—	—
Mesopolobus gemellus Baur and Muller	21.4	1.3	8.7	—
Mesopolobus moryoides Gibson	—	0.6	4.3	50.0
Neocatolaccus tylodermae (Ashmead)	—	—	—	—
Pteromalus spp.	0.7	1.9	17.4	10.0
Trichomalus lucidus (Walker)	54.5	56.4	33.3	—
Trichomalus perfectus (Walker)	—	—	—	40.0
Number of specimens	145	156	23	10

or wild radish in Canada or elsewhere in North America, even though this name was erroneously used in the literature prior to Gibson *et al.* (2005).

The parasitoid complex associated with *C. obstrictus* differed between Ontario and Quebec. In southwestern Ontario, the most abundant species were a species of *Chlorocytus*

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Table 5. Numbers of the most common parasitoids of *Ceutorhynchus obstrictus* at all sites in Ontario and Quebec, Canada, in 2006 and 2007 where collections of approximately 1000 siliques were made.

	Ontario				Quebec			
	Winter		Spring		Volunteer		Spring	
	2006 ($n = 13$)	2007 ($n = 14$)	2006 ($n = 1$)	2007 ($n = 11$)	2006 ($n = 3$)	2007 ($n = 1$)	2006 ($n = 11$)	2007 ($n = 6$)
Chlorocytus sp.	6.7 (2.4)	8.0 (3.1)	1	1.1 (0.6)	0.3 (0.3)	1	0	0
Lyrcus incertus (Ashmead)	0	0.7 (0.4)	0	0	0	0	0	0
Lyrcus maculatus (Gahan)	1.62 (0.2)	1.3 (0.7)	4	0.1 (0.1)	0	0	0	0
Lyrcus perdubius (Girault)	1.54 (0.7)	19.7 (11.0)	1	0	0	2	0	0
Necremnus tidius (Walker)	0.62 (0.2)	0.9 (0.3)	1	0.1 (0.1)	8.7 (7.7)	10	0.1 (0.1)	1.3 (1.0)
Mesopolobus gemellus Baur and Muller	0.15 (0.2)	0	0	0	10.3 (7.5)	1	0	0.2 (0.2)
Mesopolobus moryoides Gibson	0	0	1	0.3 (0.1)	0	0	0	0.2 (0.2)
Pteromalus spp.	0.85 (0.4)	0.1 (0.1)	2	0.1 (0.1)	0.3 (0.3)	1	0	0.3 (0.3)
Trichomalus lucidus (Walker)	1.08 (1.1)	0	0	1.7 (1.5)	8.3 (7.8)	4	5.0 (1.1)	14.0 (11.6)

Note: All species belong to the Pteromalidae, except *Necremnus tidius*, which belongs to the Eulophidae; n is the number of sites from which approximately 1000 siliques were collected and parasitoids emerged. Numbers in parentheses show the mean $\pm$ SE.

Graham (23.6%–48.6%) and *L. perdubius* (0%–53%), followed by *Lyrcus maculatus* (Gahan) (2.8%–14.7%) and species of *Pteromalus* Swederus (0.6%–23.1%) (Pteromalidae). In contrast, the most abundant species in Quebec were *T. lucidus* (33.3%–56.4%), followed by unidentified species of Eulophidae (2.1%–39.1%), *N. tidius* (11.5%–19.3%), and *M. gemellus* (1.3%–21.4%). Among the most abundant species, *Chlorocytus* sp. in southwestern Ontario and *T. lucidus* in Quebec constituted a relatively high proportion of the parasitoid community each year during the 2006 and 2007 surveys.

In 2008, parasitoids were recovered for the first time in Ottawa, Ontario, from *C. obstrictus* in a spring canola field on the CEF. *Euderus glaucus* and *M. gemellus* were the most abundant species (69.4% and 25.0%, respectively). In 2009, only *Pteromalus* spp. (56.3%) and *T. perfectus* (46.7%) were collected from the CEF. *Chlorocytus* sp. and *L. perdubius*, two of the most prevalent parasitoid species in southwestern Ontario, were absent at the CEF location, whereas *T. perfectus* was present at this site and absent from southwestern Ontario (Table 3). *Trichomalus perfectus* was also reared from *C. obstrictus* in Quebec in 2009. In 2006 and 2007, mean numbers of the nine most common parasitoids (Table 5) differed between southwestern Ontario and Quebec and varied among years and between early season (winter or volunteer) and summer (spring) *B. napus* siliques. These differences appear to be random.

Parasitoids associated with *C. obstrictus* in noncrop Brassicaceae

Collections of *R. raphanistrum* siliques from southern Quebec and the CEF site in 2007–2009 yielded adult *C. obstrictus* (data not shown) and seven ectoparasitoid species (Table 6). In 2007, one specimen each

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Table 6. Species composition of Chalcidoidea parasitoids reared from collections of siliques of *Raphanus raphanistrum* from southern Quebec and southern Ontario, Canada, in 2007–2009 and putatively associated with *Ceutorhynchus obstrictus*.

Parasitoid species	Number of specimens					
	Ontario			Quebec		
	2007	2008	2009	2007	2008	2009
Chalcididae						
Conura albifrons (Walsh)	—	—	—	1	—	—
Eulophidae						
Necremnus tidius (Walker)	—	—	—	2	—	1
Unidentified taxa	—	3	—	—	—	3
Pteromalidae						
Chlorocytus sp.	—	—	—	3	2	—
Pteromalus spp.	—	—	3	1	—	—
Trichomalus lucidus (Walker)	—	—	—	2	—	—
Trichomalus perfectus (Walker)	—	—	1	—	—	—
Number of specimens	0	3	4	9	2	4

of *Conura albifrons* (Walsh) (Chalcididae), *N. tidius*, and *Chlorocytus* sp. and two specimens of *T. lucidus* were reared from a single southern Quebec location (46°03.647′N, 72°03.476′W), whereas a single specimen of *Chlorocytus* sp. was reared from each of two additional locations (46°13.118′N, 72°25.515′W and 45°56.570′N, 73°04.168′W). In 2008, one specimen of *Chlorocytus* was reared from each of two locations in southern Quebec (45°58.691′N, 72°48.062′W and 45°57.267′N, 72°27.886′W) and three specimens of Eulophidae were reared from one site in southwestern Ontario (42°59.000′N, 80°22.882′W). In 2009, one specimen of *N. tidius* and one unidentified eulophid were reared from each of two locations in southern Quebec (46°11.264′N, 72°21.201′W and 45°50.179′N, 73°50.724′W, respectively) and three specimens of *Pteromalus* sp. and one specimen of *T. perfectus* were reared from the CEF site (45°23.308′N, 75°42.780′W).

Collections of *S. arvensis* siliques from 34 sites in 2006–2008 yielded no *C. obstrictus*. One unidentified eulophid emerged from siliques collected at one site in Ontario (42°48.384′N, 81°52.220′W) in 2007 ($n = 1$) and two sites in Quebec (45°17.299′N, 73°41.200′W and 45°13.874′N 73°48.891′W) in 2007 ($n = 1$ at each site) and one site (45°13.872′N, 73°48.919′W) in 2008 ($n = 4$). The host of these unidentified parasitoids could belong to any one of a number of insect families (see Yu 2005).

Discussion

Our survey showed that populations of *C. obstrictus* have continued to spread in eastern Canada. Densities of weevils varied among locations and years and between early-developing (winter/volunteer) and late-developing (spring) plant types. Early flowering/silique-producing plants supported higher numbers of *C. obstrictus* and associated parasitoids than plants that flowered and produced siliques later in the season (Table 2). Because *C. obstrictus* overwinters in the adult stage (Dosdall and Mason 2010 and references therein), heavy attacks on siliques of early-developing host plants would enable this pest to maximally exploit available resources. The early-season occurrence of volunteer canola and other weedy Brassicaceae (see below) ensures that populations of *C. obstrictus* will persist and continue to spread. Attacking early-maturing plants is the basis of pest management using trap crops (Cárcamo *et al.* 2007), together with late seeding of harvestable crops (Dosdall *et al.* 2006*a*).

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Ceutorhynchus obstrictus was found in the Ottawa area for the first time in 2007, and this represents a major range extension because it was absent from earlier surveys in eastern Ontario (Mason *et al*. 2004). The use of wild radish and wild mustard as host plants by *C. obstrictus* (Mason *et al*. 2004) and the widespread occurrence of these plant species in southern Quebec and southern Ontario (Mulligan and Bailey 1975; Warwick *et al*. 2000; Warwick and Francis 2005) may have provided a pathway for dispersal of *C. obstrictus*.

The reason for lack of parasitoids at some locations sampled may have been that too few siliques were collected (approximately 50 per site in 2003 and 2004) to yield parasitoids at low population levels, samples being collected before parasitism occurred, or a non-uniform distribution of parasitoids. The fact that only parasitoids were found in some locations may indicate that these species were associated with non-weevil hosts known to be present or were locations where healthy weevils had emerged before siliques were sampled (parasitoids emerge from siliques approximately 2–3 weeks after *C. obstrictus*).

Gibson *et al.* (2006*b*) verified that *T. perfectus* was intentionally introduced in British Columbia from Europe in 1949 for biological control of *C. obstrictus*, but it did not establish (Gillespie *et al.* (2006). The recent occurrence of *T. perfectus* in Ottawa, Ontario (45°29.121′N, 75°42.311′W), and St-Célestin, Quebec (46°11.264′N, 72°21.201′W), in 2009 suggests that this species is adventive in eastern Canada and has attained a wide regional distribution in a relatively short time. Because *C. obstrictus* was first reported in Ottawa in 2007, even though surveys have been ongoing since 2000 (Mason *et al.* 2004), it is likely that *C. obstrictus* and at least some of its parasitoids moved west to the Ottawa area from Quebec via the Ottawa Valley. Detailed population studies are required to validate this hypothesis because all other parasitoids associated with *C. obstrictus* at the CEF location in Ottawa were found in both southwestern Ontario and Quebec.

Identification of the complex of parasitoids attacking larvae of *C. obstrictus* in southwestern Ontario and Quebec is consistent with findings in other regions of North America (Gillespie *et al*. 2006; Gibson *et al*. 2006*b*; Dosdall *et al*. 2009), though different species dominate the complexes in different regions. The occurrence of the European species *M. gemellus* at all sites in this study and *T. perfectus* in Quebec and the Ottawa area suggests that these species are adventive, and both may have been introduced at the same time as the Quebec *C. obstrictus* population. However, because of host association it is more likely that *M. gemellus* was introduced with *C. typhae*, an adventive species that is widespread in eastern Canada (Ontario, Quebec, New Brunswick, Nova Scotia, and Newfoundland) (Bousquet 1991; Bouchard *et al*. 2005). In Europe, *M. gemellus* is recorded as the major parasitoid of *C. typhae*, which feeds in siliques of shepherd's purse, *Capsella bursa-pastoris* (L.) Medik. (Brassicaceae) (Baur *et al*. 2007; Muller *et al*. 2011), a common invasive weed in canola and other crops in North America (Moss 1959; Budd and Best 1969). The emergence of *M. gemellus* from siliques of canola (*i.e.*, from *C. obstrictus*) represents a curious new host association. *Mesopolobus morys* Walker (Pteromalidae), which is not known from North America (Gibson *et al.* 2006*b*), is the species of *Mesopolobus* that parasitizes *C. obstrictus* in Europe (Williams 2003; Haye *et al.* 2010).

The hypothesis that *T. perfectus* and *M. gemellus* were introduced accidentally in eastern Canada is supported by the absence of *T. perfectus* from southwestern Ontario (this study) as well as from British Columbia, Alberta, and Saskatchewan in Canada and Georgia in the United States of America (Gillespie *et al*. 2006; Dosdall *et al*. 2009; Gibson *et al*. 2006*b*) and the presence of *C. typhae* in southwestern Ontario, the Ottawa area, and southern Quebec but not in western Canada. Furthermore, the absence of *M. gemellus* from Georgia also suggests accidental introduction in eastern Canada.

The North American parasitoid communities of *C. obstrictus* vary among regions from 8 to 17 species (Table 7). In British Columbia, *T. lucidus*, *S. gracilis*, and *Mesopolobus*

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Table 7. Species composition (%) of Chalcidoidea parasitoids reared from collections of siliques of *Brassica napus* and *B. rapa* and putatively associated with *Ceutorhynchus obstrictus* in British Columbia (2005), southern Alberta and Saskatchewan (2003–2005), and Ontario and Quebec (2007) in Canada and Georgia, United States of America (1998).

	British Columbia (Gillespie *et al.* 2006)	Alberta and Saskatchewan (Dosdall *et al.* 2009)			Georgia (Gibson *et al.* 2006*a*)	Ontario	Quebec
Parasitoid species	2005	2003	2004	2005	1998	2007	2007
Chalcididae							
Conura albifrons (Walsh)	0.1	13.0	0.9	2.1	—	—	1.3
Conura torvina (Cresson)	—	16.2	0.5	10.4	0.8	—	—
Eulophidae							
Euderus albitarsus (Zetterstedt)*	—	0.8	1.1	1.1	—	0.6	—
Euderus glaucus Yoshimoto	—	—	—	—	0.2	0.4	0.6
Necremnus tidius (Walker)*	7.3	25.2	75.0	27.9	0.5	2.7	11.5
Unidentified taxa	—	—	—	—	—	8.8	23.7
Eupelmidae							
Brasema allynii (French)	—	—	—	—	0.5	—	—
Eupelmus cyaniceps Ashmead	—	—	—	—	0.4	—	—
Eupelmus vesicularis (Retzius)*	1.8	—	—	—	—	0.2	—
Eurytomidae							
Eurytoma tylodermatis Ashmead	0.8	0.0	0.7	0.0	2.2	0.6	0.6
Pteromalidae							
Catolaccus aenoviridis (Girault)	—	13.8	0.2	1.1	—	—	—
Chlorocytus sp.	—	6.7	7.5	26.9	—	23.6	0.6
Lyrcus incertus (Ashmead)	—	0.0	0.0	0.4	0.5	1.9	—
Lyrcus maculatus (Gahan)	—	0.0	0.9	3.2	86.0	3.6	—
Lyrcus perdubius (Girault)	—	—	0.4	—	5.3	53.0	1.3
Mesopolobus gemellus Baur and Muller†	—	—	—	—	—	0.4	1.3
Mesopolobus moryoides Gibson	10.8	2.4	0.2	1.1	0.2	0.8	0.6
Mesopolobus sp.	0.3	—	—	—	—	—	—
Neocatolaccus tylodermae (Ashmead)	—	—	—	—	2.9	—	—
Pteromalus cerealellae (Ashmead)	—	—	—	—	0.1	—	—
Pteromalus spp.‡	—	13.8	8.2	13.8	0.4	0.6	1.9
Stenomalinus gracilis (Walker)*	29.6	—	—	—	—	—	—
Trichomalus lucidus (Walker)*	49.6	8.1	4.8	12.0	—	3.6	56.4
Trichomalus perfectus (Walker)†	—	—	—	—	—	—§	—§

*Palaearctic Region.
†New record for North America.
‡At least two undescribed species.
§Although *T. perfectus* was not found in 2007, it was found in Ontario (Ottawa) and Quebec in 2009.

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moryoides Gibson are dominant (Gillespie *et al*. 2006), whereas *N. tidius* dominates in the Canadian prairies (Dosdall *et al*. 2009), *L. maculatus* is most abundant in Georgia (Gibson *et al*. 2006*b*), *Chlorocytus* sp. and *L. perdubius* dominate in southwestern Ontario (this study), and *T. lucidus* and unidentified species of Eulophidae are most abundant in Quebec (this study). Three species, *N. tidius*, *Eurytoma tylodermatis* Ashmead (Hymenoptera: Eurytomidae), and *M. moryoides* are present in all regions where *C. obstrictus* occurs, although *E. tylodermatis* constitutes a very small proportion of the parasitoid complex (<0.2%, except in Georgia, where it is 2.2%). Among the 24 larval parasitoids reported as associated with *C. obstrictus* in North America, 8 are also reported from the Palaearctic Region. Of these, *S. gracilis* was intentionally introduced to North America (Gibson *et al*. 2006*b*), but whether the others are naturally occurring Holarctic species or were accidentally introduced is uncertain. For example, *Eupelmus vesicularis* (Retzius) (Eupelmidae) is transcontinental in North America, but is thought likely to have been introduced from Europe in straw with early European settlers (Gibson 1990). It is a broad generalist, with over 130 known hosts, as are most of the other known parasitoids of *C. obstrictus* (Yu 2005; Dosdall *et al*. 2006*b*), though *M. moryoides* is as yet associated only with this weevil, and *M. gemellus* has previously been associated only with C. *typhae* except for a single female from *Ceutorhynchus turbatus* Schultze (Baur *et al*. 2007). The incidence of even the dominant parasitoid species varies over time (Tables 3–5, 7), although sampling protocols likely influence these estimates (*i.e.*, patchiness of hosts and parasitoids; see Dosdall *et al*. 2009).

In Europe, 32 parasitoids, including 17 chalcidoids, have been associated with *C. obstrictus* (Ulber *et al*. 2010). Although the complex varies among regions, three ectoparasitoid species, *M. morys*, *S. gracilis*, and *T. perfectus*, have been reared from *C. obstrictus* in all areas where it is present. Haye *et al*. (2010) determined that larval mortality due to parasitism accounted for 45.5%–51.9% of the seasonal mortality of *C. obstrictus* in Europe, the dominant parasitoid species being *M. morys* (44%–48%) and *T. perfectus* (37%–48%). Veromann *et al.* (2011) found substantial parasitism (up to 96%) in Estonia, a relatively new area for *C. obstrictus* and its parasitoids. Although parasitoids of the egg and adult stages of *C. obstrictus* occur in Europe, these species do not cause significant mortality (Williams 2003; Ulber *et al*. 2010). *Microctonus melanopus* Ruthe (Hymenoptera: Ichneumonoidea: Braconidae), a parasitoid of adults, has also been reported from North America but has a limited distribution (Idaho, Alberta) and has little impact on *C. obstrictus* mortality (Dosdall and Mason 2010).

The complex of parasitoids associated with *C. obstrictus* on Brassicaceae other than *B. napus* is poorly understood. Fewer species appear to be associated with *C. obstrictus* infesting siliques of wild radish (Table 6), although those that occurred tended to be the major species that attacked *C. obstrictus* in canola. The eastern Canadian populations of *C. obstrictus* did not appear to attack wild mustard. Doucette (1947) concluded that *C. obstrictus* could complete its development in wild mustard, although this was not a preferred host.

Ceutorhynchus obstrictus continues to expand its range in North America. Parasitoid communities composed of Nearctic, putatively Holarctic, and introduced species have assembled on this host, but these communities vary in composition among the regions that have been surveyed. Although existing communities appear to provide substantial parasitism, the dominant species vary among years. Overall parasitism currently does not reduce *C. obstrictus* populations sufficiently to eliminate economic loss in eastern Canada, and this is also the case elsewhere in North America (Dosdall *et al*. 2009). Monitoring of parasitism levels should continue, to assess whether the current assemblages of species will increase and disperse across the entire range of *C. obstrictus* or there is a need to introduce more host-specific species from Europe that will provide greater mortality of *C. obstrictus.* The establishment in Canada of *T. perfectus*, the most effective parasitoid of *C. obstrictus*

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in Europe (Williams 2003; Haye *et al.* 2010; Veromann *et al.* 2011), provides an opportunity to track the spread and determine the impact of this important species. Finally, because the community of parasitoids has likely assembled from locally occurring weevil species in the subfamily Ceutorhynchinae, it will be important to determine whether or not the same parasitoid communities, or components thereof, are also associated with native species and (or) species introduced for the biological control of weeds.

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