Filth fly parasitoids on dairy farms in Ontario and Quebec, Canada

GAP Gibson[1]

Agriculture and Agri-Food Canada, Biodiversity and Integrated Pest Management, KW Neatby Building, 960 Carling Avenue, Ottawa, Ontario, Canada K1A 0C6

KD Floate

Agriculture and Agri-Food Canada, Lethbridge Research Centre, 5403 – 1 Avenue South, Lethbridge, Alberta, Canada T1J 4B1

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Abstract—Hymenopterous parasitoids of filth flies (Diptera: Muscidae) were surveyed during 2 years on dairy farms in Ontario and Quebec near Ottawa, Ontario, using freeze-killed sentinel house fly (*Musca domestica* L.) pupae and naturally occurring fly pupae collected on site. *Musca domestica* and *Stomoxys calcitrans* (L.) (stable fly) represented 98.3% of the natural fly hosts from which parasitoids emerged. *Muscidifurax raptor* Girault *et* Saunders, *Nasonia vitripennis* Walker, *Pachycrepoideus vindemiae* (Rondani), *Spalangia cameroni* Perkins, *S. nigra* Latreille, *Trichomalopsis viridescens* (Walsh), and *Urolepis rufipes* (Ashmead) (Pteromalidae) were recovered from both sentinel and natural fly pupae. Another eight species, *S. drosophilae* Ashmead, *S. endius* Walker, *S. haematobiae* Ashmead, *S. nigroaenea* Curtis, *S. subpunctata* Förster, *Trichomalopsis dubia* (Ashmead) (Pteromalidae), *Aphaereta pallipes* (Say) (Braconidae), and *Phygadeuon ?fumator* Gravenhörst (Ichneumonidae), were recovered only from natural pupae. Over the 2 years, *M. raptor* comprised 90.7% of emerged parasitoids from sentinel pupae but only 17.0% of emerged parasitoids from natural pupae. From natural pupae, *S. cameroni*, *S. nigra*, and *S. nigroaenea* collectively comprised 60.3% of emerged parasitoids; *P. ?fumator* comprised 13.5% and the remaining nine species 9.2%. The recoveries of *S. endius* and *S. nigroaenea* represent new distribution records for Canada, and several new host records are identified based on structure of the host fly puparium. The parasitoid fauna is compared with that known for western Canada, and recommendations are made for both regions concerning potential natural enemy enhancement for filth fly control.

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Résumé—Nous avons fait pendant 2 ans l'inventaire des hyménoptères parasitoïdes des mouches des immondices (Diptera : Muscidae) sur des fermes laitières de l'Ontario et du Québec près d'Ottawa, Ontario, en utilisant des pupes sentinelles de mouches domestiques (*Musca domestica* L.) tuées au froid et des pupes de mouches présentes naturellement sur les lieux. *Musca domestica* et *Stomoxys calcitrans* (L.), la mouche des étables, constituent 98,3 % des hôtes naturels desquels les parasitoïdes ont émergé. Les ptéromalidés *Muscidifurax raptor* Girault *et* Saunders, *Nasonia vitripennis* Walker, *Pachycrepoideus vindemiae* (Rondani), *Spalangia cameroni* Perkins, *S. nigra* Latreille, *Trichomalopsis viridescens* (Walsh) et *Urolepis rufipes* (Ashmead) ont été obtenus à partir des pupes de mouches, tant sentinelles que naturelles. Huit autres espèces, les Ptéromalidés *S. drosophilae* Ashmead, *S. endius* Walker, *S. haematobiae* Ashmead, *S. nigroaenea* Curtis, *S. subpunctata* Förster, *Trichomalopsis dubia* (Ashmead) (Pteromalidae), *Aphaereta pallipes* (Say) (Braconidae)

[1] Corresponding author (e-mail: gibsong@agr.gc.ca).

et *Phygadeuon ?fumator* Gravenhörst (Ichneumonidae) ont émergé seulement des pupes naturelles. *Muscidifurax raptor* représente 90,7 % des parasitoïdes qui ont émergé des pupes sentinelles au cours des deux années, mais seulement 17 % des parasitoïdes issus des pupes naturelles. Chez les pupes naturelles, *S. cameroni*, *S. nigra* et *S. nigroaenea* représentent ensemble 60,3 % des émergences de parasitoïdes, alors que *P. ?fumator* représente 13,5 % et les neuf autres espèces 9,2 %. *Spalangia endius* et *S. nigroaenea* sont mentionnés pour la première fois au Canada et plusieurs nouveaux hôtes ont été identifiés d'après la structure de leur puparium. Nous comparons cette faune de parasitoïdes à celle qui est connue de l'ouest du Canada et nous faisons des recommandations applicables aux deux régions afin d'améliorer le contrôle potentiel des mouches des immondices au moyen de leurs ennemis naturels.

[Traduit par la Rédaction]

Introduction

Stable flies, *Stomoxys calcitrans* (L.), and house flies, *Musca domestica* L., (Diptera: Muscidae) are cosmopolitan livestock pests. Stress induced by stable fly bites can reduce weight gain and feed conversion efficiency in feeder cattle (Campbell *et al.* 1987) and milk flow in dairy cattle (Bruce and Decker 1958). House flies transmit pathogens and are nuisance pests that annoy individuals in livestock facilities and surrounding residential areas (Floate *et al.* 2002). Concerns regarding the efficacy and nontarget effects of chemical control have led to the search for native and exotic parasitoids and predators of filth flies to reduce dependancy on chemicals for suppression of fly populations. Numerous surveys have investigated the native parasitoid fauna of filth flies in poultry and livestock facilities throughout the United States (Legner 1995), but in Canada surveys have been conducted only in Alberta (Depner 1968; Lysyk 1995; Floate *et al.* 1999) and Manitoba (McKay and Galloway 1999*a*). Here, we report the results of a 2-year survey of the hymenopterous parasitoids of filth-breeding flies on dairy farms in Ontario and Quebec, in the vicinity of Ottawa, Ontario, and compare species diversity to that found in western Canada. This research is part of a larger study to identify unique regional differences in parasitoid faunas throughout Canada for future use in biological control programs against house and stable flies.

Materials and methods

Fly breeding sites were sampled weekly at eight dairy facilities from 11 July to 12 October 2000 and at nine facilities from 14 June to 16 October 2001. The sites consisted of the livestock manure and waste-bedding pit of the Central Experimental Farm in Ottawa plus varied fly breeding sites on commercial dairy farms within a 50-km radius, including four in Ontario south and east, two in Ontario north and west, and two in Quebec north of the Central Experimental Farm.

Freeze-killed sentinel house fly pupae and naturally occurring fly pupae were used to survey the parasitoid fauna. Fiberglass screening (1.7 mm mesh) was used to make sentinel bags about 7 cm × 7 cm. Six to 15 bags, each containing about 50 freeze-killed pupae, were placed in different fly breeding sites at each facility depending on facility size and number of available sites. The bags, concealed under 2–4 cm of substrate, were placed on the floor or on windowsills within dairy barns and in other fly breeding sites outside of barns. The exterior sites included sand, straw, or wood-chip bedding of calf hutches; soiled bedding piles; spilled feed and silage; and accumulated manure along structures, in manure mounds, or around liquid manure ponds. The bags were left for 1 week and then replaced with fresh sentinel bags. Recovered bags were brought to the laboratory, where intact pupae were reared individually in 96-well tissue culture plates and incubated at 21 ± 2 °C for at least 2 months. Emerged parasitoids, along with the associated pupa, were preserved in ethanol for identification.

Searches for natural pupae were conducted at all exterior breeding sites but not in most barns because of the difficulty of observing pupae within dark confines. Retrieved natural pupae were reared under the same conditions as sentinel pupae. Greater effort was made to locate natural pupae in 2001 based on preliminary comparison of parasitoid emergence from natural *versus* sentinel pupae in 2000. The extent to which this contributed to the greater number of retrieved natural pupae and parasitoids in 2001, relative to environmental factors influencing fly populations in the two years, is unknown.

The senior author identified the chalcid parasitoids and differentiated house fly and stable fly pupae based on structure of the puparium and spiracles. Other parasitoids and fly taxa were identified by the taxonomists listed under Acknowledgments. Host fly identifications other than house fly and stable fly were based on puparium structure and adult flies that emerged from similarly structured puparia. These identifications are tentative because the adult flies were not always from the same pupal collection and it is uncertain whether more than one species of any genus was present. A confident species identification for the genus *Phygadeuon* was also not possible because of the absence of a modern revision of the Nearctic species. Voucher specimens of all parasitoid and fly species are in the Canadian National Collection of Insects, Ottawa, Ontario.

Percent parasitism of sentinel pupae by each species was based on the number of parasitism events divided by the total number of pupae reared. Percent parasitism of natural pupae was based on the number of parasitism events divided by the total number of pupae from which either flies or parasitoids emerged (viable pupae). Pupae from which more than a single parasitoid emerged (gregarious species) were considered as single parasitism events, and pupae that did not result in either a fly or a parasitoid were excluded. No attempts were made to quantify the cause of non-emergence of flies, but in 2001 all natural pupae collected between 21 August and 4 October and between 9 and 18 October were dissected 2 and 4 months later, respectively, for evidence of unemerged parasitoids. Parasitoids were recorded as larvae, white pupae, melanized pupae, pharate adults, or free adults within the host puparium. Free adults were recorded as alive if they moved when prodded and recorded as dead if they did not move. All life stages other than larvae normally were identified to species except for species of the genus *Spalangia*. Only free adults of *Spalangia* were identified to species because the pupal case often obscured species features.

For comparison between years, precipitation and daily mean temperatures from 1 May to 31 October were obtained from the Canadian Department of Agriculture Ottawa reference climate station (45°23′N, 75°43′W; 79 m elevation).

Statistical analyses

Modified χ^2 tests with Yates' correction for continuity (P = 0.05; Zar 1984, pp 48–49) were performed for each parasitoid species using data combined across years to test for differences in the recovery of species between naturally occurring pupae of house flies and stable flies. All values are reported as means ± SE of untransformed data.

Results

Weather

On average, the Ottawa area was wetter and cooler in 2000 relative to 2001 (Figs. 1, 2). Cumulative precipitation at Ottawa from 1 May to 31 October was 575 mm in 2000 and 397 mm in 2001. The difference in cumulative precipitation between years primarily reflected the wetter spring of 2000 and the high precipitation in mid-June 2000 (Fig. 1). Daily mean temperatures at Ottawa averaged from 1 May to 31 October were 15.6 and 17.0 °C in 2000 and 2001, respectively. Figure 2 provides weekly average daily mean temperatures and cumulative daily mean temperatures.

Parasitoid and host composition

Seven species of hymenopterous parasitoids were reared from 109,966 sentinel pupae: *Muscidifurax raptor* Girault *et* Saunders, *Nasonia vitripennis* Walker, *Pachycrepoideus vindemiae* (Rondani), *Spalangia cameroni* Perkins, *S. nigra* Latreille, *Trichomalopsis viridescens* (Walsh), and *Urolepis rufipes* (Ashmead) (Pteromalidae). Fifteen species emerged from 35,561 viable natural pupae, including the seven species reared from sentinel pupae (Table 1). The eight species recovered from natural but not sentinel pupae were *S. drosophilae* Ashmead, *S. endius* Walker, *S. haematobiae* Ashmead, *S. nigroaenea* Curtis, *S. subpunctata* Förster, *Trichomalopsis dubia* (Ashmead) (Pteromalidae), *Aphaereta pallipes* (Say) (Braconidae), and *Phygadeuon ?fumator* Gravenhörst (Ichneumonidae). These latter species accounted for 31.1% of the total parasitism observed for natural fly pupae. The recoveries of *S. endius* and *S. nigroaenea* represent new distribution records for Canada, though both species were known previously from the northeastern United States (Noyes 2001).

All 15 species reared from natural pupae were previously recorded as parasitoids of muscid filth-breeding flies in North America. Our host record for *S. haematobiae* is based on a single rearing, a female from a pupa of an unidentified Sarcophagidae. The primary host of *S. haematobiae* is the horn fly, *Haematobia irritans* (L.) (Muscidae) (Noyes 2001), but Smith *et al.* (1987) recorded it from the stable fly and Ables and Shepard (1974) reared it as an abundant parasitoid from poultry manure in the apparent absence of *H. irritans*. The other 14 species were reared from one or both of the house fly and stable fly, which together represented 98.3% of all natural hosts from which parasitoids were reared. Eight species were reared also from one or more pupae other than those of the house fly or stable fly. The tentative identifications of these hosts based on pupal and fly remains are as follows, with new host records denoted by an asterisk: ?*Hydrotaea* (*Ophyra*) *leucostoma* (Widemann) (Muscidae) for *M. raptor* and *S. nigra**; ?*Lucilia illustris* (Meigen) (Calliphoridae) for *U. rufipes*; ?*Physiphora demandata* (Fabricius) (Otitidae) for *M. raptor**, *S. cameroni**, *S. nigroaenea**, and *S. subpunctata*; ?*Phormia regina* (Meigen) (Calliphoridae) for *S. nigra** and *U. rufipes**; and ?*Sarcophaga melanura* Meigen (Sarcophagidae) for *M. raptor** and *A. pallipes**.

Parasitism rates

Twice as many parasites were reared from natural house fly and stable fly pupae in 2001 (1532) as were reared in 2000 (736) (Table 1). The greater number of parasitized pupae reflects a 2.4-fold increase in the number of viable pupae collected in 2001 (25,160) compared with 2000 (10,401) (Table 1). Increased effort to collect natural pupae in 2001 undoubtedly partly explains the increase in the number of viable pupae collected, but differences in weather or other conditions between the two years may also have affected fly populations and therefore the ease of locating pupae. Parasitoids were reared from approximately 1.4 times more stable fly than house fly pupae in 2000 (442:313) in contrast to about 1.7 times more house fly than stable fly pupae in 2001 (943:548) (Table 2). The numbers represent a 3-fold increase in the number of parasitoids reared from house fly pupae in 2001 compared with 2000, but only about a 1.25-fold increase in the number of parasitoids reared from stable fly pupae.

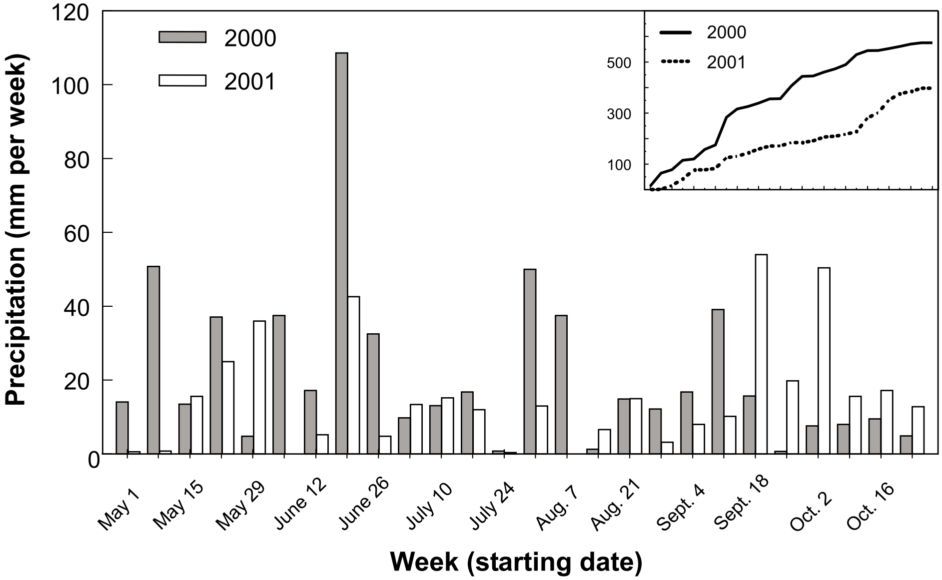

FIGURE 1. Weekly precipitation in Ottawa, Ontario, for 2000 and 2001, from 1 May to 31 October. Inset: cumulative precipitation.

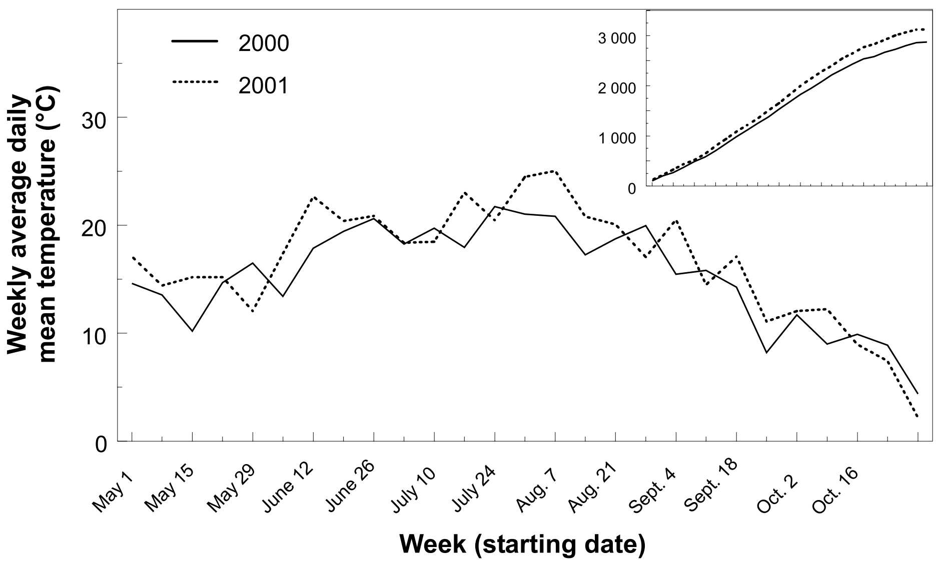

FIGURE 2. Weekly average daily mean temperature in Ottawa, Ontario, for 2000 and 2001, from 1 May to 31 October. Inset: cumulative daily mean temperature.

Differences in recovery were detected for 6 of 14 parasitoid species reared from natural house fly *versus* stable fly pupae (Table 2). For data combined across years, greater than expected numbers of *P. ?fumator*, *S. nigra*, and *U. rufipes* were recovered from stable fly pupae, whereas greater than expected numbers of *M. raptor*, *S. cameroni*, and *S. nigroaenea* were recovered from house fly pupae. For those parasitoid species recovered during both years of the study, the apparent preference for

TABLE 1. Percentage of sentinel (*Musca domestica*) and natural pupae for all species of filth-breeding flies parasitized by parasitoid species in 2000 and 2001 (number of parasitism events in parentheses).

	2000		2001	
Parasitoid species	Sentinel pupae	Natural pupae	Sentinel pupae	Natural pupae
Aphaereta pallipes	0.0 (0)	0.3 (2)	0.0 (0)	1.5 (23)
Phygadeuon ?fumator	0.0 (0)	17.2 (131)	0.0 (0)	11.6 (178)
Muscidifurax raptor	70.9 (122)	10.8 (82)	96.1 (611)	20.1 (308)
Nasonia vitripennis	1.2 (2)	0.0 (0)	0.3 (2)	1.2 (18)
Pachycrepoideus vindemiae	1.2 (2)	0.0 (0)	0.0 (0)	0.1 (1)
Spalangia cameroni	2.9 (5)	12.1 (92)	2.2 (14)	31.7 (486)
Spalangia drosophilae	0.0 (0)	0.1 (1)	0.0 (0)	0.2 (3)
Spalangia endius	0.0 (0)	1.7 (13)	0.0 (0)	1.7 (26)
Spalangia haematobiae	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)
Spalangia nigra	0.6 (1)	39.2 (300)	0.6 (4)	10.4 (159)
Spalangia nigroaenea	0.0 (0)	9.2 (70)	0.0 (0)	18.1 (277)
Spalangia subpunctata	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (6)
Trichomalopsis dubia	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)
Trichomalopsis viridescens	0.0 (0)	0.1 (1)	0.2 (1)	0.1 (2)
Urolepis rufipes	23.3 (40)	9.0 (69)	0.6 (4)	2.9 (45)
Total no. of parasitized pupae	172	736	636	1532
Total no. of pupae examined	51,130	10,401	58,836	25,160
Total parasitism (%)	0.3	7.3	1.1	6.09

one host over the other was consistent between years for all species except *S. cameroni*, which parasitized more stable fly pupae in 2000 but more house fly pupae in 2001.

Only 7 of 13 parasitoid species reared from natural house fly pupae were reared also from sentinel house fly pupae. Furthermore, in both years of the study, parasitism rates of sentinel house fly pupae were much lower than those of natural pupae (Table 1). *Muscidifurax raptor* was the only species that was commonly reared from both natural and sentinel fly pupae. It was by far the most common parasitoid of sentinel pupae in both years, but only the fourth most common parasitoid of natural pupae in 2000 and the second most common parasitoid in 2001. Total percent parasitism by *M. raptor* increased from 2000 to 2001 for both types of pupae, from 70.9% to 96.1% for sentinel pupae and 10.8% to 20.1% for natural pupae. Conversely, parasitism by the only other common parasitoid of both sentinel and natural pupae, *U. rufipes*, decreased from 2000 to 2001, from 23.3% to 0.6% for sentinel pupae and 9.0% to 2.9% for natural pupae.

Unlike sentinel pupae, parasitism of natural pupae was dominated by seven species of *Spalangia*. Three of the species, *S. cameroni*, *S. nigra*, and *S. nigroaenea*, collectively comprised 60.5% and 60.2% of emerged parasitoids in 2000 and 2001, respectively, though recovery rates of each species differed substantially between years (Table 1). The other four species, *S. drosophilae*, *S. endius*, *S. haematobiae*, and *S. subpunctata*, were incidental, together accounting for 2.2% of cumulative parasitism. *Phygadeuon ?fumator* was reared only from natural pupae and accounted for 14.4% of cumulative parasitism, whereas *N. vitripennis*, *P. vindemiae*, and *T. viridescens* were incidental parasitoids of both sentinel and natural pupae (Table 1).

TABLE 2. Differential emergence of parasitoids from naturally occurring pupae of *Musca domestica* (house fly, HF) *versus Stomoxys calcitrans* (stable fly, SF) in 2000 and 2001.

	2000		2001			
Species	HF	SF	HF	SF	χ^2_1	Preference
Muscidifurax raptor	65	17	274	28	161.8	House fly*
Phygadeuon ?fumator	48	81	75	100	28.8	Stable fly*
Spalangia cameroni	35	57	324	161	9.0	House fly†
Spalangia nigra	92	207	41	107	123.1	Stable fly*
Spalangia nigroaenea	56	12	166	95	17.4	House fly*
Urolepis rufipes	11	57	15	28	46.3	Stable fly*
Total no. of host pupae	307	431	895	519		
Total no. of host pupae for all parasitoid species	313	442	943	548		

NOTE: Deviations from random determined for data combined across years (χ^2 analyses). To reduce Type I error rates, only species for which >100 parasitism events were observed were considered. * $P < 0.001$; † $P < 0.01$.

Dissections

During the 9-week collection period for which pupae were dissected, 18,912 pupae were collected from which 12,019 flies and 830 parasitoids emerged for a total of 12,849 viable pupae. The apparent parasitism rate of 6.5% of viable pupae for the period is similar to the rate of 6.1% for the entire season (Table 1). Of the 6063 pupae from which neither a fly or a parasitoid emerged, dissections revealed another 294 recognizable parasitism events, representing an apparent parasitism rate of 4.9% for pupae that were deemed unviable. Consequently, emergence and dissections indicated a minimum parasitism rate of 5.9% for natural pupae (*i.e.*, (830 + 294)/18,912 × 100). Of the 294 parasitism events, 57 parasitoid larvae were unidentified, resulting in only 237 events for which a genus or species identification was possible. The number of events for each species, expressed as a percentage of total observed parasitism in parentheses, is as follows: *Spalangia* spp., 155 (65.4%); *M. raptor*, 34 (14.4%); *P. ?fumator*, 26 (11%); *U. rufipes*, 10 (4.2%); *A. pallipes*, 9 (3.8%); *N. vitripennis*, 2 (0.8%); and *T. viridescens*, 1 (0.4%). A species identification was not made for 62 pupae or pharate adults of *Spalangia* spp., but of the 93 free adults dissected, 84 (90.3%) were *S. nigra*, 4 were *S. cameroni*, and 3 were *S. subpunctata*; there was also 1 specimen each of *S. endius* and *S. nigroaenea*. Of the 84 adult *S. nigra*, 73 (86.9%) were alive; only 3 of the adults were recovered from dissections made 4 months following collection and all were dead. Other than *S. nigra*, only a single specimen of *S. subpunctata*, dissected from a pupa of ?*P. demandata* 4 months after dissection, was found alive. All free adult specimens of *M. raptor* (9), *P. ?fumator* (5), *U. rufipes* (4), *A. pallipes* (7 events), *N. vitripennis* (2 events), and *T. viridescens* (1 event) were dead.

Discussion

Survey results

Both the parasitoid complex recovered and the apparent parasitism rates by species differed substantially depending on the method used to survey hymenopterous parasitoids of filth-breeding flies on dairy farms in eastern Canada. Over a 2-year period, only about half of the species reared from naturally occurring fly pupae were recovered from freeze-killed sentinel pupae. The use of sentinel *versus* natural pupae also appears to overestimate the importance of *M. raptor* and underestimate the importance of *Spalangia* species and *P.* ?*fumator* as parasitoids of filth flies on dairy farms. These results support previous studies of the biological attributes of the different species. Both *M. raptor* and *P. vindemiae* have been shown to accept freeze-killed house fly pupae as readily as fresh pupae (Klunker 1982; Roth *et al.* 1991; Pawson *et al.* 1993), and *Urolepis rufipes* was shown to readily parasitize freeze-killed pupae in the laboratory, though only rarely in the field (Petersen 1986*a*). Conversely, McKay and Galloway (1999*a*) demonstrated that *Phygadeuon* sp. avoided dead hosts: they reared only a single specimen from 22,401 freeze-killed pupae compared with 1998 individuals from 4104 live sentinel pupae. Similarly, Petersen and Pawson (1993) demonstrated that *S. cameroni* exhibited a strong preference for live house fly pupae, and Floate (2002) produced 10-fold fewer females and 20-fold fewer males of *S. cameroni* on freeze-killed than on fresh house fly pupae. Pawson *et al.* (1993) showed that even at twice the parasitoid density, emergence rates of *S. nigroaenea* from dead pupae were much lower than those of *Muscidifurax zaraptor* Kogan *et* Legner or *P. vindemiae*. Other species attributes may also have contributed to the observed results. For example, field studies have shown that *M. raptor* more commonly parasitizes pupae at or within 5 cm of the surface (Rueda and Axtell 1985*a*, 1985*b*; Neves and de Faria 1988), so the use of sentinel pupae, whether fresh or freeze-killed, which typically are placed near the surface of the substrate, may overestimate the prevalence of *M. raptor* relative to some other species. Species of *Spalangia* are capable of considerable penetration into excrement and they appear to be responsible for most parasitism of filth fly pupae below a depth of 3 cm (Legner 1978; Rueda and Axtell 1985*a*; Neves and de Faria 1988).

The relative importance of several of the parasitoid species reared from natural pupae also differed substantially between years. Parasitism rates by *M. raptor*, *S. cameroni*, and *S. nigroaenea* were at least double in 2001 compared with 2000, whereas those of *S. nigra* and *U. rufipes* were 3–4 times lower in 2001 than in 2000 (Table 1). Relative parasitism by *P.* ?*fumator*, the only other common parasitoid, also decreased in 2001 (Table 1). Such variation is to be expected because different species have been shown to have different environmental optima. Several studies have shown that *U. rufipes* more effectively parasitizes house fly pupae in wet habitats (Smith and Rutz 1985, 1991*a*, 1991*b*), and McKay and Galloway (1999*b*) suggested that *P. fumator* preferentially parasitizes pupae in moist versus dry areas. Conversely, Smith and Rutz (1991*c*) showed that parasitism of *M. raptor* is greatest in dry substrates. Observed differences in species abundance between years may have been at least partly influenced by wetter and cooler conditions in the Ottawa area in 2000 relative to 2001 (Figs. 1, 2).

Based on the present study, we conclude that three species of *Spalangia* — *S. cameroni*, *S. nigra*, and *S. nigroaenea* — combine to account for the majority of house and stable fly parasitism on dairy farms in southeastern Ontario and Quebec. Although relative abundance of each species differs between years, the combined total parasitism by *Spalangia* species may be relatively stable, at about 60%. *Muscidifurax raptor*, *P.* ?*fumator*, and *U. rufipes* are also common parasitoids in southeastern Ontario and Quebec, but contribute a much smaller percentage of total parasitism.

Although the use of natural pupae is demonstrably superior to the use of freeze-killed sentinel pupae for estimating parasitoid diversity, perhaps neither method accurately samples true species abundance. Simmonds (1948) and Petersen (1986*b*) discussed several problems with trying to determine parasitism rates using field samples. Our dissections of pupae collected during a 9-week period suggest that our 2-month rearing period was insufficient to recover all *S. nigra* that may have emerged naturally from pupae and therefore underestimated the prevalence of this species. Other human factors related to searching for and observing natural pupae in different substrates undoubtedly also influenced the relative composition of parasitoids reared.

Emergence of parasitoids from naturally occurring pupae collected from fly breeding sites on dairy farms is a less time-consuming and more accurate method of establishing diversity and rates of parasitism by house and stable fly pupal parasitoids than is the use of sentinel pupae. The latter method requires maintaining a fly colony; separating, counting, and bagging the fly pupae; and then placing and retrieving the sentinel bags in the field. A 1-year study using natural pupae probably is sufficient to retrieve all but rare, inconsequential parasitoid species, assuming natural pupae can be found readily on farms. A 1-year study is, however, insufficient to establish longer term fluctuations in species abundances between years. To ensure more accurate estimates of species abundances using natural pupae, all pupae from which flies or parasitoids do not emerge should be dissected for evidence of parasitism.

Comparison of regional faunas

The parasitoid species diversity identified in our survey is similar to the diversity realized from previous studies in Alberta and Manitoba. We recovered 14 species from eight dairy farms in the vicinity of Ottawa, Ontario (about 45°23′N, 75°43′W), whereas McKay and Galloway (1999*a*) recovered 10 species from eight dairy farms near Winnipeg, Manitoba (about 49°–50°N, 95°–97°W). A combined total of 13 species has also been recovered in Alberta, including 7 species from four dairy farms near Lethbridge (about 49°40′N, 112°50′W) (Lysyk 1995) and 12 species from 22 cattle feedlots throughout Alberta (49°28′–56°4′N, 112°40′–118°24′W) (Floate *et al.* 1999). Although the numbers of parasitoid species may be similar among sites in eastern and western Canada, species compositions differ (Floate *et al.* 2002, Table 37.1). Only *M. raptor* is present in the Ottawa area, whereas both *M. raptor* and *M. zaraptor* are present in Alberta and Manitoba. Also missing from our study is *Trichomalopsis sarcophagae* (Gahan), a species indicated to be a common parasitoid of at least house flies in Alberta, though not Manitoba. Conversely, species of *Spalangia* appear to be largely missing from Alberta. Floate *et al.* (1999, 2000) did not recover any *Spalangia* species from feedlots using freeze-killed sentinel house fly pupae, and *S. cameroni* was the only species reared from dairy farms by Lysyk (1995) using live sentinel pupae. *Spalangia drosophilae*, *S. subpunctata*, and *S. erythromera* Förster are present in Alberta, as shown by the rearings of Depner (1968) from horn fly pupae (Peck 1974). McKay and Galloway (1999*a*) also reared *S. nigra* and *S. subpunctata*, in addition to *S. cameroni*, from live sentinel and naturally occurring fly pupae in Manitoba. Consequently, the apparent paucity of *Spalangia* parasitoids of house and stable flies in Alberta may reflect habitat and species composition differences or, at least partly, differences in survey methods. Other than *M. raptor*, the only parasitoid species of significance that are common to both western and eastern Canada are *P. ?fumator* and *U. rufipes*.

Comparisons of the parasitoid fauna discovered in southeastern Ontario and Quebec with that of western Canada suggest that two species, *M. zaraptor* and *T. sarcophagae*, might be investigated for introduction into eastern Canada to enhance natural control of filth-breeding flies, whereas species of *Spalangia* might be introduced into Alberta. Studies in commercial feedlots in Alberta support the potential for commercialization of *T. sarcophagae* as a biocontrol agent (Floate 2003). *Phygadeuon ?fumator* and *U. rufipes* may also have potential for commercialization because both species appear to be transcontinental and common to many livestock-producing regions of the country.

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