Individual and Combined Releases of *Muscidifurax raptor* and *M. raptorellus* (Hymenoptera: Pteromalidae) as a Biological Control Tactic Targeting House Flies in Dairy Calf Facilities

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ABSTRACT The impact of commercially reared house fly parasitoids released into nine dairy calf coverall facilities were evaluated over 3 yr. Individual and equally mixed ratios of the pteromalid parasitoids *Muscidifurax raptor* Girault and Saunders and *M. raptorellus* Kogan and Legner were released at a rate of 500 parasitoids per calf per week for 8 wk. Prerelease, release, and postrelease parasitism was monitored using nearly 100,000 sentinel house fly, *Musca domestica* L., pupae during the 3 yr study. In general, very few adult parasitoids were recovered during the prerelease period and on the no-release farms during any period. However, considerable numbers of *M. raptor* and *M. raptorellus* were recovered from sentinel pupae on respective release farms. As expected, the greatest successful parasitism occurred during release periods, with a drop during postrelease periods. High successful parasitism and uneclosed pupae on *M. raptorellus* release farms suggests that this parasitoid was aggressive in attacking hosts with progeny production at approximately four wasps per pupa. Solitary releases of *M. raptor* provided sentinel mortality between 31 and 38%, whereas sentinel mortality on *M. raptorellus*-release farms was double, at 59–80%. Using mixed releases of the two species, overall fly mortality was slightly lower than that observed on *M. raptorellus*-only farms. This study documents the advantage of releasing *M. raptorellus* rather than *M. raptor* on New York dairy calf facilities, as supported by higher parasitism rates and lower costs (35–75%) for purchase of these gregarious wasps, as 75–80% fewer parasitized pupae are needed to achieve similar adult parasitoid levels.

KEY WORDS *Musca domestica*, Pteromalidae, biological control, dairy, sentinel pupae

House flies, *Musca domestica* L. (Diptera: Muscidae), are important dairy cattle pests across the United States (Miller 1993). House flies harbor disease-causing pathogens and are annoying to animals and farm workers (Greenberg 1971, Butler et al. 2010). Movement by house flies to nonfarm areas continues to be a challenge in increasingly urbanized agricultural areas (Miller 1993). This behavior creates legal challenges and extremely poor community relations (Olejnik 2001).

Previous research has documented that calf areas are the greatest source of fly breeding on dairy farms (Meyer and Shultz 1990). Observed differences that likely lead to successful house fly development in calf areas include; calves that are too small to crush developing fly larvae, accumulating fly developmental media that includes manure and spilled grain mixing with spilled water and urine, farm management practices that use straw bedding over wood chips in calf areas, and a 6–8 wk period between animal introduction and bedding removal (Schmidtmann 1988, 1991; Rutz et al. 1994).

Large, plastic covered, half-hoop structures, resembling greenhouses are now being used for holding large numbers of calves, replacing the use of individual calf hutches on dairy farms. The benefits of these buildings are numerous and include easier animal handling, healthier calves, and easier cleanup; however, there also exists the potential for the development of large numbers of fly pests. Farmers can spend thousands of dollars attempting to control flies in these facilities, usually with insecticides. However, chemical control is limited as house fly populations across the United States have been shown to be resistant to many of the currently registered materials (Scott et al. 1989; Keiding 1999; Kaufman et al. 2001c, 2010; Kaufman and Rutz 2002; Butler et al. 2007).

In the past, biological control of flies on dairy farms relied on either naturally occurring predators and parasitoids or inundative releases of commercially reared parasitoids such as *Muscidifurax raptor* Girault and Saunders or *Spalangia cameroni* Perkins. However, a recent addition to the catalog of commercially

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available parasitoids, and one that has largely been understudied on dairies, is *Muscidifurax raptorellus* Kogan and Legner (Petersen and Currey 1996). This parasitoid has the advantage of producing multiple offspring, which can become established more rapidly and may cost producers less to purchase because of reduced production costs. The primary reason for this is that *M. raptorellus* is a gregarious species, producing more than four offspring per parasitized pupa (Geden and Hogsette 2006). Therefore, if activity is similar, not as many parasitized pupae are needed for farm releases when compared with releases of solitary species, such as the commonly released species *M. raptor.* Studies in poultry facilities and cattle feedlots have documented the benefits and challenges of *M. raptorellus* releases (Petersen and Cawthra 1995; Tobin and Pitts 1999; Floate et al. 2000; Kaufman et al. 2001a,b), but little research has been published on the effectiveness of *M. raptorellus* on dairies (Meyer et al. 1990).

Calf coveralls are fairly new to New York and until the time of this study, we had not had the opportunity to critically evaluate the effectiveness of our dairy fly integrated pest management (IPM) program recommendations under these conditions (Rutz et al. 1994). Preliminary studies examining the release of *M. raptor* during 2000 and 2001 in several calf coveralls documented the dynamics of parasitoids in these facilities (Rutz et al. 2001, 2002). Our results showed that when *M. raptor* was released, it became the predominant species. However, after an unintentional *M. raptorellus* release, this species established itself at a low, but stable population, suggesting its potential as a biological control agent in these systems (Rutz et al. 2004). As a result, in this study we evaluated sustained parasitoid releases of *M. raptor*, *M. raptorellus*, and a combination of the two species in these dairy calf facilities to determine the most appropriate parasitoid release strategy for dairy producers.

Materials and Methods

This study was conducted in nine New York dairy calf holding facilities, commonly called coveralls, in Tompkins, Cayuga, Cortland, and Onondaga counties in 2003, 2006, and 2007. Calf coveralls were plastic covered, half-hoop structures of similar design having calves penned individually or in small groups on opposite sides of the greenhouse with a central alley used for farmer and animal access. During the study, the doors at each end of the greenhouse were open and the sides were rolled up to allow for increased ventilation.

In each year of the study, nine dairy farms were used. Farms that served as no-release farms did not have a history of parasitoid releases. Farms that received *M. raptorellus* in 2003, only received *M. raptorellus*-releases in subsequent years. Farms that received *M. raptor* releases in 2003 became mixed-species release farms in subsequent years. In 2003, the study was conducted from 10 June to 02 September (13 wk). Three farms served as *M. raptor* release farms, three as *M. raptorellus* release farms and three farms served as no release controls. In 2006, the study was conducted from 06 June to 29 August (13 wk). Two farms served as no-release controls; three as *M. raptorellus* release farms and four as *M. raptor* + *M. raptorellus* (MR/MRS) release farms. The 2007 study began on 12 June and concluded on 4 September (13 wk) with a range of 20–85 calves among the farms. Three of these farms again served as no release controls, three as *M. raptorellus* release farms, and three as MR/MRS release farms. Calf numbers during the prerelease weeks ranged from an average of 16–85 among the farms.

Parasitoids were purchased from a commercial insectary (IPM Laboratories, Locke, NY). Current pest management recommendations are based on releasing parasitoid numbers in relation to animal numbers (Rutz et al. 1994). Additionally, because of differing farm sizes and calf numbers on farms, during all 3 yr of the study each release farm received ≈500 parasitoids per calf per week. The release rate for an individual farm was determined by averaging the numbers of calves on the farm during the two prerelease visits and adjusting the numbers of parasitized pupae placed on a farm according to treatment. On MR/MRS farms, parasitoid releases were adjusted such that 50% of the estimated parasitoids released were of each species. Release levels (number of parasitized pupae placed at a farm on a given week) were corrected using information on estimated percent emergence provided by IPM Laboratories to achieve a more precise parasitoid release rate. The actual number of parasitized pupae placed at each farm was adjusted weekly based on the weekly parasitism rates of the to-be-released parasitized pupae, such that a consistent release level of an estimated 500 emergent wasps per calf was maintained between farms, weeks, and years.

Released parasitoids were distributed by Cornell University personnel by shaking the parasitized pupae from a container just inside the calf pen along the length of the active calf areas. Sub-samples of these parasitoid releases were held and checked for emergence and parasitoid purity levels. For all years, parasitism was monitored for 2 wk preparasitoid release, followed by 8 wk of parasitoid releases and 3 wk of postrelease parasitism observations.

House fly pupae used as sentinels were obtained from the Cornell University laboratory colony that had been reared for 25 yr under laboratory conditions (26°C, 45–55% RH, and a photoperiod of 16:8 L:D h). Larvae were reared on a diet of a 2:3:15:8 ratio of calf protein supplement, wood chips, bran, and tap water, respectively, while adults were maintained on water, nonfat dry milk, and sucrose.

Parasitism rates on farms were monitored weekly using the sentinel pupal bag method of Rutz and Axtell (1980). Sentinel bags (10 bags per facility; 8 × 8 cm, mesh density 5.5 squares/cm), each containing 30 live (1–2 d old) house fly pupae, were placed weekly between 2 and 4 cm under the surface of bedding, under and around the calf water, and feed buckets, an area of high potential for fly breeding activity. Each

sentinel bag was enclosed in a 10 × 12 cm metal mesh cage, constructed from honey bee queen excluders, to prevent pupae from being crushed by the calves. Excluders were chained to the front of the calf pen to reduce weekly loss. After a 7-d exposure, pupae were returned to the laboratory, removed from bags and placed into 33 ml plastic cups and uneclosed flies were allowed to emerge. Uneclosed pupae were then individually gelatin capped (size 00, Pyramid, Prescott, AZ) and held for parasitoid emergence. Stable fly sentinel pupae were placed in the same manner at all farms in 2006 and 2007, but because of inconsistent host quality challenges these data were not analyzed.

After a 60-d holding period, the total number of uneclosed pupae, of successfully parasitized pupae, and of emerged parasitoids were recorded. Parasitoids were sexed and identified to species. Percentage of uneclosed pupae (UP) and percent of pupae producing a parasitoid were calculated. The percentage of fly pupae successfully parasitized was calculated by dividing the number of pupae with emergence holes by the total number of pupae retrieved. Residual mortality was characterized as mortality attributed to parasitoid stinging, host feeding and superparasitim of the host but where progeny were not produced (Mann et al. 1990, Petersen and Cawthra 1995), in addition to unknown mortality causes such as pathogens or the environment. Percent residual mortality was determined by subtracting percent successful parasitism (SP) from the corrected percent uneclosed pupae. Each week, 100 house fly pupae from the same cohort used in sentinel bags were held at ambient laboratory temperatures to assess pupal health. These lab-held controls served as the basis for the control mortality calculation. Successful parasitism and uneclosed pupae were corrected for control mortality (Abbott 1925) and percentages were arc-sine transformed for statistical analysis.

Data from the 10 sentinel bags for each treatment on each farm and exposure period were pooled, regardless of analysis. Because the parasitoid release regimes differed between 2003 and the years 2006 and 2007, the 2003 data were analyzed individually, while the 2006 and 2007 data were analyzed as a group. The percentage uneclosed pupae, successfully parasitized, and residual mortality variables for the individual species releases were analyzed using a linear analysis of variance (ANOVA) model, PROC GLM (SAS Institute 2004) to detect differences between the release periods (pre-, post-, and release) within individual parasitoid release regimes and between parasitoid release regimes within release periods. Where appropriate for each analysis, factors included study year, farm, release period, and parasitoid release regime. The variable farm was nested within release period or the parasitoid release regime and the error term for the nested effect was used to determine the F- and *P* values. When appropriate, a Tukey's mean separation was conducted.

Pest and animal management actions taken by producers were documented (i.e., improper disposal of water, etc.) to allow for a better explanation of adult fly population variation among farms. Insecticide applications were used rarely on release farms and when used only nonanimal areas were to be treated. The use of insecticides on all farms was recorded. Parasitoid releases were not allowed on no-release farms.

Results

Overall, producers did a good job of managing moisture in these facilities. Calf bedding was removed, along with the calf when it was ≈6 wks old. Facility designs allowed for moisture to pass through the bedding into a gravel or sand bed allowing additional drying. Management of adult flies on many farms consisted of sticky tapes and traps, large ventilation fans (also for cooling) and use of lime applied to bedding areas. Several producers used insecticide baits in staging areas, jug traps, and in barn aisles. The only use of a residual insecticide occurred in early August 2007 when the 1% permethrin-containing pour-on product Durasect was applied to calves on one *M. raptorellus*-release farm. A dip in parasitism was not observed after these two instances.

One of the three planned no-release farms mistakenly released a mix of *M. raptor* and *M. raptorellus* on 12 June 2006. As a result, this farm was changed from a no release farm to a MR/MRS release farm and data were not included in the affected prerelease analysis. As such, there were two no-release farms and four MR/MRS release farms in 2006. Parasitoid release targets of 500 parasitoids per calf were based on previous-weeks calf counts. Using this approach was found to be fairly accurate with calf numbers changing slightly from week-to-week and this process is representative of what a producer would use to estimate purchases from a commercial insectary.

The number of sentinel pupae placed each year on the nine farms used in this study included ≈5,200 in the prerelease period, 20,500 in the release period and 7,600 in the postrelease period. The number of *M. raptorellus* progeny per SP pupa recovered during the release period averaged between 4.0 and 4.5. These values ranged from 3.3 to 3.9 in the postrelease period. A summation of parasitoid species recovered from house fly pupae are presented (Table 1), and includes many nonreleased, indigenous species. The predominant species recovered on no-release farms was the indigenous *M. raptor.* The brachonid *Apanteles carpatus* (Say) was most frequently recovered during the first year of the project. Although stable fly sentinel pupae data were not analyzed because of quality control issues, several indigenous species were recovered from these sentinels and included small numbers of *A. carpatus* (2), *Nasonia vitripennis* Walker (15), *Pachycrepoides vindemmiae* Rondani (11), *Spalangia drosophilae* Ashmead (5), and one *S. endius* Walker.

In 2003 during the release period, a total of 241 parasitoids were recovered from the three no-release farms, 1,509 parasitoids were recovered on farms where *M. raptor* was released and 13,160 parasitoids were recovered on farms where *M. raptorellus* was released. As expected, in 2003 the majority (87%) of

Table 1. House fly progeny production after parasitism incidents under three release regimes in New York dairy calf facilities

Species	2003			2006			2007		
	None	MR	MRS	None	MRS	MR/MRS	None	MRS	MR/MRS
Muscidifurax raptorellus[a]	6	86	16,967	30	23,630	11,469	121	16,202	11,285
M. raptor	316	1,909	878	405	527	3,826	334	934	2,470
Nasonia vitripennis[a]	14	0	6	0	84	424	69	1	22
Apanteles carpatus	68	52	8	0	0	0	0	5	4
Spalangia spp.	9	7	36	—	—	—	—	—	—
S. endius	—	—	—	2	0	0	0	10	1
S. nigra	—	—	—	9	0	0	0	3	0
S. cameroni	—	—	—	0	0	0	5	5	1
Pachycrepoideus vindemmiae	0	0	0	0	0	0	0	3	0
S. nigripes	—	—	—	0	0	0		1	0
S. nigroaenea	—	—	—	0	0	0		1	0
Total	413	2,054	17,895	446	24,241	15,719	529	17,165	13,783

MR = *M. raptor;* MRS = *M. raptorellus;* MR/MRS = 50% of each species contribution. Parasitoids released at 500 emerging parasitoids per calf per week. Study consisted of 2 wk prerelease, 8 wk release, and 3 wk postrelease periods. Three farms per release type, except in 2006 when two no release and four MR/MRS release farms were used.

[a] *M. raptorellus* is a gregarious species that produced 3.3–4.5 progeny per parasitized pupae. *N. vitripennis* is also gregarious, but progeny per pupa was not tracked.

SP on *M. raptorellus*-release farms during the release period was attributed to this parasitoid. This value dropped to 60% during the postrelease period.

During the 2006 release period, 252 parasitoids were recovered from the two no-release farms, 19,754 parasitoids were recovered from the three *M. raptorellus*-release farms and 12,385 parasitoids were recovered from the four MR/MRS-release farms. On *M. raptorellus*-release farms, 90 and 87% of SP-associated pupae were attributed to this parasitoid during the release and postrelease periods, respectively. On MR/MRS-release farms, 53 and 42% of SP-associated pupae were attributed to *M. raptorellus* during the release and postrelease periods, respectively.

In 2007, 395 parasitoids were recovered during the release period from the three no-release farms, 14,478 from *M. raptorellus*-release farms and 6,407 from MR/MRS-release farms. Successful parasitism values on *M. raptorellus*- and MR/MRS-release farms attributed to *M. raptorellus* were similar to that observed in 2006 (84 and 64% and 55 and 44%) during the release and postrelease periods, respectively.

During the 2003 release period, significantly greater successful parasitism and uneclosed pupae levels ($F_{2,6} = 22.51$; $P = 0.002$) were observed on *M. raptorellus*-release farms as compared with *M. raptor*-release farms (Table 2). On the *M. raptorellus*-release farms, over 50% of sentinel pupae produced parasitoids, while these wasps killed nearly 65% of sentinel pupae. During the 2003 postrelease period, a similar trend was observed, however, no difference in SP or UP was observed between the farms (Table 2).

Successful parasitism was significantly greater ($F_{2,6} = 9.55$; $P = 0.014$) in 2003 in the release period

Table 2. 2003 successful parasitism, parasitoid-induced mortality, and killed sentinel house fly pupae (UP) exposed on dairy cattle farms where two *Muscidifurax* species were released

Parasitism measure	Release type	Mean (SE) percentage			ANOVA
		Prerelease	Release	Postrelease	
SP	None	0.0 (0.00)b	2.5 (0.71)Cab	10.0 (2.40)a	$F_{2,6} = 89.62$, $P < 0.001$
	M. raptor	0.0 (0.00)	21.8 (1.90)B	17.0 (2.83)	NS
	M. raptorellus	0.0 (0.00)c	50.8 (2.21)Aa	39.8 (3.42)b	$F_{2,6} = 9.55$, $P = 0.014$
	ANOVA	NS	$F_{2,6} = 24.05$, $P < 0.002$	NS	
RM	None	8.3 (1.95)	7.2 (0.83)B	8.5 (1.90)	NS
	M. raptor	7.3 (1.64)	16.0 (1.21)A	13.9 (1.84)	NS
	M. raptorellus	11.8 (3.25)	13.8 (0.82)A	18.7 (1.75)	NS
	ANOVA	NS	$F_{2,6} = 7.43$, $P = 0.024$	NS	
UP	None	8.3 (1.95)	9.6 (1.15)C	18.5 (3.14)	NS
	M. raptor	7.3 (1.64)b	37.8 (2.33)Ba	30.9 (3.86)a	$F_{2,6} = 5.52$, $P = 0.044$
	M. raptorellus	11.8 (3.25)	64.6 (2.49)A	58.6 (4.20)	NS
	ANOVA	NS	$F_{2,6} = 22.51$, $P = 0.002$	NS	

NS, not significant. Within a row, means followed by the same lowercase letter are not significantly different ($\alpha = 0.05$, Tukey's honestly significant difference test).

Within a column and parasitism measure, means followed by the same capital letter are not significantly different ($\alpha = 0.05$, Tukey's honestly significant difference test).

SP, successful parasitism and included sentinel pupae from which adult parasitoids were produced; UP, uneclosed pupae were sentinel pupae that did not produce an adult house fly; RM, residual mortality were pupae that neither produced an adult fly nor an adult parasitoid and was calculated as RM = UP-SP.

Table 3. 2006 and 2007 successful parasitism, parasitoid-induced mortality and killed sentinel house fly pupae (UP) exposed on dairy cattle farms where two *Muscidifurax* species were released

Parasitism measure	Release type	Mean (SE) percentage			ANOVA
		Prerelease	Release	Postrelease	
SP	None	1.8 (1.05)	3.8 (0.72)C	6.7 (1.52)	NS
	M. raptorellus	2.6 (1.13)c	56.1 (1.39)Aa	40.8 (2.56)b	$F_{2,6} = 11.45$, $P < 0.009$
	M raptor + *M. raptorellus*	0.5 (0.54)	51.6 (1.36)B	35.4 (2.17)	NS
	ANOVA	NS	$F_{2,6} = 14.92$, $P = 0.002$	NS	
RM	None	14.2 (2.46)	10.8 (1.16)B	22.6 (2.60)	NS
	M. raptorellus	8.5 (1.13)b	24.0 (0.93)Aa	23.1 (1.45)a	$F_{2,6} = 5.64$, $P = 0.042$
	M raptor + *M. raptorellus*	6.1 (0.98)b	22.5 (0.82)Aa	26.2 (1.66)a	$F_{2,6} = 8.51$, $P = 0.008$
	ANOVA	NS	$F_{2,6} = 7.70$, $P < 0.014$	NS	
UP	None	15.9 (2.72)	14.6 (1.41)C	29.3 (3.04)	NS
	M. raptorellus	11.2 (1.62)c	80.1 (1.37)Aa	63.9 (2.99)b	$F_{2,6} = 10.21$, $P = 0.012$
	M raptor + *M. raptorellus*	6.6 (1.26)	74.1 (1.42)B	61.6 (2.67)	NS
	ANOVA	NS	$F_{2,6} = 13.74$, $P = 0.003$	NS	

NS, not significant. Within a row, means followed by the same lowercase letter are not significantly different ($\alpha = 0.05$, Tukey's honestly significant difference test).

Within a column and parasitism measure, means followed by the same capital letter are not significantly different ($\alpha = 0.05$, Tukey's honestly significant difference test).

SP, successful parasitism and included sentinel pupae from which adult parasitoids were produced; UP, uneclosed pupae were sentinel pupae that did not produce an adult house fly; RM, residual mortality were pupae that neither produced an adult fly nor an adult parasitoid and was calculated as RM = UP-SP.

(51%), as compared with the postrelease period (40%) on *M. raptorellus*-release farms (Table 2). Significantly more uneclosed pupae ($F_{2,6} = 5.52$, $P < 0.044$) were observed on *M. raptor* farms during the release and postrelease periods (38 and 31%), as compared with the prerelease period (7%).

Within each release type evaluation of 2006/2007 data, significantly more sentinel pupae were successfully parasitized and had a higher total parasitism (UP) on *M. raptorellus*-release farms during the release period than the postrelease and the prerelease periods (Table 3). Successful parasitism was 56% during the release period but dropped to 41% during the postrelease period ($F_{2,6} = 11.45$; $P = 0.009$). Uneclosed pupae levels fell from 80% during the release period to 64% during the postrelease period ($F_{2,6} = 10.21$; $P = 0.012$). Residual mortality was highest during the release and postrelease periods under both parasitoid release regimes ($F_{2,6} = 5.64$; $P = 0.004$).

Within release period, significantly more sentinel pupae were successfully parasitized ($F_{2,6} = 14.92$; $P = 0.002$) on *M. raptorellus*-release farms (56%), than on MR/MRS-release farms (52%) (Table 3). Similarly, significantly more total parasitism occurred on *M. raptorellus*-release farms, where 80% of sentinel pupae were killed, than on the combination- or the no-release farms ($F_{2,6} = 13.74$; $P = 0.003$). During the postrelease period, over 60% of sentinel pupae were killed, with between 35 and 41% producing viable offspring on the parasitoid-release farms.

Discussion

This study documents the first use of *M. raptorellus* releases in dairy facilities for house fly management wherein *M. raptorellus* was specifically targeted and subsequently recovered in large numbers. Previous studies in dairy (Meyer et al. 1990), in poultry (Tobin and Pitts 1999; Kaufman et al. 2001a,b; Geden and Hogsette 2006) and in cattle feedlots (Floate et al. 2000), have reported differing dispersal patterns and parasitism rates for this species. Meyer et al. (1990) released irregular numbers of *M. raptorellus*, as reported by their insectary, as a shifting value in a multiple parasitoid release on one dairy farm. During their study on a single California dairy they were unsuccessful in recovering *M. raptorellus*. Their limited data and irregular study design makes comparisons to the current study difficult.

Tobin and Pitts (1999) reported little dispersal from release sites by *M. raptorellus*, while Kaufman et al. (2001b) reported <7% *M. raptorellus* parasitism in poultry facilities. In contrast, Kaufman et al. (2001a) demonstrated ≈50% successful parasitism, 88% of which was attributed to *M. raptorellus*. The poultry facility in the Kaufman et al. (2001a) study was a much smaller facility, about twice the size of the coverall facilities used in the current study, perhaps negating the dispersal effects and subsequent lowered parasitism rates observed by Tobin and Pitts (1999) and Kaufman et al. (2001b). Furthermore, Floate et al. (2000) and Petersen and Cawthra (1995) demonstrated dispersal from release sites in open-air cattle feedlots. Although the calf coveralls are enclosed, most have open sides and ends, making them more similar to the feedlots, than the completely enclosed poultry manure pits described previously. Geden and Hogsette (2006) documented that in paired releases with *S. cameroni* in poultry facilities, *S. cameroni* successfully parasitized more sentinel pupae than did *M. raptorellus*, even though *M. raptorellus* was released at a rate of 2.5-fold that of *S. cameroni*.

Debate over the appropriate parasitoid sampling techniques continues and was discussed in Kaufman et

al. (2001a). A holistic approach would include the use of field-collected fly pupae over various ages, perhaps in combination with pupal traps and sentinel pupae, however, this would be a time consuming process and impractical for most situations. Additionally, the use of field-collected pupae can often lead to inconsistent numbers of recovered pupae. Kaufman et al. (2001a) documented that *M. raptorellus* and *N. vitripennis* did not selectively attack either laboratory reared or field produced house fly pupae. Given the limited depth of the substrate in the sampled calf facilities with their 6–8 wk cleanout schedules and the low numbers of *Spalangia* collected (Table 1), the development of a large *Spalangia* community was unlikely to be present. As the current study objective was to document the impact of *Muscidifurax* releases on dairy farms, these species were the focus of a sampling program. Petersen and Cawthra (1995) and Tobin and Pitts (1999) suggest that the sentinel method employed herein provides an accurate representation of parasitoid activity for first-generation releases of *M. raptorellus.*

An effort was made to include stable fly sentinel pupae in 2006 and 2007, however, these data were not included in this analysis. It is important to note that stable fly adults were abundant in these facilities, and larval habitats are appropriate for their development within the calf coveralls. The two *Muscidifurax* species released on these farms are known to attack (Petersen and Cawthra 1995) and even prefer stable fly pupae (Lysyk 2004), perhaps diluting the overall impact of biological control in these facilities as observed only through sentinel house fly sampling.

Kaufman et al. (2002) examined combined (equal) releases of *M. raptor* and *M. raptorellus* in three commercial caged-layer poultry facilities. In these poultry-facilities, SP stabilized near 60% in the postrelease period, with the authors attributing this to progeny recycling. They also scattered parasitized pupae in an effort to overcome the poor dispersal effects reported in previously mentioned literature. In two of the three facilities they studied, *M. raptorellus* was responsible for 34–58% of successful parasitization, while *M. raptor* was recovered from only 3–11% of parasitized pupae. Only in the low house fly larval density facility did *M. raptor* parasitism rise appreciably (31%), but this was far lower than *M. raptorellus* (59%).

In the current study, postrelease SP was much lower (≈40%) than the 60% observed in the high-density house fly poultry facilities, but considerably higher than the low-density poultry facility (≈12%). This may be attributed to differences in poultry and dairy calf coverall management systems, with continual weekly disruption of the calf pens (a pen is cleaned about every 6 wk), leading to disruption of parasitoid cycling and introduction of new favorable fly development habitats.

Although much of the discrepancy in numbers of recovered adult parasitoids can be attributed to parasitism rates, parasitoid biology also plays an important role. *Muscidifurax raptorellus* is a gregarious parasitoid producing as few as 2.7 to as many as 8.6 progeny per parasitized pupa, while *M. raptor* is solitary (Lysyk 2001, 2004). In this study, progeny production from parasitized sentinel pupae was ≈4 *M. raptorellus* per pupa. At higher host densities, *M. raptorellus* has been shown in laboratory studies to distribute its egg allocation among more pupae (Petersen and Currey 1996, Lysyk 2004), suggesting that in this study, proportional host density was lower in the release period as compared with the postrelease period. However, both SP and UP were higher on *M. raptorellus*-release farms, suggesting that *M. raptorellus* was aggressive in attacking hosts.

Given the demonstrated significantly greater parasitism levels of individual *M. raptorellus* releases over individual and paired-releases with *M. raptor*, the current study documents the superiority of individual *M. raptorellus* releases over the previously recommended release of *M. raptor* (Rutz et al. 1994). When *M. raptor* was paired with *M. raptorellus*, the resultant decrease by 50% of *M. raptorellus* individuals in releases decreased the percentage of pupae killed by a few percentage points. That synergism between the *Muscidifurax* species was not observed in paired-releases suggests that the two species may not be complementary to each other. However, two additional outcomes are possible; either *M. raptorellus* efficacy could be maintained with fewer parasitoids released per farm, or that these two species were additive. Further research is needed to distinguish between these possibilities, as a lower *M. raptorellus* release rate would further reduce producer costs for including parasitoid releases into their IPM programs. The impact of these releases on indigenous parasitoids is unclear, as few individuals were captured, even on no-release farms, and their presentation was scattered across release types and years.

The drop in successful parasitism and uneclosed pupae from the release to the postrelease period could be because of several factors, including the inability to maintain a sustained postrelease parasitoid population or that previously parasitized pupae were subsequently killed by multiparasitizing *M. raptor*, a known aggressive species (Wylie 1971, 1972) or a combination of both. Drops in successful parasitism should be expected when releases cease, and this was evident across all treatments in this study. Given that 75% fewer *M. raptorellus* parasitized pupae were released (based on an average of four adult parasitoids per released pupa) than that currently recommended for a *M. raptor*-alone strategy and that fly abundance on open-air dairies is seasonal, producers may see little benefit from using more costly multi-species releases.

Releases of *M. raptorellus*-alone resulted in between 65 and 80% mortality of sentinel pupae, nearly twice that observed with *M. raptor* alone and equivalent to the mixed-release rate for what may be a 35–75% lower cost because of less expensive parasitoid releases. Taking current pricing and packaging options where single species purchases can be requested but are no longer standard, a producer that manages 100 calves over the 12 wk fly season in New York releasing 500 parasitoids per calf per week would expect to spend approximately $1,130.00 for a solitary species, such as

M. raptor. However, many insectaries routinely sell mixtures of gregarious and solitary species in 33:66 or 50:50 ratios, respectively. In such a case, the cost would be approximately $720.00 and $450.00 for the 12 wk release period. The selection of a *M. raptorellus*-only purchase, could cost as little as $280.00 for the 12 wk period, a 75% decrease from a *M. raptor*-only release. Such reduced costs could well encourage more producers to use parasitoids as part of their IPM program.

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