

**PARASITOID WASPS (HYMENOPTERA: PTEROMALIDAE,  
ICHNEUMONIDAE) FOR CONTROL OF HOUSE FLIES AND STABLE FLIES  
(DIPTERA: MUSCIDAE) IN DAIRY OPERATIONS IN MANITOBA**

**BY**

**TANJA MCKAY**

A Thesis  
Submitted to the Faculty of Graduate Studies  
in Partial Fulfillment of the Requirements  
for the Degree of

**MASTER OF SCIENCE**

Department of Entomology  
University of Manitoba  
Winnipeg, Manitoba

© December, 1997



National Library  
of Canada

Acquisitions and  
Bibliographic Services

395 Wellington Street  
Ottawa ON K1A 0N4  
Canada

Bibliothèque nationale  
du Canada

Acquisitions et  
services bibliographiques

395, rue Wellington  
Ottawa ON K1A 0N4  
Canada

*Your file* *Votre référence*

*Our file* *Notre référence*

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-32186-X

Canada

**THE UNIVERSITY OF MANITOBA  
FACULTY OF GRADUATE STUDIES  
\*\*\*\*\*  
COPYRIGHT PERMISSION PAGE**

**PARASITOID WASPS (HYMENOPTERA: PTEROMALIDAE, ICHNEUMONIDAE)  
FOR CONTROL OF HOUSE FLIES AND STABLE FLIES  
(DIPTERA: MUSCIDAE) IN DAIRY OPERATIONS IN MANITOBA**

**BY**

**TANJA MCKAY**

**A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University  
of Manitoba in partial fulfillment of the requirements of the degree  
of  
MASTER OF SCIENCE**

**Tanja McKay      ©1998**

**Permission has been granted to the Library of The University of Manitoba to lend or sell  
copies of this thesis/practicum, to the National Library of Canada to microfilm this thesis  
and to lend or sell copies of the film, and to Dissertations Abstracts International to publish  
an abstract of this thesis/practicum.**

**The author reserves other publication rights, and neither this thesis/practicum nor  
extensive extracts from it may be printed or otherwise reproduced without the author's  
written permission.**

## ACKNOWLEDGMENTS

First I would like to thank my advisor, Dr. Terry Galloway, for his generous support throughout my program. I thank him for his enthusiasm and introducing me to livestock entomology.

My sincere thanks to my committee members Drs. Rob Currie and Ray Ingalls, and Dr. Neil Holliday for his statistical advice. I wish to thank Drs. Gary Gibson and John Barron from the Canadian National Collection, Agriculture and AgriFood Canada, Ottawa, for identifying voucher specimens from 1994 and 1995.

I thank Danielle DeGagne, Debra Wytrykush and David Puff for their long hours in the field and lab. I would also like to thank Ginger Gill and Lisa Babey for helping out with the colonies, and Heather White in pinning the parasitoids. Thanks to the entire Department of Entomology who made my experience at U of M so enjoyable.

I must mention the generosity of the many dairy producers throughout Manitoba that made this project a reality: Jules Stengel, Vince Staerk, Bernie Wiens, David VanWalleghem, Wilf Holme, Dietmar Dueck and John Schroeder.

I would like to acknowledge CMAAS (Canada Manitoba Agreement on Agriculture Sustainability) and Manitoba Department of Agriculture for funding this project.

Last, but not least, thank you Mom for the valuable translations, and Dad for introducing me to the fascinating world of insects. Thank you both for your encouragement throughout my studies.

## ABSTRACT

In 1995, eight Manitoba dairies were chosen to evaluate the release of commercially available parasitoid wasps on house flies and stable flies. Four farms were used as release sites, while four farms were used as controls. Although *Nasonia vitripennis* (Walker) and *Muscidifurax zaraptor* Kogan & Legner were promised by the supplier, only *N. vitripennis* was present in subsamples. Numbers of parasitoids in bags within shipments were not significantly different and an average of  $67.7 \pm 2.2\%$  of pupae per bag were parasitized. Per cent parasitism among shipments was significantly different. On average, each bag contained  $91,202 \pm 6,577$  parasitoids. An estimated 3,648,093 parasitoids were released at four farms from 10 July to 10 September, 1995. Of the *N. vitripennis* released, 41% were females.

For the release farms, of the 10,622 previously frozen sentinel pupae recovered, 843 (7.9%) were parasitized. Only 223 (26.5% of the parasitized pupae) pupae were parasitized by *N. vitripennis*. *Urolepis rufipes* (Ashmead), *Muscidifurax raptor* Girault and Sanders, *M. zaraptor* Kogan and Legner, *Trichomalopsis* sp., *Muscidifurax* that could not be identified to species, *Spalangia subpunctata* Först, *Eupelmus vesicularis* (Retzius) and those parasitoids which could not be identified, accounted for 40.5, 18.6, 6.6, 3.7, 0.8, 0.4, 0.3 and 2.4% of the parasitized pupae, respectively. *Phygadeuon fumator* Gravenhörst and a Staphylinidae each accounted for 0.1% of the parasitoids. For non-release farms, of the 11,779 sentinel pupae retrieved, 129 (1.1%) were

parasitized. Only 11.6% of parasitized pupae contained *N. vitripennis*. *Urolepis rufipes*, *Trichomalopsis* sp. and *M. raptor* parasitized 53.5, 13.2 and 8.5% of the parasitized pupae. 13.2% of the parasitoids could not be identified.

For the 11,897 naturally occurring pupae collected at the release farms, 472 (4.0%) were parasitized. *Nasonia vitripennis* was reared from 76 (16.1%) of the parasitized pupae. *Muscidifurax raptor*, *P. fumator*, *U. rufipes*, *Spalangia cameroni* Perkins, *Spalangia nigra* Latreille, *S. subpunctata*, *M. zaraptor* and *Trichomalopsis* sp. accounted for 19.5, 19.1, 11.2, 10.8, 10.2, 5.7, 3.4 and 0.4% of the parasitized pupae, respectively. 3.6% of the parasitoids could not be identified. For the non-release farms, of the 8,384 fly pupae collected, 319 (3.7%) were parasitized. But *N. vitripennis* only parasitized one pupa (0.3% of the parasitized pupae). *Phygadeuon fumator*, *U. rufipes*, *M. zaraptor*, *S. cameroni*, *S. subpunctata*, *M. zaraptor*, *S. nigra* and *Muscidifurax* that could not be identified to species accounted for 73.7, 7.2, 7.2, 4.4, 2.5, 1.6, 0.9 and 0.3% of the parasitoids, respectively. 1.9% of the parasitoids could not be identified.

In 1996, 50,842 live sentinel pupae were retrieved from two non-release farms and 2,052 (4.0%) were parasitized. *Phygadeuon fumator*, *S. cameroni*, *Muscidifurax* spp., *U. rufipes*, *S. nigra*, *S. subpunctata* and *M. raptor* accounted for 97.4, 0.6, 0.4, 0.2, 0.1, 0.05 and 0.05% of the parasitized pupae, respectively. Unknown parasitoids accounted for 1.3%. Of the 4,691 naturally occurring pupae collected in 1996, 442 (9.4%) were parasitized. *Phygadeuon fumator*, *S. nigra*, *S. cameroni*, *Muscidifurax* spp. (that could not be identified), *S.*

*subpunctata*, *M. raptor*, *Aphaereta* sp. and a figitid accounted for 79.9, 5.4, 3.6, 1.4, 1.1, 0.9, 0.5 and 0.2% of the parasitized pupae, respectively. 7.0% of parasitoids could not be identified. Of the 12,376 sentinel larvae retrieved, none were parasitized.

A laboratory experiment was conducted to determine if *P. fumator* preferred to attack house fly pupae or larvae. One female *P. fumator* was given access simultaneously to ten pupae and ten 3<sup>rd</sup> instar larvae. Observations on parasitoid location were recorded every 60 seconds for one hour. 52.2 and 5.8% of observations were taken when females were in contact with containers of pupae and larvae, respectively.

At 22°C, males of *P. fumator* had significantly shorter development times ( $24.8 \pm 0.1$  days, 14 to 35 days; n=615) than females ( $26.5 \pm 0.2$  days, 18 to 35 days; n=147).

Some *P. fumator* did not emerge immediately and entered what seemed to be a larval diapause. Sentinel and naturally occurring pupae, which were still intact after 60 days, were dissected. There was a significant difference in the distribution of developmental stages of *P. fumator* found in naturally occurring and sentinel pupae (chi-square=428.3, df=2.0, P < 0.001). For sentinel pupae, 75.8% were larvae, 9.3% were pupae and 14.9% emerged as adults. For naturally occurring pupae, 29.5% of *P. fumator* were larvae, 5.9% were pupae and 64.6% emerged as adults.



## TABLE OF CONTENTS

	PAGE
ACKNOWLEDGMENTS .....	ii
ABSTRACT .....	iv
TABLE OF CONTENTS .....	vii
LIST OF TABLES .....	x
LIST OF FIGURES .....	xii
LIST OF APPENDICES .....	xv
CHAPTER I	
General introduction .....	1
CHAPTER II	
Review of pertinent literature .....	7
History of biological control in livestock facilities .....	7
Hymenopterous parasitoids attacking muscoid flies associated with livestock .....	9
I. <i>Spalangia</i> spp .....	9
II. <i>Muscidifurax</i> spp .....	10
III. <i>Nasonia vitripennis</i> .....	11
IV. <i>Phygadeuon</i> spp .....	13
Surveys of indigenous parasitoids .....	14
Parasitoid release programs .....	19
Conclusion .....	27
CHAPTER III	
Survey and release of parasitoid wasps (Hymenoptera: Pteromalidae, Ichneumonidae) of house flies and stable flies (Diptera: Muscidae) in dairy operations in Manitoba .....	31
ABSTRACT .....	31
INTRODUCTION .....	33
MATERIALS AND METHODS .....	35
Locations .....	35

I. 1995 .....	35
II. 1996 .....	37
Parasitoid release - 1995 .....	37
Rearing house flies .....	40
Determination of parasitoid activity .....	41
I. Sentinel pupae .....	41
II. Naturally occurring pupae .....	42
III. Monitoring of adult flies .....	43
Prevalence of <i>P. fumator</i> .....	44
RESULTS .....	44
Parasitoid release - 1995 .....	44
Determination of parasitoid activity .....	47
I. Sentinel pupae .....	47
II. Naturally occurring pupae .....	49
III. Monitoring of adult flies .....	52
Prevalence of <i>P. fumator</i> .....	53
I. Naturally occurring pupae - 1995 .....	53
A. Stengel farm .....	53
B. Staerk farm .....	54
II. Naturally occurring pupae - 1996 .....	54
A. Stengel farm .....	54
B. Staerk farm .....	55
III. Sentinel pupae - 1996 .....	56
A. Stengel farm .....	56
B. Staerk farm .....	56
DISCUSSION .....	57
Parasitoid release - 1995 .....	57
Parasitoid species .....	62
Prevalence of <i>Phygadeuon fumator</i> .....	65
CONCLUSION .....	67

## CHAPTER IV

Biology of <i>Phygadeuon fumator</i> Gravenhörst (Hymenoptera: Ichneumonidae) a parasitoid of house flies and stable flies (Diptera: Muscidae) .....	111
ABSTRACT .....	111
INTRODUCTION .....	112
MATERIALS AND METHODS .....	113
Locations .....	113
Sentinel pupae and larvae .....	113
Naturally occurring pupae .....	115
<i>Phygadeuon</i> choice experiment .....	115
<i>Phygadeuon</i> colony .....	116
RESULTS .....	117
Sentinel pupae and larvae .....	117
Naturally occurring pupae .....	118
<i>Phygadeuon</i> choice experiment .....	119
<i>Phygadeuon</i> colony .....	120
DISCUSSION .....	121
Sentinel pupae .....	121
Naturally occurring pupae .....	122
<i>Phygadeuon</i> colony .....	125
<i>Phygadeuon</i> choice experiment .....	127

## CHAPTER V

General discussion .....	131
Future research using <i>Phygadeuon fumator</i> .....	135
LITERATURE CITED .....	136

## LIST OF TABLES

TABLE	PAGE
1. Insect parasitoids associated with house flies and stable flies in North America .....	29
2. The effectiveness of parasitoid inundative release programs against muscoid flies .....	30
3. Estimated numbers of parasitized pupae, <i>Nasonia vitripennis</i> (Walker), mean intensity (number of parasitoids per parasitized pupa), number of adult wasps and number of females distributed in Manitoba dairies between July and 10 September, 1995. ....	69
4. Mean ( $\pm$ S.E) and range of intensity for <i>Nasonia vitripennis</i> (Walker) for shipments received from 7 July to 30 August, 1995 .....	70
5. Number and prevalence of parasitoids <sup>a</sup> reared from previously frozen sentinel pupae on each farm in Manitoba from 5 July to 21 September, 1995 .....	71
6. Number and prevalence of parasitoids <sup>a</sup> reared from live sentinel pupae per farm in Manitoba from 13 May to 17 October, 1996 .....	72
7. Number of house fly, stable fly and parasitized pupae collected at dairy farms in Manitoba from 5 July to 21 September, 1995 .....	73
8. Number and prevalence of parasitoids <sup>a</sup> collected from naturally occurring pupae per dairy farm in Manitoba from 5 July to 21 September, 1995 .....	74
9. Number and prevalence of parasitoids <sup>a</sup> collected from house fly and stable fly pupae per farm in Manitoba from 13 May to 17 October, 1996 .....	75
10. Number of house fly, stable fly and parasitized pupae collected per dairy farm in Manitoba from 13 May to 17 October, 1996 .....	76

11. Number of observations and percentage of time female *Phygadeuon fumator* Gravenhörst were found in larval dishes, in pupal dishes or in neither. Twenty-seven females were used in the choice experiment. Of the 27 females, 16 were collected in the field and 11 were from a colony. All females were assumed mated. One observation was taken every 60 seconds . . . . . 128

## LIST OF FIGURES

FIGURE	PAGE
1. One bag containing approximately 250 g of parasitized house fly pupae mixed with wood shavings. Parasitoids were purchased from Manbico Biological Ltd., Winnipeg, MB .....	78
2. Falcon® 96-well Micro Test III™ tissue culture plate containing 96 house fly pupae .....	80
3. Open sentinel container (16.0 x 9.0 x 3.5 cm), made out of aluminum window screening containing 96 previously frozen sentinel house fly pupae .....	82
4. 450 ml plastic container containing at least 100 live one-day-old house fly pupae or 3 <sup>rd</sup> instar house fly larvae (>100) and a garden claw used for sampling .....	84
5. White paper strip measuring 4 x 20 cm hung 1.5 m off the floor to monitor adult house fly populations. Fly specks were counted to estimate relative fly activity .....	86
6. Mean number ( $\pm$ S.E.) of parasitized pupae per bag received each shipment date from 7 July to 30 August, 1995. House fly pupae were parasitized by <i>Nasonia vitripennis</i> (Walker). Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison) .....	88
7. Prevalence ( $\pm$ S.E.) of <i>Nasonia vitripennis</i> (Walker) per bag for each shipment received from 7 July to 30 August, 1995. Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison) .....	90
8. Mean number ( $\pm$ S.E.) of parasitized pupae per bag released each week from 10 July to 10 September, 1995. House fly pupae were parasitized by <i>Nasonia vitripennis</i> (Walker). Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison) .....	92

9.	Frequency distribution of <i>Nasonia vitripennis</i> (Walker) for five shipments received from Manbico from 7 July to 30 August, 1995. Number of house fly pupae examined = 2083	94
10.	Mean number ( $\pm$ S.E.) of female <i>Nasonia vitripennis</i> (Walker) per bag for each shipment received from 7 July to 30 August, 1995. Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison)	96
11.	Frequency distribution of <i>Nasonia vitripennis</i> (Walker) reared from previously frozen sentinel pupae from 5 July to 21 September, 1995. Number of pupae examined = 223	98
12.	Frequency distribution of <i>Nasonia vitripennis</i> (Walker) collected from release farms in Manitoba from 5 July to 21 September, 1995. Number of naturally occurring pupae examined = 76	100
13.	Mean number ( $\pm$ S.E.) of fly specks per strip for four farms where <i>Nasonia vitripennis</i> (Walker) was released and four non-release farms. Fifteen strips were placed at each farm for each week from 13 July to 17 September, 1995. The number of fly specks between release and non-release farms were not significantly different on 25 August and 17 September ( $p < 0.05$ )	102
14.	Mean numbers ( $\pm$ S.E.) of house fly and stable fly pupae collected for five locations at the Staerk farm from 5 July to 14 September, 1995	104
15.	Mean numbers ( $\pm$ S.E.) of house fly and stable fly pupae collected for five locations at the Stengel farm from 5 July to 14 September, 1995	106
16.	Mean numbers ( $\pm$ S.E.) of house fly and stable fly pupae collected for five locations at the Stengel farm from 13 June to 17 October, 1996	108
17.	Mean numbers ( $\pm$ S.E.) of house fly and stable fly pupae collected for five locations at the Staerk farm from 13 June to 17 October, 1996	110

18. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages reared from sentinel pupae at the Staerk and Stengel farms from 6 June to 17 October, 1996. Intact pupae were dissected after 60 days. All adults had emerged from puparia . . . . . 130
  
19. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages reared from naturally occurring pupae at the Staerk and Stengel farms from 6 June to 17 October, 1996. Intact pupae were dissected after 60 days. All adults had emerged from puparia. Few pupae were collected before 8 July . . . . . 130



## LIST OF APPENDICES

APPENDIX	PAGE
I. Mean number ( $\pm$ S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth in naturally occurring pupae collected per sample location at the Stengel farm from 5 July to 14 September, 1995. Five locations were sampled . . . . .	145
II. Mean number ( $\pm$ S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth in naturally occurring pupae collected per sample location at the Staerk farm from 5 July to 14 September, 1995. Five locations were sampled . . . . .	146
III. Mean number ( $\pm$ S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth in naturally occurring pupae collected per sample location at the Stengel farm from 13 June to 17 October, 1996. Five locations were sampled . . . . .	147
IV. Mean number ( $\pm$ S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth in naturally occurring pupae collected per location at the Staerk farm from 13 June to 17 October, 1996. Five locations were sampled . . . . .	149
V. Mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth from sentinel pupae retrieved per location at the Stengel farm from 3 June to 17 October, 1996. Mean number ( $\pm$ S.E.) of sentinel pupae included. Three locations sampled . . . . .	151
VI. Mean number ( $\pm$ S.E.) and prevalence ( $\pm$ S.E.) of <i>Phygadeuon fumator</i> Gravenh6rsth from sentinel pupae retrieved per location at the Staerk farm from 13 June to 17 October, 1996. Mean number ( $\pm$ S.E.) of sentinel pupae included. Three locations sampled. . . . .	153

VII. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages every two weeks. Parasitoids collected from sentinel pupae retrieved at the Staerk farm from 6 June to 17 October, 1996. Sentinel pupae were placed at each location for 3 to 4 days ..... 155

VIII. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages every two weeks. Parasitoids collected from sentinel pupae retrieved at the Stengel farm from 6 June to 17 October, 1996. Sentinel pupae were placed at each location for 3 to 4 days ..... 156

IX. Developmental stages of *Phygadeuon fumator* Gravenhörst from house fly pupae which were parasitized in the lab ..... 157

## CHAPTER I

### GENERAL INTRODUCTION

The house fly, *Musca domestica* L., and stable fly, *Stomoxys calcitrans* (L.) are major pests associated with domestic livestock production (Glofcheskie and Surgeoner 1993; Burg *et al.* 1990). With a cosmopolitan distribution (Black and Krafur 1985), these synanthropic flies can occur in large numbers around livestock facilities where they breed in accumulations of organic waste and manure (Keiding 1974).

The number of flies is determined by environmental conditions such as temperature, moisture of breeding habitat, humidity and natural enemies (Axtell 1986). House flies have a great reproductive potential. One female house fly lays 500 to 900 eggs (Legner and Brydon 1966; Bay and Harris 1988) and the number of generations per year may vary from about 30 under tropical conditions, to 10 or less in temperate climates (Keiding 1974). Because of overlapping generations and rapid development (7-10 days egg to adult), large fly populations develop quickly and are sustained as long as temperatures are high (Axtell 1986).

The potential for increase in fly numbers is enormous, but dependent on the amount of manure available. One kilogram of medium can produce 5,000 - 10,000 flies (Keiding 1974). Since livestock facilities are artificial environments with large accumulations of manure, many flies and generations per year occur (Axtell 1986).

House flies are considered a nuisance. They annoy confined livestock and residents living in the vicinity of livestock operations (Greene 1990). Feeding primarily on the excreta of domestic animals and decaying organic matter, *M. domestica* is a potential vector of various microbes (Greenburg 1971). House flies can carry many pathogens both externally, on the mouthparts, body hairs and pulvilli of the feet, and internally in the crop and intestinal tract (Keiding 1974). They carry diseases such as mastitis, pinkeye and Newcastle disease and serve as intermediate hosts of stomach worms of horses (Bay and Harris 1988).

The adult stable fly can be readily distinguished from the house fly by its piercing mouthparts (Axtell 1986). It is a vicious biter that draws blood quickly and feeds in 3 to 4 minutes if undisturbed (Harwood and James 1979). It attacks the lower body and limbs of livestock (Kettle 1990). The stable fly is a more serious pest, with the bite resulting in pain and blood loss (Wieman *et al.* 1992). Cattle in confinement suffer considerable irritation when stable flies attempt to take their blood meals (Greene 1990) and expend energy to avoid bites by foot stomping, tail switching and tossing their heads. These behaviours can increase heat stress which accounts for weight loss (Wieman *et al.* 1992) and a decrease in milk production (Burg *et al.* 1990).

The effect of arthropod pests on weight gain and milk production in cattle is difficult to determine. However, estimated annual losses are \$398.9 million caused by the stable fly (Burg *et al.* 1990) and \$60 million caused by the house

fly in the United States (Glofcheskie and Surgeoner 1993). Dairy operators expend considerable effort to maintain their barns relatively free of flies (Andress and Campbell 1994). They use a combination of three control strategies: cultural, chemical and biological control (Axtell 1986).

Cultural control involves the manipulation of abiotic factors that eliminates breeding sites. This means proper management of the facilities (Axtell 1986) by removing spilled feed and manure frequently (Glofcheskie and Surgeoner 1993). In dairy operations, daily removal of manure from the holding pens should be carried out, including a complete wash down of the milking parlour (Lancaster and Meisch 1986). Fly control and manure management are closely related problems, with good manure management eliminating habitat for larvae (Glofcheskie and Surgeoner 1993). However, seasonal crop-production often receives higher priority than animal waste removal, allowing manure to accumulate (Andress and Campbell 1994). Therefore, flies are a time management problem, with producers often depending on the application of insecticides for effective control.

Chemical control products registered for fly control in Canada include insecticides as space sprays, baits or residuals (Glofcheskie and Surgeoner 1990). The use of insecticides in management programs for dairy farms is becoming more costly, more regulated (Geden *et al.* 1992) and is not always desirable (Andress and Campbell 1994). Insecticide resistance among flies, especially the house fly, has developed rapidly (Axtell 1986). With increasing

insecticide resistance, the number of effective chemicals available is diminishing (Geden *et al.* 1992).

With increasing insecticide resistance, and unfavourable attitudes towards residues in dairy and meat products (Pickens *et al.* 1967), producers are implementing biological control agents into their fly management programs. The most common biological control agents for house flies and stable flies are parasitoid wasps. These wasps lay their eggs on a fly pupa by piercing the puparium with their ovipositor. The parasitoid egg hatches and the larva develops within the puparium feeding on and killing the fly. The parasitoid pupates and three weeks later emerges as an adult (Axtell 1986). Most parasitoids attacking house flies and stable flies in North America are believed to have originated in the Old World, but they were introduced into the Western Hemisphere by humans as a result of shipping and migration (Legner and Brydon 1966).

In the United States, several species of Pteromalidae (Hymenoptera) have been mass released to reduce fly populations in livestock production systems (Rueda and Axtell 1985). These commercially available parasitoids and those occurring naturally may be an effective complement to cultural management practices (Smith and Rutz 1991a) by contributing to fly pupae mortality (Petersen and Meyer 1983). *Muscidifurax raptor* Girault and Sanders, *Spalangia nigroaenea* Curtis (Andress and Campbell 1994), *S. endius* Walker (Morgan and Patterson 1990) and *Nasonia vitripennis* Walker (Stage and

Petersen 1981) have been used in release programs.

In general, little research has been published concerning parasitoid use for house fly and stable fly control in Canada. Lysyk (1995) examined the parasitoids of filth fly pupae at dairies in Alberta and collected: *Muscidifurax raptor*, *M. zaraptor* Kogan & Legner, *Trichomalopsis* sp., *Urolepis rufipes* (Ashmead), *Phygadeuon* sp., *Spalangia cameroni* Perkins and *Dibrachys cavus* (Walker). The life histories of *Muscidifurax* spp. and *Spalangia* spp. have been well documented, but there is little information on *U. rufipes*, *Trichomalopsis* sp. and *Phygadeuon* sp.

There are only two references to the biology of *Phygadeuon fumator* Gravenhörst. Müller (1971) studied its biology on cabbage maggot (*Phorbia brassicae* Bouché), while Blanchot (1988) was the first to examine *Phygadeuon* as a parasitoid of *M. domestica*. References to *Phygadeuon* sp. in parasitoid surveys are only made in passing, with the species not known.

Many studies have been conducted in the US to evaluate the effectiveness of these wasps. However, in Canada, efficacy data on parasitoid release programs do not exist. Suppliers are persuading producers to adopt parasitoids into their fly management programs without evidence that they are effective for fly control. Therefore, the main objective of this study was to evaluate the effectiveness of parasitoid release for the control of house flies and stable flies. Since little is known about the parasitoid species that occur in Canada, we were also interested in determining the species that occur naturally

in Manitoba dairy operations. In a preliminary study conducted in 1994, *Phygadeuon fumator* was abundant at some farms, therefore we also wanted to examine its biology in the field and laboratory.



## **CHAPTER II**

### **REVIEW OF PERTINENT LITERATURE**

The biological control of insects has received considerable attention and produced highly successful and practical results (Debach 1965). Over two-thirds of the cases of successful biological control of insect-pest involve the use of hymenopterous parasitoids (Debach 1974). One family of Hymenoptera, the Pteromalidae (Chalcidoidea), plays an important role as control agents against muscoid flies (Rueda and Axtell 1985). Parasitoid surveys and efficacy trials on parasitoid releases have been conducted in livestock facilities in the US (Legner and Brydon 1966; Legner and Olton 1968), but the effectiveness of these biological control agents in an integrated pest management system is debatable. The following is a review of the use of parasitoid wasps to control muscoid flies in confined livestock facilities.

#### **HISTORY OF BIOLOGICAL CONTROL IN LIVESTOCK FACILITIES**

One of the first attempts at an inundative release program using pteromalid wasps was conducted in Australia in 1917. *Nasonia vitripennis* was released to control *Lucilia sericata* (Meig.), the British sheep maggot fly, and *Sarcophaga haemorrhoidalis* (Fall.), the Australian sheep maggot fly. From November, 1917 to February, 1918, 164 packets containing 10,000 parasitoids each were released in hopes of solving the fly problem. Results were disappointing. Host pupae were unattainable or the wasps were becoming

trapped inside the fly's tough puparium. In addition, the wasps also attacked beneficial Syrphidae, larvae which are predaceous on aphids (Whiting 1967).

During World War II, many residual insecticides were developed. One chemical, DDT provided effective against many pests including human body lice, mosquitoes and muscoid flies (Harwood and James 1979). Many dairy farmers neglected sanitation in fly control programs due to the simplicity of applying chemical insecticides (Pickens *et al.* 1967). With repeated use, often on fixed schedules, fly populations gradually became resistant to DDT (Doutt and Smith 1971; Keiding 1974). By 1971, 105 species of insects of public health and veterinary importance had developed resistance to one or more groups of insecticides (Harwood and James 1979). In addition, low tolerances for residues of insecticides in milk and meat made it necessary to reappraise nonchemical methods of fly control in dairy and beef facilities (Pickens *et al.* 1967).

Due to studies on the ecology, behaviour and control of flies, it was eventually recognized that livestock facilities were complex ecosystems (Anderson 1965). Anderson (1964) examined accumulations of chicken droppings and found various natural enemies of flies including nematodes, mites, spiders and parasitoid wasps. With new species to be discovered, investigations into the activity of muscoid parasitoids and predators were conducted throughout the Western and Eastern Hemispheres (Mourier and Hannine 1969). The ecology and field biology of many hymenopterous parasitoids were examined to determine life history and host-parasitoid

relationships (Gerling and Legner 1968).

In 1962, the European Parasite Laboratory was involved in foreign exploration and importation of filth fly parasitoids into the United States (Hoyer 1981). As more parasitoid species were recognized and their biologies determined, many parasitoids were reared in the laboratory (Beard 1964; Morgan *et al.* 1975). In the 1960's, parasitoids became commercially available to producers (Axtell 1997 personal communication), allowing them to be implemented into an integrated fly control program (Axtell 1986).

## **HYMENOPTEROUS PARASITIDS ATTACKING MUSCOID FLIES ASSOCIATED WITH LIVESTOCK**

The majority of parasitoid wasps attacking muscoid flies generally lay one egg on a fly pupa. However, a few species, such as *Nasonia vitripennis*, are gregarious, laying many eggs. The parasitoid larvae feed on the fly pupae, pupate, then emerge as adults (Axtell 1986). A single host is sufficient to complete development of the parasitoid(s) (Huffaker *et al.* 1974).

### **I. SPALANGIA SPP.**

Some of the most commonly encountered pupal parasitoids of filth flies in North America belong to the genus *Spalangia* Latreille (Propp and Morgan 1985) (Table 1). This genus has nine species, including *Spalangia endius* Walker, *S. cameroni* Perkins, *S. haematobiae* (Ashmead), *S. nigra* Latreille and *S. nigroaenea* Curtis. This genus is cosmopolitan (Rueda and Axtell 1985).

*Spalangia* spp. forage through different levels in manure to attack otherwise inaccessible hosts (Legner and Olton 1968). Adults can be found primarily in the upper five cm of manure, but may penetrate as deep as ten cm below the surface (Rueda and Axtell 1985). *Spalangia cameroni* and *S. endius* have a broad niche with neither moisture nor dryness influencing their distribution (Legner 1977).

*Spalangia* spp. have a wide host range. In Texas, *Spalangia* spp. parasitize up to 10 species of flies (Blume 1987). Studies on host usage have also been conducted on filth flies in confined livestock operations. King (1990) found no significant difference in the preference of *S. endius* and *S. cameroni* for house fly or stable fly pupae.

## II. *MUSCIDIFURAX* SPP.

*Muscidifurax raptor* and *M. zaraptor*, like most pteromalids that attack muscoid pupae, are solitary and ectophagous. The larva kills the host and feeds externally on the host pupa within the puparium (Rueda and Axtell 1985).

*Muscidifurax* spp. are easily collected from host pupae located near the surface of the breeding habitat (Legner 1977); adults penetrate up to five cm in search of their hosts (Rueda and Axtell 1985). *Muscidifurax raptor* is very abundant throughout Europe (Legner and Olton 1968) and the Western Hemisphere. It is nearly cosmopolitan, but has not been reported from Asia. Only known to occur in North America (Rueda and Axtell 1985), *Muscidifurax zaraptor* was first

described in 1970 by Kogan and Legner.

*Muscidifurax* spp. attack a variety of hosts. They parasitize the puparia of the face fly, *Musca autumnalis* De Geer (Skoda et al. 1987), *Musca domestica* and *Stomoxys calcitrans* (King 1990). They also parasitize Sarcophagidae and Calliphoridae (Rueda and Axtell 1985).

Mandeville and Mullens (1990) studied host preference in *M. zaraptor* with regard to the hosts *M. domestica* and *Fannia canicularis* (L.). In this study, *M. zaraptor* preferred to oviposit on *M. domestica* rather than *F. canicularis* when given a choice between equal numbers of each species. However, if young females first feed or oviposit on *F. canicularis*, they will select that host over *M. domestica*. King (1990) examined species usage for *M. raptor* using *M. domestica* and *S. calcitrans* as hosts. *Muscidifurax raptor* emerged more often from house fly pupae than from stable fly pupae.

### III. *NASONIA VITRIPENNIS*

*Nasonia vitripennis*, cosmopolitan in distribution (Reuda and Axtell 1985) has been used extensively in ecological, genetic, behavioral and evolutionary research (Darling and Werren 1990). It has been reported to parasitize the pupae of 68 species of Diptera in nature (Whiting 1967), and is found in poultry and livestock manure, carrion and birds' nests (Rueda and Axtell 1985).

Suitable hosts include the flesh fly, *Sarcophaga bullata* Parker (Rivers and Denlinger 1994), the black blow fly, *Phormia regina* (Meigen) and the green blow

fly, *Phaenicia sericata* (Meigen) (Cornell and Pimentel 1978). Although Legner (1967) stated that *N. vitripennis* does not parasitize *M. domestica* in nature, it does parasitize house flies in many regions of the world including the United States and Africa (Fried *et al.* 1990).

*Nasonia vitripennis* differs from the other species discussed in that it lays many eggs on a pupa. Thus several adult parasitoids develop and emerge from each puparium (Axtell 1986). Females of *Nasonia* pierce the puparium of the host with their ovipositor and lay eggs on the surface of the pupa (Whiting 1967). Each adult female produces an average of 139 offspring (Rueda and Axtell 1985), with varying numbers of parasitoids emerging from one host. According to van der Merwe (1943), *Sarcophaga* spp. support the greatest number of parasitoids, with up to 50 per pupa, while as many as 25 larvae per pupa are found on *M. domestica* (Rueda and Axtell 1985). When a large number of parasitoids develop on one host, smaller adults emerge. Furthermore, competition among larvae can sometimes lead to death (van der Merwe 1943).

Environmental conditions such as temperature and humidity are critical factors in determining survival of *N. vitripennis* (Whiting 1967). Moisture makes the puparium soft, rendering it difficult for parasitoids to emerge (van der Merwe 1943). In addition, very dry conditions can shorten the life of the adult and reduce the numbers of eggs laid (Whiting 1967). The upper lethal temperature limits for *N. vitripennis* are 35°C for larvae and pupae, and 38°C for survival of

adults. Lower temperatures increase longevity and the time taken for development, but below 18°C, the parasitoids cannot complete their development (van der Merwe 1943).

*Nasonia vitripennis* males, which have small wings, cannot fly and are usually found in the areas where they have developed. Mating occurs at the site of emergence followed by dispersal to new oviposition sites (King 1993). New habitats where hosts are available are only found by females (Whiting 1967). King (1993) examined flight activity of *N. vitripennis* females and determined that mating status affects flight distance with mated females flying twice as long as virgin females. It was also determined that 3-day-old females are less likely to fly than 1-day-old females.

#### **IV. PHYGADEUON SPP.**

The biology of the ichneumonid, *Phygadeuon* Gravenhörn, is not well known (Blanchot 1988). One species, *Phygadeuon trichops* Thomas., attacks *Delia* spp. (Diptera: Anthomyiidae) in Norway, Holland and Scotland in small numbers, leading Monteith (1956) to believe that it has other preferred hosts. *Phygadeuon fumator* Gravenhörn has been reared from *Delia* spp. from France and Russia (Wishart *et al.* 1957), and from the cabbage maggot (*Phorbia brassicae* Bouché) in Germany (Müller 1971). Legner and Olton (1968) examined parasitoids of the house fly, stable fly and species of *Fannia*, *Muscina* and *Ophyra* through the Palaearctic, Ethiopian and Pacific regions. *Phygadeuon*

sp. parasitized *S. calcitrans*, *Fannia* and a Syrphidae sp. in Ireland. Depner (1968) reared *Phygadeuon* sp. from horn flies, *Haematobia irritans* (L.), from field collected pupae in Alberta. *Phygadeuon* spp. have also been reported to attack *M. domestica* in Denmark, accounting for 1% of the total parasitism (Mourier 1972) and in the US (Legner *et al.* 1967; Miller and Rutz 1990; Smith and Rutz 1991a). Legner and Olton (1968) conclude that the activity of *Phygadeuon* sp. is greatest at higher latitudes in the Northern Hemisphere where other parasitoids are scarce or absent.

There are discrepancies in the literature regarding the stage of host *Phygadeuon* attacks. Müller (1971) stated that *P. fumator* attacks the larval and pupal stages of the cabbage maggot (*P. brassicae*), but can also attack the pupae of the onion fly (*Phorbia antiqua* Meig.). Rueda and Axtell (1985) alluded to *Phygadeuon* attacking fly larvae, but do not mention the host species. The biology of *P. fumator* was first described by Blanchot (1988) who found this species to attack the pupae of the house fly. Further research into the biology of *Phygadeuon* may clarify the stage of host it attacks.

## **SURVEYS OF INDIGENOUS PARASITIDS**

Considerable information is available concerning the species composition and effectiveness of hymenopterous parasites as biological control agents in poultry facilities (Rutz and Axtell 1981). These are summarized in Tables 1 and 2. Ables and Shepard (1974) reared five species of hymenopterous parasitoids



from field collected house fly pupae in South Carolina. *Spalangia nigroaenea* and *S. endius* made up the majority, accounting for 16.5 and 9.4% of the parasitoids collected, respectively. *Muscidifurax raptor*, *Aphaereta pallipes* (Say) and *Trichopria* sp. were reared in low numbers. *Apanteles carpatus* (Say), *Diaeretiella* sp. and an unidentified Encyrtidae were also collected using emergence traps. Ables and Shepard (1976) found *S. endius*, *S. nigroaenea* and *M. raptor* can significantly affect fly populations. Together, these three species parasitized up to 90% of field-collected pupae in poultry barns during certain times of the year. Of these three species, *Spalangia* spp. were the most effective parasitoids.

Lower levels of parasitism, different composition and relative abundance of species have been found in other studies. A comprehensive 12-month survey of indigenous house fly parasitoids associated with poultry manure was conducted in three geographic regions of North Carolina by Rutz and Axtell (1980a). Of the eight parasitoid species found, *M. raptor* was the most abundant attacking naturally occurring house fly pupae and accounting for 47.4, 59.2 and 62.2% of the parasitoid population, respectively. *Spalangia cameroni*, *S. endius*, and *S. nigroaenea*, were the most abundant *Spalangia* spp. collected with the relative abundance ranging from 9.3-22.3%; to 1.9-15.9%, to 13.5-25.3%, respectively. *Spalangia drosophilae* Ashmead, *S. nigra*, *Pachycrepoideus vindemiae* (Rondani) and *N. vitripennis* were collected infrequently. Parasitism was greatest from June through November and averaged 25.6, 26.5 and 17.1%

in the Coastal Plain, Piedmont and Mountain regions, respectively.

Parasitoids can invade new habitats quickly and species composition may be related to immigration patterns. Rutz and Axtell (1980b) determined the sequence of invasion and relative abundance of parasitoids in manure at new caged-layer poultry houses in North Carolina. *Muscidifurax raptor*, *S. drosophilae*, *S. cameroni*, *P. vindemiae* and *N. vitripennis* invaded within eight weeks after the chickens were placed in the houses. *Spalangia endius*, *S. nigroaenea* and *S. nigra* invaded after 16 weeks. *Muscidifurax raptor*, with a mean relative abundance of 66.1%, was the most abundant parasitoid collected. *Pachycrepoideus vindemiae* was second in overall abundance, followed by *S. cameroni*, *S. nigroaenea*, *N. vitripennis* and *S. drosophilae*. The mean prevalence was only 22.3%.

The species composition also varies between different geographical regions in North America. Rutz and Scoles (1989) surveyed parasitoids attacking house fly pupae in caged-layer poultry facilities in New York and found *N. vitripennis* was the most abundant parasitoid, killing nearly 94.8% of all pupae parasitized. The other species included *M. raptor*, *P. vindemiae*, *Spalangia* sp. and *A. carpatus*. Legner *et al.* (1967) examined house fly and stable fly pupae from Fredericton, New Brunswick and four states in the US. *Muscidifurax raptor* and *S. nigroaenea* were collected in New Brunswick. *Muscidifurax raptor*, *S. cameroni*, *S. endius* and *S. nigroaenea* were the most abundant in Wisconsin, Nebraska, Arizona and California. Small numbers of a *Phygadeuon* sp. and one

figitid were collected from house fly pupae in Wisconsin and Southern California, respectively. Overwintering house fly and stable fly pupae collected from open silage in Nebraska (Petersen and Meyer 1983) contained five species, *M. raptor*, *M. zaraptor*, *S. cameroni*, *S. nigroaenea* and *S. nigra*, of which *Muscidifurax* spp., *S. nigroaenea* and *S. cameroni* were most abundant. On cattle in central Missouri (Smith *et al.* 1987) *S. nigra* was predominant accounting for up to 84.0% of the parasitoids collected from sentinel pupae. Other parasitoids included two species of *Muscidifurax* spp., *S. nigroaenea*, *S. endius*, *S. haematobiae*, two species of *Trichopria*, *Diplazon laetatorius* (F.) and a staphylinid. The total per cent parasitism for both seasons was 6.2 and 11.8%. In northwestern Florida, *S. cameroni* was the most abundant parasitoid (69.0%) of the parasitoids collected from house fly and stable fly puparia recovered from silage, hay and manure (Greene *et al.* 1989). *Muscidifurax* spp., *S. endius* and *S. nigroaenea* were also common, parasitizing 21.0, 8.0 and 2.0% of the parasitized pupae, respectively. Total per cent parasitism was 13.5%.

Few surveys have been conducted to study the indigenous parasitoids of flies at dairies in the northern U.S or Canada. A survey of the parasitoids attacking *M. domestica* and *S. calcitrans* was conducted at eight dairies in central New York. Eleven species were found in sentinel house fly and stable fly pupae. Mean relative abundance of each species was 59% *M. raptor*, 14% *U. rufipes*, 11% *P. fumator*, 10% *S. cameroni*, 3% *S. nigroaenea* and 2% *Trichomalopsis dubius*. Rare species included *P. vindemiae*, *N. vitripennis*,

*Dibrachys cavus* (Walker), *S. nigra* and *Eupelmus vesicularis* (Retzius) (Smith and Rutz 1991a).

Smith and Rutz (1991c) examined the incidence of house fly pupae and their parasitoids at nine dairies in New York. Seven species were found. The most common parasitoids collected were *M. raptor*, *P. fumator*, *U. rufipes* and *S. cameroni*, accounting for 57.0, 21.0, 13.0, and 6.0% of the parasitized pupae. *Spalangia nigroaenea*, *T. dubius* and *P. vindemiae* each accounted for 1.0% of the parasitoids collected. Incidence of *M. raptor*, *U. rufipes* and *S. cameroni* was positively correlated with the presence of fly pupae. Total per cent parasitism was 27.8%. Locations with the highest parasitism were manure ramps, lagoons, manure piles and heifer pens.

Leamer et al.  
1967  
MS

Only one parasitoid survey of Canadian filth fly parasitoids has been published. Lysyk (1995) examined filth fly parasitoids at four dairies in southern Alberta using the sentinel technique and found seven species. *Muscidifurax raptor*, *M. zaraptor*, and *Trichomalopsis* sp. were the most abundant, accounting for 53.9, 11.2 and 15.6% of the parasitized pupae, respectively, in 1990. *Urolepis rufipes*, *Phygadeuon* sp., *S. cameroni* and *D. cavus* accounted for 9.2, 6.1, 3.3 and 0.5% of the parasitized pupae, respectively. The percentage of pupae parasitized was low, only averaging 1.5%. Only four species were collected in 1991. *Phygadeuon* sp. was represented by a single collection. *Muscidifurax raptor* and *M. zaraptor* were the most abundant, accounting for 54.1 and 38.5% respectively, of the parasitized pupae. *Trichomalopsis* sp. accounted

for 7.0% of the parasitoids. Total percentage parasitism was 1.6%.

### PARASITOID RELEASE PROGRAMS

There are two methods for the release of parasitoids to control house flies and stable flies: the classical and inundative approaches (Patterson 1981). For classical biological control, also known as an inoculative release (Olton and Legner 1975), parasitoids are introduced into the environment through one or more releases. The objective is to reestablish naturally occurring species which were eradicated due to insecticide application or to establish a parasitoid in a new habitat. Hosts are suppressed below an economic threshold (Patterson 1981).

Olton and Legner (1975) used the classical method of control in an enclosed poultry house in southern California. Prior to the study, the ranch was on a weekly manure removal schedule. When preliminary samples were taken, it was discovered that there was no entomophagous fauna associated with the fly population in approximately five cm manure accumulations. Three parasitoids, *Tachinaephagus zealandicus* Ashmead, *S. endius* and *M. raptor* were released (total of approximately 188,000) from December to April. Parasitism was 46.0% for *M. domestica* pupae, but only 16.0% for *Fannia femoralis* (Stein) and *F. canicularis* (L.). Average parasitism was 15.5%.

In contrast, Mourier (1972) mass reared two species of parasitoids, *S. cameroni* and *M. raptor* and released about 10,000 parasitoids per farm from

May to June 1970 and 1971 on six Danish dairies. After the releases, the parasitoid populations built up, but the augmentation of the natural enemies was not sufficient to regulate the host populations at an acceptable level. Mourier believed the failure of the program was probably due to the great reproductive potential of the house fly.

The second approach, the inundative method, is to mass release laboratory reared parasitoids to overwhelm host populations giving a high degree of fly suppression (Patterson 1981). Of the two methods of control, the inundative or sustained release method is used most commonly. In the following section, the effectiveness of various inundative release programs (summarized in Table 2) will be discussed.

At least nine species (five genera) of parasitoids have been employed in controlled release programs. One of these parasitoids, *S. endius*, has been used successfully in four release programs (Table 2). Morgan *et al.* (1976) released *S. endius* in a commercial dairy in Florida. Parasitized pupae (approximately 6,000) were placed three times per week at the release site over a five week period. Within one week of the initial release, parasitism increased to 80%. Ten days later, all pupae collected were parasitized. Morgan *et al.* (1975) achieved similar results in a Florida poultry installation. To evaluate the effectiveness of pupal parasitoids, 500 *S. endius* were released daily from February 11 to 14 that had been artificially infested with house flies. Within 37 days of the releases all pupae were parasitized.

Results can vary when pesticides are used in combination with parasitoids. Morgan and Patterson (1990) studied the efficacy of pesticides in combination with augmentative release of *S. endius* to suppress populations of flies at four poultry installations in Florida. The following treatment schedules were initiated in June, 1983: 1. 0.05% cyromazine was included in chicken feed for two weeks and parasitoid releases were initiated at the beginning of the third week (female parasitoid-host ratio of 1:5) and continued weekly until 17 October (n = 2 farms); 2. 0.05% cyromazine was fed to chickens through to 17 October and not treated with a release parasitoid (n = 1 farm); 3. no chemical treatments or parasitoids (n = 1 farm). Approximately 1,000,000 female parasitoids were released at each of the two farms throughout the study.

For the first farm, the combination of the pesticide plus the parasitoid releases resulted in a 90% reduction of the number house fly pupae during June and 99% in November. The efficacy of the chemical was improved by the farmer's removal of manure prior to using cyromazine. At the second farm, the presence of cyromazine and parasitoids only gave a 50% reduction in the numbers of pupae during the first month, but reduced the pupal population to 83, 99, 90 and 90% in August, September, October and November, respectively. The owner cleaned the houses, but pushed the accumulated manure along the outside of each house. The farm treated exclusively with cryomazine had an 8.1 fold increase in the fly population by November. Control in this facility may have been ineffective due to leaking water troughs and broken water pipes.

Augmentative releases of *S. endius* in conjunction with cyromazine were effective in controlling house fly populations, but manure management appears to be vital when either chemical or biological control or the combination of both were used.

*Muscidifurax* spp. have also been used in inundative release programs. At a poultry facility in North Carolina, Rutz and Axtell (1981) released an average of 150,000 *M. raptor* weekly over an 18-week period beginning in June. There was an increase in parasitism attributed to sustained releases of *M. raptor* and a significant reduction in house fly populations compared to that found in untreated facilities. Parasitism at the release farm increased from 21.1% in July to 46% in September, and declined to 32.5% in October. Parasitism at the release farm was significantly higher than that observed at the non-release farms (17%). However, *M. raptor* was not the most abundant parasitoid. *Spalangia cameroni* made up 69.4% of the parasitoids. Together, the two parasitoids accounted for an average of 91.0% of all parasitoids collected.

An indigenous strain of *M. raptor* was mass released at two caged layer poultry farms, one with narrow houses and one with a high-rise house in North Carolina. Weekly releases of 40,000 parasitoids in the narrow caged-layer houses resulted in a significant increase in the overall rate of parasitism of house fly pupae during the fly season in comparison to similar farms without releases. The higher rate of parasitism at the release farm was significant for the entire fly season (June-Oct.) at 40.9%. A two-fold increase in both the rate



of parasitism and the proportion of *M. raptor* in the parasitoid population was also noticed over the previous year. In the high-rise caged-layer house the effects of sustained releases of *M. raptor* was less obvious than in narrow houses. Weekly releases of parasitoids resulted in a significant increase in parasitism, but no reduction in the fly population was evident. Evaluation in the high-rise houses was difficult due to poor management (leaking water systems causing wet manure) (Rutz and Axtell 1979).

Parasitoid dispersal is critical to the success of any release program. Knowledge of dispersal patterns can result in more effective use of biological control agents. Pawson and Petersen (1988) found that *M. zaraptor* dispersed up to 8 m from the release site. They also compared parasitoid releases in open-piled manure to releases under feedbunks. Releases were successful in increasing parasitism in both habitats, but were more effective under the feedbunk. It appeared that the feedbunk protected the parasitoids from the harsh environmental conditions. Parasitoids should be provided with some form of protection for best results. Efforts should be taken to protect release stations from cattle and harsh environmental conditions (Petersen *et al.* 1995)

The number of parasitoids released is also important in an inundative release program. In a study using *M. zaraptor* in 11 beef cattle feedlots in eastern Nebraska, three treatments averaging 4,480, 20,300 and 37,100 parasitoids were released weekly over a 15 week period. The sites receiving the high treatment rate averaged 38% host mortality, compared with 26% for the

medium and 17% for the low treatment rates (Petersen *et al.* 1995).

Even though pteromalid wasps can suppress fly populations, there has been some disagreement about their reliability. Attempts to use pteromalids to control flies in open feedlots and dairies generally have resulted in inadequate control (Petersen *et al.* 1992) (Table 2). Petersen *et al.* (1983) evaluated *Spalangia endius* for control of house flies and stable flies. Parasitoids were released weekly from April to July on two eastern Nebraska livestock feedlots with two similar feedlots serving as controls. Although ca. 940,000 and 1,310,000 *S. endius* were released monthly, parasitism levels were not high. Parasitism of stable flies averaged 7.8 and 8.8% on nonrelease and release lots, respectively, while parasitism of house flies averaged 12.8 and 18.4% for the control and release lots, respectively. In this study, *S. endius* did not have a significant impact on fly populations. Being shipped from an insectary, these parasitoids may not have been climatically adapted to the outdoor environment.

The most important aspect of a release program involves matching the parasitoid species to the target host. The following examples illustrates the problems associated with the biology of *N. vitripennis* and its ineffectiveness as a release species in biological control programs for house flies and stable flies.

Stage and Petersen (1981) mass released pupal parasitoids for control of stable flies and house flies in Nebraska feedlots. Four lots were selected for the study with two lots serving as controls. One of three species of parasitoids (*N. vitripennis*, *S. endius* or *M. raptor*) was released each week from 13 May to 11

October with the species and number of parasitoids scheduled for a given release determined by the distributor. Although *N. vitripennis* was released in large numbers (2,200,000 per lot), only one specimen was reared from approximately 12,000 pupae sampled. Of the three species released, *M. raptor* was the most frequently collected. It was difficult to assess the effect of *M. raptor* on fly populations since it was released in low numbers (106,000 per lot) and it was also collected in substantial numbers on the control lots. Average per cent parasitism was 20.6 and 19.6% for house flies and stable flies, low parasitism for a release program. The inability of *N. vitripennis* to penetrate to the host pupation sites in manure and its random searching behaviour restrict this parasitoid from attacking the house fly under field conditions (Legner 1967). In many instances of documented control failures, parasitoid distributors may be uninformed of the biology of the parasitoids they are selling or have ignored biological information when making recommendations to owners (Stage and Petersen 1981).

Meyer *et al.* (1990) evaluated the effect of sequential releases of commercial fly parasitoids on pupal parasitism and adult population densities of house flies and stable flies on southern California dairies. Two different parasitoid release regimes were evaluated using material from different insectaries. One treatment was monthly releases of 200,000 parasitoids of *M. zaraptor*, *M. raptorellus* and *S. endius* from June to April. Shipments were variable in species composition and numbers. The second treatment involved

monthly release of 350,000 parasitoids consisting of predominantly *M. zaraptor*, with many of the shipments containing some *N. vitripennis* and *P. vindemiae*. Both parasitoid treatments had no apparent effect on adult fly populations, with per cent parasitism being 16.8 and 17.2% for field-collected stable fly pupae and 23.3 and 20.9% for field-collected house fly pupae, respectively. In their study, species composition of parasitoids received from the insectaries was irregular with the majority of shipments containing *N. vitripennis* which is generally considered ineffective for the control of house flies (Rueda and Axtell 1985).

Andress and Campbell (1994) examined the use of *M. raptor* and *S. nigroaenea* to control stable flies in central Nebraska. Parasitoids were released on a weekly basis. During 1990, parasitoids failed to reduce the numbers of stable flies, despite a total estimated release of 860,000 parasitoids at a feedlot and 970,000 at a dairy. Similar results were obtained in 1991 with a different feed lot and dairy, but equally high numbers of parasitoids were released. In both years, shipments of parasitoids contained neither the number of parasitoids requested nor the species purity that had been anticipated. *Nasonia vitripennis* was a common contaminant.

No successes have been documented using *N. vitripennis* (Table 2). Beard (1964) attempted a small scale trial using *N. vitripennis*. At weekly intervals during one month, a total of about 30,000 parasitized house fly pupae were introduced into a pasture. Not a single recovery was made, either from naturally occurring muscoid pupae in the field or from sentinel pupae. Failure in

the field using *N. vitripennis* could have been predicted from the experience in Australia, where millions of *Nasonia* were released for blow fly control (Whiting 1967). *Nasonia vitripennis* was also ineffective for control of house flies and stable flies on two cattle feedlots in Nebraska (Petersen *et al.* 1983). *Nasonia vitripennis* is not a useful parasitoid for fly control in open field situations (Meyer *et al.* 1990).

## CONCLUSION

Suppliers are mass producing and aggressively selling parasitoids to producers without evidence that they are effective for fly control. In dairies and feedlots, release programs have been ineffective (Legner 1981). Insectary owners are ignoring the basic biology of parasitoids and disregarding important aspects of an effective fly control program. For example, the species composition is important and sometimes ignored by suppliers. *Nasonia vitripennis* should not be implemented in a house fly and stable fly control program since it is not adapted to penetrate to the host pupation sites (Legner 1967). In addition, as a result of the rearing techniques, insectaries are passively selecting parasitoids for certain traits. When these parasitoids are released, they are ineffective since they have been adapted to specific conditions in the laboratory. Though *N. vitripennis* has been shown to be ineffective for house fly and stable fly control, this species is still being used as a biological control agent.

The mass release of parasitoids seems to be effective only in well managed accumulations of manure as found in poultry facilities (Legner 1981). A producer should practice efficient manure management, reducing house fly and stable fly breeding sites before implementing biological control.

Table 1. Insect parasitoids associated with house flies and stable flies in North America.

Family	Species	Reference
Pteromalidae	<i>Dibrachys cavus</i> (Walker)	6,15
	<i>Muscidifurax raptor</i> Girault and Sanders	1,2,3,4,5,6,7,8,9,10,11, 12,13,15,16
	<i>M. raptorellus</i> Kogan and Legner	17
	<i>M. raptoroides</i> Kogan and Legner	17
	<i>M. zaraptor</i> Kogan and Legner	3,4,6,7,8,9,10
	<i>Nasonia vitripennis</i> (Walker)	4,5,10,11,12,13,15
	<i>Pachycrepoides vindemiae</i> (Rondani)	10,11,12,13,15
	<i>Spalangia</i> sp.	13
	<i>Spalangia cameroni</i> Perkins	3,4,5,6,8,9,10,12,15,16
	<i>S. drosophilae</i> Ashmead	10,11,12
	<i>S. endius</i> Walker	1,2,3,4,5,7,10,11,12,17
	<i>S. haematobiae</i> Ashmead	1,17
	<i>S. nigra</i> Latreille	3,8,9,10,11,12,15,17
	<i>S. nigroaenea</i> Curtis	1,2,3,4,5,7,8,9,10,11, 12,15,16,17
	<i>Trichomalopsis dubius</i> (Ashmead)	6,15,16
	<i>Urolepis rufipes</i> (Ashmead)	3,6,10,15,16
Ichneumonidae	<i>Diplazon laetatorius</i> (F.)	17
	<i>Phygadeuon</i> sp.	5,6
	<i>Phygadeuon fumator</i> Gravenhörst	15,16
Braconidae	<i>Apanteles carpatus</i> (Say)	13
	<i>Aphaereta pallipes</i> (Say)	1
Eupelmidae	<i>Eupelmus vesicularis</i> (Retzius)	15
Encyrtidae	Encyrtidae sp.	2
	<i>Tachinaephagus zealandicus</i> Ashmead	14
Diapriidae	<i>Trichopria</i> sp.	1,2,5,7,17
Figitidae	Figitidae sp.	5
Staphylinidae	Aleocharinae sp.	17
	<i>Aleochara bimaculata</i> Gravenhörst	3

1, Ables and Shepard 1974; 2, Ables and Shepard 1976; 3, Andress and Campbell 1994; 4, Legner and McCoy 1966; 5, Legner *et al.* 1967; 6, Lysyk 1995; 7, Pawson and Petersen 1988; 8, Petersen and Meyer 1983; 9, Petersen *et al.* 1983; 10, Rueda and Axtell 1985; 11, Rutz and Axtell 1980a; 12, Rutz and Axtell 1980b. 13, Rutz and Scoles 1989; 14, Smith and Rutz 1991a; 15, Smith and Rutz 1991b; 16, Smith and Rutz 1991c; 17, Smith *et al.* 1987.

Table 2. The effectiveness of parasitoid inundative release programs against muscoid flies.

Reference	Facility	Parasitoid spp.	Location
<b>Success</b> Olton and Legner (1975)	poultry	<i>M. raptor</i> <i>S. endius</i> <i>T. zealandicus</i>	CA
Morgan <i>et al.</i> (1975)	poultry	<i>S. endius</i>	FL
Morgan <i>et al.</i> (1976)	dairy	<i>S. endius</i>	FL
Rutz and Axtell (1979)	poultry	<i>M. raptor</i>	NC
Rutz and Axtell (1981)	poultry	<i>Muscidifurax</i> sp.	NC
Morgan and Patterson (1990)	poultry	<i>S. endius</i>	FL
<b>Failures</b> Beard (1964)	pasture	<i>N. vitripennis</i>	-
Whiting (1967)	-	<i>N. vitripennis</i>	Aust.
Mourier (1972)	dairy	<i>M. raptor</i> <i>S. cameroni</i>	Den.
Stage and Petersen (1981)	feedlots	<i>M. raptor</i> <i>N. vitripennis</i> <i>S. endius</i>	NE
Petersen <i>et al.</i> (1983)	feedlots	<i>S. endius</i>	NE
Meyer <i>et al.</i> (1990)	dairies	<i>M. raptorellus</i> <i>M. zaraptor</i> <i>N. vitripennis</i> <i>P. vindemiae</i> <i>S. endius</i>	NE
Andress and Campbell (1994)	feedlot dairy	<i>M. raptor</i> <i>S. nigroaenea</i>	NE



### CHAPTER III

#### **SURVEY AND RELEASE OF PARASITOID WASPS (HYMENOPTERA: PTEROMALIDAE, ICHNEUMONIDAE) OF HOUSE FLIES AND STABLE FLIES (DIPTERA: MUSCIDAE) IN DAIRY OPERATIONS IN MANITOBA**

##### **ABSTRACT**

In 1995, eight Manitoba dairies were chosen to evaluate the release of commercially available parasitoid wasps on house flies and stable flies. Four farms were used for release, while four farms were used as controls. Although *Nasonia vitripennis* (Walker) and *Muscidifurax zaraptor* Kogan & Legner were promised by the supplier, only *N. vitripennis* was present in subsamples. Numbers of parasitoids in bags within shipments were not significantly different. Total mean per cent parasitism was  $67.7 \pm 2.2\%$  parasitized pupae per bag. Per cent parasitism differed among shipments. Each bag contained an average of  $91,202 \pm 6,577$  parasitoids. An estimated 3,648,093 parasitoids were released at four farms from 10 July to 10 September, 1995. Of the *N. vitripennis* released, 41% were females.

For the release farms, 10,622 previously frozen sentinel pupae were recovered, of which 843 (7.9%) were parasitized. Only 223 (26.5% of the parasitized pupae) pupae were parasitized by *N. vitripennis*. *Urolepis rufipes* (Ashmead), *Muscidifurax raptor* Girault and Sanders, *M. zaraptor* Kogan and Legner, *Trichomalopsis* sp., *Muscidifurax* that could not be identified to species, *Spalangia subpunctata* Först, *Eupelmus vesicularis* (Retzius) and those parasitoids which could not be identified, accounted for 40.5, 18.6, 6.6, 3.7, 0.8,

0.4, 0.3 and 2.4% of the parasitized pupae, respectively. *Phygadeuon fumator* Gravenh orst and a Staphylinidae each accounted for 0.1% of the parasitoids. For non-release farms, 11,779 sentinel pupae were retrieved, 129 (1.1%) of which were parasitized. *Nasonia vitripennis* accounted for 11.6% of the parasitized pupae. *Urolepis rufipes*, *Trichomalopsis* sp. and *M. raptor* parasitized 53.5, 13.2 and 8.5% of the parasitized pupae. 13.2% of the parasitoids could not be identified.

At the release farms, 11,897 naturally occurring pupae were collected, 472 (4.0%) of which were parasitized. *Nasonia vitripennis* was reared from 76 (16.1%) of the parasitized pupae. *Muscidifurax raptor*, *P. fumator*, *U. rufipes*, *Spalangia cameroni* Perkins, *Spalangia nigra* Latreille, *S. subpunctata*, *M. zaraptor* and *Trichomalopsis* sp. accounted for 19.5, 19.1, 11.2, 10.8, 10.2, 5.7, 3.4 and 0.4% of the parasitized pupae, respectively. 3.6% of the parasitoids could not be identified. At non-release farms, 8,384 fly pupae were collected, 319 (3.7%) of which were parasitized. *Nasonia vitripennis* only parasitized one pupa (0.3%). *Phygadeuon fumator*, *U. rufipes*, *M. zaraptor*, *S. cameroni*, *S. subpunctata*, *M. zaraptor*, *S. nigra* and *Muscidifurax* that could not be identified to species accounted for 73.7, 7.2, 7.2, 4.4, 2.5, 1.6, 0.9 and 0.3% respectively, of the parasitoids. 1.9% of the parasitoids could not be identified.

In 1996, 50,842 live sentinel pupae were retrieved from two of the non-release farms from 1995. Of the sentinel pupae, 2,052 (4.0%) were parasitized. *Phygadeuon fumator*, *S. cameroni*, *U. rufipes*, *S. nigra*, *S. subpunctata* and *M.*

*raptor* accounted for 97.4, 0.6, 0.2, 0.1, 0.05 and 0.05% of the parasitized pupae, respectively. *Muscidifurax* that could not be identified to species accounted for 0.3% of the parasitoids. Unknown parasitoids accounted for 1.3%. 4,691 naturally occurring pupae were collected in 1996, 442 (9.4%) of which were parasitized. *Phygadeuon fumator*, *S. nigra*, *S. cameroni*, *Muscidifurax* that could not be identified, *S. subpunctata*, *M. raptor*, *Aphaereta* sp. and a figitid accounted for 79.9, 5.4, 3.6, 1.4, 1.1, 0.9, 0.5 and 0.2% of the parasitized pupae, respectively. Parasitoids which could not be identified accounted for 7.0% of the parasitism.

## INTRODUCTION

The house fly, *Musca domestica* L., and stable fly, *Stomoxys calcitrans* (L.) are major pests associated with domestic livestock production (Glofcheskie and Surgeoner 1993; Burg *et al.* 1990). These flies can occur in large numbers around livestock facilities where they breed in accumulations of organic waste and manure (Keiding 1974). Dairy operators expend considerable effort to control flies (Andress and Campbell 1994) and use a combination of three control strategies: cultural, chemical and biological control (Axtell 1986).

Cultural control involves proper management of manure, feed and facilities (Axtell 1986) by removing spilled feed and manure frequently, eliminating potential development sites for larvae (Glofcheskie and Surgeoner 1993). However, cultural control alone is often not sufficient and fly control

depends on application of insecticides (Andress and Campbell 1994).

Chemical control products in Canada include insecticides as space sprays, baits or residuals (Glofcheskie and Surgeoner 1990). Insecticides are becoming more costly and more regulated (Geden *et al.* 1992), and their use is not always desirable (Andress and Campbell 1994). With increasing development of insecticide resistance in flies (Axtell 1986), producers are exploring methods of biological control.

In the United States, several species of Pteromalidae (Hymenoptera) have been mass released to reduce fly populations in livestock production systems (Rueda and Axtell 1985). By providing an important source of mortality of fly pupae (Petersen and Meyer 1983), commercially available and naturally occurring parasitoids may be an effective complement to cultural management practices (Smith and Rutz 1991c).

Many parasitoid surveys and release programs have been conducted in the US. However, little research has been published concerning filth fly parasitoids in Canada. Lysyk (1995) examined the parasitoids of filth fly pupae in Alberta dairies, but did not implement a release program. In Manitoba, there is no efficacy data on inundative release programs. Suppliers are persuading producers to adopt parasitoids into their fly management programs without evidence that they are effective for control. Therefore, the objectives of this study were to evaluate an inundative release program of pteromalid wasps and to identify naturally occurring parasitoids of house flies and stable flies in

Manitoba dairy operations.

## **MATERIALS AND METHODS**

### **LOCATIONS**

#### **I. 1995**

Eight Manitoba dairies were chosen to evaluate the release of pupal parasitoids on house fly and stable fly populations. In 1994, a preliminary survey on parasitoids was conducted to provide a basis for selection of farms in 1995. During that survey, most farms had large numbers of flies, but varying degrees of parasitism. In 1995, dairies were selected according to the numbers of parasitoids collected the previous year. Those dairies with a prevalence of >10% were classified as having an abundance of parasitoids. Of the eight farms, four had parasitism exceeding 10%.

In 1995, parasitoids were released at four farms. Of the four release sites, two farms had >10% parasitism in 1994. The other four dairies were established as controls to compare fly numbers and parasitism. Of the non-release dairies, two had >10% parasitism during 1994.

The following is a description of the dairies used during 1995: release farms with parasitoids were Glenlea Research Station and the Holme dairy. The Glenlea Research Station, Glenlea, MB, had approximately forty heifers. This was the only farm which was not considered a dairy since cattle were confined in semi-open pens measuring 18 x 20 m. Animal waste was removed biweekly and

piled adjacent to the facility. This farm was used since it had an abundance of parasitoids in 1994. Wilf Holme, Grunthal, MB, had a main barn (10 x 60 m) with 91 milking cows. Manure from this area was removed daily. Calves were housed separately in a room (6 x 10 m) adjacent to the barn with weekly waste removal. Heifers were confined in a nearby barn with access to a pasture.

Wiens and VanWalleghem were release farms with low prevalence of parasitoids in 1994. Bernie Wiens, Glenlea, MB, had approximately 40 cows. Calves were confined at the far end of the milking parlour that measured 10 x 40 m. Calf pens were cleaned weekly. A large extension (9 x 16 m) adjacent to the milking parlour contained two pens separating the heifers from the rest of the herd. Animal waste from this area was removed weekly. David VanWalleghem, Winnipeg, MB, had approximately 40 cows. Animals roamed freely throughout the 60 x 160 m free-stall barn, with easy access to a pasture. Manure was removed weekly and placed in a pit located inside the barn. The use of wood shavings and the presence of Muscovy ducks for fly control made this dairy unique.

Non-release sites with parasitoids were the Staerk and Stengel farms. Vince Staerk, Whitemouth, MB, had approximately 20 cows. Calves, heifers and hogs were confined in pens in the back of the barn (10 x 38 m). Manure was removed daily from the milking parlour, but was removed biweekly from the calf pens. Jules Stengel, Beausejour, MB had 40 cows. Calves and heifers were penned in the North end of the main barn (12 x 36 m). Animal waste from

the milking parlour was removed daily, with weekly removal from the calf and heifer pens.

Non-release farms with <10% parasitism in 1994 were the Dueck and Schroeder farms. Deitmar Dueck, Kleefeld, MB, had approximately 40 cows. Manure was removed daily from the milking parlour which measured 9 x 34 m. Calves and heifers were housed in a separate area (7 x 14 m), where manure was removed weekly. John Schroeder, Kleefeld, MB, had approximately 45 cows. Calves and heifers were housed separately from the parlour. Calves and heifers were penned in a barn measuring 8 x 18 m. Manure from this area was removed on a weekly basis.

## II. 1996

In 1996, the Stengel and Staerk farms (described above) were chosen to examine parasitoid activity and the biology of *Phygadeuon fumator*. During the preliminary survey in 1994 and 1995, *P. fumator* was most abundant at these two dairies. Both producers in 1996 practiced similar manure management as seen in 1995. Farms were sampled twice weekly from the 13 May to 17 October, 1996.

## PARASITOID RELEASE - 1995

Parasitoids were purchased from Manbico Biological Ltd., Winnipeg, MB. Manbico buys the parasitoids from Arizona Biological Control, Inc. According to

ARBICO, there were to be two species of parasitoids occurring in this inundative program, *Nasonia vitripennis* and *Muscidifurax zaraptor*. Parasitoids were received from Manbico every 2 weeks. Five shipments were received from 7 July to 30 August, 1995.

The numbers of parasitoids scheduled for a given release were determined by the distributor. For a farm consisting of 40 cows, Manbico suggested to release one bag containing two units of parasitoids every week. One bag should have contained 160,000 live parasitoids and consisted of approximately 250 g of parasitized house fly pupae mixed with wood shavings in paper bags (Fig. 1).

Immediately on receipt of a shipment, each bag was weighed and five 5.0 g subsamples were taken. The numbers of intact pupae were counted for each subsample. An average number of pupae was calculated for the five subsamples. The mean number of pupae in five grams was multiplied by the weight of the contents of each bag and divided by the number of grams per subsample. This gave an approximate number of pupae per bag. Those pupae which were still intact were assumed to be parasitized. An ANOVA was used to determine if shipments had the same number of pupae per bag.

Ninety-six pupae were taken from each bag and placed in Falcon® 96-well Micro Test III™ tissue culture plates (Fig. 2) to determine the species and parasitoid emergence. Polyfoam, 8.5 cm x 12.0 cm and 0.2 cm thick, was placed between the lid and the plate to prevent parasitoids from escaping. Parasitoids



could chew their way into the polyfoam, but could not escape. Each parasitoid trapped in the polyfoam could be traced back to the well in which it was reared. The lid, polyfoam and plate were firmly held together with two elastic bands. Bags and plates were stored at 12°C until the day of release as recommended by the distributor. Half the shipment was released three days after pick up. The longest period of time parasitoids were stored was one week and three days. Release bags were each placed in plastic bags during transport to the field to prevent contamination of the sentinel pupae.

On the day of release, pupae from each bag were incubated at 25°C (L16:D8) for a minimum of 60 days to await emergence. After which, all pupae which had not emerged were dissected. Species, per cent parasitism, sex and intensity (the number of parasitoids per parasitized host) were recorded for pupae from each plate. The percentage of emergence in a plate was multiplied by the number of pupae estimated for that bag. This gave an estimated number of parasitized pupae for each bag. ANOVA's were used to determine if the same number of parasitized pupae were:

- in each bag within each shipment.
- in each shipment.
- released at each farm.

Mean intensity was determined and multiplied by the number of parasitized pupae to estimate number of parasitoids released. ANOVA's were used to determine if intensity and the number of females were the same among

shipments and if sex ratios differed between shipments. A Chi-square was used to compare the parasitoid emergence between stored and non-stored bags.

The supplier suggested to begin releases in early May. In examining farms for house flies and stable flies, no larvae or pupae could be found until early July. Therefore, releases were conducted for ten weeks starting 10 July to 10 September, 1995. One bag was distributed on a weekly basis at each of the four release farms. Parasitized pupae were released only in fly breeding areas inside dairy barns by taking a handful of parasitized pupae and wood shavings and lightly covering them with a small amount of manure. The same release areas were used consistently throughout the season to prevent parasitized pupae from being mistakenly collected as naturally occurring pupae.

#### **REARING HOUSE FLIES**

Sentinel house fly pupae used in 1995 and 1996 were reared from a laboratory colony. Adult house flies were kept at 25 - 27°C (L18:D6) in cages (32 cm x 32 cm x 32 cm), and fed milk powder and sugar. Fresh water was supplied daily. To collect eggs, an egg pad was made as follows: a moist ball of wheat bran (80g) was placed in the middle of a black cloth (20 cm x 20 cm). The cloth was folded around the wheat bran and fastened with an elastic band. Egg pads, half submerged in 120 ml of water, were placed in cages overnight and collected the following morning. Eggs found in the folds of the cloth were removed by lightly flushing with water (18°C). Using an eye dropper, eggs (10 -

15 drops) were placed in trays (13.0 cm x 12.0 cm x 5.5 cm) containing larval medium. The larval medium was made as follows: 180 g Calf Manna<sup>®</sup> (milk replacer for dairy and beef cattle) were dissolved in 1 L of warm tap water; 240 g wheat bran were added to the Calf Manna and thoroughly mixed. Another 500 ml of water and 160 g of bran were added to the mixture. Seeded trays were enclosed in a pillow case and incubated at 25°C (L18:D6).

## DETERMINATION OF PARASITOID ACTIVITY

### I. SENTINEL PUPAE

In 1995, sentinel pupae, as described by Petersen and Matthews (1984), were used to determine parasitoid activity. This technique allows parasitoid sampling regardless of host availability (Smith and Rutz 1991*b*). One-day-old house fly pupae were frozen for approximately one week before being placed in the field. Five containers, each containing 96 previously frozen sentinel pupae, were placed at each farm from 5 July to 21 September, 1995. Containers (16.0 cm x 9.0 cm x 3.5 cm) were placed on the surface of accumulations of manure in areas protected from livestock. An open container (Fig. 3), made out of standard aluminum window screening, was used rather than sentinel bags (e.g. used by Rutz and Scoles 1989). *Phygadeuon fumator* is too large to pass easily through an enclosed mesh bag. Sentinel pupae were kept in the field for seven days and replaced weekly. After field exposure, pupae were taken to the lab, put into tissue culture plates and incubated at 25°C (L16:D8). After at least 60 days,

intact pupae were dissected to determine if they were parasitized. The species, sex and numbers of parasitoids from each fly pupa were recorded.

Sentinel pupae were also used in 1996. However, three 450 ml plastic containers (Fig. 4), each containing at least 100 live one-day-old house fly, pupae were placed at the Stengel and Staerk farms from the 13 May to 17 October. Plastic containers were used in 1996 because predators invaded the screened containers in 1995. Sentinels, placed in known fly breeding sites, were protected from livestock and replaced during each visit. The number of sentinel pupae retrieved from each dish varied throughout the summer due to availability of pupae from the house fly colony, missing sentinel dishes and interference from livestock. Sentinel pupae were taken to the lab and placed in cages (32 cm x 32 cm x 32 cm) to await house fly emergence. After the flies emerged, the emerged pupal cases and intact puparia were counted. Intact puparia, from which flies had not emerged, were placed in tissue culture plates and incubated at 25°C (L16:D8). After at least 60 days, intact puparia were dissected and the same data as in 1995 recorded.

## II. NATURALLY OCCURRING PUPAE

House fly and stable fly pupae found in accumulated manure were also sampled for parasitoids. In 1995, five locations at each farm were sampled from 5 July to 21 September. In 1996, the Stengel and Staerk farms were similarly sampled from 13 May to 17 October. Pupae were collected using forceps, a

garden claw (Fig. 4) and flashlight. Each location within a barn was examined for 10 minutes or until at least fifty pupae were found. This sampling method is biased; however, it was used due to the highly aggregated distribution of pupae. Since per cent parasitism in 1994 was low, a large number of pupae had to be collected to determine prevalence. Pupae were taken to the lab and placed in tissue culture plates. Pupae were incubated at 25°C (L16:D8). After a minimum of six weeks, all intact puparia were dissected. Host species were identified as house fly or stable fly. The species, sexes and numbers of parasitoids from each fly pupa were recorded.

Voucher specimens from 1994 and 1995 were identified by Drs. Gary Gibson and John Barron from the Canadian National Collection, Agriculture and AgriFood Canada, Ottawa and used as reference specimens to identify pupal parasitoids collected during 1995 and 1996.

### **III. MONITORING ADULT FLIES**

To determine if the release of parasitoids had any effect on numbers of flies, adult house fly populations were monitored. From 13 July to 21 September, 1995, relative levels of fly activity were estimated using the spot card technique described by Axtell (1970). Fifteen white paper strips measuring 4 x 20 cm were hung weekly at intervals around each barn, approximately 1.5 m off the floor (Fig. 5). The number of faecal and regurgitation spots on each card was counted. A split plot design ANOVA was used to determine differences in

numbers of fly specks among release and non-release dairies throughout the summer.

#### **PREVALENCE OF *P. FUMATOR***

In 1995, prevalence of *P. fumator* throughout the summer was determined using naturally occurring pupae. In 1996, both sentinel and naturally occurring pupae were used.

### **RESULTS**

#### **PARASITOID RELEASE - 1995**

Bags, weighing an average of  $235.2 \pm 4.8$  g (N = 40), contained an estimated mean of  $15,200 \pm 4,001$  pupae. The mean numbers of pupae per bag among shipments were significantly different ( $F = 74.7$ ,  $df = 4, 35$ ,  $P < 0.001$ ). Shipments ranged from  $10,268 \pm 316$  on 30 August (shipment 5) to  $20,454 \pm 431$  pupae per bag on 2 August (shipment 3) (Fig. 6). An estimated total of 607,997 pupae was received throughout the summer.

Only *Nasonia vitripennis* was present in the subsamples. Mean per cent parasitism of intact puparia per bag was  $67.7 \pm 2.2\%$ . On examination of the pupae in the subsamples, many parasitoids had emerged during shipping. Occasionally, individuals of *N. vitripennis* were seen crawling on the outside of the bags when received from the supplier. Average total prevalence of parasitoids per bag among shipments on different dates was significantly different ( $F = 25.8$ ,  $df = 4, 35$ ,  $P < 0.001$ ). Shipments received from 7 July to 2

August and on 30 August had similar per cent parasitism, while the shipment received on 16 August had less (Fig. 7).

Overall the average number of parasitized pupae per bag was  $10,379 \pm 603$ . Though bags within shipments had similar numbers of parasitized pupae ( $F = 1.2$ ,  $df = 7, 28$ ), the mean number of parasitized pupae per bag among shipments was significantly different ( $F = 49.2$ ,  $df = 4, 28$ ,  $P < 0.001$ ). Shipment three had the largest number with an average of  $15,501 \pm 479$  per bag, while shipments four and five had the least numbers of parasitized pupae ( $7,170 \pm 597$  and  $7,207 \pm 359$  per bag, respectively). Therefore, the numbers of parasitized pupae dispersed each week were significantly different ( $F = 23.1$ ,  $df = 9, 27$ ,  $P < 0.001$ ) (Fig. 8). Weeks five (4 August) and six (11 August) had the largest number of parasitized pupae per bag with  $15,567 \pm 885$  and  $16,025 \pm 698$ . Fewer parasitized pupae were released in the last four weeks (18 August to 9 September) with numbers per bag ranging from  $6,846 \pm 675$  to  $7,568 \pm 346$ .

The number of parasitized pupae released ranged from 96,277 to 112,055 and was not significantly different for each farm ( $F = 2.9$ ,  $df = 3, 27$ ). In total, 415,153 parasitized pupae were released (Table 3).

There were 1 to 28 parasitoids per pupa, with a mean intensity of  $8.7 \pm 0.2$  (number of pupae = 2083) (Fig. 9). The average number of *N. vitripennis* per pupa was significantly different between shipments ( $F = 17.1$ ,  $df = 4, 35$ ,  $P < 0.001$ ) (Table 4).

With an average of  $91,202 \pm 6,577$  parasitoids per bag, an estimated

3,648,093 were released on all farms. But total numbers of parasitoids released did not differ between farms (Table 3). The average number of parasitoids released per cow per week was 2250 at Glenlea, 1081 at Holme, 2258 at Wiens and 2152 at VanWalleghem.

With an average of  $37,566 \pm 2,685$  females per bag, an estimated 1,502,643 females were released (Table 3). The numbers of females per shipment were significantly different ( $F = 24.0$ ,  $df = 4, 35$ ,  $P < 0.001$ ) (Fig. 10). Shipments three (2 August) and one (7 July) had the most females with  $60,651 \pm 5,718$  and  $47,305 \pm 2,088$  per bag. Shipments two (19 July), four (16 August) and five (30 August) had an average of  $31,711 \pm 2,058$ ,  $22,689 \pm 3,268$  and  $25,475 \pm 1,322$  females per bag. The numbers of females released at all farms were not significantly different ( $F = 0.05$ ,  $df = 3, 37$ ) (Table 3). The largest numbers of females were released at the Holme and Wiens farms (414,852 and 375,131 respectively). An estimated 369,597 and 343,063 females were released at the Glenlea and VanWalleghem farms (Table 3). Of the 3.6 million parasitoids released, 41% were females. The sex ratio for released *Nasonia* was 0.77 females/males. The sex ratios among shipments were significantly different and ranged from  $0.6 \pm 0.04$  to  $1.1 \pm 0.07$  ( $F = 11.4$ ,  $df = 4, 35$ ,  $P < 0.001$ ).

There was no significant difference in parasitoid emergence between stored and non-stored pupae (Chi-square = 0.01,  $df = 1$ ). Storing parasitoids at 12°C for more than one week had no apparent effect on emergence.



## DETERMINATION OF PARASITOID ACTIVITY

### I. SENTINEL PUPAE

For the release farms, 11 species were collected in 1995 (Table 5). The total number of sentinel pupae recovered was 10,622 (55.3%). Many sentinel containers went missing throughout the season. Predation on pupae was also a problem. Of the sentinel pupae retrieved, 843 (7.9%) were parasitized. *Urolepis rufipes* (Ashmead) was the most abundant at two of four sites, accounting for 40.5% of the parasitized pupae. Only 223 (26.5% of the parasitized pupae) pupae were parasitized by *N. vitripennis*. *Muscidifurax raptor* Girault and Legner, *M. zaraptor* Kogan and Legner, *Trichomalopsis* sp., *Spalangia subpunctata* Först and *Eupelmus vesicularis* (Retzius) accounted for 18.6, 6.6, 3.7, 0.4, and 0.3% parasitism. *Muscidifurax* that were broken and could only be identified to genus accounted for 0.8% of the parasitism. *Phygadeuon fumator* Gravenhörst and Staphylinidae each accounted for 0.1% of the parasitized pupae, while unknown parasitoids (those which were pteromalid larvae and could not be identified) made up 2.4% of the parasitized pupae. Glenlea had the highest per cent parasitism with 13.0%, while Wiens and VanWalleghem had 6.4 and 6.0% parasitism. Total percentage of parasitism was low, averaging 7.9%. The only farms to have *N. vitripennis* as the majority of parasitoids collected were Wiens and VanWalleghem (Table 5). Holme had a smaller percentage with 3.8%. Mean intensity of *N. vitripennis* for all parasitized sentinel pupae collected at release farms was  $5.0 \pm 0.2$  parasitoids per pupa and ranged from 1

to 15 (number of pupae = 223)(Fig. 11). The sex ratio for *Nasonia* collected from the sentinel pupae was 3.2 females/males.

For the non-release farms, 129 out of 11,779 pupae were parasitized (1.1% parasitism). Of the sentinel pupae placed in the barns, 61.3% were recovered. Missing containers and predation accounted for pupal loss. *Urolepis rufipes* and *Trichomalopsis* sp. were most abundant at three of the four sites, accounting for 53.5 and 13.2% of the parasitized pupae. Only 15 (11.6% of the parasitized pupae) pupae were parasitized by *N. vitripennis*. *Muscidifurax raptor* parasitized 11 (8.5%) of the parasitized pupae. Parasitoids in the unknown category accounted for 13.2% of the parasitized pupae. Schroeder and Dueck farms had the highest per cent parasitism with 1.8 and 1.2%. Stengel and Staerk farms had lower percentages with 1.0 and 0.4% parasitism.

In 1996, of the 22,075 pupae recovered at the Staerk farm, 633 (2.9%) were parasitized by *P. fumator*, *Muscidifurax* spp., *M. raptor*, and *U. rufipes* (Table 6). Of the 633 parasitized pupae, *P. fumator* parasitized 597 (94.3%). Unknown, *M. raptor* and *U. rufipes* accounted for 4.1, 0.2 and 0.2% respectively, of the parasitized pupae. *Muscidifurax* that were broken and could only be identified to genus accounted for 1.2% of the parasitism. At the Stengel farm, of the 28,767 sentinel pupae recovered, 1,419 (4.9%) were parasitized by *P. fumator*, *Spalangia cameroni* Perkins (0.9%), *Spalangia nigra* Latreille (0.1%), *U. rufipes* (0.1%), and *S. subpunctata* (0.07%). Of the parasitized pupae, 1,401 (98.7%) were parasitized by *P. fumator*.

*Phygadeuon fumator* was the most abundant parasitoid accounting for 97.4% parasitism in sentinel pupae in 1996 (Table 6). Prevalence of pteromalids was low with *S. cameroni*, *U. rufipes*, *S. nigra*, *M. raptor* and *S. subpunctata* accounting for 0.6, 0.2, 0.1, 0.05, and 0.05% of the parasitized pupae, respectively. *Muscidifurax* that could only be identified to genus accounted for 0.3% of the parasitism. Unknown parasitoids accounted for 1.3% of the parasitism. Total percentage parasitism for all species was low at 4.0%.

## II. NATURALLY OCCURRING PUPAE

For the release farms, 7,266 house fly and 4,631 stable fly pupae were collected in 1995. More house fly than stable fly pupae were collected at Holme's Wien's and VanWalleghem's. Glenlea was an exception, where more stable fly pupae were collected (Table 7). Of the 11,897 fly pupae collected, 472 (4.0%) were parasitized. Of the 472 parasitized pupae, 271 (57.4%) pupae were house flies and 201 (42.6%) pupae were stable flies.

*Muscidifurax raptor* and *P. fumator* were the most abundant parasitoids at release sites in 1995, accounting for 19.5 and 19.1% of the parasitoids. *Nasonia vitripennis* was reared from 76 (16.1%) of the parasitized pupae (Table 8). *Urolepis rufipes*, *S. cameroni*, *S. nigra*, *S. subpunctata*, *M. zaraptor* and *Trichomalopsis* accounted for 11.2, 10.8, 10.2, 5.7, 3.4 and 0.4% of the parasitized pupae, respectively. Of the parasitoids collected, 3.6% could not be identified and were placed in the unknown category. Of the release farms,

Glenlea and Wiens had the highest per cent parasitism with 7.4 and 4.3%. VanWallegghem and Holmes had lower percentages with 1.7 and 1.6% parasitism (Table 8). Total percentage of parasitism was 4.0%. Mean intensity of *N. vitripennis* in naturally occurring pupae at release farms was  $7.7 \pm 0.5$  parasitoids per pupa with a range of 1 to 22 (number of pupae = 76) (Fig. 12). Using a t-test, the mean intensity of *N. vitripennis* in parasitized sentinel and naturally occurring pupae were significantly different ( $t = 3.6$ ,  $P < 0.001$ ). The sex ratio for *Nasonia* reared from naturally occurring pupae was 1.3 females/males.

For the non-release farms, 7,148 house fly and 1,236 stable fly pupae were collected. More house fly than stable fly pupae were collected at all non-release farms. Of the 8,384 fly pupae, 319 (3.7%) were parasitized. Of the 319 parasitized pupae, 259 (81.2%) were house flies and 60 (18.8%) were stable flies (Table 7). *Phygadeuon fumator* was the most abundant, accounting for 73.7% of the parasitized pupae. The numbers of pupae parasitized by pteromalids were small. *Urolepis rufipes*, *M. raptor*, *S. cameroni*, *S. subpunctata*, *M. zaraptor* and *S. nigra* accounted for 7.2, 7.2, 4.4, 2.5, 1.6, and 0.9% respectively, of the parasitized pupae. *Nasonia vitripennis* only parasitized one (0.3%) pupa, from which a single female wasp emerged. Parasitoids in the unknown category made up 1.9% of the parasitized pupae. Of the non-release farms, Stengel's and Staerk's had the highest per cent parasitism with 8.0 and 6.3%. Most of the parasitoid population was made up of *Phygadeuon fumator*

with 90.8 and 66.4% of the parasitoids, respectively. Dueck and Schroeder had smaller total percentage parasitism (1.3 and 0.5%). Of the 12 parasitized pupae collected at Schroeder's, four (33.3%) were parasitized by *P. fumator*. Only one *P. fumator* was collected at Dueck's (Table 8). Total percentage of parasitism was 3.8%.

Of the 2,753 fly pupae collected at Staerk's in 1996, 332 (12.1%) were parasitized (Table 9), of which 260 (78.3%) were parasitized by *P. fumator*. Unknown, *S. nigra*, *S. cameroni*, *S. subpunctata*, Figitidae and *Aphaereta* accounted for 8.1, 6.6, 3.0, 1.5, 0.3 and 0.3% of the parasitized pupae, respectively. *Muscidifurax* that were broken and could only be identified to genus accounted for 1.9% of the parasitized pupae.

Of the 1,938 fly pupae collect at Stengel's, 110 (5.7%) were parasitized of which 93 (84.6%) were parasitized by *P. fumator*. *Spalangia cameroni*, unknown, *M. raptor* and *S. nigra* accounted for 5.5, 3.6, 3.6, and 1.8% of the parasitized pupae, respectively. One pupa was parasitized by *Aphaereta* and accounted for 0.9% of the parasitized pupae.

Of the 4,691 pupae collected, 442 (9.4%) were parasitized by seven species of parasitoids (Table 9). Of the 442 parasitized pupae, 392 (88.7%) were house flies and 50 (11.3%) were stable flies (Table 10). *Phygadeuon fumator* accounted for most of the parasitoids (79.9%). *Spalangia nigra*, *S. cameroni*, *S. subpunctata*, *M. raptor*, *Aphaereta* and a figitid accounted for 5.4, 3.6, 1.1, 0.9, 0.5 and 0.2% of the parasitized pupae, respectively. *Muscidifurax*

that were broken and could only be identified to genus parasitized 1.4% of the pupae. Unknown parasitoids accounted for 7.0% of the parasitism. There was a single pupa parasitized by a figitid. *Aphaereta* parasitized two pupae, with six parasitoids reared from each.

### III. MONITORING ADULT FLIES

The number of fly specks per strip was small ranging from 0 to 246. Release and non-release farms had significantly different numbers of fly specks per strip ( $F = 5.9$ ,  $df = 1$ ,  $97$ ,  $P < 0.017$ ). Release farms had more fly specks per strip (mean  $38.2 \pm 2.3$ ) than non-release farms (mean  $27.5 \pm 1.6$ ). For non-release farms, a maximum of  $31.7 \pm 6.3$  specks per strip occurred in the first week (July 13-21). There were no sudden increases or decreases in fly specks until 17-21 September when mean numbers decreased to  $10.0 \pm 1.5$  (Fig. 13). For release farms, average numbers of specks per strip did fluctuate. Mean numbers of specks were high in the first week, averaging  $50.6 \pm 6.5$ . Numbers decreased in the second week to a mean of  $35.4 \pm 5.7$  specks per strip. An increase in the average number of specks occurred from 21-28 July to 11-18 August, reaching a peak of  $53.2 \pm 6.5$ . Numbers of specks decreased to a mean of  $30.6 \pm 5.3$  for the week of 25 August - 1 September. From 1-9 and 9-17 September, mean number of specks were high,  $52.1 \pm 7.1$  and  $51.0 \pm 10.2$ , respectively. Numbers decreased to an average of  $8.5 \pm 1.6$  specks per strip from 17-21 September.

## PREVALENCE OF *P. FUMATOR*

To illustrate trends in the prevalence of *P. fumator*, the numbers of house fly and stable fly pupae parasitized by *P. fumator* were pooled since few stable fly pupae had been collected.

### I. Naturally occurring pupae - 1995

*Phygadeuon fumator* was first reared from naturally occurring pupae collected on 5 July (from both locations), the first date when pupae could be found. At the Staerk farm, pupae were collected until 14 September (Fig. 14). Total mean number of naturally occurring pupae collected each day was  $47.6 \pm 5.4$  and ranged from  $16.6 \pm 10.7$  to  $85.4 \pm 56.4$ . After 14 September, no fly larvae, pupae or adults could be found. For the Stengel farm, mean number of pupae collected each day was  $25.7 \pm 5.8$  and ranged from  $0.4 \pm 0.4$  to  $69.2 \pm 6.6$ . Pupae were collected until 14 September (Fig. 15).

#### A. Stengel farm

Of the 81 pupae parasitized by *P. fumator*, 66 were house flies and 15 were stable flies. From 5 July to 14 September, mean prevalence of *P. fumator* from all five locations ranged from 0.0 to 9.1% (Appendix I). Highest mean prevalence occurred on 20 July ( $9.1 \pm 9.1\%$ ) when one sampling location had 16 out of 35 pupae parasitized by *P. fumator*. No parasitized pupa were collected after 31 August.

## **B. Staerk farm**

Of the 149 pupae parasitized by *P. fumator*, 135 were house flies and 14 were stable flies. From 5 July to 14 September, mean prevalence of *P. fumator* from all five locations ranged from 0.0 to 25.1% (Appendix II). The highest prevalence occurred on 3 August when 41 out of 170 ( $25.1 \pm 13.9\%$ ) house fly and stable fly pupae were parasitized by *P. fumator*. No parasitized pupae were collected after 14 September.

## **II. Naturally occurring pupae - 1996**

### **A. Stengel farm**

Adult house flies were first seen on 30 May. Two adult specimens of *P. fumator* were collected on 17 June. The first stable fly pupa was collected on 8 July, while house fly pupae were not found until 22 July (Fig. 16). *Phygadeuon fumator* was first reared from naturally occurring pupae collected on 22 July. Pupae were collected until 17 October after which no larvae, pupae or adult flies could be found.

Of the 93 pupae parasitized by *P. fumator*, 92 were house flies and 1 was a stable fly. From the 22 July to 17 October, mean prevalence of *P. fumator* ranged from 0.0 to 17.0% (Appendix III). The highest mean prevalence ( $17.0 \pm 8.6\%$ ) occurred 2 September when 163 pupae were collected. Of the 163 pupae, 48 were parasitized by *Phygadeuon*.



## B. Staerk farm

House fly adults were first seen 10 June. House fly pupae were first collected on 13 June, while stable fly pupae were first collected on 15 July (Fig. 17). Mean number of pupae collected each day was  $17.2 \pm 3.0$  and ranged from 0.0 to  $77.0 \pm 12.3$ . Of the 260 pupae parasitized by *P. fumator*, 258 were house flies and 2 were stable flies. *Phygadeuon fumator* was first reared from naturally occurring pupae collected on 8 July. Pupae were collected until 17 October when only 26 pupae could be found. No fly larvae or adults could be found on 17 October.

From 8 July to 17 October, mean prevalence of *P. fumator* ranged from 0.0 to 46.9% (Appendix IV). The highest prevalence of  $46.9 \pm 15.7\%$  occurred on 2 September. Though *P. fumator* was collected in 4 out of 5 locations, the number of pupae collected was small (only 10 to 34 pupae at each location). Mean prevalence of  $26.8 \pm 13.5\%$  occurred on 23 August. However, only 36 pupae were collected at all five collection sites. Of the 36 pupae collected, 16 were parasitized. A mean prevalence of  $16.5 \pm 5.0\%$  occurred on 12 September when 394 pupae were collected. Mean number of pupae collected at all five collection sites was  $77.0 \pm 12.3$ . Of the 394 pupae collected, 60 were parasitized by *P. fumator*.

### III. Sentinel pupae - 1996

#### A. Stengel farm

*Phygadeuon fumator* was first reared from sentinel pupae placed in the field from 6 -10 June. From 3 June to 17 October, mean prevalence of *P. fumator* ranged from 0.0 to  $34.8 \pm 24.8\%$  (Appendix V). Highest prevalence occurred on the week of 4 - 8 July, when 564 pupae were retrieved, and 157 parasitized (mean prevalence of  $34.8 \pm 24.8\%$ ). *Phygadeuon fumator* was last collected from sentinel pupae placed in the field from 2 - 5 September. Of the 541 pupae retrieved, 10 (mean prevalence of  $2.4 \pm 2.4\%$ ) were parasitized by *P. fumator*. No *P. fumator* parasitized pupae in October. Due to accidental tip overs and missing dishes, the numbers of sentinel pupae retrieved each week varied. Mean number of pupae in each dish was  $282.0 \pm 13.8$ . Mean number of sentinel pupae retrieved each week was  $787.7 \pm 50.0$ .

#### B. Staerk farm

*Phygadeuon* was first reared from pupae placed from 13 - 17 June. On this date, of the 953 pupae retrieved, 6 (mean prevalence  $0.63 \pm 0.3\%$ ) were parasitized by *P. fumator*. From 13 June to 17 October, prevalence of *P. fumator* ranged from 0.0 to  $14.1 \pm 14.1\%$  (Appendix VI). From 2 - 5 September, of the 491 pupae, 94 (mean prevalence of  $14.1 \pm 14.1\%$ ) were parasitized by *Phygadeuon*. *Phygadeuon fumator* was last collected during 5 - 9 September when 1 ( $0.2 \pm 0.2\%$ ) out of 592 pupae were parasitized. Mean number of pupae

in each container was  $325.4 \pm 21.2$ . Mean number of pupae retrieved each week was  $829.9 \pm 59.0$ .

## DISCUSSION

### PARASITOID RELEASE - 1995

Quality control of parasitoids was well below what was promised by the supplier. Two parasitoids, *Muscidifurax zaraptor* and *N. vitripennis* were guaranteed by the distributor. Only *N. vitripennis* was present in the subsamples.

The distributor also promised 100% of the fly pupae in each bag to be parasitized. However, mean per cent parasitism was only  $67.7 \pm 2.2\%$  per bag. Many intact puparia contained dead house flies. Some parasitoids had emerged before release and could be seen crawling on the outside of the bags when they were first obtained from the supplier. On examination of the subsamples, many pupae were empty and evidence of parasitoid emergence was seen.

It was recommended that parasitoids should be stored at 12°C until the day of release. Storing parasitoids at this temperature did not reduce emergence. However, it is not known if storage had an effect on the subsequent activity of adult *Nasonia* and their progeny.

The numbers of parasitoids in the five parasitoid shipments received from the supplier were significantly different. Since the five shipments did not have the same number of pupae per bag (Fig. 6), the numbers of parasitized pupae,

numbers of parasitoids and numbers of females dispersed each week were significantly different. Four of the five shipments had over 70% parasitism (Fig. 7). The shipment received on 16 August (shipment 4) had  $44.6 \pm 3.4\%$  parasitism, considerably less than in the other four shipments. Mean intensity on 16 August was  $9.5 \pm 0.3$  and was not significantly different than the first three shipments (Table 4). However, the numbers of parasitoids received on 16 August was small. Examination of the parasitized pupae from this shipment revealed that many pupae had collapsed and were not parasitized.

The supplier promised 160,000 parasitoids per bag. For all release farms, 6.4 million parasitoids should have been released throughout the 10 week period. Numbers of parasitoids received were well below expected. With an average of  $91,202 \pm 6,577$  parasitoids per bag received, only 3,648,093 were released throughout the study. Of the parasitoids promised by the supplier, 57% were received for this release program. Of the 3.6 million parasitoids released, 41% were females. The sex ratio was 0.77 females/males. Wylie (1965) reported a reduced percentage of females in the adult progeny when there is a superabundance of individuals of *N. vitripennis*. This low ratio could have been caused by over crowding under insectary conditions. Mean intensity of parasitized pupae received from the distributor was  $8.7 \pm 0.2$  (Fig. 9), slightly higher than the value of  $7.1 \pm 2.1$  reported by Rivers and Denlinger (1995b).

The supplier suggested to begin releases in early May and to terminate the program in the fall after the first freeze. In 1995, in Manitoba dairies, no fly

larvae or pupae could be found until late June, early July. Since hosts were not available in the spring, early release of parasitoids is unnecessary. Adult *Nasonia* have short life spans. In the laboratory, males and females live an average of  $1.6 \pm 0.1$  and  $7.0 \pm 0.6$  days (Nagel and Pimentel 1963). If *N. vitripennis* were to be released in May, adults could not survive until hosts were available.

*Nasonia vitripennis* should not be used as a control for house flies and stable flies in dairy operations in Manitoba. Though an estimated 3,648,093 parasitoids were released at four dairies, *N. vitripennis* did not parasitize a large proportion of pupae. Second and third in relative abundance for parasitoids found in sentinel and naturally occurring pupae, *Nasonia vitripennis* only parasitized 223 (26.2% of parasitized pupae) sentinel and 76 (16.0% of parasitized pupae) naturally occurring pupae. *Nasonia vitripennis* has been ineffective in control of house flies and stable flies in other studies. Stage and Petersen (1981) released one of three species of parasitoids (*N. vitripennis*, *S. endius* or *M. raptor*) each week from 13 May to 11 October in confined Nebraska feedlots. Although *N. vitripennis* was released in large numbers (2,200,000 per lot), only one specimen was collected from 12,000 pupae sampled. In another trial, Beard (1964) released 30,000 house fly pupae parasitized by *N. vitripennis* at weekly intervals for one month. Not a single recovery was made, either from naturally occurring pupae in the field or from sentinel pupae. Failure in the field using *N. vitripennis* could have been predicted from the experience in Australia,

where millions of *Nasonia* were released for blow fly control (Whiting 1967).

Legner (1967) reported that *N. vitripennis* should not be used as control for house flies and stable flies. If hosts pupate in manure more than five cm beneath the surface, *N. vitripennis* females cannot reach them (Whiting 1967). This explains why more sentinel pupae were parasitized in our study, than naturally occurring pupae. Sentinel pupae were placed on the surface of manure and were accessible to *N. vitripennis*.

Monitoring adult flies with the spot card technique illustrated that the release of *N. vitripennis* did not reduce adult fly populations. If fly control was effective, we would have expected fly strips to have more faecal and regurgitation spots at the non-release farms than at release sites. Release dairies had more fly specks per strip. Since there were no decreases in numbers of fly specks for the release farms relative to non-release sites throughout the season, *Nasonia* did not have an impact on fly populations. However, the spot card technique did give an estimate of relative abundance of flies at each farm.

Naturally occurring pupae, which were parasitized by *N. vitripennis* at the release farms, had a mean intensity of  $7.7 \pm 0.5$ . Sentinel pupae parasitized by *Nasonia* at the release farms had a mean intensity of  $5.0 \pm 0.2$ . Rivers and Denlinger (1995a) found hosts that were killed by exposure to  $-70^{\circ}\text{C}$  were less suitable for *N. vitripennis* than living hosts. Since the mean intensity for sentinel pupae was significantly different and smaller than the mean intensity of naturally

occurring pupae, it may be that previously frozen pupae were not as acceptable for parasitism by *N. vitripennis* as fresh pupae. A single *N. vitripennis* emerged from many sentinel pupae (Fig. 11).

Adult *N. vitripennis* fertilize fewer eggs when parasitoid:host ratios are high because females encounter more previously attacked hosts (Wylie 1966). The sex ratios for sentinel (3.2 females/males) and naturally occurring (1.3 females/males) pupae that were parasitized by *N. vitripennis* were slightly higher than the sex ratio of *Nasonia* received from the supplier (0.77 females/males). In the field, individual females of *N. vitripennis* might not have encountered other females, therefore more fertilized eggs might have been laid.

Commercial insectaries recommend releasing numbers of parasitoids based on numbers of cattle (Andress and Campbell 1994). Andress and Campbell (1994) released 95.6 parasitoids per animal per week at a feedlot and 538.9 parasitoids per animal per week at a dairy. With over 100 parasitoids per animal per week released on two Nebraska feedlots, Petersen *et al.* (1983) failed to reduce fly numbers. We released 860,711 to 983,662 parasitoids at the four release farms. We released 1,081 to 2,258 parasitoids per animal per week. Despite releasing more parasitoids per animal per week than in any other study, prevalence of *N. vitripennis* was low. Results are further evidence of the ineffectiveness of *N. vitripennis* as a house fly and stable fly parasitoid under field conditions.

For this study, the cost of releasing parasitoids each week was \$60.00

per farm. We released parasitoids weekly for 10 weeks for a total cost of \$600.00 per farm. If a producer were to implement an inundative release program following the recommendations of the distributor, parasitoids would have to be released for a minimum of 14 weeks. This would cost the producer with approximately 40 cattle \$840.00, an expensive investment for a fly control program which is ineffective.

#### PARASITOID SPECIES

Disregarding *N. vitripennis*, *U. rufipes* and *M. raptor* were the most abundant parasitoids found in sentinel pupae in 1995 at the release farms. Though *M. raptor* is commonly found in animal manure elsewhere in the Western Hemisphere (Legner *et al.* 1967; Petersen *et al.* 1983; Pawson and Petersen 1988; Andress and Campbell 1994), *Urolepis rufipes* has only been reported in Alberta (Lysyk 1995), Nebraska (Andress and Campbell 1994) and in dairy farms in New York (Smith and Rutz 1991a). In Manitoba, *Nasonia vitripennis* was found at the non-release farms, but in small numbers. Fifteen sentinel pupae collected from two of the four non-release dairies were parasitized by *N. vitripennis*. Since this species occurs naturally and was also third in abundance for non-release farms, we can assume that a small proportion of the sentinel pupae parasitized by *N. vitripennis* at the release farms could have come from an indigenous population. It is unlikely that *N. vitripennis* was accidentally released at the control farms, since release and non-release farms



were visited on separate days. However, it is disturbing that no *N. vitripennis* were collected in 1994 or 1996. There is a possibility that *N. vitripennis* could have parasitized sentinel pupae in the laboratory before being placed at non-release locations.

*Nasonia vitripennis*, *S. subpunctata*, *S. nigra*, a staphylinid and *E. vesicularis* are new records for house fly and stable fly parasitoids found in Canada. Lysyk (1995) examined the parasitoids associated with live sentinel house fly pupae at dairies in Alberta. In his two year study, he found seven species of parasitoids, one of which has not yet been collected in Manitoba, *Dibrachyus cavus* (Walker). In Alberta, *Muscidifurax raptor*, *M. zaraptor* and *Trichomalopsis* sp. were the most abundant parasitoids.

The importance of *P. fumator* was underestimated in 1995 by using previously frozen pupae. Only one previously frozen sentinel pupa was parasitized by *P. fumator* (Table 5). In live sentinel pupae, *P. fumator* was most abundant, accounting for 97.4% of the parasitoids. Though pteromalids will parasitize freeze-killed pupae, female *P. fumator* prefer to parasitize live pupae.

The activity of *Phygadeuon* is greatest at higher latitudes in the Northern Hemisphere (Legner and Olton 1968). *Phygadeuon* has been collected from live sentinel house fly pupae in Alberta (Lysyk 1995) and New York (Smith and Rutz 1991a), and has been reared from horn fly, *Haematobia irritans* (L.), pupae (Depner 1968) in Alberta.

In 1995, *Muscidifurax raptor* and *P. fumator* were the most abundant

parasitoids found in house fly and stable fly pupae collected at release farms.

The unique manure management system at the VanWalleghem farm might have contributed to low numbers of naturally occurring pupae and parasitoids collected. The use of Muscovy dusks and wood shavings might have affected microhabitat, influencing parasitoid activity.

Legner and Olton (1968) believed that the activity of *Phygadeuon* sp. is greatest where other parasitoids are rare or other parasitoids are scarce or absent. In 1995, release farms, Stengel's and Staerk's had the highest per cent parasitism of naturally occurring pupae with 8.0 and 6.3%, respectively. *Phygadeuon fumator* was most abundant with 90.9 and 66.4% of the parasitoids, respectively. In 1996, Stengel's and Staerk's had 5.7 and 12.1% parasitism with *P. fumator* accounting for 84.6 and 78.3% of the parasitoids.

Parasitoid composition varied between years. A figitid and two specimens of *Aphaereta* collected from naturally occurring pupae in 1996 were not collected in 1995. Three parasitoids, *Trichomalopsis* sp., *U. rufipes* and *N. vitripennis*, were collected in 1995, but were absent from collections in 1996. Parasitoid composition between years was also different in sentinel pupae. At the Stengel and Staerk farms, two species, *N. vitripennis* and *Trichomalopsis* sp., were collected in 1995, but not in 1996. *Spalangia cameroni*, *S. nigra* and *S. subpunctata* were not collected in 1995, but were in 1996.

House flies and stable flies were abundant in Manitoba from early July to October. Though pupal sampling methods were not quantitative, trends in

house fly and stable fly populations were estimated by the number of pupae available for collection. The length of the fly season can vary between years. In 1995, it was not known when fly pupae first became available since house fly and stable fly pupae were not collected until 5 July. However, the last date for pupal collection was 14 September, after which no larvae or pupae were seen (Figs. 14, 15). Since the search for pupae began in May 1996, the first date of pupal collection in 1996 was reliable. At the Staerk farm house fly pupae were first collected on 13 June, but in very low numbers. Stable fly pupae were not collected until 15 July (Fig. 17). At the Stengel farm, stable flies were collected on 8 July, with the first collections of house fly pupae on 22 July (Fig. 16). In 1996, the fly season was extended for an additional five weeks, with the last collections of pupae on 17 October.

Most stable fly pupae collected were obtained in July at the beginning of the fly season (Figs. 16, 17). Since many adult stable flies were seen from July to October, stable flies must have been breeding elsewhere. Adult house flies were seen in late May, but no immature stages were evident. Thus, the majority of female house flies must not have laid eggs until late June, early July. Collections of house fly pupae peaked in August and September.

#### **PREVALENCE OF *PHYGADEUON FUMATOR***

Since sentinel pupae were routinely retrieved, time of parasitism can be roughly estimated. However, for naturally occurring pupae, time of parasitism is

not known. Naturally occurring pupae parasitized by *P. fumator* could have been in the field for 3–4 weeks or more before they were collected. Therefore, prevalence of *P. fumator* in naturally occurring and sentinel pupae could not be compared.

In 1996, at the Stengel farm, the first collection of stable fly pupae was 8 July, while house fly pupae were not found until 22 July. Since sentinel pupae were first parasitized by *P. fumator* from 10 to 13 June (Appendix V), and *P. fumator* adults were found on 17 June, this species was active in the barns before hosts were available. Results at the Staerk farm are similar. Few house fly pupae were collected in the first weeks of June. The first sentinel pupae were parasitized by *P. fumator* on 10 to 13 June. Alternative host pupae might be present and available elsewhere.

In Manitoba, house flies can only overwinter inside heated facilities (Hanec 1956). No fly breeding occurred inside the dairies in late September and no overwintering fly pupae could be found. *Phygadeuon fumator* must overwinter elsewhere in fly pupae other than house flies and stable flies. *Phygadeuon fumator* emerge in early June, before house fly and stable fly pupae become available inside the dairies. Since *Phygadeuon* spp. can parasitize *Fannia* (Legner and Olton 1968), horn flies, *H. irritans* (Depner 1968), and the cabbage maggot, *Phorbia brassicae* (Müller 1971), *P. fumator* may parasitize one of these species, before house fly and stable fly pupae become available inside the barns. Information on the overwintering host species and

location in Manitoba is needed before this species can be introduced for biological control.

## CONCLUSION

Suppliers are mass producing and aggressively selling parasitoids to Canadian producers without evidence that they are effective for fly control. The release program for *N. vitripennis* was ineffective for control of house flies and stable flies in Manitoba. A possible explanation for this release failure could be attributed to the use of *N. vitripennis*, an inappropriate species since it is not adapted to penetrate host pupation sites (Legner 1967).

Several species have been used in inundative release programs to evaluate their potential for controlling fly populations (Smith and Rutz 1991c). Many of these programs have failed (Mourier 1972; Stage and Petersen 1981; Petersen *et al.* 1983; Meyer *et al.* 1990). Instead of emphasizing parasitoids, manure management should be top priority. Time and money should be spent on eliminating house fly and stable fly breeding sites rather than an ineffective parasitoid release program.

Since parasitism for both years in sentinel and naturally occurring pupae was low, it appears that parasitoids occurring naturally in Manitoba dairies are not providing effective control of house fly and stable fly populations. More parasitoid surveys should be conducted in Manitoba in other livestock operations such as poultry houses and feedlots, allowing parasitoid species to

be compared among facilities.

Of all the species collected, *Phygadeuon fumator* has shown potential. More research should be conducted to evaluate its capability as a house fly and stable fly parasitoid. Research should focus on its general biology, foraging behaviour and overwintering strategies before it can be utilized into an inundative release program.

Table 3. Estimated numbers of parasitized pupae, *Nasonia vitripennis* (Walker), mean intensity (number of parasitoids per parasitized pupa), number of adult wasps and number of females distributed in Manitoba dairies between 10 July and 10 September, 1995.

Farm	No. parasitized pupae	Mean intensity $\pm$ S.E. <sup>a</sup>	Estimated total no. wasps	Estimated total no. females
Glenlea	112,055	8.3 $\pm$ 0.5	900,345	369,597
Holme	109,562	8.6 $\pm$ 0.4	983,662	414,852
VanWalleghem	97,259	8.6 $\pm$ 0.4	860,711	343,063
Wiens	96,277	9.2 $\pm$ 0.5	903,375	375,131
TOTAL	415,153	8.7 $\pm$ 0.2	3,648,093	1,502,643

<sup>a</sup> S.E., Standard error.

Table 4. Mean ( $\pm$  S.E.) and range of intensity for *Nasonia vitripennis* (Walker) for shipments received from 7 July to 30 August, 1995.

Shipment	Shipment date	Intensity range	Mean intensity
1	7 July	1 - 25	8.3ab $\pm$ 0.3
2	19 July	1 - 23	8.5ab $\pm$ 0.4
3	2 August	1 - 28	10.5c $\pm$ 0.3
4	16 August	1 - 25	9.5bc $\pm$ 0.3
5	30 August	1 - 22	7.2a $\pm$ 0.1

Values within mean intensity followed by the same letter are not significantly different ( $P \leq 0.05$ ; Bonferroni's pairwise multiple comparison).



Table 5. Number and prevalence of parasitoids<sup>a</sup> reared from previously frozen sentinel pupae on each farm in Manitoba from 5 July to 21 September, 1995.

Treatment	Farm	Ev	Mr	Mz	M	Nv	Pf	Ss	S	T	Ur	Unk	Total <sup>b</sup>	No. of pupae	Prevalence %
Release	Glenlea	3	150	50	7	39	0	0	0	5	208	10	472	3,619	13.0
	Holme	0	1	6	0	6	0	3	0	25	58	2	101	2,670	3.8
	Wiens	0	0	0	0	118	1	0	0	1	26	7	153	2,397	6.4
	VanWalleghem	0	6	0	0	60	0	0	1	0	49	1	117	1,936	6.0
	Total <sup>c</sup>	3	157	56	7	223	1	3	1	31	341	20	843	10,622	7.9
	Per cent	0.3	18.6	6.6	0.8	26.5	0.1	0.4	0.1	3.7	40.5	2.4	100		
Non-release	Dueck	0	1	0	0	14	0	0	0	6	19	3	43	3,651	1.2
	Schroeder	0	0	0	0	0	0	0	0	2	39	1	42	2,290	1.8
	Staerk	0	5	0	0	0	0	0	0	0	0	6	11	2,611	0.4
	Stengel	0	5	0	0	1	0	0	0	9	11	7	33	3,227	1.0
	Total <sup>c</sup>	0	11	0	0	15	0	0	0	17	69	17	129	11,779	1.1
	Per cent	0	8.5	0	0	11.6	0	0	0	13.2	53.5	13.2	100		

<sup>a</sup> Ev, *Eupelmus vesicularis* (Retzius); Mr, *Muscidifurax raptor* Girault and Sanders; Mz, *Muscidifurax zaraptor* Kogan and Legner; M, *Muscidifurax* spp.; Nv, *Nasonia vitripennis* (Walker); Pf, *Phygadeuon fumator* Gravenhörst; Ss, *Spalangia subpunctata* Först; S, Staphylinidae sp.; T, *Trichomalopsis* sp.; Ur, *Urolepis rufipes* (Ashmead); Unk, Unknown parasitoids that could not be identified.

<sup>b</sup> Total number of parasitoids for each farm and treatment.

<sup>c</sup> Total number of parasitoids and pupae, including total prevalence for release and non-release treatments.

Table 6. Number and prevalence of parasitoids<sup>a</sup> reared from live sentinel pupae per farm in Manitoba from 13 May to 17 October, 1996.

Farm	Mr	M	Pf	Sc	Sn	Ss	Unk	Ur	Total <sup>b</sup>	No. of Pupae	Prevalence %
Staerk	1	8	597	0	0	0	26	1	633	22,075	2.9
Stengel	0	0	1,401	13	2	1	0	2	1,419	28,767	4.9
Total <sup>c</sup>	1	8	1,998	13	2	1	26	3	2,052	50,842	4.0
Per cent	0.05	0.3	97.4	0.6	0.1	0.05	1.3	0.2	100		

<sup>a</sup> Mr, *Muscidifurax raptor* Girault and Sanders; M, *Muscidifurax* spp.; Pf, *Phygadeuon fumator* Gravenhörst; Sc, *Spalangia cameroni* Perkins; Sn, *Spalangia nigra* Latreille; Ss, *Spalangia subpunctata* Först; Unk, Unknown (parasitoids which could not be identified); Ur, *Urolepis rufipes* (Ashmead).

<sup>b</sup> Total number of parasitoids.

<sup>c</sup> Total number of parasitoids and pupae.

Table 7. Number of house fly, stable fly and parasitized pupae collected at dairy farms in Manitoba from 5 July to 21 September, 1995.

Treatment	Farm	House fly pupae	Parasitized house fly pupae		Stable fly pupae	Parasitized stable fly pupae		Total pupae
			No.	%		No.	%	
Release	Glenlea	1,121	100	8.9	1,801	116	6.4	2,922
	Holme	3,358	52	1.5	194	5	2.6	3,552
	Wiens	2,085	106	5.1	1,991	70	3.5	4,076
	VanWallegghem	702	13	1.9	645	10	1.6	1,347
	Total	7,266	271	3.7	4,631	201	4.3	11,897
Non-release	Dueck	1,311	19	1.4	348	2	0.6	1,659
	Schroeder	2,152	9	0.4	426	3	0.7	2,578
	Staerk	2,470	149	6.0	148	15	10.1	2,618
	Stengel	1,215	82	6.7	314	40	12.7	1,529
	Total	7,148	259	3.6	1,236	60	4.9	8,384

Table 8. Number and prevalence of parasitoids<sup>a</sup> collected from naturally occurring pupae per dairy farm in Manitoba from 5 July to 21 September, 1995.

Treatment	Farm	Mr	Mz	M	Nv	Pf	Sc	Sn	Ss	T	Unk	Ur	Total <sup>b</sup>	No. of pupae	Prevalence %
Release	Glenlea	66	10	0	13	16	6	30	19	1	11	44	216	2,922	7.4
	Holme	0	1	0	43	1	0	4	0	0	4	4	57	3,552	1.6
	Wiens	24	5	0	19	73	38	2	8	1	2	4	176	4,076	4.3
	VanWalleggem	2	0	0	1	0	7	12	0	0	0	1	23	1,347	1.7
	Total <sup>c</sup>	92	16	0	76	90	51	48	27	2	17	53	472	11,897	4.0
	Per cent	19.5	3.4	0	16.1	19.1	10.8	10.2	5.7	0.4	3.6	11.2	100		
Non-release	Dueck	0	4	1	1	1	1	0	0	0	0	13	21	1,659	1.3
	Schroeder	3	0	0	0	4	3	1	0	0	1	0	12	2,576	0.5
	Staerk	3	0	0	0	149	9	0	0	0	3	0	164	2,618	6.3
	Stengel	17	1	0	0	81	1	2	8	0	2	10	122	1,529	8.0
	Total <sup>c</sup>	23	5	1	1	235	14	3	8	0	6	23	319	8,384	3.8
	Per cent	7.2	1.6	0.3	0.3	73.7	4.4	0.9	2.5	0	1.9	7.2	100		

<sup>a</sup> Mr, *Muscidifurax raptor* Girault and Sanders; Mz, *Muscidifurax zaraptor* Kogan and Legner; M, *Muscidifurax* spp.; Nv, *Nasonia vitripennis* (Walker); Pf, *Phygadeuon fumator* Gravenh orst; Sc, *Spalangia cameroni* Perkins; Sn, *Spalangia nigra* Latreille; Ss, *Spalangia subpunctata* F orst; T, *Trichomalopsis* sp.; Ur, *Urolepis rufipes* (Ashmead); Unk, Unknown (parasitoids which could not be identified).

<sup>b</sup> Total number of parasitoids for each farm and treatment.

<sup>c</sup> Total number of parasitoids and pupae, including total prevalence for release and non-release treatments.

Table 9. Number and prevalence of parasitoids<sup>a</sup> collected from house fly and stable fly pupae per dairy farm in Manitoba from 13 May to 17 October, 1996.

Farm	A	F	Mr	M	Pf	Sc	Sn	Ss	Unk	Total	No. of pupae	Prevalence %
Staerk	1	1	0	6	260	10	22	5	27	332	2,753	12.1
Stengel	1	0	4	0	93	6	2	0	4	110	1,938	5.7
Total	2	1	4	6	353	16	24	5	31	442	4,691	9.4
Per cent	0.5	0.2	0.9	1.4	79.9	3.6	5.4	1.1	7.0	100		

<sup>a</sup> A, *Aphaereta* sp.; F, Figitidae, Mr, *Muscidifurax raptor* Girault and Sanders; M, *Muscidifurax* spp.; Pf, *Phygadeuon fumator* Gravenhörst; Sc, *Spalangia cameroni* Perkins; Sn, *Spalangia nigra* Latreille; Ss, *Spalangia subpunctata* Först; Unk, Unknown (parasitoids which could not be identified).

Table 10. Number of house fly, stable fly and parasitized pupae collected per farm in Manitoba from 13 May to 17 October, 1996.

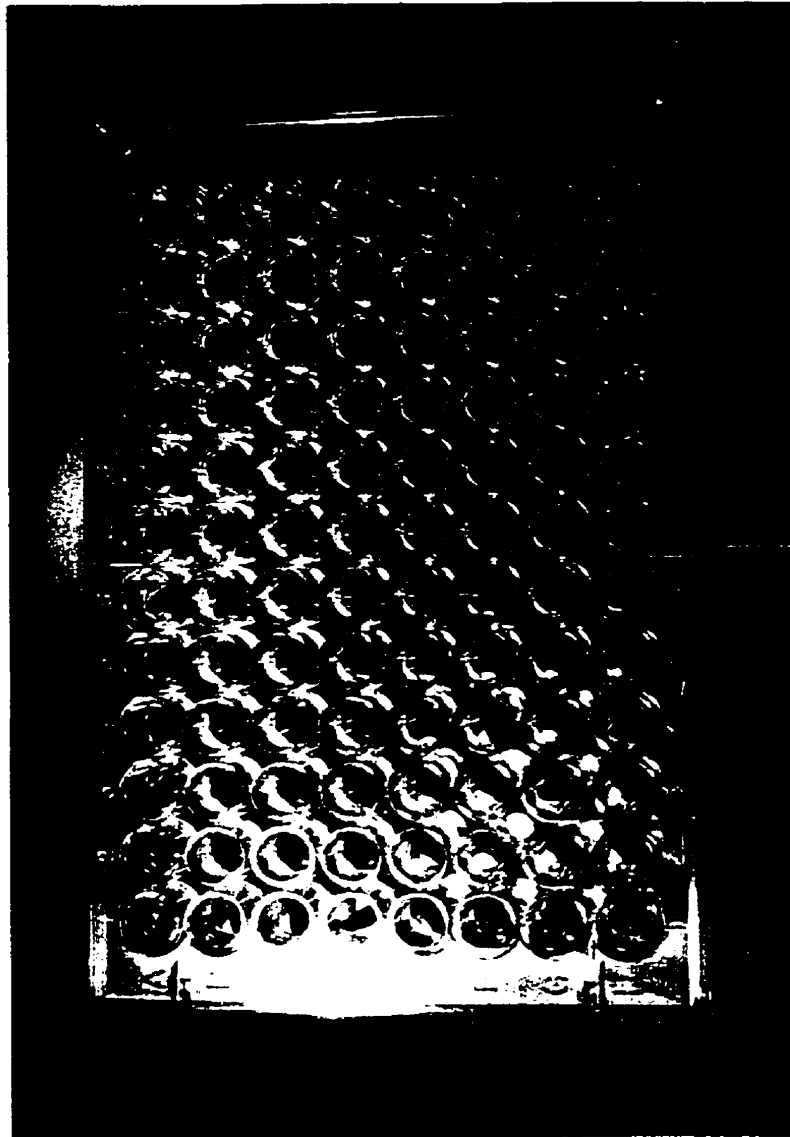
Farm	House fly pupae	Parasitized house fly Pupae		Stable fly pupae	Parasitized stable fly pupae		Total fly pupae	Total parasitized pupae	
		No.	%		No.	%		No.	%
Staerk	2,431	284	11.7	322	48	14.9	2,753	332	12.1
Stengel	1,707	108	6.3	231	2	0.9	1,938	110	5.7
Total	4,138	392	9.5	553	50	9.0	4,691	442	9.4

**Figure 1. One bag containing approximately 250 g of parasitized house fly pupae mixed with wood shavings. Parasitoids were purchased from Manbico Biological Ltd., Winnipeg, MB.**





Figure 2. Falcon® 96-well Micro Test III™ tissue culture plate containing 96 house fly pupae.



**Figure 3. Open sentinel container (16.0 x 9.0 x 3.5 cm), made out of aluminum window screening containing 96 previously frozen sentinel house fly pupae.**

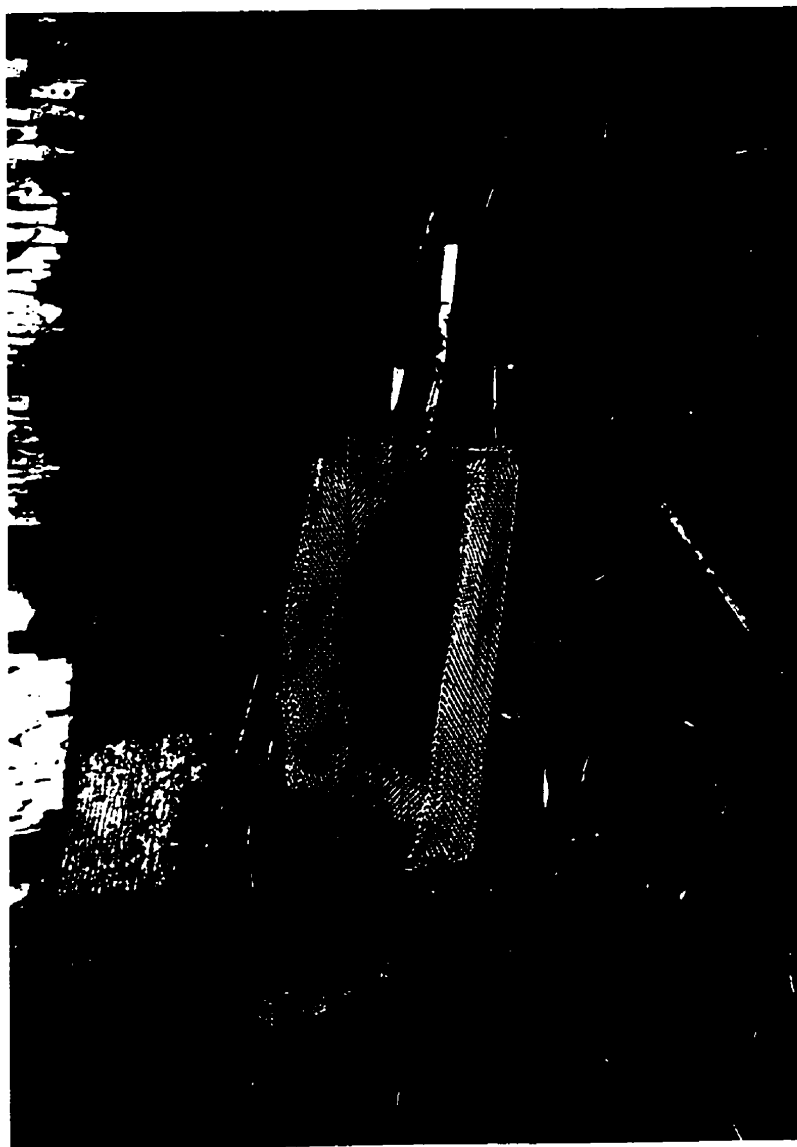


Figure 4. 450 ml plastic container, containing at least 100 live one-day-old house fly pupae or 3<sup>rd</sup> instar house fly larvae (>100) and a garden claw used for sampling.



Figure 5. White paper strip measuring 4 x 20 cm hung 1.5 m off the floor to monitor adult house fly populations. Fly specks were counted to estimate relative fly activity.





Figure 6. Mean number ( $\pm$  S.E.) of parasitized pupae per bag received each shipment date from 7 July to 30 August, 1995. House fly pupae were parasitized by *Nasonia vitripennis* (Walker). Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison).

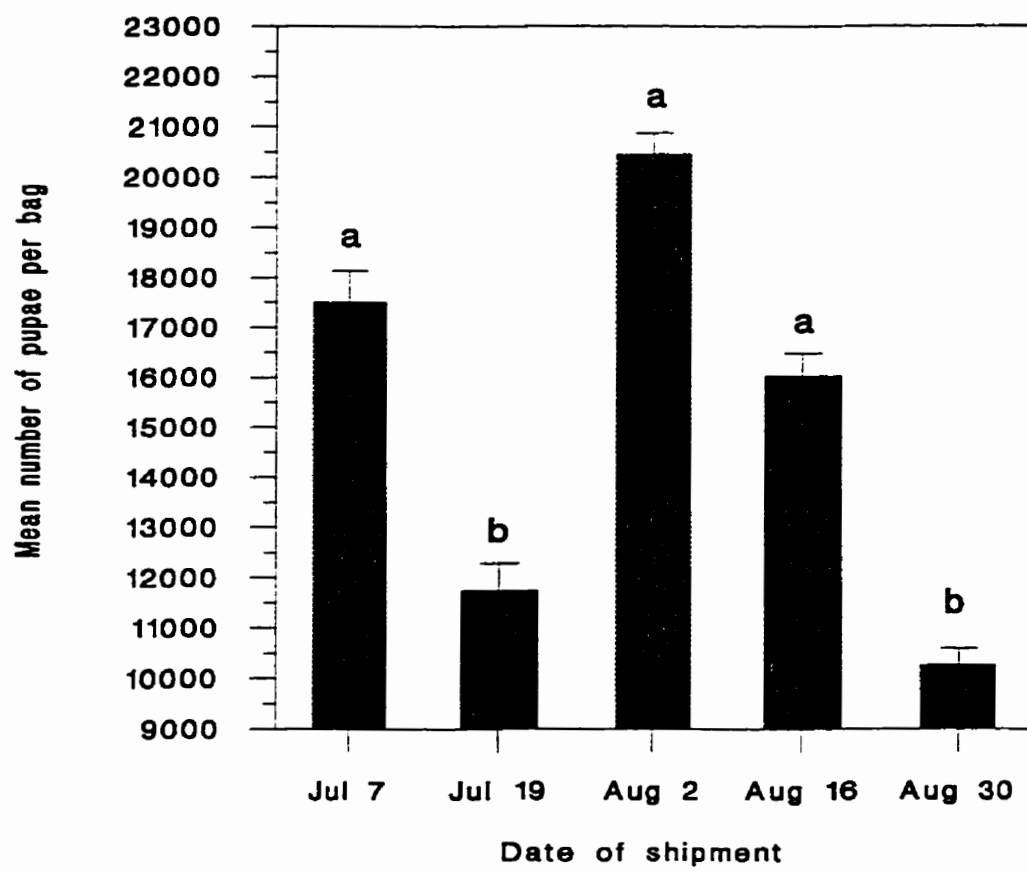


Figure 7. Prevalence ( $\pm$  S.E.) of *Nasonia vitripennis* (Walker) per bag for each shipment received from 7 July to 30 August, 1995. Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison).

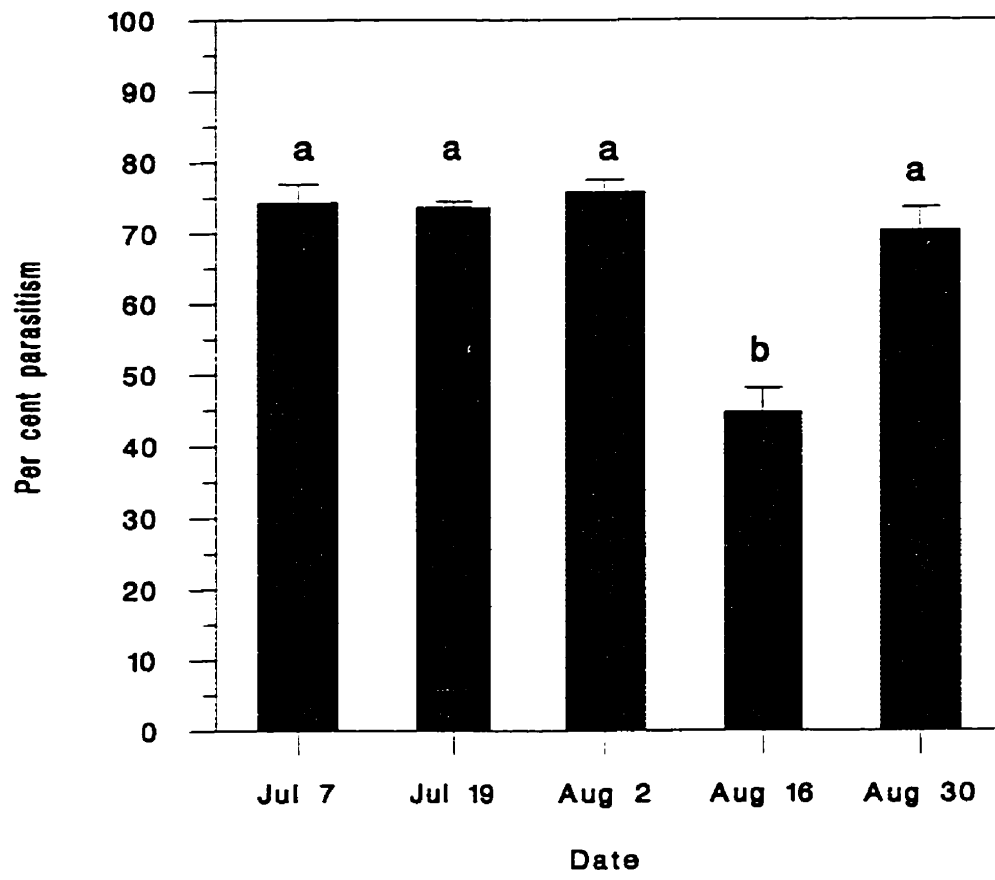


Figure 8. Mean number ( $\pm$  S.E.) of parasitized pupae per bag released each week from 10 July to 10 September, 1995. House fly pupae were parasitized by *Nasonia vitripennis* (Walker). Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison).

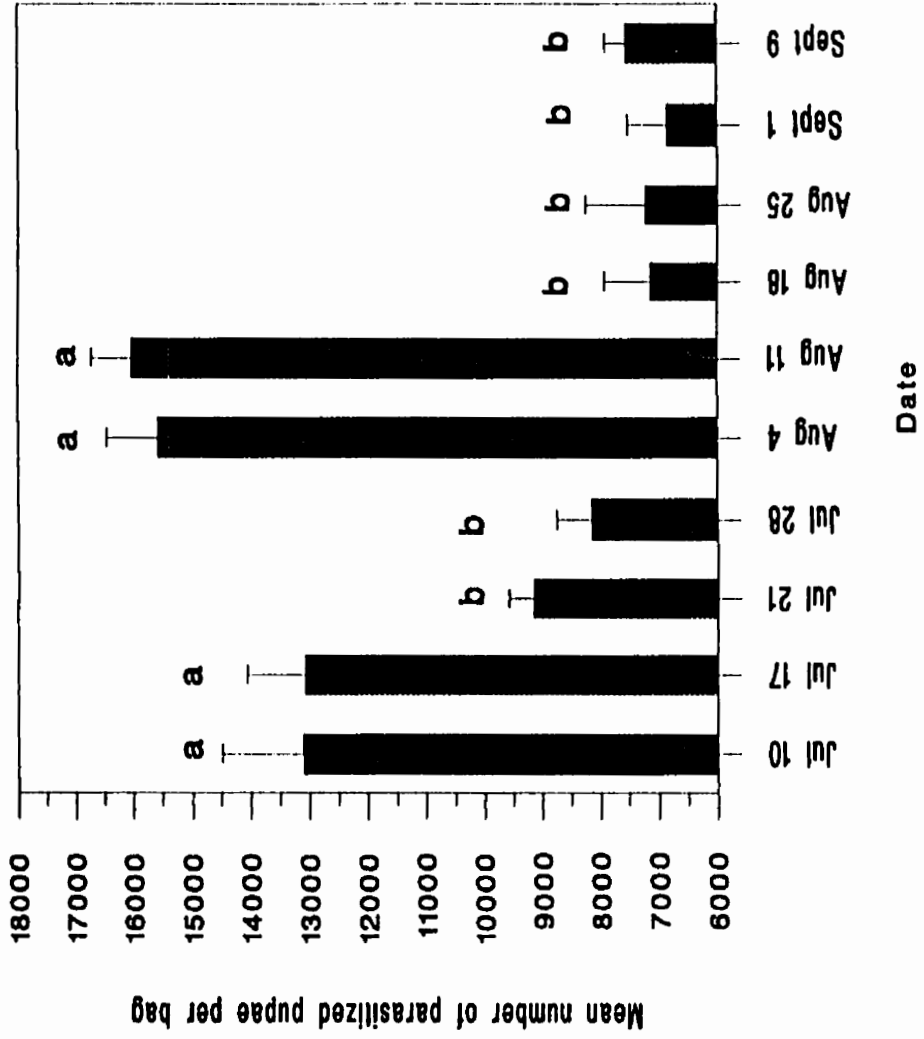


Figure 9. Frequency distribution of *Nasonia vitripennis* (Walker) for five shipments received from Manbico from 7 July to 30 August, 1995. Number of house fly pupae examined = 2083.

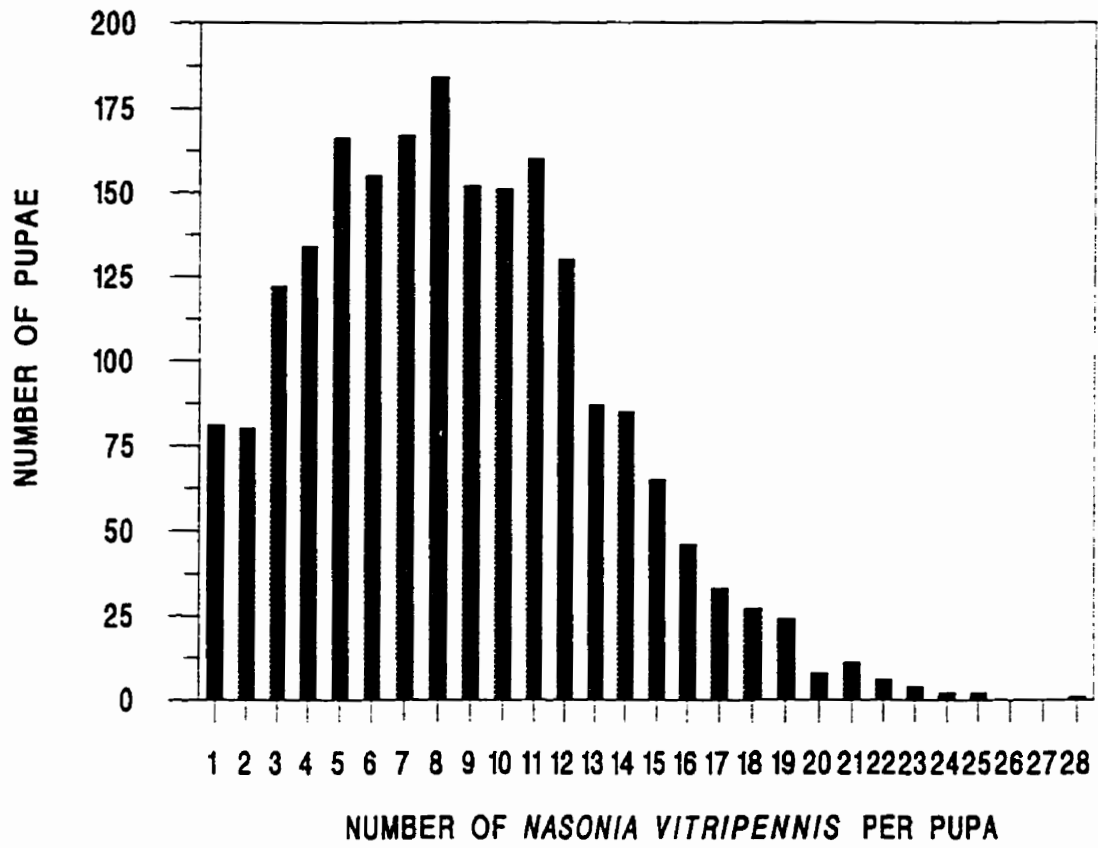




Figure 10. Mean number ( $\pm$  S.E.) of female *Nasonia vitripennis* (Walker) per bag for each shipment received from 7 July to 30 August, 1995. Bars with the same letter are not significantly different ( $p < 0.05$ ; Bonferroni's pairwise multiple comparison).

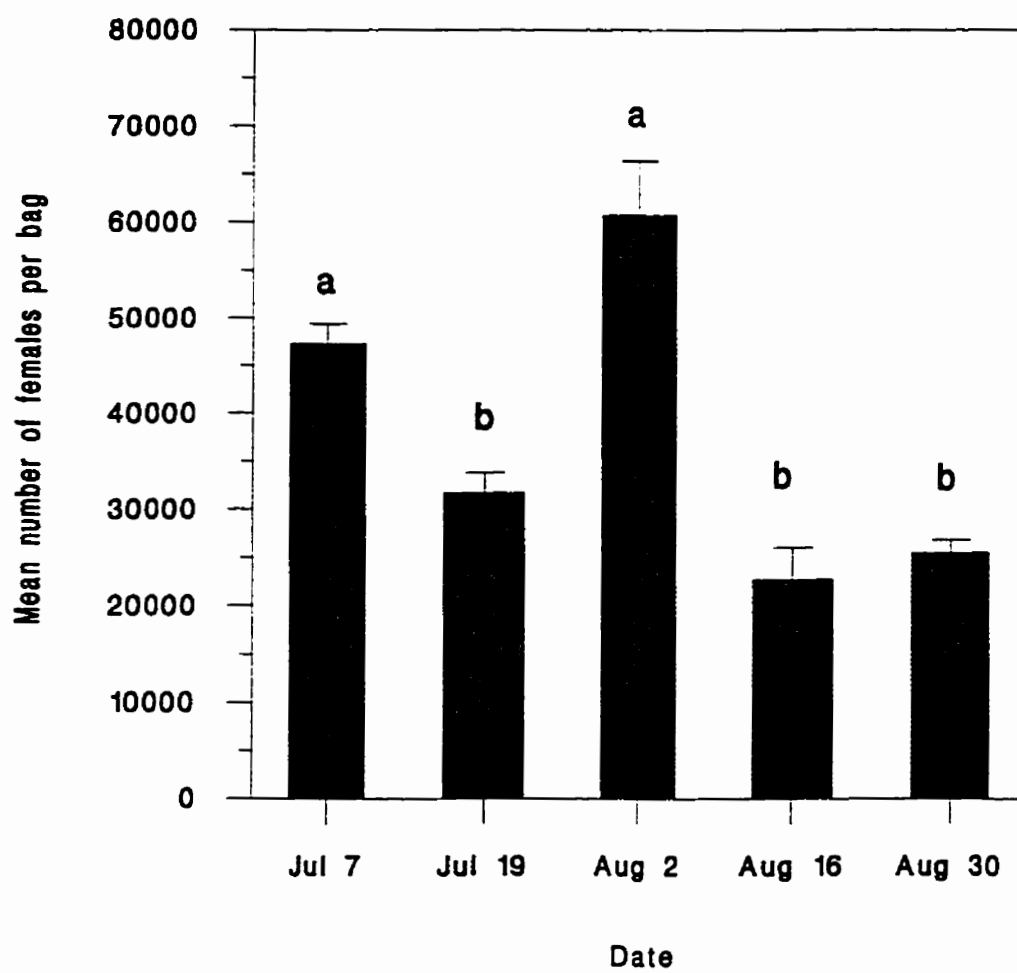


Figure 11. Frequency distribution of *Nasonia vitripennis* (Walker) reared from previously frozen sentinel pupae from 5 July to 21 September, 1995. Number of pupae examined = 223.

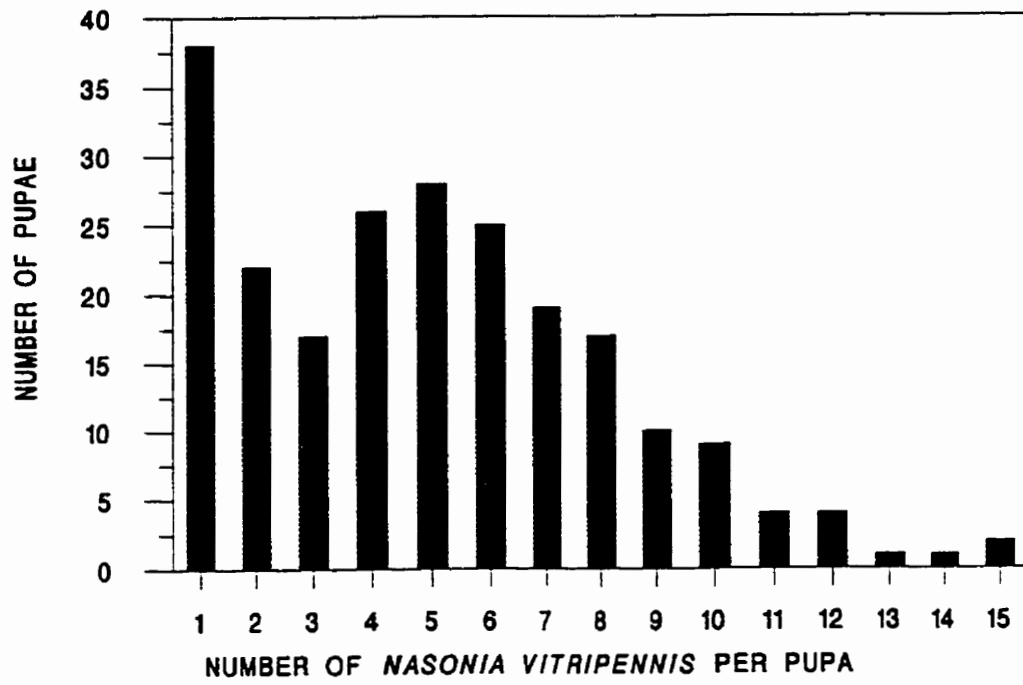


Figure 12. Frequency distribution of *Nasonia vitripennis* (Walker) collected from release farms in Manitoba from 5 July to 21 September, 1995. Number of naturally occurring pupae examined = 76.

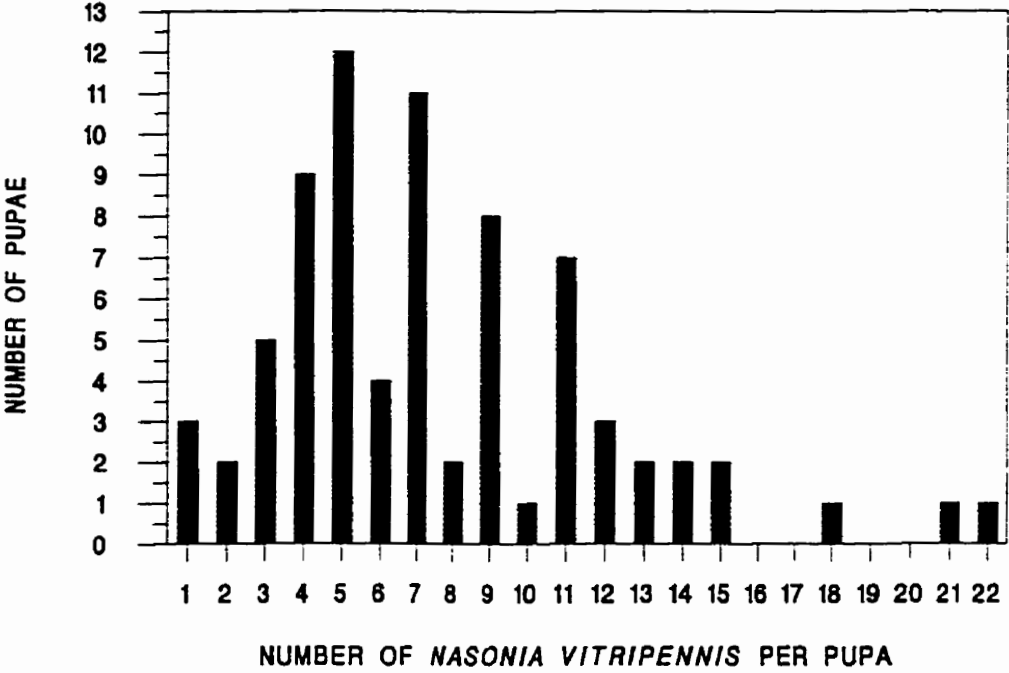


Figure 13. Mean number ( $\pm$  S.E.) of fly specks per strip for four farms where *Nasonia vitripennis* (Walker) was released and four non-release farms. 15 strips were placed at each farm for one week from 13 July to 17 September, 1995. The number of fly specks between release and non-release farms were not significantly different on 25 August and 17 September ( $p < 0.05$ ).

MEAN NUMBER OF FLY SPOTS PER STRIP

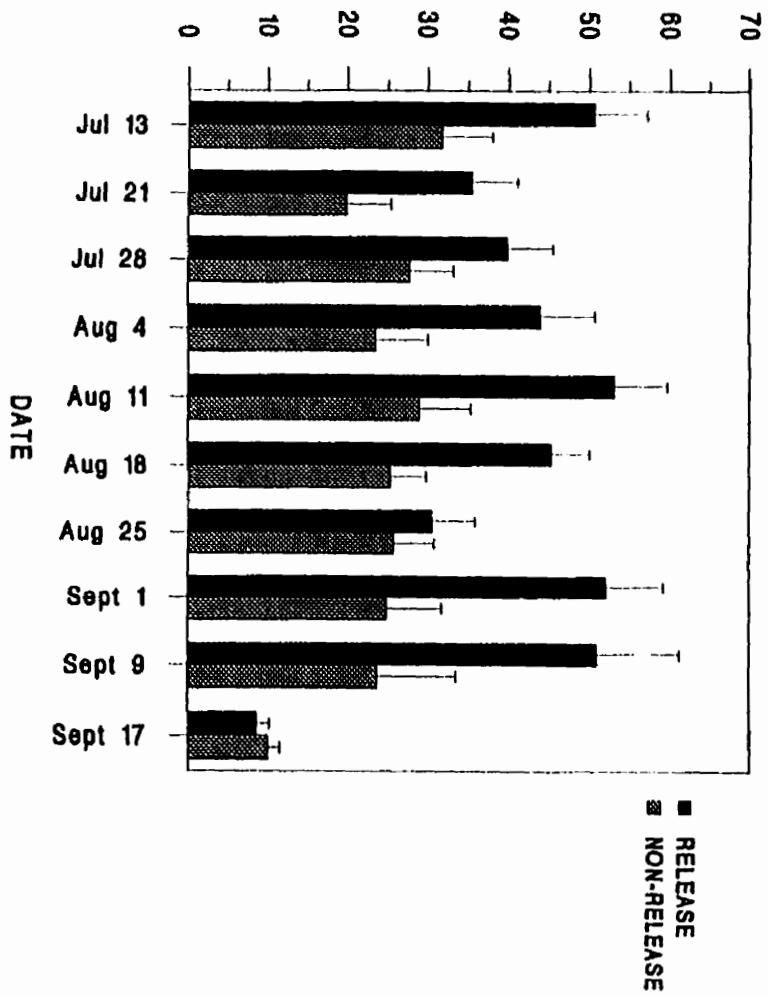




Figure 14. Mean numbers ( $\pm$  S.E.) of house fly and stable fly pupae collected for five locations at the Staerk farm from 5 July to 14 September, 1995.

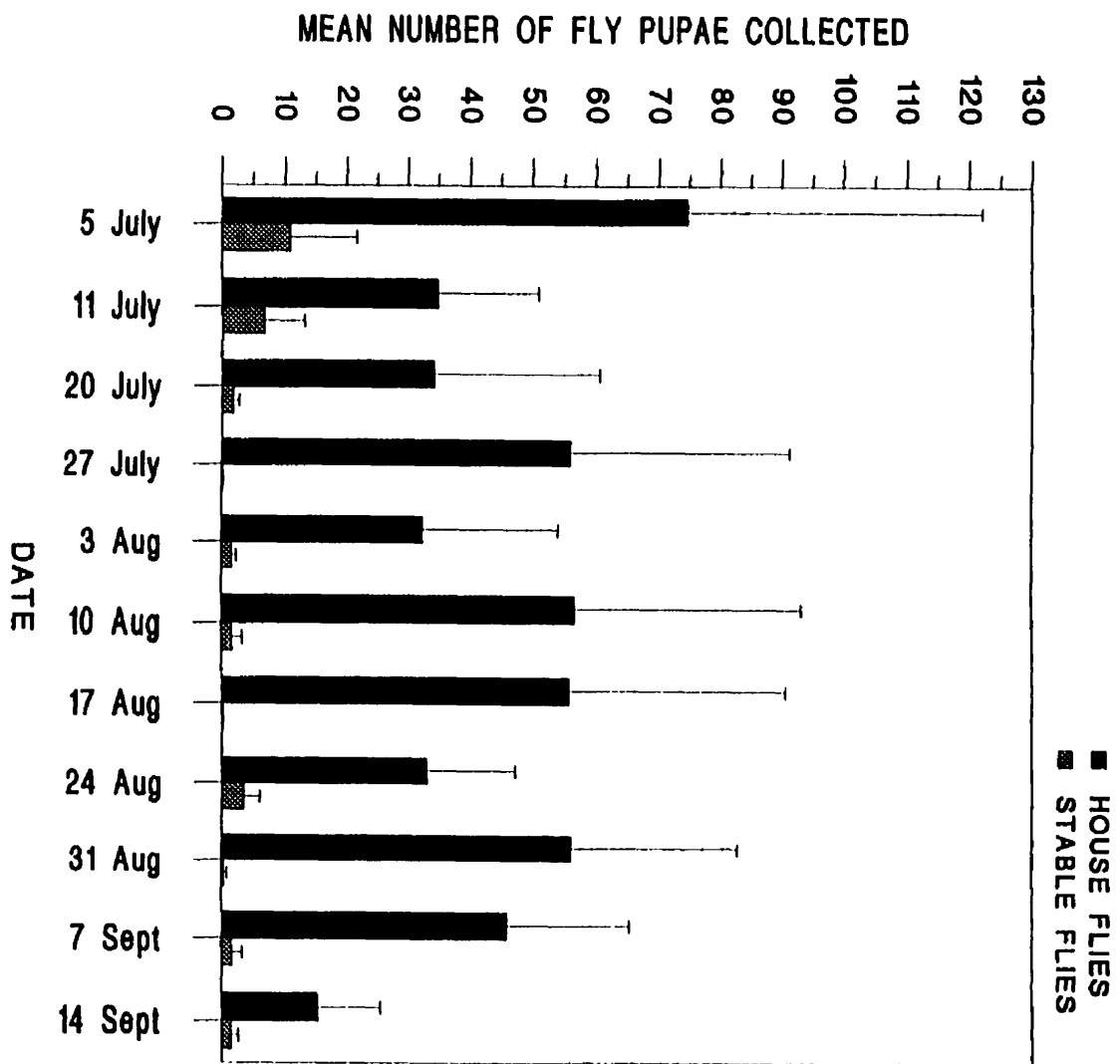


Figure 15. Mean numbers ( $\pm$  S.E.) of house fly and stable fly pupae collected for five locations at the Stengel farm from 5 July to 14 September, 1995.

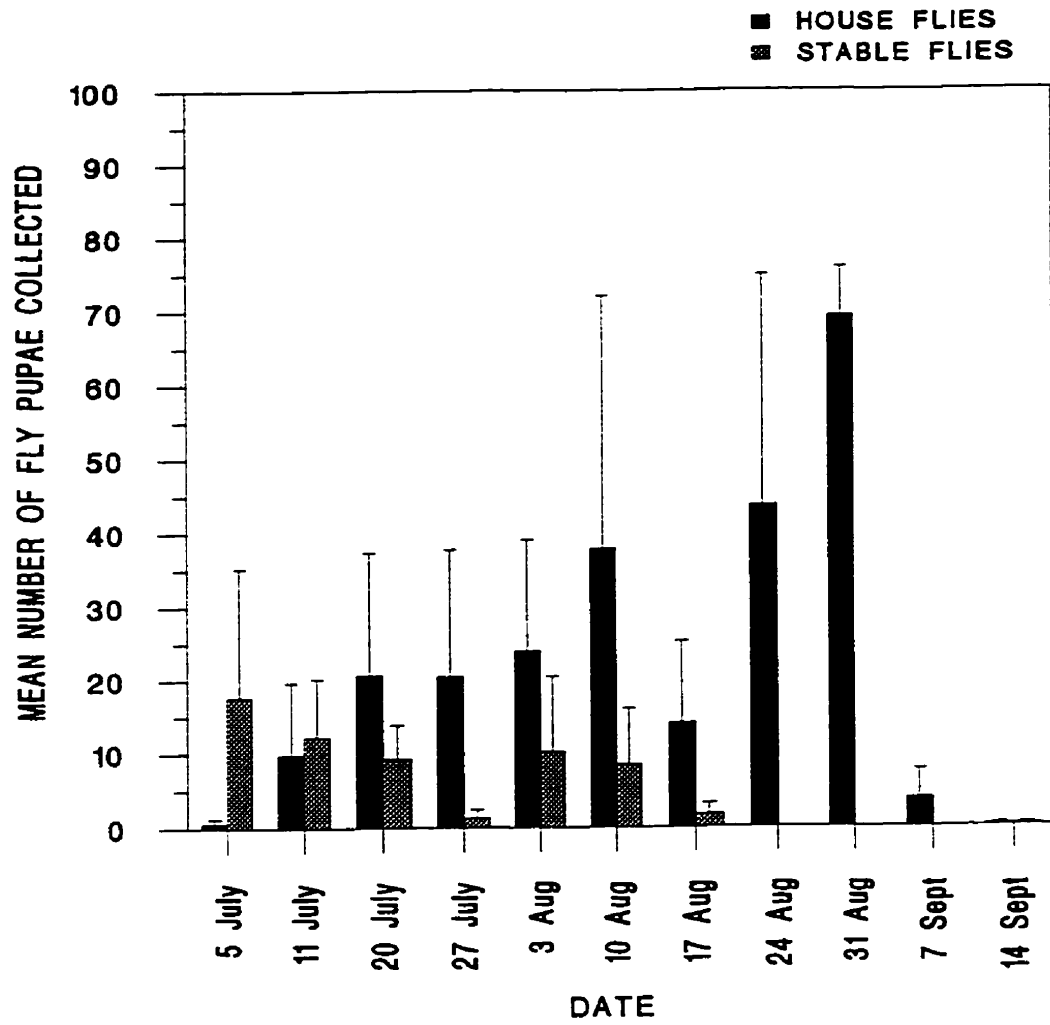


Figure 16. Mean numbers ( $\pm$  S.E.) of house fly and stable fly pupae collected for five locations at the Stengel farm from 13 June to 17 October, 1996.

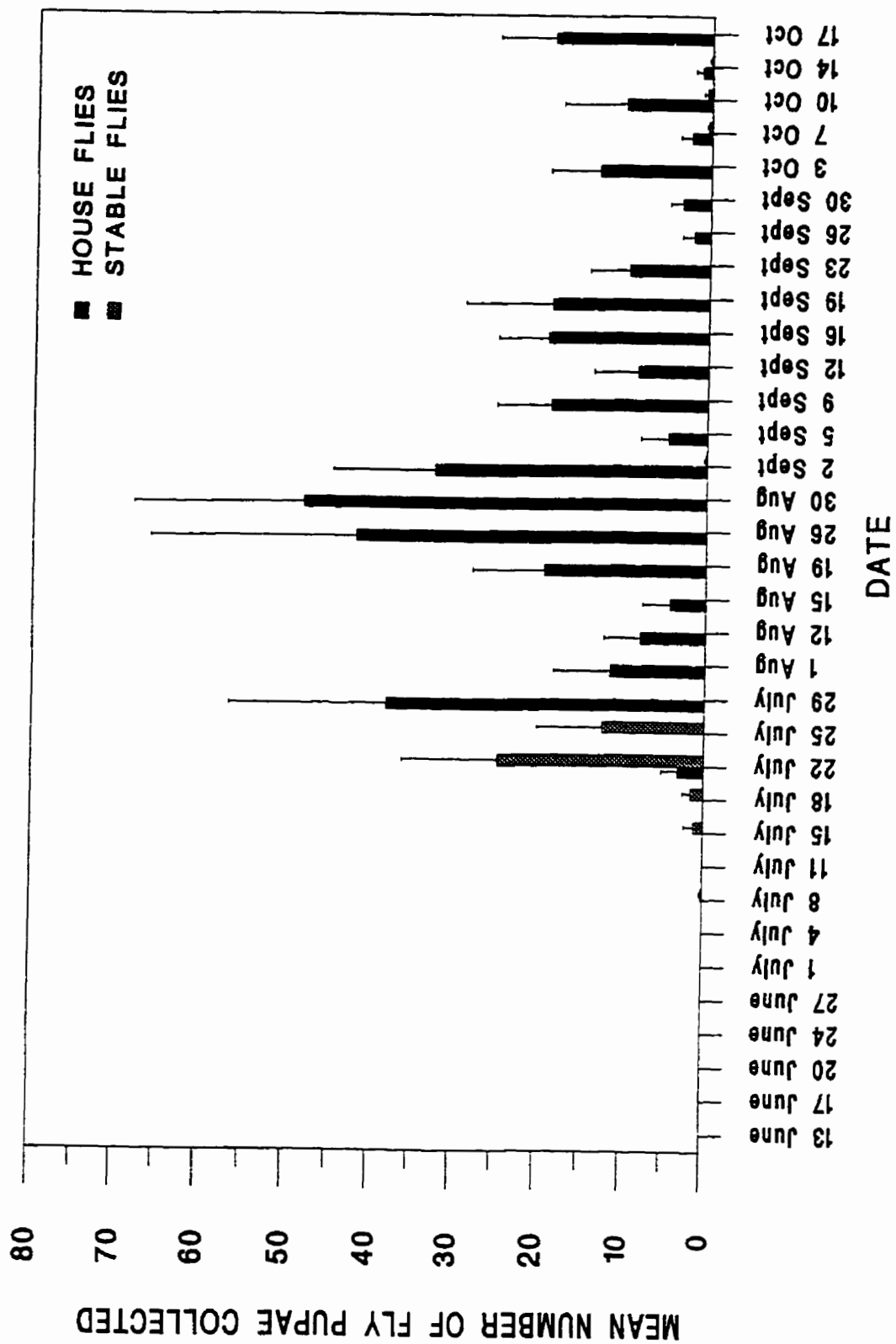
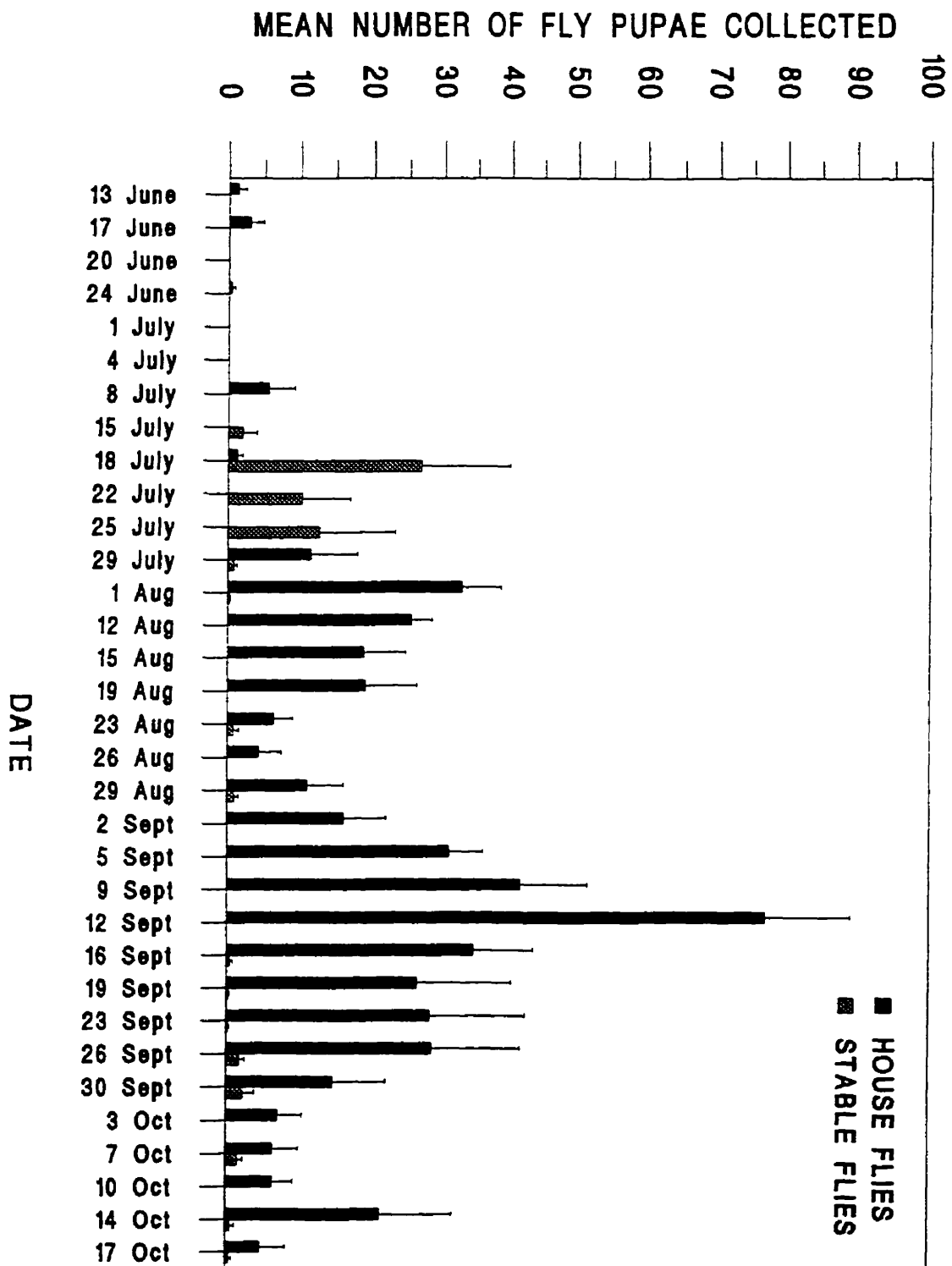


Figure 17. Mean numbers ( $\pm$  S.E.) of house fly and stable fly pupae collected for five locations at the Staerk farm from 13 June to 17 October, 1996.





## CHAPTER IV

### **BIOLOGY OF *PHYGADEUON FUMATOR* GRAVENHÖRST (HYMENOPTERA: PTEROMALIDAE), A PARASITOID OF HOUSE FLIES AND STABLE FLIES (DIPTERA: MUSCIDAE)**

#### **ABSTRACT**

Live house fly larvae and pupae were placed twice weekly in two Manitoba dairy farms in 1996. Of the 50,842 live sentinel pupae retrieved at two Manitoba dairies, 1,998 were parasitized by *P. fumator*, accounting for 97.4% of the parasitism. *Phygadeuon fumator* attacked only pupae.

A laboratory experiment was conducted to determine if *P. fumator* would attack pupae or larvae. One female was exposed to ten pupae and ten 3<sup>rd</sup> instar larvae each in separate plastic containers. Observations on parasitoid location were recorded every 60 seconds for one hour. 52.2 and 5.8% of observations were taken when females were in contact with containers of the pupae and larvae, respectively.

At 22°C, males of *P. fumator* had significantly shorter development times ( $24.8 \pm 0.1$  days, 14 to 35 days; n=615) than females ( $26.5 \pm 0.2$  days, 18 to 35 days; n=147). Some *P. fumator* did not emerge immediately and entered what seemed to be a larval diapause. Sentinel and naturally occurring pupae, which were still intact after 60 days, were dissected. There was a significant difference in the distribution of developmental stages of *P. fumator* between naturally occurring and sentinel pupae (chi-square=428.3, df=2.0,  $P < 0.001$ ). For sentinel pupae, 75.8% were larvae, 9.3% were pupae and 14.9% had emerged

as adults. For naturally occurring pupae, 29.5% of *P. fumator* were larvae, 5.9% were pupae and 64.6 emerged as adults.

## INTRODUCTION

The biology of *Phygadeuon* Gravenhörn is not well known (Blanchot 1988). *Phygadeuon fumator* Gravenhörn has been reared from *Delia* spp. in France and Russia (Wishart *et al.* 1957 ) and from the cabbage maggot (*Phorbia brassicae* Bouché) in Germany (Müller 1971). Legner and Olton (1968) examined parasitoids of the house fly, stable fly and species of *Fannia*, *Muscina* and *Ophyra* throughout the Palaearctic, Ethiopian and Pacific regions. *Phygadeuon* spp. parasitized *Stomoxys calcitrans* (L.), *Fannia* and a Syrphidae sp. in Ireland. Depner (1968) reared a *Phygadeuon* sp. from horn flies, *Haematobia irritans* (L.), from field collected pupae in Alberta. *Phygadeuon* sp. has also been reported to attack *Musca domestica* L. in Denmark, accounting for 1.0% of the total parasitism (Mourier 1972), and in the US (Legner *et al.* 1967; Miller and Rutz 1990; Smith and Rutz 1991*b*). Legner and Olton (1968) concluded that the activity of *Phygadeuon* sp. is greatest at higher latitudes in the Northern Hemisphere where other parasitoids are scarce or absent.

Müller (1971) stated that *P. fumator* attacked the larval and pupal stages of the cabbage maggot (*P. brassicae*), but also attacked the pupae of the onion and turnip flies. Rueda and Axtell (1985) alluded to *Phygadeuon* attacking fly larvae, but did not mention the host species. Blanchot (1988), who was the first

to describe the biology of *P. fumator*, found this species to attack the pupae of the house fly in France.

In 1995, of the 22,401 previously frozen sentinel pupae retrieved from eight dairies in Manitoba, one pupa was parasitized by *P. fumator*. With conflicting literature about what stage of host *Phygadeuon* attacks, it was not known if *P. fumator* rejected sentinel pupae because they were previously frozen or if it was because it was a larval parasitoid. Therefore, the objectives of this study were to determine if *P. fumator* was a larval or pupal parasitoid, and to provide information on its basic biology in the field and under laboratory conditions.

## MATERIALS AND METHODS

### LOCATIONS

The Stengel and Staerk farms, located near Beausejour and Whitemouth, MB, were chosen to examine the biology of *P. fumator*. Two farms were selected on the basis of the numbers of *Phygadeuon* found in parasitoid surveys conducted in 1994 and 1995. On the farms that were selected, *Phygadeuon* made up the majority of parasitoids reared from naturally occurring house flies and stable flies.

### SENTINEL PUPAE AND LARVAE

Live sentinel pupae were reared in a laboratory house fly colony (Chapter

III), and used to determine the presence of parasitoids. Three 450 ml plastic containers, holding a minimum of 100 live one-day-old house fly pupae and two containers (450 ml) holding at least 100 third instar lab-reared house fly larvae were placed twice weekly at each farm from the 13 May to 17 October. Plastic containers were used in 1996 rather than aluminum screened containers. In 1995, predators invaded the containers and larvae would escape the screened containers. Containers were nestled on the surface in known fly breeding sites and protected from livestock. Containers were taken to the lab and examined for *P. fumator* adults. All *P. fumator* found were placed into a cage (16.5 cm x 16.5 cm x 16.5 cm) with access to a dilute honey solution and water which were replaced every second day. Pupae and larvae remaining were held in cages (32 cm x 32 cm x 32 cm) at 22°C until all adult flies had emerged. Empty puparia and intact puparia were then counted. Intact puparia were placed in Falcon® 96-well Micro Test III™ tissue culture plates and incubated at 25°C (L18:D6), then checked each day for the emergence of *P. fumator*. *Phygadeuon* that emerged were maintained as described above. Data on species and sex of each parasitoid were recorded. After 60 days, intact puparia were dissected and the per cent parasitism determined. Stage of development, as larva, pupa or adult, was recorded. A Chi-square statistic was used to determine if the proportions of *P. fumator* in the various developmental stages were the same for both locations.

### **NATURALLY OCCURRING PUPAE**

House fly and stable fly pupae found in accumulated manure were also sampled for parasitoids (Chapter III). Five locations at each farm were sampled twice weekly from 13 May to October 17. Pupae were taken to the lab and placed in Falcon 96-well Micro Test III tissue culture plates. Pupae were incubated at 25°C (L18:D6). *Phygadeuon* that emerged were added into the colony as described above. After a minimum of six weeks, all intact puparia were dissected. Data on species, sex, prevalence and stage of development (larva, pupa or adult) were recorded. A Chi-square statistic was used to determine if the proportions of *P. fumator* in the various developmental stages were the same for both locations. This statistic was also used to determine if the proportions of *Phygadeuon* in the developmental stages were the same for naturally occurring and sentinel pupae.

### **PHYGADEUON CHOICE EXPERIMENT**

A choice experiment was conducted to determine if *Phygadeuon* parasitizes pupae or larvae. Individual females were placed in each of two cages (16.5 cm x 16.5 cm x 16.5 cm) and each was offered ten one day old pupae and ten third instar larvae. Two dishes, one for pupae and one for larvae, were placed on opposite sides of the cage. Cages were juxtaposed and an incandescent light (100 watts) was positioned 10 cm behind both cages allowing light to be equally dispersed. The location of the female wasp in each cage was

recorded every 60 seconds (one observation) for one hour. Observations such as in pupal dish, in larval dish or in neither were recorded. Since two cages were monitored at the same time, the recording of activity was alternated between cages every 30 seconds. After 30 minutes, the positions of the cages were reversed allowing each cage to have the same light exposure. Pupae were removed from the cages and placed in Falcon 96-well Micro Test III tissue culture plates to await emergence. Larvae were allowed to pupate before placing them in the plates. If nothing had emerged after approximately three months, they were dissected. Twenty-seven females were used in this experiment. Of the 27 females, 16 females were field collected and 11 were lab-reared with no previous exposure to pupae or larvae. All females used had been caged with males and were assumed to be mated. A Chi-square statistic was used to determine if there was a difference between females from the field and colony and if there was a preference for larvae or pupae.

#### PHYGADEUON COLONY

A colony of *P. fumator* was established by collecting adults found in containers of sentinel pupae, and those that emerged from sentinel and naturally occurring pupae. Since it appeared that females were attracted to light, the colony was covered with black cloth and kept at 22°C (L18:D6). One day old pupae, mixed with 250-300 ml of fly-medium retained after larvae had pupated, were exposed to the females for three days. After exposure, the pupae were

removed and placed into cages (16.5 cm x 16.5 cm x 16.5 cm). After the flies had emerged and died, the tray containing the remaining parasitized pupae was placed into a separate cage to allow *Phygadeuon* to emerge (22°C). Adult *Phygadeuon* were removed daily from the emergence cages and placed back into the colony. The dates of male and female emergence were recorded. Intact puparia were incubated at 22°C (L18:D6) and dissected after 60 days. Developmental stages of live *Phygadeuon* that were dissected from house fly pupae were recorded. Development times for males and females were compared using a two-sample t-test.

Eight females from the colony were dissected to determine the numbers of ovarioles and mature eggs for each female. However, the age of females and number of eggs laid were not known since females were selected randomly for dissection from the colony.

## RESULTS

### SENTINEL PUPAE AND LARVAE

At the Staerk farm, of the 22,075 live sentinel pupae recovered, 633 (2.9%) were parasitized (Table 6). Of the 633 parasitized pupae, *P. fumator* parasitized 597 (94.3%). At the Stengel farm, of the 28,767 sentinel pupae recovered, 1,419 (4.9%) were parasitized. Of the parasitized pupae, 1,401 (98.7%) were parasitized by *P. fumator*. See Chapter III for other species of parasitoids and their prevalence. Of the 5,426 and 6,950 sentinel larvae

recovered from Staerk's and Stengel's, none were parasitized.

Of the 1,998 sentinel pupae parasitized by *P. fumator*, 298 adults emerged. The remaining 1,700 sentinel pupae were dissected with most of *P. fumator* being in the larval stage (Fig. 18). Since these larvae were alive after being incubated for a minimum of 60 days, *P. fumator* is thought to have a larval diapause. Larval, adult and pupal stages accounted for 75.8, 14.9 and 9.3%, respectively. It is not known why some *Phygadeuon* were still in the pupal stage. There was a significant difference between the proportion of individuals in each stage of development at the two farms (Chi-square = 135.5, df = 2,  $P < 0.001$ ). At the Staerk farm, 92.1% of *P. fumator* remained in the larval stage after 60 days, with pupal and adult stages accounting for 5.9 and 2.0% (Appendix VII). At the Stengel farm, only 68.9% *P. fumator* were in the larval stage and more *Phygadeuon* were in the adult (20.4%) and pupal (10.7%) stages (Appendix VIII).

#### NATURALLY OCCURRING PUPAE

Of the 2,753 fly pupae collected at Staerk's, 332 (12.1%) were parasitized. Of the 332 parasitized pupae, 260 (78.3%) were parasitized by *P. fumator*. Of the 1,938 fly pupae collected at Stengel's, 110 (5.7%) were parasitized. Of the 110 parasitized pupae, 93 (84.6%) were parasitized by *P. fumator* (Table 9). See previous chapter for other species of parasitoids attacking house fly and stable fly pupae.



For naturally occurring pupae, there was no difference between the proportion of individuals in each stage of development at the two farms (Chi-square=5.44, df=2.00). More *P. fumator* emerged as adults (64.6%) than remained in the larval (29.5%) and pupal (5.9%) stages (Fig. 19). There was however, a significant difference in stage of development between naturally occurring and sentinel pupae (Chi-square=428.3, df=2.0,  $P < 0.001$ ). For sentinel pupae, more *P. fumator* were in the larval stage after 60 days.

One incident of hyperparasitism was recorded from a house fly pupa collected from the Stengel farm. There may have been other cases that went undetected since the host puparia for emerged parasitoids were not dissected. An adult *Muscidifurax* sp. emerged from a pupa which was also parasitized by *P. fumator*. *Muscidifurax* sp. fed on and killed the *Phygadeuon* larva.

#### **PHYGADEUON CHOICE EXPERIMENT**

*Phygadeuon fumator* preferred pupae over larvae, but females from the colony and the field differed in their response (Chi-square test = 189.32, df = 2.00,  $P < 0.001$ ) (Table 11). For females from the colony, of the 660 observations, 401 (60.8%) observations were made when females were away from either the larval or pupal dishes. 257 (38.9%) observations were taken from females in the pupal dishes, while only 2 (0.3%) were made in the larval dishes. For females collected from the field, of the 957 observations, 587 (61.3%) were taken when females were in contact with the pupal dishes. 278

(29.1%) observations were made when females were away from both dishes, while 92 (9.6%) observations were taken from females in the larval dishes. For both categories of females, of the 1617 observations made, 844 (52.2%) were taken when females were in contact with the pupal dishes, 679 (42.0%) away from both dishes and 94 (5.8%) in the larval dishes.

For the 16 females from the field, out of 52 pupae examined by the females, 24 were stung. For the 11 females from the colony, out of 21 pupae examined, only 5 were stung. Since there seemed to be differences in stinging behaviour between the two categories of females, a Mann-Whitney U-test was performed. No significant difference in stinging was found between females with known and unknown histories (Mann-Whitney U test = 53.0,  $P < 0.08$ ). Of all the pupae which were stung, only three were parasitized. Of the parasitized pupae, they were stung by two females with unknown histories. All three *Phygadeuon* died in the larval stage.

#### **PHYGADEUON COLONY**

At 22°C, males of *P. fumator* have significantly shorter development times ( $t = 7.03$ ,  $df = 760$ ,  $P < 0.001$ ) than females. Mean development time was  $24.8 \pm 0.1$  days (14.0 to 35.0 days;  $n=615$ ) for males and  $26.5 \pm 0.2$  days (18.0 to 35.0 days;  $n=147$ ) for females, a difference of 1.7 days.

Of the 1,256 parasitized house fly puparia examined, 44.8% emerged as *P. fumator* adults, while 50.2% and 4.9% remained in the larval and pupal

stages, respectively (Appendix IX).

Eight females were dissected. Each had 2 ovaries, each with 5 ovarioles. The number of mature eggs in each female varied from 0 to 16 eggs.

## DISCUSSION

There are discrepancies in the literature regarding which stage of host is attacked by *P. fumator*. Rueda and Axtell (1985) described *Phygadeuon* as being a larval parasitoid, while Blanchot (1988) reported *P. fumator* attacking house fly pupae. In 1995, *P. fumator* did not parasitize previously frozen sentinel pupae (McKay Chapter IV), therefore it seemed possible *Phygadeuon* was a larval parasitoid. However, using live sentinel pupae, *P. fumator* was the most abundant parasitoid. Of all the live sentinel larvae recovered, none were parasitized by *P. fumator* or any other parasitoid. In a choice experiment in the laboratory, female *Phygadeuon* preferred pupae. Of all observations, females were in contact with the pupal and larval dishes 52.2 and 5.8%, respectively. No larvae were stung during the choice experiment. Therefore *P. fumator* is a pupal parasitoid of house flies in Manitoba.

## SENTINEL PUPAE

In 1996, though total per cent parasitism was small for live sentinel pupae, *Phygadeuon fumator* accounted for 97.4% of the parasitism. Prevalence by pteromalids accounted for 2.6% of the parasitized pupae. This

study highlights the inherent danger in using previously frozen sentinel pupae to estimate parasitism by *P. fumator*. Though few pteromalids parasitized previously frozen pupae (Table 5), female *P. fumator* clearly preferred live pupae (Table 6) to previously frozen pupae and to live larvae.

#### NATURALLY OCCURRING PUPAE

The majority of field collected pupae were house flies (Table 10) with *Phygadeuon fumator* being the most abundant parasitoid, accounting for 79.9% of the parasitoids. Results from sentinel and naturally occurring pupae conform with Legner and Olton's (1968) hypothesis that the activity of *Phygadeuon* sp. is greatest where other parasitoids are scarce or absent. An incident of hyperparasitism that occurred in a house fly pupa collected from the Stengel farm might lead to an explanation why *Phygadeuon* may prefer areas which are low in parasitoid abundance. An adult *Muscidifurax* sp. emerged from a pupa which was parasitized by *P. fumator*. *Phygadeuon* may not be able to survive competition by other parasitoids. More research should focus on the relationship of *Phygadeuon* with other parasitoids, determining if this species is consistently more prevalent in locations which are low in parasitoid diversity.

*Phygadeuon fumator* has been reared from, *Delia* spp. (Wishart *et al.* 1957), *Phorbia brassicae*, *Fannia*, Syrphidae (Legner and Olton 1968) and horn flies (Depner 1968). In previous studies, *Phygadeuon* sp. accounted for 11.0% of the parasitism of house flies in central New York (Smith and Rutz 1991a),

6.1% in Alberta (Lysyk 1995) and 1.0% in Denmark (Mourier 1972). Of all parasitoid surveys, results from the current study are the first in which *P. fumator* was the most abundant parasitoid. Smith and Rutz (1991c) examined microhabitat associations of parasitoids and found *P. fumator* preferred sheltered sites primarily in moist bedding and feed. Small numbers of pteromalids and a suitable microhabitat might also contribute to high numbers of *P. fumator*.

The majority of *P. fumator* attacked sentinel pupae from 6 June to 15 July (Fig. 18) and naturally occurring pupae from 19 August to 17 October (Fig. 19). Naturally occurring hosts were unavailable in early June, thus sentinel pupae were the only hosts available inside the barns. After 15 July, when naturally occurring fly pupae became available, parasitism by *P. fumator* was reduced in the sentinels and increased in naturally occurring pupae. When given the choice, *Phygadeuon* may prefer to parasitize naturally occurring pupae in moist areas over dry sentinel pupae. Smith and Rutz (1991c) found that *P. fumator* frequently entered larval diapause. Intact house fly puparia that had been exposed to the *Phygadeuon* in the lab were dissected after 60 days. Of all pupae parasitized, 50.2 and 4.9% of the *P. fumator* were in the larval and pupal stages, respectively. 44.8% had emerged as adults. (Appendix IX). Interestingly, some *Phygadeuon* entered what seemed to be a larval diapause. In most instances, extrinsic factors such as temperature and photoperiod induce diapause and affect the generation entering diapause (Schneiderman and

Horwitz 1958). However, extrinsic factors did not appear to influence diapause of *Phygadeuon* in this study. Like *N. vitripennis* and the trichogrammatid egg parasitoid, *Trichogramma evanescens* Westw., diapause might be maternally influenced (Godfray 1994). This has yet to be determined.

Most sentinel pupae were parasitized by *P. fumator* from June to July. When intact sentinel pupae were dissected, the majority of *P. fumator* were in the larval stage (Fig. 18). However, for naturally occurring pupae, most were parasitized by *Phygadeuon* from August to October with the majority emerging as adults (Fig. 19). In *N. vitripennis*, there is a correlation between host deprivation and the incidence of diapause (Schneiderman and Horwitz 1958). Per cent diapause increases from 0 to 97.3% when *N. vitripennis* experienced 1 to 5 days of host deprivation, respectively. If, after overwintering in fly puparia (Blanchot 1988) away from the barns, female *Phygadeuon* emerged in search of hosts and were unable to find live pupae in the field, they may have eventually moved inside the facilities where there were sentinel pupae. Having been deprived of hosts, females parasitized sentinel pupae and produced diapausing offspring. When naturally occurring hosts became available, females were no longer deprived of hosts, therefore the majority of the offspring developed to maturity and emerged as adults.

Temperature and photoperiod regime (25°C; L16:D8) were unlikely to have had an affect on developing parasitoids since there were differences in the proportion of individuals in each stage of development between naturally

occurring and sentinel pupae. For the colony, though the proportions of larvae to adult were similar, it is not known if temperature and photoperiod (22°C; L16:D8) had an influence on the female before oviposition or on the developing larva.

More research should focus on *Phygadeuon* larvae to determine if they may enter a true diapause at any time in the season, or if some larvae have a period of extended development which might be unique to this species. More information is needed on the factors which induce and terminate diapause.

#### ***PHYGADEUON* COLONY**

Blanchot (1988) determined that *P. fumator* males and females developed in 21 and 22 days, respectively at 22°C (L14:D10). In the colony, males and females developed in  $24.8 \pm 0.1$  and  $26.5 \pm 0.2$  days, respectively at the same temperature (L18:D6). Differences in development times from Blanchot's study were 3.8 and 4.5 days for males and females. Blanchot used a shorter photoperiod which may have contributed to the difference in development times.

*Phygadeuon fumator* is similar to *N. vitripennis* and *U. rufipes*, in that males emerge prior (Whiting 1967; Matthews and Petersen 1989) to females (Godfray 1994). Since *Nasonia vitripennis* males have small wings, they cannot fly. Therefore, mating takes place at the female emergence site (Whiting 1967). However, *P. fumator* males do have well developed wings and can fly. To ensure mating takes place, males wait for females at the emergence sites.

Mating is accomplished immediately after females emerge (Blanchot 1988).

In dissecting the reproductive systems of eight females, each female had five ovarioles in each ovary. Mature eggs were found, but the number varied from 0 to 16. Since females were taken randomly from the colony, the age of the females and number of eggs already deposited were not known. Müller (1971) reported females of *P. fumator* lay an average of 47.9 eggs, with a maximum of 72. Freshly emerged female *P. fumator* were not sacrificed for dissection since the numbers of females in the colony were too small.

*Phygadeuon fumator* was difficult to rear. With low female emergence, the colony slowly diminished to the point where it consisted of predominantly males. Throughout the colony's duration, females were a small proportion of the population. Females that were needed for experiments could not be sacrificed from the colony. Since the factors that affect sex ratios of *P. fumator* have never been examined, it is not known why the colony became predominantly male. However, if the factors that affect sex ratios of *P. fumator* are similar to pteromalids, a number of variables could have contributed. The proportion of *Phygadeuon* to hosts might have influenced sex ratio. Female *N. vitripennis* produce a smaller percentage of female progeny at high parasitoid:host ratios (Wylie 1967). The pupae exposed to the colony might not have been suitable for parasitism. King (1994) reported *S. cameroni* females to lay a greater proportion of daughters than sons in large hosts rather than small hosts. Before this parasitoid can be mass released for biological control, the factors which



affect sex ratios must be understood.

#### **PHYGADEUON CHOICE EXPERIMENT**

Though there was a preference for pupae, females from the colony versus females collected in the field were different. Colonized females might not have been mated or ready for egg laying, therefore explaining their unattractiveness towards pupae or larvae. However, no differences in stinging were found between the two categories of females. To better understand stinging behaviour, host seeking strategies should first be addressed with more research conducted with regards to the mating system of *Phygadeuon*.

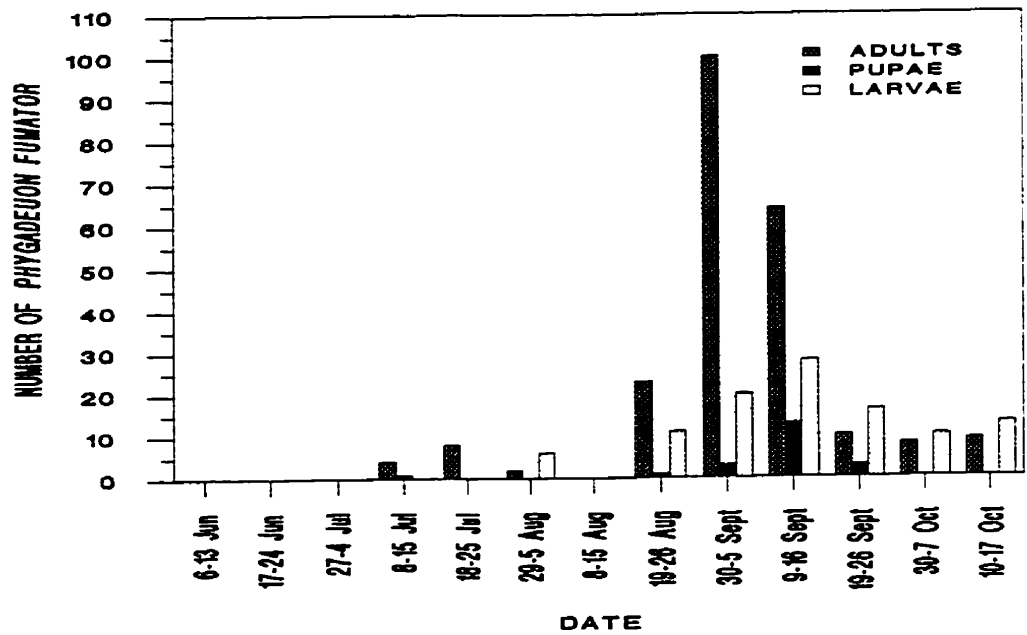
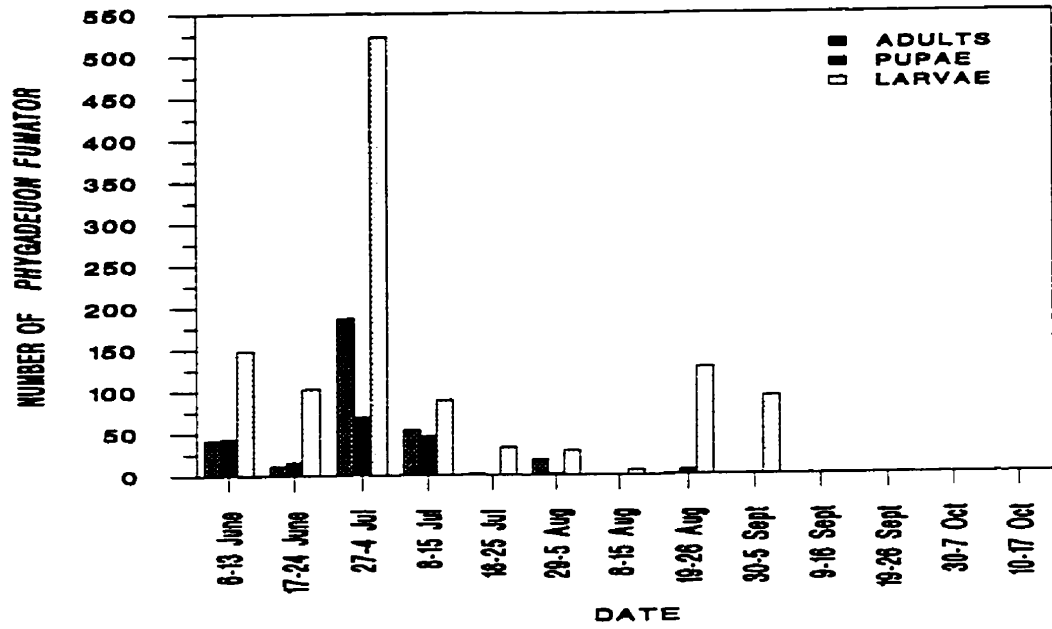
Table 11. Number of observations and percentage of time female *Phygadeuon fumator* Gravenhörst were found in larval dishes, in pupal dishes or in neither. Twenty-seven females were used in the choice experiment. Of the 27 females, 16 were collected in the field and 11 were from a colony. All females were assumed mated. One observation was taken every 60 seconds.

FEMALES	LARVAL DISH	PUPAL DISH	NEITHER	TOTAL
COLONY	2 (0.3%)	257 (38.9%)	401 (60.8%)	660
FIELD	92 (9.6%)	587 (61.3%)	278 (29.1%)	957
TOTAL	94 (5.8%)	844 (52.2%)	679 (42.0%)	1617

Chi-square = 33.9, df = 2.0, P < 0.001

Figure 18. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages collected from sentinel house fly pupae at the Staerk and Stengel farms from 6 June to 17 October, 1996. Intact pupae were dissected after 60 days. All adults had emerged from puparia.

Figure 19. Number of *Phygadeuon fumator* Gravenhörst in various developmental stages reared from naturally occurring pupae at the Staerk and Stengel farms from 6 June to 17 October, 1996. Intact pupae were dissected after 60 days. All adults had emerged from puparia. Few pupae were collected before 8 July.



## CHAPTER V

### GENERAL DISCUSSION

The inundative release program using *Nasonia vitripennis* was ineffective in controlling house flies and stable flies in dairy operations in Manitoba. This could have been predicted by the many release failures in the US (Stage and Petersen 1981; Petersen *et al.* 1983; Meyer *et al.* 1990; Andress and Campbell 1994). Though a greater number of parasitoids per animal per week were released than in any other study, *N. vitripennis* was still ineffective. *Nasonia vitripennis* is a parasitoid which seeks out habitats containing *Calliphora* (Legner 1981), *Phormia regina* (Meigen) and *Sarcophaga bullata* Parker (Rivers and Denlinger 1994), where house flies and stable flies do not breed (Legner 1981). Its inability to penetrate to the host pupation sites in the manure and its random foraging behaviour (Legner 1967) make *N. vitripennis* an impractical house fly and stable fly parasitoid.

With literature available on the ineffectiveness of *N. vitripennis* as a house fly and stable fly parasitoid, it is not known why this species is still being used in release programs. It may be a contaminant in the insectary. Legner (1981) examined eight insectaries in the US where *Spalangia endius* was advertised for sale, but *N. vitripennis* was predominant. In another study, Andress and Campbell (1994) released *M. raptor* and *S. nigroaenea* purchased from commercial insectaries. They reported *N. vitripennis* as a common contaminant. The supplier in the current study promised *M. zaraptor* and *N. vitripennis*, but no

*Muscidifurax* were found in subsamples. Though *N. vitripennis* was promised, this species could also have contaminated cultures of *M. zaraptor*.

Parasitoids that are released should be adapted to local climatic conditions (Smith and Rutz 1991c). Many insectaries are inadvertently selecting parasitoids in culture to be adapted to specific laboratory conditions (temperature, photoperiod and humidity). When lab-reared parasitoids are released into the environment, they are often ineffective for fly control. This might explain why parasitoids are so frequently ineffective in decreasing of fly populations (Mourier 1972; Stage and Petersen 1981; Petersen *et al.* 1983; Meyer *et al.* 1990). If parasitoids were to be reared under climatic conditions specific to regions of the US and Canada, insectaries input costs would increase. Parasitoids would become more expensive to the producer and their effectiveness could still not be (100%) guaranteed.

Suppliers are aggressively selling parasitoids to producers without evidence of efficacy for fly control. They promote an integrated fly control program, and specify the use of parasitoids with proper manure management. Since release programs are not cost effective, producers should eliminate the source of the fly problem. If a producer follows a strict regime of manure removal and disposal, the majority of fly breeding sites could be eliminated, decreasing the necessity for control by other means.

Little information is known on parasitoids that attack house flies and stable flies in Canada. Lysyk (1995) used live sentinel pupae to examine

parasitoids in Alberta dairies and collected seven parasitoid species. In this survey, previously frozen sentinel pupae were used in 1995 and live sentinel pupae in 1996. The present study is the first available in Canada where naturally occurring house fly and stable pupae have been extensively collected to examine parasitoid populations. In total, nine species of parasitoid wasps and a staphylinid were collected. *Nasonia vitripennis*, *S. nigra*, *S. subpunctata*, *E. vesicularis*, *Aphaereta* sp. and a staphylinid were new records for house flies and stable flies in Canada. *Dibrachys cavus* has been found in Alberta and has yet to be collected in Manitoba. It is important to use both sentinel and naturally occurring pupae in a parasitoid survey. Using sentinel pupae permits sampling regardless of the presence of hosts (Smith and Rutz 1991a) and gives an approximate time of parasitism. By sampling naturally occurring pupae, information on relevance of data for sentinel pupae can be interpreted according to what is happening elsewhere in the barn. Previously frozen sentinel pupae were not acceptable for *P. fumator*, thus the importance of this parasitoid was underestimated in 1995. If naturally occurring pupae had not been sampled, the importance of this species would have been overlooked.

*Phygadeuon fumator* has been reared from fly pupae in Maryland (Miller and Rutz 1990), New York (Smith and Rutz 1991b) and Manitoba. *Phygadeuon* sp. has been collected in other surveys (Lysyk 1995; Legner *et al.* 1967), but those specimens have not been identified as *P. fumator*. The genus *Phygadeuon* Gravenhörn is a large one, desperately in need of revision (Barron

personal communication 1996). During this study, John Barron at the Canadian National Collection, Agriculture and AgriFood Canada, identified all *Phygadeuon* spp. collected from filth fly pupae in Canada. However, sadly, he passed away in 1997.

Of parasitoid surveys conducted in North America (Smith and Rutz 1991a; Lysyk 1995; Miller and Rutz 1990), this study is the first in which *P. fumator* was the predominant parasitoid. One reason may be that open sentinel pupal containers were used instead of enclosed sentinel mesh bags used in other studies (Smith and Rutz 1991a; Lysyk 1995; Miller and Rutz 1990). This might have contributed to the greater abundance of *P. fumator*, since this ichneumonid is too large to pass easily through an enclosed mesh bag.

At the Staerk and Stengel farms, prevalence of pteromalids was low, with the majority of parasitism by *P. fumator*. Results here are consistent with Legner and Olton's (1968) hypothesis, that the activity of *Phygadeuon* is greatest at higher latitudes in the Northern Hemisphere where other parasitoids are scarce. However, it is difficult to determine if *Phygadeuon* is most abundant only in northern regions. Since little is known about the distribution of *P. fumator* in North America, it is difficult to compare our results with other surveys. To determine factors which influence the abundance of *P. fumator*, more complete surveys must be conducted in a variety of livestock facilities throughout Manitoba and Canada.



### **FUTURE RESEARCH USING *P. FUMATOR***

Since *P. fumator* was relatively abundant, it may have the potential as a biological control agent in Manitoba. Before *P. fumator* is mass reared and a release program implemented, its complete biology must be examined. More information is needed on:

1. Overwintering. No dairies in this study were heated during the winter months and no fly pupae were found in the barns at the end of season. A study should be conducted to determine how *P. fumator* overwinters and in what host species.

2. Competition between pteromalids and *P. fumator*. A dominant species, *P. fumator* occurred in farms where pteromalids were low in abundance. Does *P. fumator* prefer habitats which are low in parasitoid diversity? Can pteromalids out compete *P. fumator*?

3. Diapause. After 60 days, pupae which had been parasitized by *P. fumator*, were dissected. Interestingly, some *P. fumator* entered what seemed to be a larval diapause. How is diapause induced?

4. Factors which effect sex ratios. In the laboratory, the majority of *P. fumator* emerging from parasitized house fly pupae were male. Are the factors that affect the sex ratio of *P. fumator* similar to pteromalids (e.g. parasitoid:host ratios, size of host)? Are there problems with mating in the lab?

5. Alternative hosts. What if *P. fumator* attacks potentially beneficial host sp.? How important is this?

## LITERATURE CITED

- Ables, J.R. and M. Shepard. 1974. Hymenopterous parasitoids associated with poultry manure. *Environ. Entomol.* **3**: 884-886.
- Ables, J.R. and M. Shepard. 1976. Seasonal abundance and activity of indigenous hymenopterous parasitoids attacking the house fly (Diptera: Muscidae). *Can. Entomol.* **108**: 841-844.
- Ables, J.R., M. Shepard and J.R. Holman. 1976. Development of the parasitoids *Spalangia endius* and *Musidifurax raptor* in relation to constant and variable temperature: Simulation and validation. *Environ. Entomol.* **5**: 329-332.
- Anderson, J.R. 1964. The behavior and ecology of various flies associated with poultry ranches in Northern California. *Proc. and Papers of the 32<sup>nd</sup> Ann. Conf. Calif. Mosq. Con. Assoc., Inc.* pp. 30-34.
- Anderson, J.R. 1965. A preliminary study of integrated fly control on Northern California poultry ranches. *Proc. and Papers of the 33<sup>rd</sup> Ann. Conf. Calif. Mosq. Con. Assoc., Inc.* pp. 42-44.
- Andress, E.R. and J.B. Campbell. 1994. Inundative release of pteromalid parasitoids (Hymenoptera: Pteromalidae) for the control of stable flies, *Stomoxys calcitrans* (L.) (Diptera: Muscidae), at confined cattle installations in west central Nebraska. *J. Econ. Entomol.* **87**:714-722.
- Axtell, R.C. 1970. Integrated fly-control program for caged-poultry houses. *J. Econ. Entomol.* **63**: 400-405.
- Axtell, R.C. 1986. Fly control in confined livestock and poultry production. Technical Monograph. CIBA-GEIGY Corporation, Greensboro, N.C.
- Bay, D.E. and R.L. Harris. 1988. Introduction to veterinary entomology. Stonefly Publishing. Bryan, TX. pp. 55-56.
- Beard, R.L. 1964. Parasites of muscoid flies. *Bull. wld. Hlth Org.* **31**: 491-493.
- Black, W.C., IV and E.S. Krafusur. 1985. Use of sticky traps to investigate seasonal trends in spatial distribution of house flies and stable flies (Diptera: Muscidae). *J. Med. Entomol.* **22**: 550-557.

- Blanchot, P. 1988. Note préliminaire sur la biologie de *Phygadeuon fumator* Gravenhörst (Hym.: Ichneumonidae), parasite de *Musca domestica* L. (Dipt.: Muscidae). *Bull. soc. ent. Mulhouse*. (Apr.-June): 26-30.
- Blume, R.R. 1987. Bionomics of some species of the genus *Spalangia* Latreille. *Southwest. Entomol.* **12**: 191-195.
- Burg, J.G., F.W. Knapp and D.G. Powell. 1990. Seasonal abundance and spatial distribution patterns of three adult muscoid (Diptera: Muscidae) species on equine premises. *Environ. Entomol.* **19**: 901-904.
- Cornell, H. and Pimentel, D. 1978. Switching in the parasitoid *Nasonia vitripennis* and its effects on host competition. *Ecology*. **59**: 297-308.
- Darling, D.C. and J.H. Werren. 1990. Biosystematics of *Nasonia* (Hymenoptera: Pteromalidae): two new species reared from birds' nests in North America. *Ann. Entomol. Soc. Am.* **83**: 352-370.
- Debach, P. 1965. The scope of biological control. *In* Biological control of insect pests and weeds. Reinhold Publishing Corp., New York. pp. 3-18.
- Debach, P. 1974. Biological control by natural enemies. Cambridge University Press, New York.
- Depner, K.R. 1968. Hymenopterous parasites of the horn fly, *Haematobia irritans* (Diptera: Muscidae), in Alberta. *Can. Entomol.* **100**: 1057-1060.
- Doutt, R.L. and R.F. Smith. 1971. The pesticide syndrome - diagnosis and suggested prophylaxis. *In* Biological control. Ed. C.B. Huffaker. Plenum Press, New York. pp. 3-6.
- Fried, C.S., D.A. Rutz and D. Pimentel. 1990. Host parasitism and progeny production of two geographic strains of the parasitoid *Nasonia vitripennis* (Hymenoptera: Pteromalidae) on house fly (Diptera: Muscidae) hosts. *Environ. Entomol.* **19**: 322-326.
- Geden, C.J., D.A. Rutz, J.G. Scott and S.J. Long. 1992. Susceptibility of house flies (Diptera: Muscidae) and five pupal parasitoids (Hymenoptera: Pteromalidae) to abamectin and seven commercial insecticides. *J. Econ. Entomol.* **85**: 435-440.

- Gerling, D. and E.F. Legner. 1968. Developmental history and reproduction of *Spalangia cameroni*, parasite of synanthropic flies. *Ann. Entomol. Soc. Am.* **61**: 1436-1443.
- Glofcheskie, B.D. and G.A. Surgeoner. 1990. Muscovy ducks as an adjunct for the control of the house fly (Diptera: Muscidae). *J. Econ. Entomol.* **83**: 788-791.
- Glofcheskie, B.D. and G.A. Surgeoner. 1993. Efficacy of Muscovy ducks as an adjunct for house fly (Diptera: Muscidae) control in swine and dairy operations. *J. Econ. Entomol.* **86**: 1686-1692.
- Godfray, H.C.J. 1994. Parasitoids. Princeton University Press. Princeton, New Jersey.
- Greenburg, B. 1971. Flies and disease. Volume I. Princeton University Press. Princeton, New Jersey.
- Greene, G.L. 1990. Biological control of filth flies in confined cattle feedlots using pteromalid parasites. *In* Biocontrol of arthropods affecting livestock and poultry. Eds D.R. Rutz and R.S. Patterson. Westview Press, San Francisco. pp. 29-42.
- Greene, G.L., J.A. Hogsette and R.S. Patterson. 1989. Parasites that attack stable fly and house fly (Diptera: Muscidae) puparia during the winter on dairies in northwestern Florida. *J. Econ. Entomol.* **82**: 412-415.
- Hanec, W. 1956. Investigations concerning overwintering of house flies in Manitoba. *Can. Entomol.* **88**: 516-519.
- Harwood, R.F. and M.T. James. 1979. Entomology in human and animal health. Macmillan Publishing Co., Inc. Toronto.
- Hoyer, H. 1981. Foreign exploration, collection, and shipment of parasites and predators. *In* Status of biological control of filth flies. U.S. Dept. Agriculture. pp. 128-130.
- Huffaker, C.B., P.S. Messenger and P. DeBach. 1974. The natural enemy component in natural control and the theory of biological control. *In* Biological control. Ed. C.B. Huffaker. Plenum Publishing Corporation, New York.

- Keiding, J. 1974. The house fly - biology and control. World Health Organization. The vector biology and control division of WHO. Technical Report. No. 561.
- Kettle, D.S. 1990. Medical and veterinary entomology. CAB International. Bristol.
- King, B.H. 1990. Interspecific differences in host (Diptera: Muscidae) size and species usage among parasitoid wasps (Hymenoptera: Pteromalidae) in a poultry house. *Environ. Entomol.* **19**: 1519-1522.
- King, B.H. 1993. Flight activity in the parasitoid wasp *Nasonia vitripennis* (Hymenoptera: Pteromalidae). *J. Insect Behav.* **6**: 313-321.
- King, B.H. 1994. Effects of host size experience on sex ratios in the parasitoid wasp *Spalangia cameroni*. *Anim. Behav.* **47**: 815-820.
- Kogan, M. and E.F. Legner. 1970. Biosystematic revision of the genus *Muscidifurax* (Hymenoptera: Pteromalidae) with descriptions of four new species. *Can. Entomol.* **102**: 1268-1290.
- Lancaster, J.L and M.V. Meisch. 1986. Arthropods in livestock and poultry production. John Wiley and Sons. Toronto. pp. 158-166.
- Legner, E.F. 1967. The status of *Nasonia vitripennis* as a natural parasite of the house fly, *Musca domestica*. *Can. Entomol.* **99**: 308-309.
- Legner, E.F. 1977. Temperature, humidity and depth of habitat influencing host destruction and fecundity of muscoid fly parasites. *Entomophaga.* **22**: 199-206.
- Legner, E.F. 1981. Improving commercial biological control of filth flies with parasites. In Status of biological control of flies. U.S. Dept. Agriculture. pp. 5-10.
- Legner, E.F., E.C. Bay and E.B. White. 1967. Activity of parasites from Diptera: *Musca domestica*, *Stomoxys calcitrans*, *Fannia canicularis*, and *F. femoralis*, at sites in the Western Hemisphere. *Ann. Entomol. Soc. Am.* **60**: 462-468.
- Legner, E.F. and H.W. Brydon. 1966. Suppression of dung-inhabiting fly populations by pupal parasites. *Ann. Entomol. Soc. Am.* **59**: 638-651.

- Legner, E.F. and C.W. McCoy. 1966. The housefly, *Musca domestica* Linnaeus, as an exotic species in the Western Hemisphere incites biological control studies. *Can. Entomol.* **98**: 243-248.
- Legner, E.F. and G.S. Olton. 1968. Activity of parasites from Diptera: *Musca domestica*, *Stomoxys calcitrans*, and species of *Fannia*, *Muscina*, and *Ophyra*. II. At sites in the Eastern Hemisphere and Pacific area. *Ann. Entomol. Soc. Am.* **61**: 1306-1314.
- Lysyk, T.J. 1995. Parasitoids (Hymenoptera: Pteromalidae, Ichneumonidae) of filth fly (Diptera: Muscidae) pupae at dairies in Alberta. *J. Econ. Entomol.* **88**: 659-665.
- Matthews, J.R. and J.J. Petersen. 1989. Effect of temperature on parasitism, development, and diapause of the filth fly parasite, *Urolepis rufipes* (Hymenoptera: Pteromalidae). *Environ. Entomol.* **18**: 728-731.
- Mandeville, J.D. and B.A. Mullens. 1990. Host preference and learning in *Muscidifurax zaraptor* (Hymenoptera: Pteromalidae). *Ann. Entomol. Soc. Am.* **83**: 1203-1209.
- Merwe, J.S. van der. 1943. Investigations on the biology and ecology of *Mormoniella vitripennis* Walk. (Pteromalidae, Hym.). *J. Entomol. Soc. S. Africa.* **6**: 48-64.
- Meyer, J.A., B.A. Mullens, T.C. Cyr and C. Stokes. 1990. Commercial and naturally occurring fly parasitoids (Hymenoptera: Pteromalidae) as biological control agents of stable flies and house flies (Diptera: Muscidae) on California dairies. *J. Econ. Entomol.* **83**: 799-806.
- Miller, R.W., and D.A. Rutz. 1990. Survey of house fly pupal parasitoids on dairy farms in Maryland and New York. *In* Biocontrol of arthropods affecting livestock and poultry. Eds. D.A. Rutz and R.S. Patterson. Westwood Press, San Francisco. pp. 59-69.
- Monteith, A.E. 1956. *Phygadeuon trichops* Thoms. (Hymenoptera: Ichneumonidae), an occasional parasite of *Hylemya* spp. (Diptera: Anthomyiidae). *Can. Entomol.* **88**: 69-73.

- Morgan, P.B. and R.S. Patterson. 1990. Efficiency of target formulations of pesticides plus augmentative releases of *Spalangia endius* Walker (Hymenoptera: Pteromalidae) to suppress populations of *Musca domestica* L. (Diptera: Muscidae) at poultry installations in the southeastern United States. *In* Biocontrol of arthropods affecting livestock and poultry. Eds. D.A. Rutz and R.S. Patterson. pp. 69-78.
- Morgan, P.B., R.S. Patterson and G.C. LaBrecque. 1976. Controlling house flies at a dairy installation by releasing a protelean parasitoid, *Spalangia endius* (Hymenoptera: Pteromalidae). *J. Georgia Entomol. Soc.* **11**: 39-43.
- Morgan, P.B., R.S. Patterson, G.C. LaBrecque, D.E. Weidahaas, A. Benton and T. Whitfield. 1975. Rearing and release of the house fly pupal parasite *Spalangia endius* Walker. *Environ. Entomol.* **4**: 609-611.
- Mourier, H. 1972. Release of native pupal parasitoids of houseflies on Danish farms. *Vidensk. Meddr dansk naturh. Foren.* **135**: 129-137.
- Mourier, H. and S.B. Hannine. 1969. Activity of pupal parasites from *M. domestica* (Diptera) in Denmark. *Vidensk. Meddr dansk naturh. Foren.* **132**: 211-216.
- Müller, H.P. 1971. Zur biologie der Schlupfwespe *Phygadeuon fumator* Grav. [*Hymenopt.*, *Ichneum.*], eines Parasiten der kleinen Kohlflye (*Phorbia brassicae* Bouché). *Entomophaga.* **16**: 45-49.
- Nagel, W.P. and D. Pimentel. 1963. Some ecological attributes of a pteromalid parasite and its house fly host. *Can. Entomol.* **95**: 208-213.
- Olton, G.S. and E.F. Legner. 1975. Winter inoculative release of parasitoids to reduce houseflies in poultry manure. *J. Econ. Entomol.* **68**: 35-38.
- Patterson, R.S. 1981. Importance of monitoring house fly and stable fly immature and adult populations in IPM programs using biological control. *In* Status of biological control of filth flies. U.S. Dept. Agriculture. pp. 95-102.
- Pawson, B.M. and J.J. Petersen. 1988. Dispersal of *Muscidifurax zaraptor* (Hymenoptera: Pteromalidae), a filth fly parasitoid at dairies in eastern Nebraska. *Environ. Entomol.* **17**: 398-402.
- Petersen, J.J. and J.R. Matthews. 1984. Effects of freezing of host pupae on the production of progeny by the filth fly parasite *M. zaraptor* (Hymenoptera: Pteromalidae). *J. Kansas Entomol. Soc.* **57**: 387-393.

- Petersen, J.J. and J.A. Meyer. 1983. Host preference and seasonal distribution of pteromalid parasites (Hymenoptera: Pteromalidae) of stable flies and house flies (Diptera: Muscidae) associated with confined livestock in eastern Nebraska. *Environ. Entomol.* **12**: 567-571.
- Petersen, J.J., J.A. Meyer, D.A. Stage and P.B. Morgan. 1983. Evaluation of sequential releases of *Spalangia endius* (Hymenoptera: Pteromalidae) for control of house flies and stable flies (Diptera: Muscidae) associated with confined livestock in eastern Nebraska. *J. Econ. Entomol.* **76**: 283-286.
- Petersen, J.J., D.W. Watson and J.K. Cawthra. 1995. Comparative effectiveness of three release rates for a pteromalid parasitoid (Hymenoptera) of house flies (Diptera) in beef cattle feedlots. *Bio. Control.* **5**: 561-565.
- Petersen, J.J., D.W. Watson and B.M. Pawson. 1992. Evaluation of field propagation of *Muscidifurax zaraptor* (Hymenoptera: Pteromalidae) for control of flies associated with confined beef cattle. *J. Econ. Entomol.* **85**: 451-455.
- Pickens, L.G., N.O. Morgan, J.G. Hartsock and J.W. Smith. 1967. Dispersal patterns and populations of the house fly affected by sanitation and weather in rural Maryland. *J. Econ. Entomol.* **60**: 1250-1255.
- Propp, G.D. and P.B. Morgan. 1985. Effect of host distribution on parasitoidism of house-fly (Diptera: Muscidae) pupae by *Spalangia* spp. and *Muscidifurax raptor* (Hymenoptera: Pteromalidae). *Can. Entomol.* **117**: 515-524.
- Rivers, D.B. and D.L. Denlinger. 1994. Developmental fate of the flesh fly, *Sarcophaga bullata*, envenomated by the pupal ectoparasitoid, *Nasonia vitripennis*. *J. Insect. Physiol.* **40**: 121-127.
- Rivers, D.B. and D.L. Denlinger. 1995a. Fecundity and development of the ectoparasitic wasp *Nasonia vitripennis* are dependent on host quality. *Entomol. exp. App.* **76**: 15-24.
- Rivers, D.B. and D.L. Denlinger. 1995b. Venom-induced alterations in fly lipid metabolism and its impact on larval development of the ectoparasitoid *Nasonia vitripennis* (Walker) (Hymenoptera: Pteromalidae). *J. Invert. Pathol.* **66**: 104-110.
- Rueda, L.M. and R.C. Axtell. 1985. Guide to common species of pupal parasites (Hymenoptera: Pteromalidae) of the house fly and other muscoid flies associated with poultry and livestock manure. Technical Bulletin 278. North Carolina State University, Raleigh, N.C.



- Rutz, D.A. and R.C. Axtell. 1979. Sustained releases of *Muscidifurax raptor* (Hymenoptera: Pteromalidae) for house fly (*Musca domestica*) control in two types of caged-layer poultry houses. *Environ. Entomol.* **8**: 1105-1110.
- Rutz, D.A. and R.C. Axtell. 1980a. House fly (*Musca domestica*) parasites (Hymenoptera: Pteromalidae) associated with poultry manure in North Carolina. *Environ. Entomol.* **9**: 175-180.
- Rutz, D.A. and R.C. Axtell. 1980b. Invasion and establishment of house fly, *Musca domestica* (Diptera: Muscidae), parasites (Hymenoptera: Pteromalidae) in new caged-layer poultry houses. *J. Med. Entomol.* **17**: 151-155.
- Rutz, D.A. and R.C. Axtell. 1981. House fly (*Musca domestica*) control in broiler-breeder poultry houses by pupal parasites (Hymenoptera: Pteromalidae): indigenous parasite species and releases of *Muscidifurax raptor*. *Environ. Entomol.* **10**: 343-345.
- Rutz, D.A. and G.A. Scoles. 1989. Occurrence and seasonal abundance of parasitoids attacking muscoid flies (Diptera: Muscidae) in caged-layer poultry facilities in New York. *Environ. Entomol.* **18**: 51-55.
- Schneiderman, H.A. and J. Horwitz. 1958. The induction and termination of facultative diapause in the chalcid wasps *Mormoniella vitripennis* (Walker) and *Tritneptis klugii* (Ratzeburg). *J. Exp. Biol.* **35**: 520-551.
- Skoda, S.R., J.B. Campbell and G.D. Thomas. 1987. Parasites of face flies (Diptera: Muscidae) in South Central Nebraska. *Environ. Entomol.* **16**: 902-904.
- Smith, J.P., R.D. Hall and G.D. Thomas. 1987. Field parasitism of the stable fly (Diptera: Muscidae). *Ann. Entomol. Soc. Am.* **80**:391-397.
- Smith, L. and D.A. Rutz. 1991a. Seasonal and relative abundance of hymenopterous parasitoids attacking house fly pupae at dairy farms in Central New York. *Environ. Entomol.* **20**: 661-668.
- Smith, L. and D.A. Rutz. 1991b. Relationship of microhabitat to incidence of house fly (Diptera: Muscidae) immatures and their parasitoids at dairy farms in central New York. *Environ. Entomol.* **20**: 669-674.

- Smith, L. and D.A. Rutz. 1991c. Microhabitat associations of hymenopterous parasitoids that attack house fly pupae at dairy farms in central New York. *Environ. Entomol.* **20**: 675-684.
- Stage, D.A. and J.J. Petersen. 1981. Mass release of pupal parasites for control of stable flies and house flies in confined feedlots in Nebraska. *In* Status of biological control of filth flies. U.S. Dept. of Agriculture. p.p. 52-58.
- Whiting, A.R. 1967. The biology of the parasitic wasp *Mormoniella vitripennis* [= *Nasonia brevicornis*] (Walker). *Quart. Rev. Biol.* **42**: 333-406.
- Wieman, G.A., J.B. Campbell, J.A. Deshazer and I.L. Berry. 1992. Effects of stable flies (Diptera: Muscidae) and heat stress on weight gain and feed efficiency of feeder cattle. *J. Econ. Entomol.* **85**: 1835-1842.
- Wishart, G., E.H. Colhoun, and A.E. Monteith. 1957. Parasites of *Hylemya* spp. (Diptera: Anthomyiidae) that attack cruciferous crops in Europe. *Can. Entomol.* **89**: 510-517.
- Wylie, H.G. 1965. Effects of superparasitism on *Nasonia vitripennis* (Walk.) (Hymenoptera: Pteromalidae). *Can. Entomol.* **97**: 326-331.
- Wylie, H.G. 1966. Some mechanisms that affect the sex ratio of *Nasonia vitripennis* (Walk.) (Hymenoptera: Pteromalidae) reared from superparasitized housefly pupae. *Can. Entomol.* **98**: 645-653.

Appendix I. Mean number ( $\pm$  S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenh6rst in naturally occurring pupae collected per sample location at the Stengel farm from 5 July to 14 September, 1995. Five locations were sampled.

DATE	MEAN NO. PUPAE <sup>a</sup> COLLECTED $\pm$ S.E.	MEAN NO. <i>PHYGADEUON</i> $\pm$ S.E.	MEAN PREVALENCE (%) $\pm$ S.E.
5 July	18.2 $\pm$ 18.2	0.4 $\pm$ 0.4	0.4 $\pm$ 0.4
11 July	22.0 $\pm$ 14.4	3.0 $\pm$ 2.5	4.7 $\pm$ 3.6
20 July	29.8 $\pm$ 20.6	3.2 $\pm$ 3.2	9.1 $\pm$ 9.1
27 July	21.6 $\pm$ 17.0	2.6 $\pm$ 2.6	2.9 $\pm$ 2.9
3 August	3.8 $\pm$ 3.8	0.0	0.0
10 August	46.2 $\pm$ 34.3	1.2 $\pm$ 0.8	1.2 $\pm$ 0.8
17 August	15.6 $\pm$ 12.8	2.6 $\pm$ 2.4	5.3 $\pm$ 3.6
24 August	43.6 $\pm$ 31.2	0.4 $\pm$ 0.4	0.3 $\pm$ 0.3
31 August	69.2 $\pm$ 6.6	1.4 $\pm$ 1.2	2.8 $\pm$ 2.5
7 September	3.8 $\pm$ 3.8	0.0	0.0
14 September	0.4 $\pm$ 0.4	0.0	0.0

<sup>a</sup>House fly and stable fly.

Appendix II. Mean number ( $\pm$  S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenh6rst in naturally occurring pupae collected per sample location at the Staerk farm from 5 July to 14 September, 1995. Five locations were sampled.

DATE	MEAN NO. PUPAE <sup>a</sup> COLLECTED $\pm$ S.E.	MEAN NO. <i>PHYGADEUON</i> $\pm$ S.E.	MEAN PREVALENCE (%) $\pm$ S.E.
5 July	85.4 $\pm$ 56.4	1.2 $\pm$ 1.2	0.4 $\pm$ 0.4
11 July	41.4 $\pm$ 17.0	1.8 $\pm$ 1.4	2.7 $\pm$ 2.1
20 July	36.0 $\pm$ 26.3	0.4 $\pm$ 0.2	0.8 $\pm$ 0.6
27 July	56.0 $\pm$ 35.7	5.4 $\pm$ 3.3	4.2 $\pm$ 2.8
3 August	34.0 $\pm$ 21.8	9.8 $\pm$ 6.8	25.1 $\pm$ 13.9
10 August	58.2 $\pm$ 37.2	6.4 $\pm$ 5.5	5.4 $\pm$ 4.9
17 August	55.8 $\pm$ 35.0	2.4 $\pm$ 2.2	2.0 $\pm$ 1.9
24 August	36.4 $\pm$ 16.0	6.8 $\pm$ 4.5	13.5 $\pm$ 10.1
31 August	56.4 $\pm$ 26.6	7.4 $\pm$ 5.4	6.3 $\pm$ 3.9
7 September	47.4 $\pm$ 20.1	3.6 $\pm$ 3.4	6.0 $\pm$ 5.7
14 September	16.6 $\pm$ 10.7	0.6 $\pm$ 0.4	1.7 $\pm$ 1.3

<sup>a</sup>House fly and stable fly.

Appendix III. Mean number ( $\pm$  S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenh6rst in naturally occurring pupae collected at the Stengel farm from 13 June to 17 October, 1996. Five locations were sampled.

DATE	MEAN NO. PUPAE COLLECTED $\pm$ S.E.	MEAN NO. <i>PHYGADEUON</i> $\pm$ S.E.	MEAN PREVALENCE (%) $\pm$ S.E.
13 June	0.0	0.0	0.0
17 June	0.0	0.0	0.0
20 June	0.0	0.0	0.0
24 June	0.0	0.0	0.0
27 June	0.0	0.0	0.0
1 July	0.0	0.0	0.0
4 July	0.0	0.0	0.0
8 July	0.2 $\pm$ 0.2	0.0	0.0
11 July	0.0	0.0	0.0
15 July	1.2 $\pm$ 1.2	0.0	0.0
18 July	1.6 $\pm$ 1.0	0.0	0.0
22 July	27.8 $\pm$ 12.2	1.4 $\pm$ 1.4	2.7 $\pm$ 2.7
25 July	12.4 $\pm$ 7.6	0.0	0.0
29 July	38.2 $\pm$ 18.4	0.0	0.0
1 Aug	11.6 $\pm$ 6.6	1.2 $\pm$ 1.2	12.0 $\pm$ 12.0
5 Aug <sup>a</sup>	-	-	-
12 Aug	8.0 $\pm$ 4.3	0.0	0.0
15 Aug	4.4 $\pm$ 3.3	0.0	0.0
19 Aug	19.4 $\pm$ 8.4	0.6 $\pm$ 0.4	2.9 $\pm$ 2.3
23 Aug <sup>a</sup>	-	-	-
26 Aug	42.0 $\pm$ 23.9	1.4 $\pm$ 0.9	1.5 $\pm$ 1.0
30 Aug	48.2 $\pm$ 19.7	2.2 $\pm$ 1.4	5.2 $\pm$ 3.3
2 Sept	32.6 $\pm$ 12.4	9.6 $\pm$ 5.3	17.0 $\pm$ 8.6
5 Sept	4.8 $\pm$ 3.3	0.0	0.0
9 Sept	18.8 $\pm$ 6.3	0.0	0.0

DATE	MEAN NO. PUPAE COLLECTED ± S.E.	MEAN NO. <i>PHYGADEUON</i> ± S.E.	MEAN PREVALENCE (%) ± S.E.
12 Sept	8.6 ± 5.2	0.2 ± 0.2	1.5 ± 1.5
16 Sept	19.2 ± 5.8	0.4 ± 0.2	1.6 ± 1.1
19 Sept	18.8 ± 10.2	0.0	0.0
23 Sept	9.8 ± 4.6	0.2 ± 0.2	0.9 ± 0.9
26 Sept	2.0 ± 1.4	0.0	0.0
30 Sept	3.4 ± 1.5	0.0	0.0
3 Oct	13.4 ± 5.7	0.0	0.0
7 Oct	2.8 ± 1.3	0.8 ± 0.8	20.0 ± 20.0
10 Oct	11.0 ± 7.7	0.0	0.0
14 Oct	1.4 ± 1.0	0.0	0.0
17 Oct	18.8 ± 6.4	0.8 ± 0.4	4.3 ± 2.9

\*No collections.

Appendix IV. Mean number ( $\pm$  S.E.) of house fly and stable fly pupae collected, and mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenh6rst in naturally occurring pupae collected per sample location at the Staerk farm from 13 June to 17 October, 1996. Five locations were sampled.

DATE	MEAN NO. PUPAE COLLECTED $\pm$ S.E.	MEAN NO. PHYGADEUON $\pm$ S.E.	MEAN PREVALENCE (%) $\pm$ S.E.
13 June	1.2 $\pm$ 1.2	0.0	0.0
17 June	3.0 $\pm$ 1.8	0.0	0.0
20 June	0.0	0.0	0.0
24 June	0.4 $\pm$ 0.4	0.0	0.0
27 June	0.0	0.0	0.0
1 July	0.0	0.0	0.0
4 July	0.0	0.0	0.0
8 July	5.6 $\pm$ 3.6	1.0 $\pm$ 0.6	7.8 $\pm$ 5.4
11 July	0.0	0.0	0.0
15 July	2.0 $\pm$ 2.0	0.0	0.0
18 July	28.0 $\pm$ 13.8	0.0	0.0
22 July	10.4 $\pm$ 6.6	0.2 $\pm$ 0.2	0.6 $\pm$ 0.6
25 July	12.8 $\pm$ 10.3	0.0	0.0
29 July	12.4 $\pm$ 6.8	0.0	0.0
1 Aug	33.0 $\pm$ 5.9	0.4 $\pm$ 0.4	1.0 $\pm$ 1.0
5 Aug <sup>a</sup>	-	-	-
12 Aug	25.4 $\pm$ 2.9	0.0	0.0
15 Aug	18.8 $\pm$ 5.8	0.0	0.0
19 Aug	19.0 $\pm$ 7.2	1.0 $\pm$ 0.6	3.0 $\pm$ 1.8
23 Aug	7.2 $\pm$ 3.1	3.2 $\pm$ 1.6	26.8 $\pm$ 13.5
26 Aug	4.4 $\pm$ 3.1	0.8 $\pm$ 0.6	11.3 $\pm$ 9.8
30 Aug	12.2 $\pm$ 5.5	1.6 $\pm$ 0.8	15.0 $\pm$ 9.2
2 Sept	16.2 $\pm$ 5.7	9.6 $\pm$ 3.9	46.9 $\pm$ 15.7

DATE	MEAN NO. PUPAE COLLECTED ± S.E.	MEAN NO. <i>PHYGADEUON</i> ● S.E.	MEAN PREVALENCE (%) ± S.E.
5 Sept	31.0 ± 4.9	1.8 ± 1.4	5.2 ± 3.7
9 Sept	41.6 ± 10.0	4.0 ± 2.4	6.9 ± 4.0
12 Sept	77.0 ± 12.3	12.0 ● 3.4	16.5 ● 5.0
16 Sept	54.4 ± 11.0	4.4 ± 2.2	10.4 ± 5.2
19 Sept	26.6 ± 13.9	3.2 ± 1.6	7.7 ± 3.5
23 Sept	28.4 ± 14.5	1.0 ± 0.6	1.9 ± 1.4
26 Sept	30.4 ± 13.9	1.4 ± 0.9	2.3 ± 1.5
30 Sept	17.2 ± 18.3	1.2 ± 0.8	4.0 ± 3.0
3 Oct	7.2 ± 3.4	0.4 ± 0.4	2.2 ± 2.2
7 Oct	8.0 ± 4.5	1.2 ± 0.6	15.2 ± 9.2
10 Oct	6.4 ± 3.0	0.4 ± 0.4	2.5 ± 2.5
14 Oct	21.8 ± 10.4	2.4 ± 1.5	7.1 ± 4.9
17 Oct	5.2 ± 3.9	0.8 ± 0.5	8.6 ± 6.5

<sup>a</sup>No collections.



Appendix V. Mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenhorst from sentinel pupae retrieved per location at the Stengel farm from 3 June to 17 October, 1996. Mean number ( $\pm$  S.E.) of sentinel pupae included. Three locations sampled.

DATE	MEAN NO. SENTINEL PUPAE $\pm$ S.E.	MEAN NO. PHYGADEUON $\pm$ S.E.	MEAN PREVALENCE OF PHYGADEUON (%) $\pm$ S.E.
3-6 June	368.5 $\pm$ 26.5	0.0	0.0
10-13 June	364.0 $\pm$ 7.0	4.5 $\pm$ 0.5	1.2 $\pm$ 0.1
13-17 June	344.0 $\pm$ 48.0	72.3 $\pm$ 40.8	25.7 $\pm$ 17.5
17-20 June	139.8 $\pm$ 134.1	4.2 $\pm$ 3.3	3.9 $\pm$ 3.9
20-24 June	189.0 $\pm$ 48.0	22.7 $\pm$ 12.7	12.1 $\pm$ 8.2
24-27 June	479.5 $\pm$ 50.5	16.5 $\pm$ 13.5	3.8 $\pm$ 3.2
27-1 July	100.8 $\pm$ 100.8	11.8 $\pm$ 11.8	2.3 $\pm$ 2.3
1-4 July	413.0 $\pm$ 111.3	72.3 $\pm$ 16.1	21.7 $\pm$ 7.8
4-8 July	282.0 $\pm$ 79.0	78.5 $\pm$ 42.5	34.8 $\pm$ 24.8
8-11 July	216.3 $\pm$ 36.5	38.3 $\pm$ 12.8	18.6 $\pm$ 6.3
11-15 July	37.8 $\pm$ 16.2	7.0 $\pm$ 5.6	11.8 $\pm$ 10.1
15-18 July	277.0 $\pm$ 44.3	70.7 $\pm$ 25.4	24.1 $\pm$ 4.9
18-22 July	342.0 $\pm$ 51.5	3.0 $\pm$ 2.5	0.8 $\pm$ 0.6
22-25 July	302.0 $\pm$ 47.5	3.0 $\pm$ 2.1	1.1 $\pm$ 0.7
25-29 July	14.2 $\pm$ 8.8	1.8 $\pm$ 1.5	4.6 $\pm$ 3.9
29-1 Aug	359.0 $\pm$ 21.9	3.0 $\pm$ 2.5	0.8 $\pm$ 0.7
1-5 Aug	45.4 $\pm$ 27.9	1.8 $\pm$ 1.8	1.5 $\pm$ 1.5
5-8 Aug	311.0 $\pm$ 45.0	0.0	0.0
8-12 Aug	13.8 $\pm$ 13.8	0.0	0.0
12-15 Aug	123.3 $\pm$ 14.8	0.0	0.0
15-19 Aug	126.0 $\pm$ 14.5	0.0	0.0
19-22 Aug	190.0 $\pm$ 51.0	0.0	0.0
22-26 Aug	208.3 $\pm$ 11.3	0.0	0.0
26-30 Aug	47.8 $\pm$ 19.6	0.0	0.0

DATE	MEAN NO. SENTINEL PUPAE ● S.E.	MEAN NO. PHYGADEUON ± S.E.	MEAN PREVALENCE OF PHYGADEUON (%) ± S.E.
30-2 Sept	83.8 ± 37.8	0.0	0.0-
2-5 Sept	180.3 ± 31.1	3.3 ± 3.3	3.3 ± 3.3
5-9 Sept	192.7 ± 18.2	0.0	0.0
9-12 Sept	263.7 ± 12.2	0.0	0.0
12-16 Sept	282.0 ± 7.8	0.0	0.0
16-19 Sept	241.0 ± 11.4	0.0	0.0
19-23 Sept	278.3 ± 73.0	0.0	0.0
23-26 Sept	0.0	0.0	0.0
26-30 Sept	404.0 ± 138.0	0.0	0.0
30-3 Oct	139.7 ± 29.5	0.0	0.0
3-7 Oct	298.7 ± 56.0	0.0	0.0
7-10 Oct	538.7 ± 77.8	0.0	0.0
10-14 Oct	342.3 ± 12.8	0.0	0.0
14-17 Oct	294.3 ± 133.5	0.0	0.0

Appendix VI. Mean number ( $\pm$  S.E.) and prevalence ( $\pm$  S.E.) of *Phygadeuon fumator* Gravenhrst from sentinel pupae retrieved per sample location at the Staerk farm from 13 June to 17 October, 1996. Mean number ( $\pm$  S.E.) of sentinel pupae included. Three locations sampled.

DATE	MEAN NO. SENTINEL PUPAE $\pm$ S.E	MEAN NO. <i>PHYGADEUON</i> $\pm$ S.E	MEAN PREVALENCE OF <i>PHYGADEUON</i> (%) $\pm$ S.E
3-6 June	6.4 $\pm$ 6.4	0.0	0.0
10-13 June	0.0	0.0	0.0
13-17 June	317.7 $\pm$ 27.4	2.0 $\pm$ 1.2	0.6 $\pm$ 0.3
17-20 June	457.5 $\pm$ 174.5	16.0 $\pm$ 4.0	4.5 $\pm$ 2.6
20-24 June	234.8 $\pm$ 119.5	4.8 $\pm$ 2.6	2.0 $\pm$ 1.3
24-27 June	512.0 $\pm$ 85.0	7.0 $\pm$ 5.0	1.6 $\pm$ 1.3
27-1 July	627.0 $\pm$ 9.0	43.5 $\pm$ 29.5	6.9 $\pm$ 4.6
1-4 July	351.7 $\pm$ 26.2	33.7 $\pm$ 32.2	9.2 $\pm$ 8.7
4-8 July	40.0 $\pm$ 40.0	0.0	0.0
8-11 July	73.8 $\pm$ 33.5	5.6 $\pm$ 4.1	4.2 $\pm$ 3.3
11-15 July	22.8 $\pm$ 14.2	4.6 $\pm$ 3.5	7.6 $\pm$ 5.4
15-18 July	248.0 $\pm$ 44.0	1.5 $\pm$ 1.5	0.7 $\pm$ 0.7
18-22 July	429.5 $\pm$ 34.5	4.0 $\pm$ 2.0	0.9 $\pm$ 0.4
22-25 July	284.0 $\pm$ 35.9	0.3 $\pm$ 0.3	0.9 $\pm$ 0.9
25-29 July	15.6 $\pm$ 9.6	0.0	0.0
29-1 Aug	343.3 $\pm$ 36.9	6.7 $\pm$ 6.7	1.7 $\pm$ 1.7
1-5 Aug	74.2 $\pm$ 30.5	0.0	0.0
5-8 Aug	291.7 $\pm$ 66.1	0.0	0.0
8-12 Aug	16.8 $\pm$ 16.8	0.0	0.0
12-15 Aug	58.8 $\pm$ 28.2	1.2 $\pm$ 1.2	0.8 $\pm$ 0.8
15-19 Aug	54.2 $\pm$ 33.2	0.0	0.0
19-22 Aug	167.0 $\pm$ 19.5	9.7 $\pm$ 9.7	7.1 $\pm$ 7.1

DATE	MEAN NO. SENTINEL PUPAE ± S.E	MEAN NO. PHYGADEUON ± S.E	MEAN PREVALENCE OF PHYGADEUON (%) ± S.E
22-26 Aug	181.0 ± 19.3	24.0 ± 4.9	13.8 ± 4.0
2-5 Sept	163.7 ± 41.4	31.3 ± 31.3	14.1 ± 14.1
5-9 Sept	197.3 ± 6.7	0.3 ± 0.3	0.2 ± 0.2
9-12 Sept	349.0 ± 18.0	0.0	0.0
12-16 Sept	79.4 ± 49.3	0.0	0.0
16-19 Sept	277.0 ± 77.0	0.0	0.0
19-23 Sept	56.6 ± 43.9	0.2 ± 0.2	0.4 ± 0.4
23-26 Sept	0.0	0.0	0.0
26-30 Sept	77.4 ± 77.4	0.0	0.0
30-3 Oct	49.6 ± 30.8	0.0	0.0
3-7 Oct	255.5 ± 2.5	0.0	0.0
7-10 Oct	465.5 ± 114.5	0.0	0.0
10-14 Oct	614.5 ± 66.5	0.0	0.0
14-17 Oct	408.7 ± 35.2	0.0	0.0

Appendix VII. Total number of *Phygadeuon fumator* Gravenhörst in various developmental stages every two weeks. Parasitoids collected from sentinel pupae retrieved at the Staerk farm from 6 June to 17 October, 1996. Sentinel pupae were placed at each location for 3 to 4 days.

DATE	ADULT	PUPA	LARVA	TOTAL
3-17 June	0	1	30	31
17-1 July	6	23	176	205
1-15 July	5	3	89	97
15-29 Aug	0	1	27	28
29-12 Aug	0	0	6	6
12-26 Aug	1	6	128	135
26-9 Sept	0	1	93	94
9-23 Sept	0	0	1	1
23-7 Oct	0	0	0	0
7-17 Oct	0	0	0	0
Total	12 (5.9%)	35 (2.0%)	550 (92.1%)	597

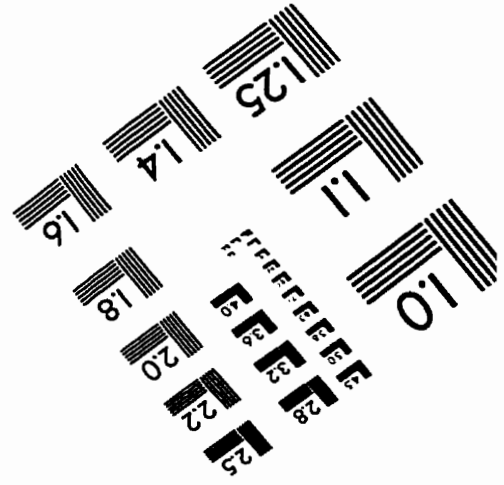
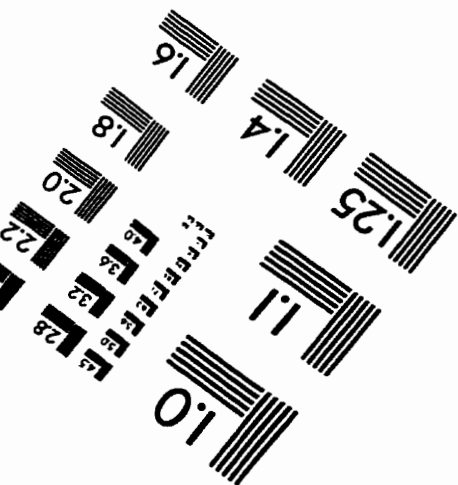
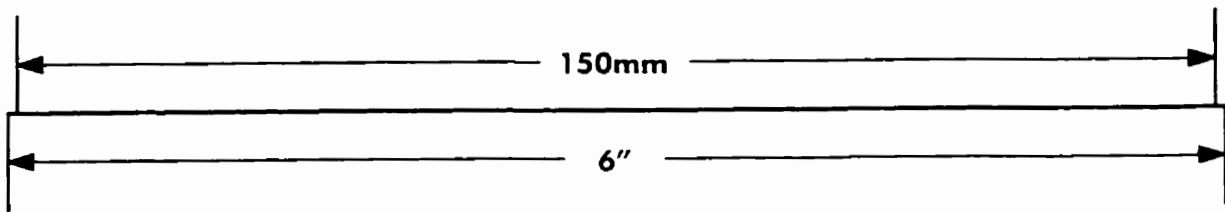
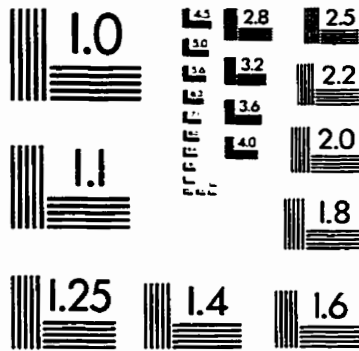
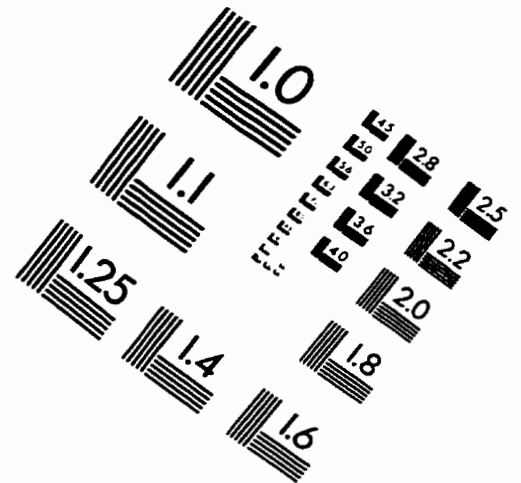
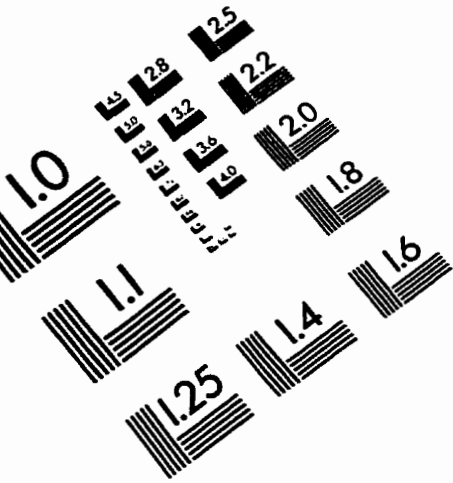
Appendix VIII. Total number of *Phygadeuon fumator* Gravenhörst in various developmental stages every two weeks. Parasitoids collected from sentinel pupae retrieved at the Stengel farm from 6 June to 17 October, 1996. Sentinel pupae were placed at each location for 3 to 4 days.

DATE	ADULT	PUPA	LARVA	TOTAL
3-17 June	43	44	162	249
17-1 July	74	24	330	428
1-15 July	167	81	419	667
15-29 July	2	1	33	36
29-12 Aug	0	0	11	11
12-26 Aug	0	0	0	0
26-9 Sept	0	0	10	10
9-23 Sept	0	0	0	0
23-7 Oct	0	0	0	0
7-17 Oct	0	0	0	0
Total	286 (20.4%)	150 (10.7%)	965 (68.9%)	1401

Appendix IX. Developmental stages of *Phygadeuon fumator* Gravenh6r6st from house fly pupae parasitized in the lab.

DATE	ADULT	PUPAE	LARVAE	TOTAL
27-3 July	5	15	93	113
4-7 July	5	3	180	188
8-14 July	1	0	87	88
16-26 July	5	5	66	76
30-16 Aug	0	0	21	21
20-25 Aug	0	0	7	7
29-7 Sept	122	13	91	226
10-18 Sept	89	5	18	112
19-29 Sept	179	13	16	208
1-10 Oct	23	0	13	36
11-17 Oct	65	2	14	81
19-23 Oct	20	1	6	27
25-28 Oct	49	5	19	73
Total	563 (44.8%)	62 (4.9%)	631 (50.2%)	1256

# IMAGE EVALUATION TEST TARGET (QA-3)



APPLIED IMAGE, Inc  
1653 East Main Street  
Rochester, NY 14609 USA  
Phone: 716/482-0300  
Fax: 716/288-5989

© 1993, Applied Image, Inc., All Rights Reserved