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Impact of the Darkling Beetle *Alphitobius diaperinus* (Panzer) on Establishment of the Predaceous Beetle *Carcinops pumilio* (Erichson) for *Musca domestica* Control in Caged-Layer Poultry Houses

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Understanding the insect natural history in a caged-layer poultry house is essential to developing Integrated Pest Management strategies. In this study we observed the interaction of three insects commonly found in poultry manure: a filth fly predator, *Carcinops pumilio* (Erichson) (Histeridae), and two poultry pests, the house fly, *Musca domestica* L. (Muscidae), and the darkling beetle, *Alphitobius diaperinus* (Panzer) (Tenebrionidae). Manure samples were collected weekly and the insects were extracted using Berlese–Tullgren funnels. Collected insects were identified to species and life stage. When *C. pumilio* populations equaled or exceeded those of the larval house fly, subsequent adult house fly populations were not considered pestiferous. *C. pumilio* adult and larval cohorts varied significantly among poultry houses. Few *C. pumilio* larvae were found in houses with abundant darkling beetle populations, suggesting a negative impact on the establishment of *C. pumilio*. Laboratory studies confirmed that larval darkling beetles significantly reduce the survival of *C. pumilio* eggs and larvae. Adult darkling beetles did not reduce *C. pumilio* egg or larval survival. © 2000 Academic Press

Key Words: **house fly; litter beetle; darkling beetle; hister beetle; poultry; biological control; Integrated Pest Management.**

INTRODUCTION

Biological control plays an important role in a fully integrated fly management program. Enclosed poultry houses are well suited to the development of the biological control component because they offer a stable environment supporting populations of pest species, including the house fly, *Musca domestica* L., and the darkling beetle, *Alphitobius diaperinus* (Panzer) (Axtell and Arends, 1990). In addition, this environment supports numerous beneficial species such as parasitoids, predatory mites, and the predaceous hister beetle, *Carcinops pumilio* (Erichson) (Rueda and Axtell, 1997; Geden and Stoffolano, 1987; Rueda and Axtell, 1985).

Poultry and livestock integrated pest management programs often include parasitoids to augment fly control efforts (Rutz and Axtell, 1979; Axtell and Rutz, 1986; Miller *et al.*, 1993; Petersen *et al.*, 1995). Given the proper conditions, naturally occurring predators such as adult and larval *C. pumilio* may also impose significant natural mortality on numerous mite and dipteran prey, including house flies (Axtell, 1981; Geden *et al.*, 1988; Geden, 1990). Both adult and larval stages of the beetle feed on house fly eggs and first instars, and poultry houses with abundant predaceous beetle populations generally experience few fly problems (Geden, 1984; Geden *et al.*, 1988).

Unlike the hister beetle, the darkling beetle, *A. diaperinus*, is a common pest of chicken and turkey houses. All life stages are found in poultry litter and manure where they feed on manure, litter, meal, dead birds, and other insects (Leschen and Steelman, 1988). Darkling beetles harbor and transmit numerous diseases: Newcastle disease, avian influenza, infectious bursal disease, Marek's disease, and fowl pox (De la Casa *et al.*, 1973, 1976). Furthermore, darkling beetles have been shown to transmit several other infectious agents including *Salmonella*, *Aspergillus* spp., *Escherichia coli*, *Bacillus* spp., *Streptococcus* spp., Reovirus, Rotavirus, *Eimeria* (coccidiosis), and tapeworms (McAllister *et al.*, 1994, 1995; Despins *et al.*, 1994). In addition to their potential to spread disease, darkling beetles also cause severe structural damage and can be the object of nuisance complaints (Vaughan *et al.*, 1984; Miller, 1997).

Our goal was to explore the potential for improving fly suppression using *C. pumilio*. Establishment of *C. pumilio* very likely depends on several abiotic and biotic factors including available prey (Geden *et al.*,

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1987). To establish an optimal beetle to fly population ratio for fly management, we chose to monitor hister beetle and house fly populations in poultry houses and to observe darkling beetle interaction. Laboratory studies were conducted to evaluate the impact of the darkling beetle on the survival of *C. pumilio.*

MATERIALS AND METHODS

Five high-rise caged-layer poultry houses, numbered 1, 2, 3, 4, and 5 were selected for field study. Houses 1 and 2 were negative-flow turbo houses in which the air exhaust was fan-driven from the manure storage area. Fans in the pit forced air out of the house and fresh air was drawn from intake vents located on the roof soffit. Manure dropping through narrow slots in the floor beneath the birds produced tall, sharply peaked manure mounds. Houses 3 and 4 were conventionally ventilated high-rise poultry houses. Exhaust air was forced from the pit by pit-fans and the manure, which dropped through wide slots in the floor generally, produced wide and flat manure mounds. House 5 was a positive-flow turbo house in which air was pulled into the house by fans located in the roof ridge and exhausted passively from the pit area. Like Houses 1 and 2, the manure drops were narrow.

Our study was limited to poultry houses in various stages of production, resulting in diverse insect populations. Houses 1 and 4 were cleaned during the surveillance period. Houses 2, 3, and 5 had been cleaned before the surveillance began. During clean-out, all manure was removed, and no pad was retained. All houses had naturally occurring house fly, darkling beetle, and hister beetle populations. Augmenting *C. pumilio* populations in some houses was encouraged by the producer through deliberate transfers of an unspecified number of adult beetles captured from houses with abundant beetle populations.

House fly larvae, and adult and larval life stages of both hister beetle and darkling beetle, were surveyed using the corer technique developed by Geden and Stoffolano, (1988). Ten samples of manure were randomly taken from the manure surface with a 400-cc bulb planter when manure levels were shallow or as the manure pack deepened from the mid-lateral surface (Geden and Stoffolano, 1988). Samples were taken to the laboratory and placed in Berlese–Tullgren funnels to extract the insects. Houses were sampled weekly for a minimum of 18 weeks from 1 June through 30 November, 1995. Egg and pupal densities were not determined. Larval life stages were not differentiated to instar. From these manure samples we estimated the hister beetle, darkling beetle, and larval house fly densities for each house. The impacts of hister beetles were estimated from changes in house fly larval densities. Similarly, darkling beetle population densities were used to estimate the impact on the house fly and hister beetles populations.

Adult house fly densities were monitored using sticky cards (76 by 127 mm). Ten sticky cards were placed on the support structures in the manure pit of each house and removed after 12–18 h. Data collected from these surveys were used to compare house fly and hister beetle populations so that the number of beetles required to hold the fly population at tolerable levels (i.e., as determined by the producer) could be established.

Laboratory experiments were conducted to test the hypothesis that darkling beetle adults or larvae could negatively impact *C. pumilio* egg and larval survival. Fresh chicken manure was collected and frozen to kill any arthropods within. Thawed chicken manure (180 cc) was placed in 1.5-liter plastic containers. *C. pumilio* egg numbers were kept constant at 10 eggs per 180 cc of thawed chicken manure. Zero, 10, 20, and 50 adult darkling beetles were added to each container. Experiments to evaluate the effect of *A. diaperinus* adult on *C. pumilio* larvae and eggs were replicated 8 and 7 times, respectively. Similarly, experiments on the effects of *A. diaperinus* larvae on *C. pumilio* larvae and eggs were replicated 10 and 15 times. Cold-killed fly eggs were added to each container to supplement larval feeding. Containers were covered with organdy cloth and held under constant light at 28 ± 1.5°C. To reduce excessive manure drying, 5–10 ml of water was added every 1–2 days. Following a 14-day holding period the manure containing the beetles was placed in Berlese–Tullgren funnels to extract the insects. The numbers of surviving *C. pumilio* larvae were counted and recorded and percentage mortality was calculated. Three additional experiments were conducted to evaluate the effects of adult darkling beetle on *C. pumilio* larval survival and the effect of darkling beetle larvae on survival of hister beetle eggs and larvae. Beetle ratios and experimental design were as described above.

The ratio of fly larvae to hister beetles was calculated by dividing the number of fly larvae by the number of beetles. The differences between hister beetle, house fly, and darkling beetle densities within poultry houses were analyzed using one-way ANOVA (Minitab, 1997). The impact of the darkling beetle on the hister beetle in the laboratory was analyzed using GLM, ANOVA (SAS Institute, 1992) following correction of control mortality and a log $(x + 1.1)$ transformation (Abbott, 1925).

RESULTS AND DISCUSSION

Production in House 1 had been underway for nearly 10 months and manure depth was near 1 m when the project began on June 1 (Table 1). Surveillance continued for 13 weeks when House 1 was depopulated and cleaned. Larval house fly and *C. pumilio* populations were well established and averaged 0.8 ± 0.5 and

TABLE 1

Mean (SE) Densities of *Carcinops pumilio*,[1] *Alphitobius diaperinus*,[1] and *Musca domestica* Larvae in Manure Samples and the Corresponding Adult House Fly Collection from Caged-Layer Poultry Houses over a 25-Week Period Beginning June 1, 1995

	House 1				House 2				House 3	
Week	*C. pumilio*	Fly larvae	Adult flies	*A. diaperinus*	*C. pumilio*	Fly larvae	Adult flies	*A. diaperinus*	*C. pumilio*	Fly larvae
1	32.5 (11.9)	0.8 (0.5)	21.5 (3.7)	81.6 (8.7)	—[2]	10.5 (5.0)	110.8 (15.6)$^{\beta}$	—[2]	0	24.0 (6.1)
2	67.1 (39.0)	4.1 (0.2)	17.4 (2.1)	67.8 (8.2)	—[2]	30.8 (5.3)	59.9 (7.9)$^{\beta}$	—[2]	0	73.4 (12.5)
3	21.6 (6.6)	3.0 (1.8)	25.7 (2.5)	69.5 (12.2)	48.9 (5.7)	5.5 (2.0)	61.1 (8.0)$^{\beta}$	27.4 (7.6)	0.2 (0.1)	36.2 (18.4)
4	26.4 (8.6)	0.1 (0.1)	31.9 (9.0)	85.0 (23.6)	50.0 (8.7)	5.3 (3.6)	72.9 (9.6)$^{\beta}$	32.5 (8.1)	0.1 (0.1)	21.1 (10.2)
5	42.2 (4.3)	0.8 (0.4)	29.6 (7.2)	105.6 (9.1)	38.3 (9.2)	7.1 (3.2)	79.4 (12.9)	57.5 (10.1)	1.8 (0.3)	33.9 (20.2)
6	38.8 (23.8)	18.0 (14.9)	17.9 (5.5)	46.5 (16.1)	29.3 (7.5)	0.6 (0.4)	50.3 (6.6)	57.0 (23.8)	1.0 (0.2)	45.2 (19.4)
7	29.1 (18.1)	1.3 (0.3)	12.5 (2.9)	33.8 (10.1)	26.1 (10.2)	9.2 (8.0)	46.2 (10.1)	56.2 (20.7)	6.5 (0.7)	32.7 (11.2)
8	36.1 (18.4)	0.5 (0.2)	24.3 (6.6)	96.7 (6.5)	20.8 (7.8)	6.0 (3.8)	44.1 (8.7)	99.2 (32.6)	13.9 (0.8)	24.2 (6.7)
9	14.9 (3.7)	2.5 (0.7)	18.0 (3.8)	127.3 (11.7)	22.8 (5.5)	21.6 (16.4)	40.1 (12.6)	152.3 (31.7)	39.2 (4.6)	35.7 (19.2)
10	31.1 (12.0)	10.3 (5.4)	26.3 (8.8)	67.0 (7.5)	21.8 (4.5)	3.8 (1.4)	31.6 (4.6)	86.3 (31.8)	60.0 (6.1)	10.5 (3.9)
11	10.5 (2.8)	26.4 (12.8)	24.0 (6.0)	56.3 (8.0)	22.0 (5.3)	11.7 (7.8)	22.1 (6.5)	218.0 (76.0)	64.4 (12.7)	1.9 (0.7)
12	9.5 (3.1)	20.0 (9.1)	16.5 (3.8)	175.3 (8.5)	18.6 (7.2)	2.9 (1.7)	26.0 (4.8)	126.7 (49.7)	78.4 (6.5)	2.4 (1.5)
13	24.9 (19.0)	220.9 (73.2)	19.7 (3.7)	201.6 (6.4)	15.6 (4.5)	4.9 (1.6)	31.9 (5.1)	122.4 (47.5)	52.8 (7.8)	3.3 (0.8)
14	Clean out				13.7 (12.4)	52.1 (28.9)	19.2 (3.4)	86.6 (28.9)	62.3 (4.5)	2.9 (1.1)
15	Clean out				19.0 (3.3)	35.8 (9.5)	13.4 (3.1)	41.1 (22.9)	65.1 (3.3)	0.9 (0.3)
16	Clean out				12.2 (4.4)	83.7 (24.2)	11.8 (2.2)	60.3 (24.2)	38.4 (3.5)	1.5 (1.0)
17	Clean out				23.4 (4.8)	52.7 (14.1)	21.1 (3.9)	315.2 (14.1)	40.0 (3.9)	3.0 (0.9)
18	0.7 (0.3)	0.6 (0.3)	0	2.6 (0.8)	20.7 (3.2)		22.7 (6.0)	296.6 (62.7)	33.3 (2.3)	4.7 (1.4)
19	1.5 (0.5)	0.0 (0)	0.4 (0.4)	1.4 (0.1)	19.3 (3.6)			166.6 (30.3)	31.3 (5.4)	2.5 (0.7)
20	1.6 (0.1)	2.6 (1.1)	0.2 (0.2)	1.7 (0.2)	21.6 (3.7)			367.0 (90.3)	54.9 (2.8)	2.4 (0.8)
21	0.4 (0.1)	49.9 (22.1)	3.6 (1.4)	4.9 (0.3)	22.1 (2.9)					
22	3.5 (0.8)	291.6 (97.0)	2.3 (1.2)	2.7 (0.5)						
23	12.4 (0.7)	305.0 (70.7)	4.5 (1.2)	8.7 (0.9)						
24	7.4 (0.8)	536.0 (131.0)	11.1 (2.2)$^{\beta}$	1.0 (0.1)						
25	9.7 (1.3)	211.2 (45.7)	20.5 (3.7)$^{\beta}$	2.1 (0.1)						

$^{\beta}$ Represents one insecticide treatment to control adult house flies.
$^{\Delta}$ Insecticide applied to control darkling beetles following litter removal and clean out.
[1] Combined adult and larval life stages.
[2] No data.

32.5 ± 11.5 per sample, respectively. Densities favoring the beetles continued through week 10 (Table 1). The mean number of hister beetles per sample through week 13 was 29 ± 4.90 per sample. For unknown reasons, the larval fly densities increased 20-fold 1 week prior to depopulation and clean-out on week 14. Meanwhile the adult fly densities remained relatively stable during this 13-week period, indicative of the delay between larval and pupal development and adult eclosion (Table 1). Interestingly, the producer did not perceive that the adult fly population warranted insecticide use. Insecticides were used, however, during weeks 24 and 25, when adult house fly densities were similar.

The *C. pumilio* population was composed primarily of adult beetles (18.82 ± 3.1 per sample), but the larval mean was 1.54 ± 0.3 per sample ($F = 28.49$, $df = 379$, $P \leq 0.0001$) (Table 2). Few or no hister beetle larvae were collected until week 22 of the study. From week 1 through 13, adult beetle collections reflected a reduction in beetle density relative to house fly larvae (Table 1). This reduction may have resulted from the producer transferring adult beetles to House 2 or from natural beetle dispersal or mortality.

House 1 was repopulated with hens on week 18. House fly populations responded positively to the abundance of fresh, moist manure and the fly larval densities exceeded *C. pumilio* from weeks 20 to 25 (Table 1). Adult fly populations were low from weeks 18 to 23, averaging 2.2 flies per card. House 1 was treated with insecticide (low residual, 2.5% pyrethrin applied as a thermal space fog) during weeks 24 and 25. These treatments targeted the adult flies in an effort to break the fly life cycle (Morgan and Patterson, 1990). Adult fly densities had increased to a mean of 11.1 ± 2.2 flies per card and 20.5 ± 3.7 flies per card on weeks 24 and 25, respectively. This increase was a result of the high fly larval densities observed during weeks 22, 23, and 24 with means of 291.6 ± 97.0, 305.0 ± 70.7, and 536.0 ± 131.0 larvae per sample, respectively.

The darkling beetle was the most abundant insect collected from the manure samples. Darkling beetle densities exceeded those of *C. pumilio* during weeks 1 through 13 (Table 1). Unlike *C. pumilio,* darkling beetle larval densities were significantly greater than those of adult beetles, 36.86 ± 8.2, and 16.56 ± 2.2, respectively ($F = 5.71$, $df = 391$, $P < 0.01$) (Table 2). Darkling beetles tend to work the manure by tunneling

TABLE 1—*Continued*

	House 3 cont.		House 4				House 5			
Week	Adult flies	*A. diaperinus*	*C. pumilio*	Fly larvae	Adult flies	*A. diaperinus*	*C. pumilio*	Fly larvae	Adult flies	*A. diaperinus*
1	4.4 (1.4)$^{\beta}$	1.3 (0.6)	14.8 (1.8)	0.2 (0.2)	18.0 (5.2)	96.6 (7.3)	1.0 (0.1)	31.4 (12.8)	0.1 (0.1)	0.9 (0.9)
2	20.8 (5.1)$^{\beta\beta}$	0.1 (0.1)	—[2]	—[2]	19.0 (4.0)	141.9 (16.3)	0	6.9 (4.4)	1.8 (0.6)$^{\beta}$	1.1 (0.3)
3	72.9 (13.2)$^{\beta\beta}$	0.4 (0.4)	11.4 (4.4)	0.4 (0.4)	16.7 (3.2)	208.7 (42.8)	0	66.3 (12.2)	22.8 (4.5)	33.3 (21.7)
4	53.3 (5.4)$^{\beta\beta}$	20.3 (0.3)	7.1 (1.2)	10.3 (1.3)	14.8 (3.2)	—[2]	1.3 (0.4)	3.2 (1.5)	22.8 (6.2)$^{\beta}$	55.5 (10.6)
5	39.6 (5.4)$^{\beta\beta}$	3.6 (0.1)	Clean out$^{\Delta}$				1.3 (0.6)	12.1 (4.9)	30.7 (8.5)	94.1 (16.4)
6	20.7 (3.3)$^{\beta\beta}$	17.2 (0.1)	Clean out				1.1 (0.5)	6.8 (5.6)	17.4 (4.2)	46.9 (7.0)
7	17.0 (2.6)$^{\beta\beta}$	3.8 (2.9)	Clean out				1.0 (0.5)	9.5 (2.6)	21.8 (5.1)$^{\beta}$	43.4 (5.4)
8	34.8 (4.4)	12.5 (7.6)	Clean out				0.6 (0.1)	38.8 (9.1)	14.7 (3.3)$^{\beta}$	19.3 (5.2)
9	20.5 (4.8)	11.3 (1.4)	Clean out				1.4 (0.3)	47.6 (32.3)	15.9 (5.5)	33.5 (8.4)
10	32.8 (5.2)	39.2 (6.7)	1.2 (0.5)	22.4 (18.3)	6.2 (2.5)	16.1 (4.1)	4.6 (1.2)	30.1 (9.9)	15.0 (3.6)	50.5 (11.8)
11	10.6 (2.3)	15.5 (2.6)	1.4 (0.3)	7.8 (3.3)	50.2 (9.5)	38.6 (10.0)	2.0 (0.6)	32.8 (8.5)	9.8 (3.5)	32.4 (7.8)
12	7.3 (1.9)	40.4 (1.5)	3.2 (0.2)	152.8 (90.3)	28.2 (6.5)	30.7 (6.9)	1.7 (1.4)	11.1 (5.2)	6.6 (1.3)	67.3 (22.6)
13	9.5 (2.1)	32.8 (4.0)	7.0 (0.8)	94.6 (20.9)	44.1 (7.5)	51.0 (15.3)	4.4 (0.9)	118 (4.5)	4.9 (1.3)	84.7 (15.3)
14	5.8 (1.3)	44.8 (3.8)	6.8 (1.5)	50.8 (10.9)	38.4 (5.6)	5.3 (1.2)	3.8 (0.8)	4.1 (1.7)	3.5 (1.2)	59.4 (14.8)
15	4.6 (1.0)	52.4 (17.1)	7.5 (0.8)	73.5 (21.0)	25.5 (1.9)	17.3 (3.9)	6.1 (1.2)	33.1 (12.7)	2.1 (0.5)	50.5 (11.7)
16	5.2 (1.5)	100.2 (9.5)	4.9 (0.7)	93.8 (16.8)	27.7 (4.5)	17.4 (7.6)	5.6 (1.3)	92.3 (36.2)	5.7 (1.6)	46.1 (28.6)
17	4.2 (1.0)	61.2 (2.1)	8.6 (0.9)	25.3 (5.2)	43.9 (8.1)	8.8 (1.2)	11.0 (1.1)	80.2 (13.0)	6.7 (1.4)	92.3 (11.0)
18	4.7 (1.4)	16.6 (4.2)	10.4 (1.8)	38.8 (7.5)	25.9 (2.7)	9.5 (2.7)	13.9 (0.8)	122.4 (46.2)	8.1 (2.4)	41.3 (14.1)
19	2.5 (0.7)	43.1 (11.5)	22.3 (3.5)	57.8 (19.2)	27.6 (4.8)	41.6 (11.0)	12.9 (1.1)		7.3 (1.3)	71.5 (12.8)
20	2.4 (0.8)	36.5 (10.1)	25.9 (5.5)	65.9 (14.0)	34.1 (4.2)	25.7 (10.7)				
21	5.1 (3.3)	63.7 (21.0)	16.7 (2.4)	26.7 (6.9)	21.4 (5.4)	111.1 (15.9)				
22										
23										
24										
25										

and turning the manure as they forage and may impact *C. pumilio* egg and larval survival. Such activity could account for the low frequency of *C. pumilio* larvae in the manure samples (1.54 ± 0.3 per sample).

When the surveillance started, House 2 had been cleaned recently, with manure depth about 30 cm, and the fly larval population averaged 10.5 ± 5.0 per sample. The producer was actively transferring *C. pumilio* beetles from House 1 to establish a predator population. The *C. pumilio* 19-week mean was 26.5 ± 6.0 per manure sample. Densities of *C. pumilio* exceeded house fly larvae from week 3 through week 13 (Table 1). Weeks 14 to 18 favored the flies slightly with ratios of 2:1, 2:1, 4:1, and 3:1, respectively.

House 2 *C. pumilio* adult mean density was significantly higher (24.89 ± 1.8) than the larval mean (1.56 ± 0.3) ($F = 153.65$, $df = 321$, $P < 0.0001$). Similar to House 1, the adult beetle population declined (Table 1). The hister beetle larval densities remained low and in some weeks no larvae were collected from the manure samples. Indications of reproducing beetles were not evident until week 17.

Collections of darkling beetle adults and larvae indicated that this was the most abundant species in the

TABLE 2

Ratio of *Carcinops pumilio* to *Alphitobius diaperinus,* Combined Adult and Larval Life Stages, in Manure Samples Collected from Caged-Layer Poultry Houses over a 25-Week Period Beginning June 1

	Means and (SE)				
Species and lifestage	House 1	House 2	House 3	House 4	House 5
C. pumilio					
Adults	18.8 (3.1)a	24.9 (1.8)a	15.3 (1.4)a	7.1 (0.8)a	1.7 (0.2)a
Larvae	1.5 (0.3)b	1.6 (0.3)b	15.1 (1.4)a	2.6 (0.3)b	2.5 (0.4)a
M. domestica					
Adults	17.5 (1.3)a	42.3 (2.7)a	19.2 (1.7)a	24.1 (1.5)c	11.8 (1.1)b
Larvae	84.7 (14.1)c	20.4 (3.2)a	18.1 (2.5)a	45.4 (6.9)d	35.6 (4.6)c
A. diaperinus					
Adults	16.6 (2.2)a	25.3 (2.3)a	5.9 (1.2)b	14.4 (2.8)c	7.7 (1.1)ab
Larvae	36.8 (8.1)d	109.6 (12.5)c	23.0 (2.9)a	35.2 (6.9)d	39.8 (3.6)c

Note. Means followed by the same letter are not significantly different. ANOVA $P \leq 0.001$.

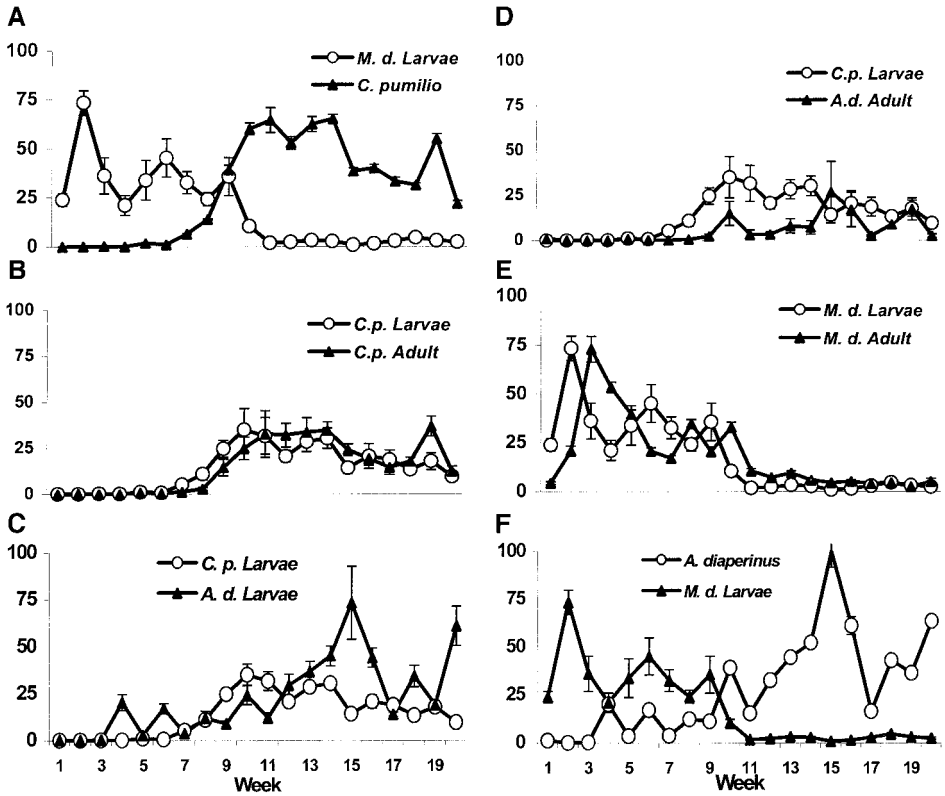

FIG. 1. Comparative population trends for *Musca domestica* (*M. d.*), *Carcinops pumilio* (*C. p.*), and *Alphitobius diaperinus* (*A. d.*) in caged-layer House 3.

poultry house, averaging 134.9 ± 7.35 individuals per sample. Larval populations were significantly higher than adult beetle, 109.6 ± 12.5 and 25.3 ± 2.3, respectively ($F = 153.65$, $df = 321$, $P < 0.0001$) (Table 2). Darkling beetle densities exceeded *C. pumilio* throughout the sampling period (Table 1), again suggesting that darkling beetles negatively effected the establishment of *C. pumilio.*

The adult fly populations were high throughout the study period, averaging 42.3 ± 2.7 flies/card over the 18-week period. Four applications of pyrethrin (2.5%) were used to curb the adult fly population between weeks 1 and 4 (Table 1). Mean house fly larval density (20.37 ± 3.2) was less than adult fly density.

The events that occurred in House 3 were indicative of the fly management potential of *C. pumilio.* House 3 had been recently cleaned and the manure depth was about 15 cm. As expected in a repopulated chicken house, the fresh manure was conducive to house fly growth and development. House fly larval densities averaged 24.0 ± 6.1 per sample, and the *C. pumilio* beetle population was undetectable even though releases were underway (Fig. 1A, Table 1). By week 3 the fly larval density was 36.2 ± 18.4. House fly larva and *C. pumilio* densities were nearly equal by week 9, with 35.7 ± 19.2 and 39.2 ± 4.6, respectively. *C. pumilio* densities exceeded those of the house fly from weeks 9 through 21 (Table 1).

The *C. pumilio* beetle population density within House 3 was unlike those of Houses 1 and 2. Although the numbers of collected beetles were low initially, the *C. pumilio* densities had increased to a mean of 30.4 ± 1.4 per sample over the 21-week sampling period (Fig. 1A). Interestingly, the number of larval and adult *C. pumilio* were nearly equal throughout the study, 15.30 ± 1.4 and 15.10 ± 1.4, respectively ($F = 0.01$, $df = 385$, $P < 0.920$) (Table 2, Fig. 1B). One contributing factor to the increased number of *C. pumilio* larvae may have been the density of darkling beetles, 5.93 ± 1.2 and 23.03 ± 2.9 for adult and larvae, respectively (Table 2). Densities favored *C. pumilio* over *A. diaperinus* throughout the 21-week study (Fig. 1C and D).

House 3 was treated with low residual pyrethrin (2.5%) thermal space fog 13 times during the first 7 weeks of the study period. Mean density of 33.95 ± 3.6 flies per card was observed during this period (Fig. 1E, Table 1). Hister beetle releases were timed to occur between planned spraying of House 3. From week 7 through week 21 no insecticides were used. During the latter weeks of the study, the house fly larval population decline was similar to that of the adult flies. This

decline coincided with the increases in *C. pumilio* and *A. diaperinus* populations (Figs. 1A and F). The activity of the darkling beetles probably contributed to the decline of the house fly population.

House 4 had been in production for nearly a year and was scheduled for depopulation and cleaning 4 weeks after surveillance started. The manure depth was about 2 m. During week 1, fly larval densities were low (0.2 ± 0.2 per sample) and the adult fly mean density was 18.0 ± 5.2 per sticky card, whereas *C. pumilio* beetle densities averaged 14.8 ± 1.8 per sample (Table 1). The 3-week mean *C. pumilio* collection was 11.1 ± 2.1 specimens per sample (9.5 ± 1.49 adults and 1.8 ± 0.5 larvae). In the absence of house fly prey, *C. pumilio* adults may have fed on other prey species or by cannibalizing the immature stages (Ruggles, 1977).

New birds were brought into the house during week 9 and the fly population became established within a week, with larval densities of 22.4 ± 18.3 per sample. By week 12 the fly larval densities were 152.8 ± 90.3 per sample. The *C. pumilio* densities increased steadily for the 12-week period after clean-out. *C. pumilio* collections averaged 9.7 ± 1.3 per sample from week 10 through 21.

Life stage composition of the *C. pumilio* beetle collections favored the adult beetles over larvae, 7.07 ± 0.78 and 2.60 ± 0.34, respectively ($F = 27.14$, $df = 294$, $P < 0.0001$) (Table 2). This was expected since the producer had twice transferred an estimated 10,000 adult beetles from other houses to augment the population. *C. pumilio* larvae were not often collected from the manure samples until week 12 of the study period. After the house was cleaned, the darkling beetle population was relatively low, which may have reduced the impact on the *C. pumilio* larval population. Adult darkling beetles were significantly less abundant than larvae, 14.36 ± 2.8, and 35.22 ± 6.9, respectively ($F = 7.90$, $df = 297$, $P < 0.005$).

House 4 was not treated with insecticide for fly control during the surveillance period. The adult house fly population over the 12 weeks, following the clean out period, was relatively high, averaging 31 ± 1.6 flies/card (Table 1). Darkling beetle densities in House 4 were also high (149.0 ± 18.6 per sample) during weeks 1 through 3. One insecticide treatment (cyfluthrin) for darkling beetle control was applied during the clean-out period to slow their reinfestation of the house following repopulation. Although complete control was not achieved (Table 1), the insecticide treatment had the desired effect because the darkling beetle mean densities for the remaining 12 weeks of the study was lower (31.1 ± 8.7 per sample).

House 5 fly larval densities were relatively high (31.4 ± 4.6 per sample) and the *C. pumilio* population was low (1.0 ± 0.2 per sample) early in the survey. The adult flies captured on sticky cards from week 3 to week 10 were relatively stable, averaging 20.1 ± 4.8 flies/card (Table 1). Insecticides were applied during weeks 2, 4, 7, and 8 to control the adult fly populations. The mean number of flies was 6.1 ± 1.5 per card from weeks 11 to 19.

Few adult *C. pumilio* beetles were collected during the first 10 weeks, regardless of a relative abundance of prey. Later, however, adult and larval *C. pumilio* were frequently observed in the manure samples and larvae were more abundant than adults in the samples from weeks 15 to 19. Overall mean *C. pumilio* adult and larval collections were 1.73 ± 0.22 and 2.49 ± 0.40, respectively, for the 19-week period ($F = 6.74$, $df = 339$, $P < 0.09$) (Table 2).

Darkling beetles were common in House 5, averaging 7.74 ± 1.1 adults per sample and 39.86 ± 3.6 larvae per sample. Densities heavily favored the darkling beetle relative to *C. pumilio* (Table 1).

Without controlled experimentation it was difficult to conclude that the darkling beetle negatively impacted the establishment of *C. pumilio.* Subsequent laboratory studies, however, suggest that darkling beetle larvae may impact the establishment of *C. pumilio* by consuming the eggs. Darkling beetle larvae significantly reduced the survival of hister beetle eggs ($F = 10.68$, $df = 35$, $P = 0.004$) (Table 3). Hister beetle eggs hatched within 5–6 days at room temperature. Natural mortality was high in the control group 78.8%

TABLE 3

Mean Percentage Mortality of *Carcinops pumilio* Eggs and Larvae when Held with Adult and Larval Darkling Beetles (*Alphitobius diaperinus*)

Hister beetle to darkling beetle lifestage ratio	Mean percentage mortality (SE)	*P*
Egg to adult		
10:0	72.8 (0.06)a	0.07
10:10	73.5 (0.15)a	
10:20	53.0 (0.17)a	
10:50	60.2 (0.16)a	
Larva to adult		
10:0	62.5 (0.05)a	0.47
10:10	50.5 (0.11)a	
10:20	70.0 (0.08)a	
10:50	39.6 (0.12)a	
Egg to larva		
10:0	78.8 (0.04)a	0.004
10:10	77.7 (0.12)a	
10:20	72.2 (0.15)a	
10:50	100 (0.00)b	
Larva to larva		
10:0	72.8 (0.02)a	0.0001
10:10	63.6 (0.09)b	
10:20	90.4 (0.05)c	
10:50	96.4 (0.04)c	

Note. Category means followed by the same letter in column are not significant. Tukey mean separation was used to delineate differences.

± 0.02 during the 14-day assay. No significant differences were found when hister beetle egg and darkling beetle larval ratios were 10:0, 10:10, and 10:20. However, when 50 darkling beetle larvae were added to containers with 10 hister beetle eggs, mean mortality was 100% after correction for control mortality.

Differences were more evident in experiments evaluating the impact of darkling beetle larvae on hister beetle larvae. Darkling beetle larvae significantly impacted the survival of hister beetle larvae at all ratios compared to the control group ($F = 34.12$, $df = 55$, $P = 0.0001$) (Table 3). Hister beetle to darkling beetle ratios of 10:50 and 10:20 were not significantly different. Although darkling beetle larvae negatively impacted hister beetle establishment, adult darkling beetles did not have a significant effect on either hister beetle eggs ($F = 3.29$, $df = 27$, $P = 0.0672$) or larvae ($F = 6.43$, $df = 31$, $P = 0.3165$).

CONCLUSION

Five high-rise caged-layer houses were studied to determine the role of *C. pumilio* in the management of the house fly. House fly populations in houses with abundant *C. pumilio* appeared to have been managed, based on a subjective evaluation of the producer and the research team. House fly larva and *C. pumilio* populations reached the desired ratio of 1:1 within 9 weeks in House 3. However, manure condition, insecticide use, house design, and the presence of darkling beetles must be considered as contributing factors. Increases in fly populations soon after new flocks were placed in the houses confirmed the positive response of flies to fresh manure. Older manure is less conducive to fly development. The selective use of insecticides to control adult fly populations may have supported beetle establishment, which was particularly evident in House 3 where adult and larval *C. pumilio* appeared to be somewhat tolerant of pyrethrin space sprays. Of the caged-layer houses selected for this study, House 3 was older and of conventional design. It was apparent that established populations of *C. pumilio* contributed to the management of house flies in turbo houses as well. However, population sampling demonstrated that most of the *C. pumilio* were adult beetles with few larval cohorts. We found darkling beetles to be the most abundant insect in several study houses; coincidentally these houses contained relatively few immature *C. pumilio.* We reasoned that because darkling beetles are omnivorous, the *C. pumilio* larvae may not survive either through reduced food supplies and starvation or through, perhaps, becoming prey. The relatively low population of darkling beetles probably contributed to the successful hister beetle colonization of House 3.

These results suggest that managing the darkling beetle and the house fly are important for the successful use of predatory *C. pumilio* beetles in poultry houses. Based on our results, establishment of *C. pumilio* in the poultry house must be encouraged through integration of several management practices. These include the following steps. (1) Release *C. pumilio* at a rate of one adult beetle for every fly larva. However, prior to releasing *C. pumilio,* the *A. diaperinus* population must be sampled. If darkling beetle densities are twice that of the released *C. pumilio,* establishment may be impacted. (2) Keep the fly population low using insecticides effectively, targeting adult fly populations while the hister beetle population becomes established. Use a low residual pyrethrin, applied as a thermal fog, or fly baits. Such insecticides are recommended because of the minimal impact that they have on beneficial insects. (3) After clean-out, treat the entire house with insecticide for darkling beetles. Keep the darkling beetle population level below that of *C. pumilio.* Do not move manure containing darkling beetles into a new house and selectively release only *C. pumilio.* Although the laboratory studies demonstrated that darkling beetles could affect successful reintroduction and establishment of hister beetles in caged-layer houses, further field and laboratory studies are needed to define the interactions between these insects.

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REFERENCES

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol.* **18,** 265–267.

Anonymous, 1993. "*Salmonella enteritidis* (SE) control program. Status report." November 30, 1993, APHIS Veterinary Services.

Axtell, R. C. 1981. "Use of Predators and Parasites in Filth Fly IPM Programs in Poultry Housing." Proc. Wrkshp. Biol. Contrl. Filth Flies, pp. 26–43. Gainesville, FL.

Axtell, R. C., and Rutz, D. A. 1986. Role of parasites and predators as biological fly control agents in poultry production facilities. *In* "Biological Control of Muscoid Flies" (R. S. Patterson and D. A. Rutz, Eds.), pp. 88–100. Misc. Publ. Entomol. Soc. Am. 61, Annapolis, MD.

Axtell, R. C., and Arends, J. J. 1990. Ecology and management of arthropod pests of poultry. *Annu. Rev. Entomol.* **35,** 101–126.

De la Casa, E., Harein, P. K., Deshmukh, D. R., and Pomeroy, B. S. 1973. The relationship between the lesser mealworm and avian viruses. I. Reovirus 24. *Environ. Entomol.* **2,** 1043–1047.

De la Casa, E., Harein, P. K., Deshmukh, D. R., and Pomeroy, B. S. 1976. Relationship between the lesser mealworm, fowl pox, and Newcastle disease virus in poultry. *J. Econ. Entomol.* **69,** 775–779.

Despins, J. L., Axtell, R. C., Rives, D. V., Guy, J. S., and Ficken, M. D. 1994. Transmission of enteric pathogens of turkeys by darkling beetle larvae (*Alphitobius diaperinus*). *J. Appl. Poultry Res.* **3,** 61–65.

Geden, C. J. 1984. "Population Dynamics, Spatial Distribution, Dispersal Behavior and Life History of the Predaceous Histerid, *Carcinops pumilio* (Erichson), with Observation of Other Members of the Poultry Manure Arthropod Community." Ph.D. dissertation, University of Massachusetts, Amherst.

Geden, C. J. 1990. Coleopteran and acarine predators of house fly immatures in poultry production systems. *In* "Biocontrol of Arthropods Affecting Livestock and Poultry" (D. A. Rutz and R. S. Patterson Eds.), pp. 177–200. Westview Press, Boulder, CO.

Geden, C. J., and Stoffolano, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *J. Med. Entomol.* **24,** 212–220.

Geden, C. J., and Stoffolano, J. G. 1988. Dispersion patterns of arthropods associated with poultry manure in enclosed houses in Massachusetts: Spatial distribution and effects of manure moisture and accumulation time. *J. Entomol. Sci.* **23,** 136–148.

Geden, C. J., Stoffolano, J. G., and Elkinton, J. S. 1987. Prey-mediated dispersal behavior of *Carcinops pumilio* (Coleoptera: Histeridae). *Environ. Entomol.* **16,** 415–419.

Geden, C. J., Stinner, R. E., and Axtell, R. C. 1988. Predation by predators of the house fly in poultry manure: Effects of predator density, feeding history, interspecific interference, and field condition. *Environ. Entomol.* **17,** 320–329.

Leschen, R. A. B., and Steelman, D. D. 1988. *Alphitobius diaperinus* (Coleoptera: Tenebrionidae) larva and adult mouthparts. *Entomol. News* **99,** 221–224.

McAllister, J. C., Steelman, D. D., and Skeeles, J. K. 1994. Reservoir competence of the lesser mealworm (Coleoptera: Tenebrionidae) for *Salmonella typhimurium* (Eubacteriales: Enterobacteriaceae). *J. Med. Entomol.* **31,** 369–372.

McAllister, J. C., Steelman, D. D., Newberry, L. A., and Skeeles, J. K. 1995. Isolation of infectious bursal disease virus from the lesser mealworm *Alphitobius diaperinus* (Panzer). *Poultry Sci.* **74,** 45–49.

Miller, J. P. 1997. That crunchy stuff in you cereal bowl may not be granola. Beetles invade an Ohio town when chicken farms plan for fly control goes awry. *Wall Street J.* November 3, 1997.

Miller, R. W., Rutz, D. A., Pickens, L. G., and Geden, C. J. 1993. Evaluation of traps and parasitoid *Muscidifurax raptor* Girault and Sanders to manage house flies and stable flies on diary farms. *J. Agric. Entomol.* **10,** 9–19.

Minitab. 1997. Minitab Release 11. State College, PA.

Morgan, P. B., and Patterson, R. S. 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" (D. A. Rutz and R. S. Patterson, Eds.), pp. 169–178. Westview Press, Boulder, CO.

Petersen, J. J., Watson, D. W., and Cawthra, J. 1995. Comparative effectiveness of three release rates for a pteromalid parasitoid (Hymenoptera: Pteromalidae) for controlling house flies (Diptera) in beef cattle feed lots. *Biol. Control* **5,** 561–565.

Ruggles, L. H. 1977. "Observation on Biological Fly Control in Massachusetts Cages Layer Houses." Bulletin C-106, Massachusetts Coop. Ext. Serv., pp. 1–12., Univ. of Massachusetts, Amherst.

Rueda, L. M., and Axtell, R. C. 1985. Comparison of hymenopterous parasites of house fly, *Musca domestica* (Diptera: Muscidae), pupae in different livestock and poultry production systems. *Environ. Entomol.* **14,** 217–222.

Rueda, L. M., and Axtell, R. C. 1997. Arthropods in litter of poultry (Broiler chicken and turkey houses. *J. Agric. Entomol.* **14,** 81–91.

Rutz, D. A., and Axtell, R. C., 1979. Sustained releases of *Muscidifurax raptor* (Hymenoptera: Pteromalidae) for house fly (*Musca domestica*) control in two types of cage-layer poultry houses. *Environ. Entomol.* **8,** 1105–1110.

Rutz, D. A., Scoles, G. A., and Howser, G. G. 1987. Evaluation of fly-electrocuting black light devices in caged-layer poultry facilities. *Poultry Sci.* **67,** 871–877.

Rutz, D. A., and Watson, D. W. 1998. Parasitoids as a component in an integrated fly- management program on dairy farms. *In* "Mass-Reared Natural Enemies: Applications, Regulation, and Needs" (R. L. Ridgeway, M. Hoffman, C. S. Glenister, and M. Inscoe, Eds.), pp. 185–201. Entomol. Soc. Am. Monograph, Annapolis, MD.

SAS Institute Inc. 1992. Release 6.09. SAS Campus Drive, Cary, NC.

Vaughan, J. A., Turner, E. C., Jr., and Ruszler, P. L. 1984. Infestation and damage of poultry house insulation by the lesser mealworm, *Alphitobius diaperinus* (Panzer). *Poultry Sci.* **63,** 1094–1100.