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Larval Production from Field-Collected *Carcinops pumilio* (Coleoptera: Histeridae) Following Three Starvation Periods

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ABSTRACT *Carcinops pumilio* (Erichson) were collected from high-rise, caged-layer poultry facilities using two trapping methods, a blacklight pitfall trap and a mesh-bottomed trap placed on poultry manure. Starvation for 14 d significantly reduced larval production during the first 3-d oviposition period regardless of trapping method. Beetles collected with blacklight traps and subsequently starved for 14 d had higher larval production in the third through fifth oviposition periods than those fed daily, indicating that lack of nutrition was a limiting factor in *C. pumilio* larval production. No differences were observed in larval production, after the first oviposition period, between the 14-d starved and daily fed groups collected with the mesh-bottom trap. In all blacklight-captured treatments, larval production was lowest during the first oviposition period with the largest differences found among the three starved treatments. Larval production in the 14-d starved treatment increased significantly during the later oviposition periods in mesh-bottom trap studies. Within the fed treatment, larval production was consistently greater among beetles collected with the mesh-bottom trap than among beetles collected with blacklight traps.

KEY WORDS *Carcinops pumilio*, biological control, house fly, larval production

Carcinops pumilio (ERICHSON) has been identified as an important predator of house fly, *Musca domestica* L., eggs and larvae in poultry facilities (Ruggles 1979, Geden and Stoffolano 1987). In laboratory studies, Morgan et al. (1983) reported on *C. pumilio* fecundity and Smith (1975) reported on the life-history of this beetle. Geden et al. (1988) reported that adult *C. pumilio* destroyed significantly more house fly immatures per day after a 5-d-starvation period than after 5 d of feeding. At high densities, the ovaries of field-collected adult *C. pumilio* from high density populations were less developed than those from low density populations (Geden and Stoffolano 1987).

Augmentation of house fly biological control in poultry facilities using pteromalid parasitoids has been practiced for many years. Commercial releases of predatory beetles have not been practiced, and producers generally rely on natural succession. Geden and Stoffolano (1987) reported on successional establishment of *C. pumilio* and other predators in New England poultry facilities.

Adult *C. pumilio* can be trapped effectively in large numbers using suspended black lights in poultry manure pits. *C. pumilio* also may be collected in more limited numbers using a commercially available mesh-bottomed trap placed on poultry manure, the Hister House integrated (IPM Laboratories, Locke, NY). These beetles subsequently can be released into recently repopulated caged-layer poultry facilities as an effective fly biological control agent. However, because of the poultry producer practice of removing all manure from the facility when changing flocks, recently repopulated facilities may not contain food supplies adequate for successful beetle reestablishment. Geden and Stoffolano (1987) reported that adult *C. pumilio* initially increased rapidly from external recolonization; however, the number of larval *C. pumilio* peaked 9 wk after cleanout. Furthermore, the number of adult beetles recovered dropped until 6 wk after cleanout when numbers again rose.

The relationship between *C. pumilio* and their associated prey and predator dispersal behavior has been investigated (Geden et al. 1987, Geden and Axtell 1988, Kaufman et al. 2000). Geden et al. (1987) reported that flight behavior of dispersing *C. pumilio* was reversed after administration of a dipteran prey meal, whereas the removal of prey induced a dispersal response. In studies with adult *C. pumilio*, Geden and Axtell (1988) did not detect a predator density effect on predation of house fly eggs. To date, a relationship between food deprivation and *C. pumilio* larval production has not been documented.

If previously starved *C. pumilio* are to be introduced effectively as a self-replenishing biological control agent, a better understanding is needed regarding the effect of starvation on fecundity. In previous work with these two trapping methods, Kaufman et al. (2000) reported that blacklight- and Hister House-captured beetles had dissimilar dispersal behaviors. To determine the effects of trapping method and food availability on *C. pumilio* reproduction, we enumer-

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ated larval production following differential starvation periods.

Materials and Methods

Carcinops pumilio adults were obtained from manure piles in high-rise caged-layer poultry facilities located near Wolcott, NY, using the Hister House, a commercial, disposable trap (IPM Laboratories, Locke, NY, patent number 5,930,945), and blacklight pitfall traps. Hister House traps are 8 by 10 by 6.5-cm cardboard boxes with a nylon screen to allow beetle entrance. Traps contain vermiculite treated with a proprietary insect-based, beetle feeding attractant. When ready for use, the vermiculite is saturated with water and traps placed screen side down directly on poultry manure. Hister House traps were placed one-third of the way up the manure pile on either side of pitfall traps. Black lights were suspended in the manure pit 0.7–1 m above the floor in depressions between manure rows. On the floor (or manure if accumulations were sufficiently high), under each black light we placed a pitfall trap, a trough constructed from a PVC pipe (20 cm diameter by 1.23 m long) cut in half lengthwise and capped at each end. Manure was piled around the trap forming a ramp that allowed beetles to climb to the edge of the trap. Beetles were collected at 24-h intervals. After removal from the poultry facility, Hister House-collected beetles were extracted from traps using Tullgren funnels. Blacklight-collected beetles were separated from other arthropods and debris with brass sieves (12 and 20 mesh). Extracted and sieved beetles were counted and randomly assigned to treatment groups using a draw-from-the-hat technique. The four treatments included daily feeding and starvation for 5, 10, and 14 d. Beetles were held in petri dishes with filter paper bottoms (50/dish) and each treatment was replicated 12 times. This assay was repeated twice for each trap type with beetle collections made in December 1997 and April 1998.

During the feeding period, beetles were provided refrigerated, dead house fly (*M. domestica* L.) eggs daily ad libitum in a water slurry. Beetles were provided with a moist filter paper (9 cm) during the food deprivation periods. In all assays, beetles were held on the laboratory benchtop under constant fluorescent light and room temperatures (≈21–23°C) in 100 by 25-mm plastic petri dishes sealed with parafilm.

Groups of *C. pumilio* were starved for either 14, 10, 5, or 0 d before introduction of oviposition material. On days 15–29, all groups received house fly eggs as described above and an egg collection device (5 by 5 by 2 cm; egg collection substrate, IPM Laboratories) was placed in each petri dish. Each collection device was replaced every 72 h, yielding five 3-d periods.

Carcinops pumilio are cannibalistic as adults on intraspecific eggs (Geden 1984). The density of the material used in the egg collection device protected the eggs from cannibalistic adults, but made it impossible to count the eggs without destroying them. Therefore, we estimated production at larval emergence by suspending egg collection devices individually over 50 ml of soapy water in a 118-ml plastic cup with lid. After a 21-d holding period, during which all viable eggs eclosed, first-instar *C. pumilio* that had fallen into the water were counted.

Sex determinations of adult *C. pumilio* were detrimental to beetle health and subsequent performance and, therefore, were performed at the conclusion of the oviposition period. The number of female beetles in each petri dish was determined for each 3-d time period, and all results are reported as the number of larvae per living adult female. The number of larvae per living female was calculated for specific oviposition periods (days 1–3, 4–6, 7–9, 10–12, 13–15, and 1–15), and for each of the four starvation periods (0, 5, 10, and 14). All data were transformed to $\sqrt{y + 0.5}$ and analyzed using a multifactorial analysis of variance (ANOVA) and Tukey's multiple mean separation test (PROC GLM, SAS Institute 1996). Data were examined in two ways; first by comparing starvation periods (0, 5, 10, and 14 d) to each other within the oviposition period (e.g., days 1–3, 4–6), and second by comparing oviposition periods to each other within individual starvation periods. A comparison of trap type was conducted within each starvation period and oviposition period. Two analyses were performed to examine differences in cumulative larval production. The first examined differences between starvation periods within trap type, whereas the second compared differences between trapping methods within starvation periods. The fixed effect variables were the number of days starved, oviposition period, and trap type. Arithmetic means are presented in all tables.

Results and Discussion

Paternal sex ratios in the blacklight treatment slightly favored males over females 1.03:1, whereas the male to female ratio in the Hister House treatment was male biased 1.19:1. The day 10–12 oviposition material for the first Hister House trial was discarded accidentally before complete larval emergence, and these data were not included in the analysis. Starvation for 14 d significantly reduced larval production during the first 3-d oviposition period, regardless of trapping method (Table 1). Beetles collected with blacklight traps and subsequently starved for 14 d produced significantly more larvae in the third through fifth oviposition periods than the fed treatment, indicating that this group had compensatory oviposition gains and that starvation was a limiting factor in early *C. pumilio* larval production. No differences were observed in larval production, after the first oviposition period, between Hister House-collected beetles in the 14-d starved and fed groups. Beetles starved for 10 d produced fewer larvae than the fed treatment during all but the final oviposition period.

Except for the 4- to 6-d oviposition period, larval production was consistently greater among beetles collected with the Hister House than with blacklight traps, within the fed treatment (0 d starved) (Table 1). This trend also was observed with 5-d starved beetles,

Table 1. Larval production of blacklight and Hister House-collected *Carcinops pumilio* adults during five 3-d oviposition periods following three starvation periods

Oviposition period	No. days starved	No. larvae per female	
		Blacklight Mean (SE)	Hister House Mean (SE)
1–3	0	0.61 (0.04)Ab	1.12 (0.15)Aa
	5	0.56 (0.04)Ab	0.89 (0.13)Aa
	10	0.48 (0.04)ABa	0.40 (0.09)Ba
	14	0.39 (0.03)Ba	0.45 (0.13)Ba
4–6	0	0.82 (0.07)ABa	1.08 (0.11)Aa
	5	0.75 (0.04)Bb	0.92 (0.07)ABa
	10	0.63 (0.05)Ba	0.73 (0.06)Ba
	14	0.98 (0.05)Aa	0.86 (0.15)ABa
7–9	0	0.66 (0.05)Cb	0.93 (0.07)Aa
	5	0.72 (0.04)BCb	0.91 (0.07)Aa
	10	0.86 (0.06)ABa	0.62 (0.05)Bb
	14	0.94 (0.07)Aa	0.85 (0.09)ABa
10–12	0	0.90 (0.08)Bb	1.23 (0.06)ABa
	5	1.03 (0.06)ABa	1.06 (0.06)BCa
	10	0.97 (0.06)Ba	0.88 (0.12)Ca
	14	1.22 (0.07)Aa	1.50 (0.12)Aa
13–15	0	0.63 (0.06)Cb	0.82 (0.06)Ba
	5	0.97 (0.07)ABa	0.89 (0.07)ABa
	10	0.78 (0.06)BCa	0.77 (0.07)Ba
	14	1.06 (0.08)Aa	1.27 (0.13)Aa

Means within columns and oviposition periods followed by the same uppercase letter are not significantly different at alpha = 0.05, Studentized 5% level for multiple range test = 3.70, df = 91. HH days 10–12; Studentized 5% level for multiple range test = 3.78, df = 44. Means within rows followed by the same lowercase letter are not significantly different at alpha = 0.05, Studentized 5% level for multiple range test = 2.85, df = 45. HH days 10–12 Studentized 5% level for multiple range test = 2.88, df = 33.

but for only the first three oviposition periods. Significant differences only existed during the third oviposition period among 10-d starved groups, when blacklight-captured beetles produced more larvae than Hister House-captured beetles. No differences in larval production were observed between trap types among 14-d starved beetles, indicating that the starvation of beetles for 10–14 d lessened the advantage that Hister House-captured beetles initially had by reducing nutritional reserves.

In all blacklight-captured treatments, larval production was lowest during the first oviposition period. This was evident especially among the starved treatments where significantly more larvae were recovered after administration of prey ($F = 13.04$; df = 4, 114; $P = 0.0001$). The increased larval production observed in the later oviposition periods indicates that starvation initially reduced viable egg production, but that *C. pumilio* successfully recovered and reproduced after starvation periods as long as 14 d. No differences in larval production existed between oviposition periods among beetles in the Hister House-collected 5-d starved treatment ($F = 0.32$; df = 4, 102; $P = 0.8661$). Beetles in the 10-d starved treatment produced significantly fewer larvae only during the first oviposition period ($F = 6.21$; df = 4, 102; $P = 0.0002$), whereas the number of larvae recovered from the 14-d starved treatment continued to increase during the later oviposition periods ($F = 60.41$; df = 4, 102; $P = 0.0001$). These results also indicate that nutrition may have affected either egg production or viability, or both.

Table 2. Comparison of cumulative larval production by *Carcinops pumilio* adults collected with two trapping methods

No. days starved	No. larvae per female[a]	
	Black Light Mean (SE)	Hister House Mean (SE)
0	3.62 (0.19)Bb	6.36 (0.34)ABa
5	4.01 (0.15)ABb	5.66 (0.16)ABa
10	3.68 (0.15)Ba	3.77 (0.27)Ba
14	4.55 (0.19)Ab	6.31 (0.48)Aa

Means within columns followed by the same uppercase letter are not significantly different at alpha = 0.05. BL—Studentized 5% level for multiple range test = 3.701, df = 91; HH—Studentized 5% level for multiple range test = 3.775, df = 44. Means within rows followed by the same lowercase letter are not significantly different at alpha = 0.05, Studentized 5% level for multiple range test = 2.874, df = 34.

[a] Total from 15-d collection period.

Fourteen-day starved, blacklight-captured beetles cumulatively produced more larvae than beetles in the fed (0-d starved) and 10-d starved treatments (Table 2). Larval production was higher among Hister House-captured beetles in the 14-d starved treatment than the 10-d starved treatment, but not higher than beetles in the fed and 5-d starved treatments. Cumulatively, Hister House-captured beetles in the 0-, 5-, and 14-d starved treatments produced more larvae per female per treatment than blacklight-captured beetles. The greatest difference between trap type groups was observed among beetles that were not starved. Furthermore, starvation did not decrease the number of larvae produced among blacklight-captured beetles, indicating that these beetles may have been in poor nutritional and reproductive health when collected. Although significant differences in larval production between trap type were not evident among 14-d starved groups within specific oviposition periods (Table 1), a significant difference was exposed for cumulative production (Table 2). This further supports our hypothesis that Hister House-captured beetles have greater nutritional reserves than blacklight-captured beetles. This also suggests that releases of Hister House-captured beetles into recently cleaned and potentially food-deprived poultry facilities may allow for faster recolonization of manure and enhanced house fly control.

In laboratory studies, Morgan et al. (1983), observed that 277 of 664 collected *C. pumilio* eggs hatched (41.7%). Overall, oviposition per female per day averaged 1.801 ± 1.212 (or 0.75 larvae). Oviposition was erratic with beetles ovipositing for several days followed by 1- to 3-d nonoviposition periods, whereas other beetles would oviposit daily for up to 12 d. In our study of multi-aged, field-collected beetles, the daily fed blacklight treatment averaged 0.241 larvae per female per day and the Hister House treatment averaged 0.423 larvae per female per day. We were not able to determine egg mortality or cannibalism of eggs by larvae and adults. Therefore, using the 41.7% egg hatch rate reported by Morgan et al. (1983), in our study egg production would have been 0.578 eggs per female per day for the blacklight-captured treatment and 1.014 eggs per female per day for

the Hister House treatment. Although we were unable to evaluate actual egg production, blacklight-captured beetles appeared to have produced fewer viable eggs per female per day.

Using black lights to collect *C. pumilio* has several advantages over the Hister House, including ease of use, numbers of beetles gathered, and cost. However, our study demonstrated that Hister House-captured *C. pumilio* were reproductively healthier and recovered from starvation more quickly. The use of both trapping techniques in an IPM program should provide both an initial large population of predaceous adults and a smaller reproductively fit group of beetles that will hasten manure recolonization.

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