Impact of Alternating Manure Removal Schedules on Pest Flies (Diptera: Muscidae) and Associated Predators (Coleoptera: Histeridae, Staphylinidae; Acarina: Macrochelidae) in Caged-Layer Poultry Manure in Southern California

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ABSTRACT Pest fly larvae and adults (*Musca, Fannia* spp.) and key predator arthropods (*Macrocheles* mites, *Carcinops* adults and Histeridae larvae, Staphylinidae larvae) were monitored for 2 yr on 3 southern California caged-layer poultry facilities. In each manure cleanout cycle, all manure rows were removed initially in normal removal houses (Normal), while half of the manure was left undisturbed in alternate removal houses (Alternate). After 1 mo the remaining rows of manure were removed in the Alternate houses. In each cycle the manure fauna was sampled before removal, 1 wk after initial removal, 4 wk after initial removal (before secondary removal in Alternate houses), and 8 wk after initial removal (4 wk after secondary removal in Alternate houses). Cleanout caused significant decreases in key predator taxa 1 wk afterward and increased numbers of pest flies for 1–2 mo. Cleanout between March and May usually resulted in a resurgence of *Fannia* spp., whereas late summer cleanouts could cause *M. domestica* problems. Presence of undisturbed manure within the Alternate houses did not result in increased numbers of predaceous Coleoptera in nearby disturbed manure relative to Normal houses. Numbers of *Macrocheles* in disturbed manure after cleanout were higher when undisturbed manure was immediately adjacent. Pest flies following a cleanout were not reduced in Alternate houses relative to Normal houses. In these open-sided poultry houses, which leave a dry base manure pad at cleanout, any slight advantage of fly control afforded by alternate manure removal probably is overshadowed by the increased time and effort involved.

KEY WORDS Diptera, biological control, predators, flies, conservation, cultural control

MANURE MANAGEMENT is a key component of integrated control of pest flies in confined animal agriculture (Axtell 1986). Accumulations of poultry manure, for example, provide excellent developmental sites for larvae of the house fly, *Musca domestica* L. and species of *Fannia*. Many California egg producers now allow the manure to build up beneath caged hens for 3–6 mo (narrow, open-sided housing) to up to 2–3 yr (deep pit, environmentally controlled housing) before cleanout. Manure forms mounds beneath the cages, accumulating at ≈1 cm depth per d. With good air flow and drying conditions, the manure rapidly loses moisture and suitability for fly oviposition or development.

Over several wk the manure mass also is colonized by a broad array of predaceous and parasitic arthropods, forming complex food webs and providing a fair degree of ecological stability and subsequent suppression of flies. Poultry manure mass (depth) is inversely related to fly numbers (Legner et al. 1973). Predators are credited with destruction of up to 97% of immature filth flies in poultry manure (Propp and Morgan 1985). The key fly predators in poultry manure in the United States are the histerid beetle *Carcinops pumilio* Erichson and the mite *Macrocheles muscaedomesticae* (Scopoli), whereas the key parasites are pteromalid wasps (species of *Muscidifurax* and *Spalangia*), which attack fly pupae (Legner and Olton 1971, Legner et al. 1975, Axtell 1986, Axtell and Arends 1990, Geden 1990, Wills et al. 1990).

Eventually, accumulated manure must be removed. Given the recognized importance of natural enemies, it is intuitive that one might try to reduce deleterious effects on them resulting from manure cleanout. One way of doing this might be to remove the manure in stages, presumably allowing time for natural enemies in undisturbed manure to colonize adjacent new manure deposits more efficiently (Legner 1971, Axtell 1986, Geden 1990). This management technique, however, has never been evaluated experimentally on a realistic or sufficiently replicated field scale in any confined animal agriculture system.

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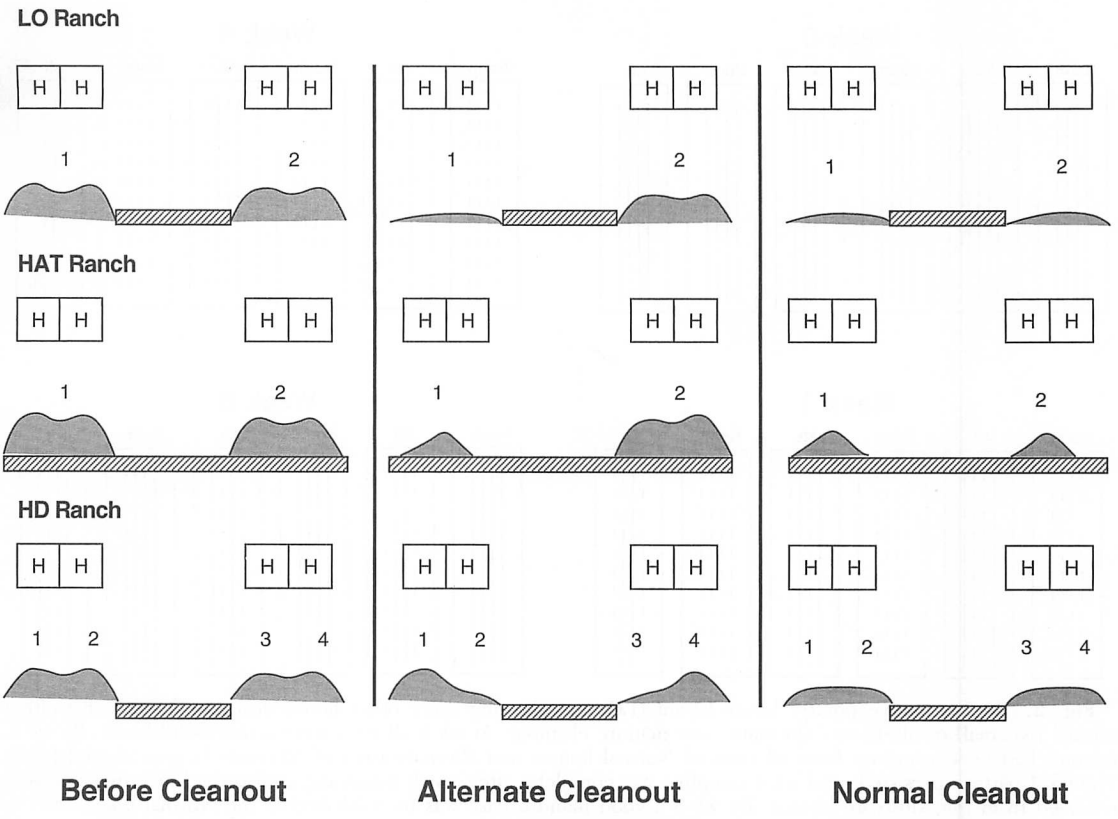

Fig. 1. Manure removal patterns (row end view) at the 3 poultry sites before and 1 wk after a cleanout. Back-to-back, single-tier wire cages held laying hens (H) above dirt or concrete (striped pattern) floors. Most manure was removed from the LO site, leaving a shallow base of dry manure; manure rows were separated by raised, concrete walkways (rows 1 and 2 shown). A central core of dry manure was left at the HAT site, cleaning the rest out to a solid concrete floor (rows 1 and 2 shown). At the HD site, half of each row was removed, leaving a deeper base of dry manure; each half was treated as a separate row for purposes of analysis and sampling (rows 1–4 shown).

Our study addressed the following 3 questions: (1) What were the short-term effects of cleanout on the key taxa? (2) Did an alternating manure cleanout pattern enhance predator populations over the duration of a cleanout cycle? (3) Did alternate cleanout reduce fly numbers, possibly as a result of higher predator populations in undisturbed manure nearby?

Materials and Methods

House Location and Design. Three caged-layer poultry ranches (LO, HD, and HAT) in western Riverside and San Bernardino County, California were selected for these tests. Such ranches usually have multiple, identical, long, narrow, open-sided, or semienclosed houses (50–100 m long and 7–15 m wide) (Fig. 1). Hens were suspended 1–1.5 m above the ground in single-tier wire cages, 2–3 hens per cage. Cages were arranged back to back in long rows running the length of each house. Sites were selected representing typical house designs, but producers had to have their own manure removal equipment, and their willingness and ability to accommodate our experimental needs was critical. Each facility had somewhat different house layout, house design, and manure management methods. All producers allowed manure to accumulate for 3–6 mo before cleanout and had equipment designed to meet their particular removal methods. We worked with the producers to adapt our experimental design to each ranch and existing equipment.

Six houses were used at the LO ranch. These houses were semienclosed with wooden lath siding and were 15 m apart. Manure accumulated on the soil beneath the cages, and the 4 manure rows were separated by raised concrete walkways ≈1 m wide. When manure was cleaned out, a thin pad of older, dry manure (2–6 cm deep) typically was left behind (Fig. 1). This seldom was higher than the concrete walkway. In alternate row removal houses, rows 1 and 2 were selected randomly (coin flip) to be removed normally or to be left behind (Fig. 1); the same was done with rows 3 and 4.

Houses at the HAT ranch were much wider than those at the other ranches and had 15 rows of manure per house. They measured ≈35 m wide and 100 m long. Two of these large houses were used in the experiment. The entire floor of each house

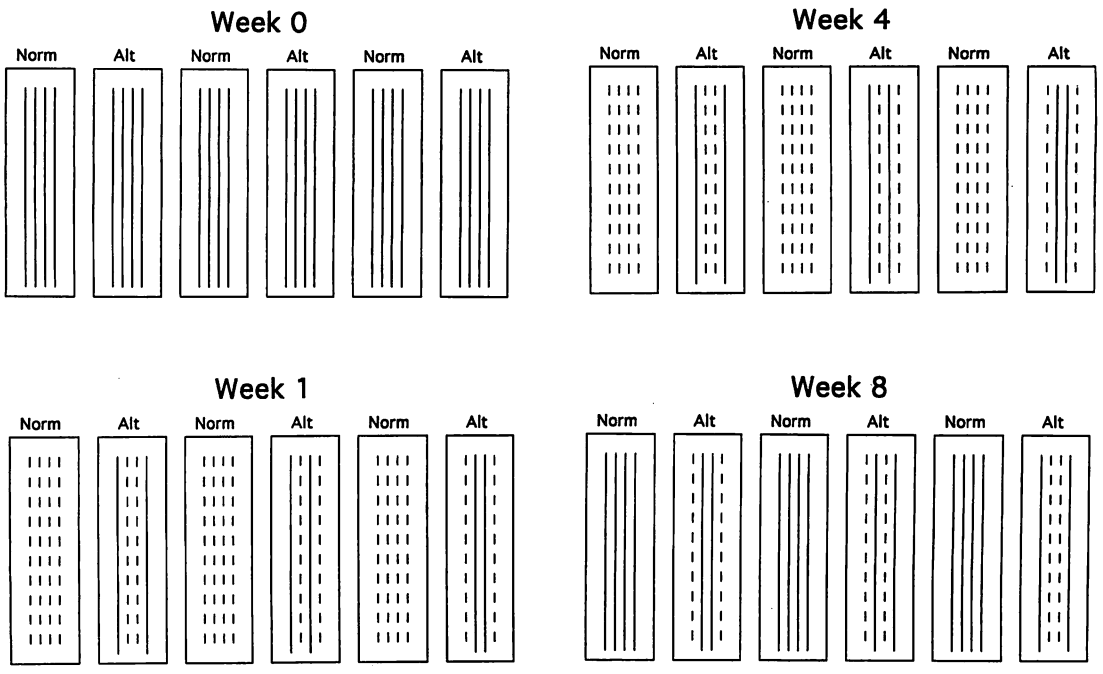

Fig. 2. Representative poultry house layout (LO site) showing every other house designated to receive either normal (Normal) or alternate (Alternate) row manure cleanout. At wk 0 all rows were intact (solid lines). By wk 1, manure had been removed from all rows of Normal houses and alternate rows of Alternate houses (dotted lines). The wk 1 pattern persisted until wk 4 sampling was complete, after which remaining undisturbed manure rows were removed from the Alternate houses. By wk 8 a good manure base was reestablished in the Normal houses and in initially disturbed rows of the Alternate houses (solid lines).

was concrete. In these large houses 4 rows on opposite sides were designated separate houses for the purpose of this experiment; 1 of these houses was designated for alternate row cleanout and the other for normal cleanout. This arrangement yielded 4 houses for the experiment at this site; each pair was separated by ≈12 m. When manure was cleaned out, a mound of older, dry manure 15–20 cm deep was left in the center; this actually was the interior of the preexisting pile (Fig. 1). In alternate row removal houses, 2 of the 4 rows were selected randomly for removal as at the LO site above. All rows between the 2 houses were removed normally at the same time as the initial cleanout in the experimental areas.

Six houses also were used at the HD ranch. These houses were separated by 6 m and had completely open sides, although partial plastic curtains were used at times during cold weather. Manure accumulated on soil which was level with concrete walkways (1 m wide) between the rows. These houses had single rows of cages running down each side and back-to-back rows running down the center. The single peripheral rows contained a much smaller volume of manure and dried relatively quickly; they were not used in the study and were cleaned out normally. The remaining 2 center rows each were split into 2 halves, which were considered separate rows for the experiment. This yielded 4 rows per house, as was the case at the other ranches. When manure was removed, a pad of dry, older manure 15–20 cm deep remained (Fig. 2). Although rows at the LO and HAT ranches were separated by concrete walkways, rows were contiguous at the HD ranch.

Our cooperating producers did not use fly larvicides. In one cleanout cycle (HD3), however, county regulatory personnel insisted on immediate action to mitigate a serious *M. domestica* problem after the initial and secondary cleanouts had been done. To salvage this cleanout cycle for our experiment, we supplied the producer with Larvadex 2 EC (emulsifiable concentrate), which was applied throughout the experimental houses as a larvicide ≈3 d after the 4-wk samples were taken. This material is regarded as relatively benign to predator taxa (Axtell and Edwards 1983, Meyer et al. 1984).

Manure Removal Schedules. Manure was removed every 3–6 mo as determined and carried out by each producer. The primary goal of our experiments was to contrast houses cleaned out normally with those in which half the manure nearby (≤1 m away) was left undisturbed. Test houses were numbered consecutively at each ranch. We designated every other house (e.g., houses 1, 3 and 5) to receive normal manure cleanout (Normal), and the remaining houses (e.g., houses 2, 4, and 6) received alternate row cleanout (Alternate) (Fig. 2). Normal houses were cleaned out in the normal way for that site; other houses on the ranch that

were not being used in our experiments often were cleaned out at this time (±1–2 wk) as well. In Alternate houses, designated rows were cleaned out at the regular time and other rows were left undisturbed by the producer.

The primary manure removal time was at the beginning of a cleanout cycle. Because of the size of the houses, such a cleanout usually required 2–4 d for our test houses at a given site, depending on the producer's schedule and the weather. After a 4 wk period we asked the producers to remove the remaining manure from the previously undisturbed rows in the Alternate houses. This usually could be accomplished in a single day and was termed the secondary cleanout. To minimize possible house location effects at a given site, houses designated for Normal cleanout in the previous cycle were designated for Alternate cleanout, and vice-versa. Each producer stored manure on-site in large piles for periods of a wk to perhaps as long as 6 mo, depending on when they could arrange for the manure to be purchased and removed for use as crop fertilizer and on the weather. These piles were between 20 and 80 m from the test houses.

The study began in November 1993 (1st cleanout at the HD site) and continued until June 1995. We monitored a single cleanout cycle at the HAT site, 4 cycles at the LO site, and 5 cycles at the HD site.

Sampling Schedules and Extraction Procedures. Sampling was done before initial cleanout (0 wk), 5–12 d after initial cleanout (1 wk), 4 wks after initial cleanout and before secondary cleanout (4 wks), and 8 wks after initial cleanout (i.e., 4 wks after secondary cleanout in Alternate houses) (8 wks). In 1 cycle (HD ranch, cycle 4) the initial cleanout was prolonged because of the cold, rainy weather. Preremoval sampling was done on 18 January 1995, but actual manure removal was done between 23 January and 2 February 1995. The 1 wk post-removal sampling was done on 9 February 1995.

The basic sampling unit was the manure row. Arthropods in manure tend to exhibit clumped distributions, yet taking and separately processing enough random samples to allow distinction of minor population density changes is logistically a difficult problem (e.g., Stafford and Bay 1987). We tried to reduce the effects of clumped distributions by taking 4 samples from approximately equidistant locations along each row and pooling them to comprise a single sample for that row. We thus had 4 composite samples per house per sampling date.

Samples were taken in 2 ways. First, a small sample (≈125 ml) was removed from the surface 2 cm of manure in the fresh deposition zone into a plastic bag using a trowel. The 4 samples were pooled to comprise a single composite 500-ml sample per row. The composite samples were placed into an ice chest for transport back to the laboratory. Each sample was placed into a Berlese funnel

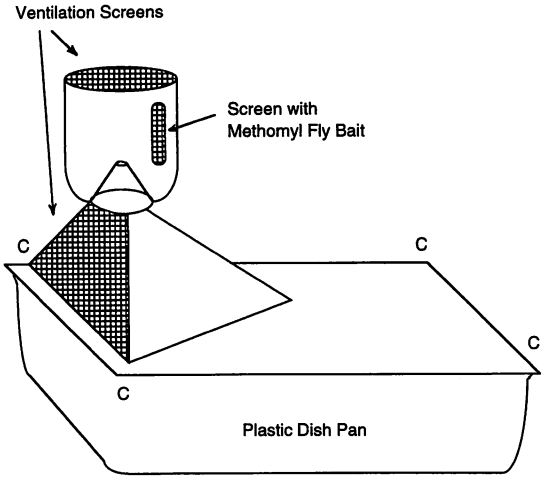

Fig. 3. Emergence trap for assessing on-site emergence of pest Diptera from poultry manure.

(40 W light bulbs) for 48 h; arthropods in the sample exited the funnel into a jar of 80% ethanol. Collected arthropods were washed through a 100-mesh sieve and preserved in vials of 80% ethanol for later sorting and counting. This yielded a direct count of most predator taxa and fly larvae in the sample.

Second, a large sample (1 liter) was removed from the top 6–8 cm (if available) of manure immediately adjacent to the place where the small (125 ml) sample was taken. The four large samples were pooled by row into an 8-liter plastic dishpan. Dishpans containing the larger samples were covered with painted plywood tops with a 1-liter plastic jar at the apex (Fig. 3); these were held in place with large metal clips. An inverted funnel impeded movement of emerged flies back into the dishpan below. Each collecting jar had an open screen top for ventilation and a small piece of plastic window screen glued to the side. Before field deployment, these screens were wetted slightly and then sprinkled with methomyl fly bait, which melted and then quickly dried to adhere to the screen. Emerged flies fed on the bait and died rapidly in the collecting jars. The emergence traps were held atop the wire hen cages, where they were held in place with flexible wire. Flies were allowed to emerge under representative field conditions for 7 wk.

Taxa monitored. The study focused on pest fly larvae and emerging adults and on the key predatory Coleoptera and Acarina in the poultry manure community. We did not monitor parasitic Hymenoptera because of the different sampling methods and added effort required. Details of cooccurrence of many of the other predators and flies are beyond the scope of this article and will be published separately.

Berlese extraction yielded fly larvae, which were counted and catagorized as either Fanninae (*Fan-*

nia spp.) or Muscinae. Staphylinid beetles were counted and categorized at the family level as adults or larvae; dominant species were in the genus *Philonthus,* but several other species exist locally in poultry manure habitats (Wills et al. 1990). Histerid beetles were counted and categorized as adult *C. pumilio* and histerid larvae. Adult females of the key predaceous mite *M. muscaedomesticae* also were counted.

Adult flies emerged in the dishpan traps on site and were counted and identified as *Musca domestica* L., *Fannia canicularis* (L.), and *F. femoralis* (Stein). Identifications were done with the aid of reference specimens (Wills et al. 1990). Voucher specimens are deposited in the Entomology Museum, Department of Entomology, University of California, Riverside.

Statistical Analysis. Although raw means were plotted for examination, statistical comparisons were conducted with transformed data [$\log_{10}$ (n + 1)] to stabilize variances. Initial comparisons of taxa in cleaned rows before and 1 wk after cleanout were done using paired *t*-tests (same row before and after cleanout) by site and cycle. Analyses to determine the effect of Alternate versus Normal cleanout on predator populations were done on counts for each taxon, excluding taxa with low numbers. Contrasts using *t*-tests within each time interval after initial cleanout (0, 1 and 4 wk) were done by site and cycle on rows removed in Normal versus Alternate houses. Finally, analyses using GLM (SAS Institute Inc., 1990) were done on pest fly data by taxon and stage. Main effects in these analyses were site, cycle, time within a cycle, and whether the houses were Normal or Alternate cleanout, plus interactions. All rows were used in these analyses for the time intervals 0, 4 and 8 wk. A statistical significance level of $\alpha = 0.05$ was used throughout, except for final presentation of pest fly data, in which $\alpha = 0.1$ was used.

Results

Numbers of the monitored taxa were highly variable; the clumped nature of the distributions in both time and space was reflected in consistently higher mean than median values (Table 1). The large number of 0 values made statistical analysis inadvisable for certain taxa or times, even with logarithmic transformation. We will focus here on cleanout cycles amenable to analysis for key taxa.

With regard to *Musca* and *Fannia,* 2 general points were evident (Table 1). First, house flies usually were not a severe problem; the median emergence for this species was 0. Second, *F. canicularis* comprised only 3% of emerging *Fannia* spp.; *F. femoralis* comprised 97% of the total *Fannia.*

Short-Term Cleanout Effects on Fauna. Numbers of arthropods before and 1 wk after cleanout are shown by site and cycle in Table 2. Date of preremoval sampling also is included in Table 2 to provide general information on time of year each cleanout cycle occurred.

Table 1. Predatory arthropods and pest Diptera monitored in southern California poultry manure (960 samples from 3 sites)

Order	Taxon	Mean	Median	Max
Coleoptera				
	Carcinops (adults)	5.0	1.0	102
	Histeridae (larvae)	11.2	3.0	234
	Staphylinidae (adults)	0.6	0.0	28
	Staphylinidae (larvae)	2.5	1.0	93
Acarina				
	Macrocheles (adults)	52.8	18.0	494
Diptera				
	Muscinae (larvae)	69.3	4.0	7,222
	Fannia (larvae)	136.0	19.0	2,097
	Musca (adults)	53.9	0.0	2,089
	F. canicularis (adults)	13.5	0.0	605
	F. femoralis (adults)	405.6	108.0	8,001

Coleoptera, Acarina, and Diptera larvae are expressed in number per 500-ml sample, whereas emerged adult Diptera are number per 4-liter sample. Minimum values are 0.

Predators were substantially reduced by cleanout, although this varied considerably among cycles. *Macrocheles* were reduced by >90% in half of the cleanout cycles (LO1, LO2, LO3, HD1, HD5). Reductions were less severe in other cleanout cycles, and numbers actually were higher after cleanout in cycle HD4. *Carcinops* adults also were reduced substantially (>60%) in some cycles (LO3, HD1, HD3, HAT1); slight increases after some cleanouts either were not statistically significant or not analyzed because of low numbers. Histerid larvae were reduced by >87% in 3 of the LO cleanouts, but reductions were less severe at the HD and HAT sites. Numbers of histerid larvae actually were significantly higher after cycle HD4. Staphylinid larvae were less abundant than the other predators, but numbers were sufficient for analysis in 5 cycles. Without exception, staphylinid numbers were significantly lower (up to 96% reduction in cycles LO1 and LO3) after a cleanout.

Numbers of fly larvae also differed after cleanout, although fly numbers after cleanout more often were elevated compared with the predators. *Fannia* larvae increased significantly 1 wk after cleanout in cycles LO4 and HD4, but were reduced at this time in several other cycles (LO3, HD1, HD5). Larvae of Muscinae tended to be more numerous after cleanout, with significant increases in cycles LO2, LO4, HD3 and HAT1. In other cases, numbers were lower 1 wk after cleanout than before (LO1, HD1, HD2).

Predatory Arthropod Response to Alternate Removal. Manure rows cleaned out initially in Normal versus Alternate houses for the 1st mo following cleanout were examined. A difference in this case might be attributed to the presence of nearby undisturbed manure in the Alternate houses. In general, predatory Coleoptera did not reach higher numbers, or increase more quickly, in Al-

Table 2. Numbers (raw average per 500-ml poultry manure sample) of principal arthropod taxa before and 1 wk after manure cleanout according to poultry ranch and cleanout cycle (n = 18 in all cases except HAT1, where n = 12)

Taxon	Date[a]	Site	Cycle	Before	After	t[b]	P
Macrocheles adult females							
	26 Jan. 1994	LO	1	10.9	0.3	6.78	0.000
	13 July 1994	LO	2	101.7	14.3	6.62	0.000
	31 Oct. 1994	LO	3	15.8	0.2	8.65	0.000
	19 April 1995	LO	4	53.6	33.2	0.44	0.667
	5 Nov. 1993	HD	1	93.3	7.1	9.89	0.000
	16 Feb. 1994	HD	2	4.9	2.3	1.30	0.210
	6 Sept. 1994	HD	3	18.6	8.7	1.88	0.077
	18 Jan. 1995	HD	4	8.2	36.4	−5.72	0.000
	11 April 1995	HD	5	178.1	13.4	8.56	0.000
	5 Jan. 1994	HAT	1	2.8	1.5	0.76	0.461
Carcinops adults	26 Jan. 1994	LO	1	0.4	0.1	ND	
	13 July 1994	LO	2	16.9	8.8	3.28	0.005
	31 Oct. 1994	LO	3	12.3	0.2	8.10	0.000
	19 April 1995	LO	4	0.1	0.8	ND	
	5 Nov. 1993	HD	1	21.8	3.8	5.91	0.000
	16 Feb. 1994	HD	2	0.7	0.9	ND	
	6 Sept. 1994	HD	3	24.6	9.3	3.63	0.002
	18 Jan. 1995	HD	4	0.0	0.4	ND	
	11 April 1995	HD	5	2.7	1.3	2.02	0.060
	5 Jan. 1994	HAT	1	7.3	1.7	2.37	0.037
Histeridae larvae	26 Jan. 1994	LO	1	4.8	0.6	3.19	0.005
	13 July 1994	LO	2	45.3	6.1	7.69	0.000
	31 Oct. 1994	LO	3	9.3	0.7	6.69	0.000
	19 April 1995	LO	4	1.3	2.0	ND	
	5 Nov. 1993	HD	1	15.0	8.2	2.44	0.026
	16 Feb. 1994	HD	2	5.4	7.2	−1.01	0.328
	6 Sept. 1994	HD	3	35.3	10.3	3.78	0.002
	18 Jan. 1995	HD	4	2.0	6.2	−5.43	0.000
	11 April 1995	HD	5	5.7	5.2	0.52	0.608
	5 Jan. 1994	HAT	1	2.1	1.0	ND	
Staphylinidae larvae	26 Jan. 1994	LO	1	2.7	0.1	6.59	0.000
	13 July 1994	LO	2	0.2	0.0	ND	
	31 Oct. 1994	LO	3	2.7	0.1	5.12	0.000
	19 April 1995	LO	4	5.5	0.6	6.19	0.000
	5 Nov. 1993	HD	1	2.1	0.1	2.44	0.026
	16 Feb. 1994	HD	2	1.3	0.4	ND	
	6 Sept. 1994	HD	3	0.8	0.2	ND	
	18 Jan. 1995	HD	4	0.2	0.6	ND	
	11 April 1995	HD	5	2.7	1.4	2.14	0.047
	5 Jan. 1994	HAT	1	0.3	6.2[c]	ND	
Fannia larvae	26 Jan. 1994	LO	1	2.8	1.5	1.72	0.104
	13 July 1994	LO	2	7.6	39.8	−2.10	0.051
	31 Oct. 1994	LO	3	121.9	1.6	7.13	0.000
	19 April 1995	LO	4	18.7	207.4	−5.61	0.000
	5 Nov. 1993	HD	1	27.4	3.6	4.16	0.001
	16 Feb. 1994	HD	2	15.9	47.8	−1.39	0.184
	6 Sept. 1994	HD	3	73.8	80.4	−0.33	0.744
	18 Jan. 1995	HD	4	55.9	449.5	−3.92	0.001
	11 April 1995	HD	5	20.4	12.1	2.94	0.009
	5 Jan. 1994	HAT	1	42.1	23.0	0.468	0.649
Muscinae larvae	26 Jan. 1994	LO	1	7.9	4.4	2.15	0.046
	13 July 1994	LO	2	3.7	27.8	−4.77	0.000
	31 Oct. 1994	LO	3	1.3	26.9	ND	
	19 April 1995	LO	4	7.5	110.8	−8.21	0.000
	5 Nov. 1993	HD	1	31.1	1.8	3.69	0.002
	16 Feb. 1994	HD	2	87.8	23.7	3.21	0.005
	6 Sept. 1994	HD	3	90.0	1,319.9	−4.16	0.001
	18 Jan. 1995	HD	4	0.0	1.8	ND	
	11 April 1995	HD	5	1.1	8.3	ND	
	5 Jan. 1994	HAT	1	4.5	23.8	−2.34	0.039

[a] Date indicates time of preremoval sample for that cycle.

[b] T value for paired t-test on $\log_{10}(n + 1)$-transformed data. Value or probability (P) not done (ND) if over half of preremoval samples had 0 of that taxon.

[c] Mean value heavily skewed by single sample with 93 larvae.

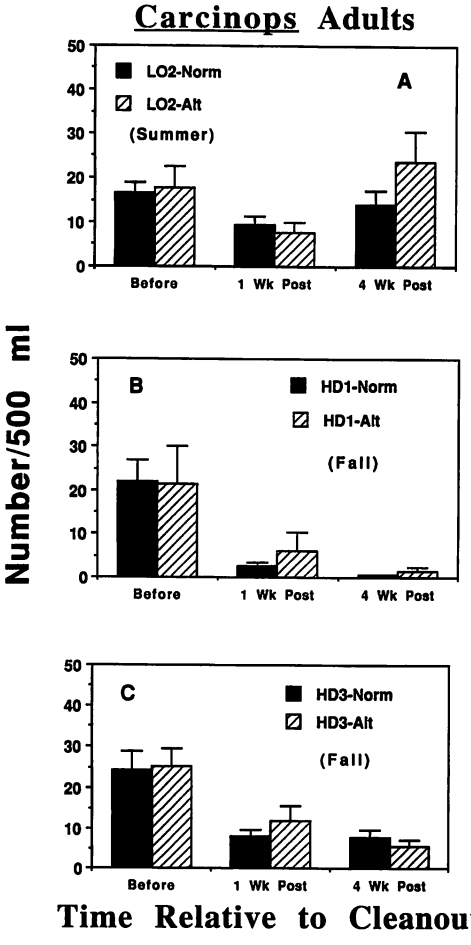

Fig. 4. Mean ± SE *Carcinops pumilio* adults recovered from caged layer poultry manure in 3 representative cleanout cycles. Comparisons are made within sample time for rows cleaned out initially in Normal houses (n = 12) and those cleaned out initially in Alternate houses (n = 6). Values are not significantly different ($P > 0.05$) for Normal versus Alternate houses by time.

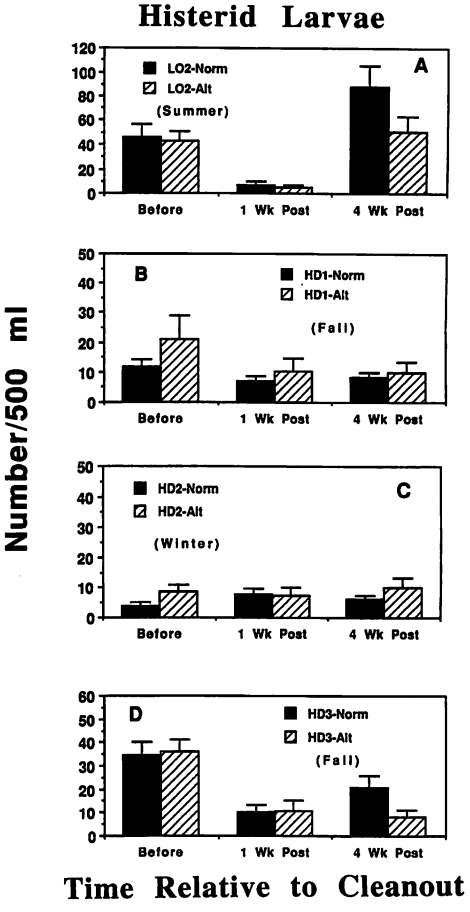

Fig. 5. Mean ± SE histerid larvae recovered from caged layer poultry manure in 4 representative cleanout cycles. Comparisons are made within sample time for rows cleaned out initially in Normal houses (n = 12) and those cleaned out initially in Alternate houses (n = 6). Values are not significantly different ($P > 0.05$) for Normal versus Alternate houses by time.

ternate houses. Numbers of *C. pumilio* adults were stable or increased during the summer cleanout at LO (cycle 2) (Fig. 4A), whereas numbers generally declined over time in the fall cleanouts at HD (Fig. 4 B and C). The difference between numbers in Alternate versus Normal houses was not statistically significant ($P > 0.05$) for a given sampling interval in any cleanout cycle. The same was true for histerid larvae in Alternate versus Normal houses, regardless of absolute density or cleanout cycle (Fig. 5). Staphylinid adults run quickly on the manure surface and were not well represented in the 500 ml pooled samples. Larvae were much slower and within the substrate, and could be examined. Numbers of staphylinid larvae did differ significantly 4 wk after cleanout in cycle LO4, but numbers actually were higher in the Normal houses (Fig. 6). Otherwise, there were no significant differences between Alternate versus Normal houses in numbers of staphylinid larvae.

The key predator mite, *M. muscaedomesticae*, occurred regularly in good numbers, as evidenced by the relatively small discrepancy between mean and median values (Table 1). At the LO ranch, where rows were separated by concrete walkways, there was no significant difference between Normal and Alternate houses before or after a cleanout (Fig. 7 A and B). At the HD site, disturbed manure was immediately adjacent to undisturbed manure. Here *M. muscaedomesticae* numbers tended to be higher in the Alternate houses after a cleanout when compared with the Normal houses. However, the difference was statistically significant only during cycles 1 and 4 (Fig. 8 A and C).

Pest Fly Response to Alternate Removal. Pest flies clearly increased after manure was disturbed. This trend was easiest to visualize with *Fannia* larvae (Fig. 9). Following initial removal of all rows

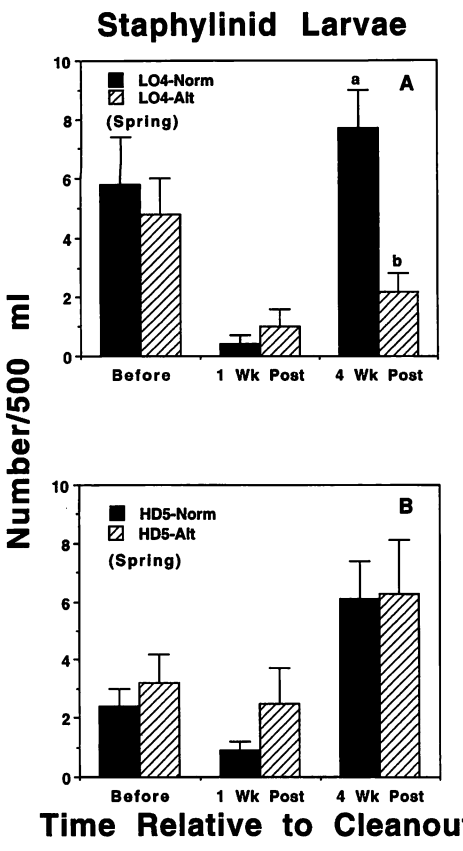

Fig. 6. Mean ± SE staphylinid larvae recovered from caged layer poultry manure in 2 representative cleanout cycles. Comparisons are made within sample time for rows cleaned out initially in Normal houses (n = 12) and those cleaned out initially in Alternate houses (n = 6). Values are not significantly different ($P > 0.05$) for Normal versus Alternate houses by time except where noted by different letters.

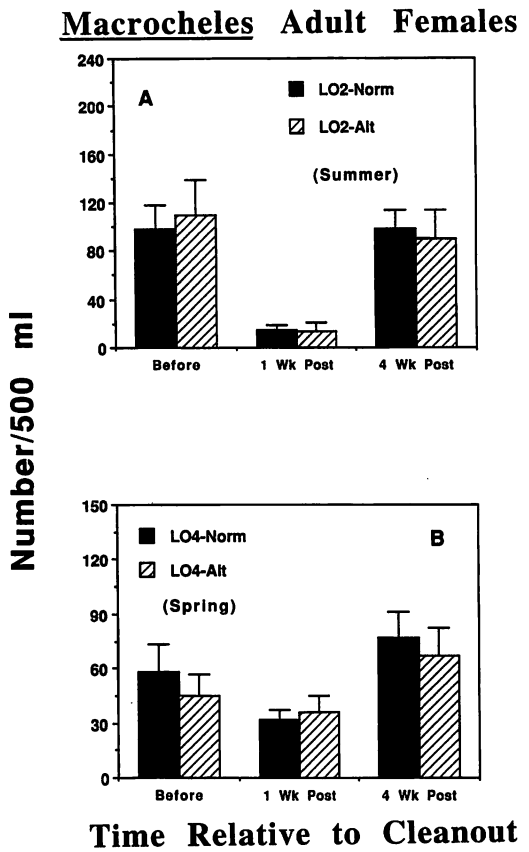

Fig. 7. Mean ± SE *M. muscaedomesticae* recovered from caged layer poultry manure in 2 representative cleanout cycles at the LO site. Comparisons are made within sample time for rows cleaned out initially in Normal houses (n = 12) and those cleaned out initially in Alternate houses (n = 6). Values are not significantly different ($P > 0.05$) for Normal versus Alternate houses by time.

in the Normal houses, numbers were greatly elevated 4 wk afterward, and had declined by 8 wk. The pattern was similar in rows removed initially in the Alternate houses. Undisturbed manure rows in the Alternate houses maintained low fly numbers until they were disturbed after 4 wk. Fly numbers in these rows increased by 8 wk (4 wk after the secondary cleanout), sometimes exceeding densities seen in other rows after the initial cleanout. This was dependent on seasonal timing of the 2 cleanouts. In cycle HD2, for example, initial cleanout was in mid-February, when weather was still quite cool. By mid-March, when the secondary cleanout occurred, *Fannia* spp. were becoming numerous in response to warmer temperatures.

Analysis of variance (ANOVA) was used on each pest fly taxon or stage (Adult *M. domestica, F. femoralis, F. canicularis*; larval *Fannia* spp., larval Muscinae) as a response variable. The model incorporated site, cycle, sample time, and whether the houses had a Normal or Alternate cleanout pattern, plus interactions. Only 0-, 4-, and 8-wk sample intervals were used. The 1-wk interval was excluded in order not to bias the data toward higher numbers in the Normal houses (i.e., there was no 5-wk sample). The one variable that never was significant was that of primary concern: Normal versus Alternate cleanout. The F (df = 1, 678) and P values for the Normal-Alternate contrast were as follows: $F = 1.92$, $P = 0.17$ (*F. femoralis* adults); $F = 0.34$, $P = 0.56$ (*F. canicularis* adults); $F = 0.43$, $P = 0.51$ (*M. domestica* adults); $F = 0.26$, $P = 0.61$ (Muscinae larvae); $F = 0.28$, $P = 0.59$ (*Fannia* larvae).

The statistically significant interactions in the above models indicated that the preferred method would be to examine each cleanout cycle separately. We used a 2-way ANOVA on data from each cycle, using sample time (0, 4 and 8 wk) and whether the houses were Normal or Alternate. The P values for the Normal versus Alternate contrast are shown in Table 3. Contrasts significant at the 0.10 level are indicated for ease of visualization. In

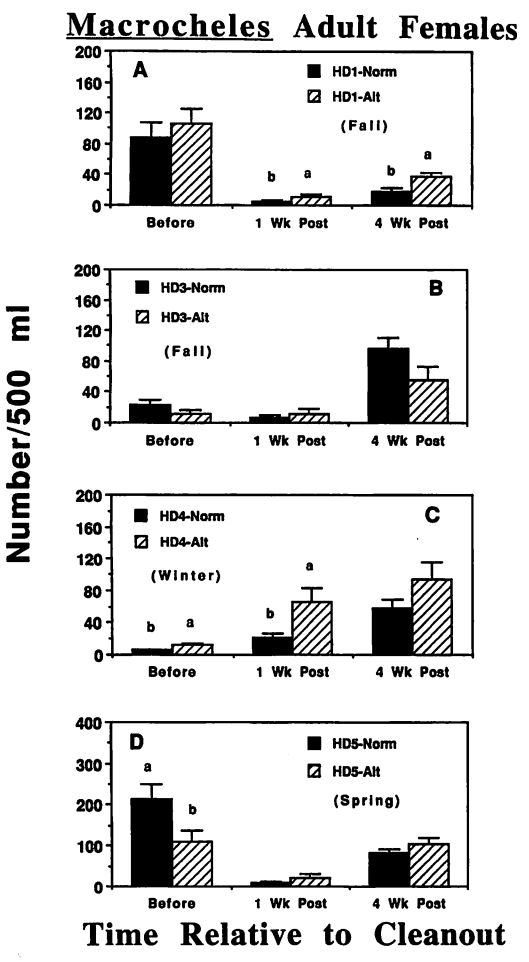

Fig. 8. Mean ± SE *M. muscaedomesticae* recovered from caged layer poultry manure in 4 representative cleanout cycles at the HD site. Comparisons are made within sample time for rows cleaned out initially in Normal houses (n = 12) and those cleaned out initially in Alternate houses (n = 6). Values are not significantly different ($P > 0.05$) for Normal versus Alternate houses by time except where noted by different letters.

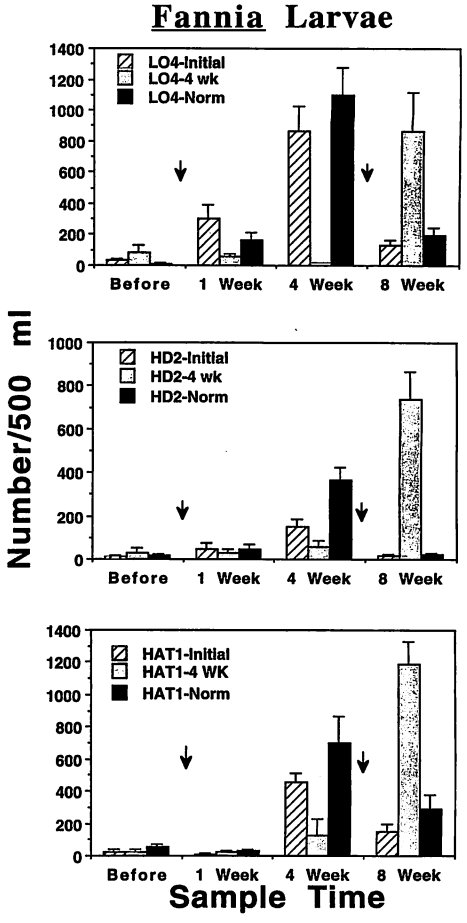

Fig. 9. Mean ± SE *Fannia* spp. larvae recovered from caged layer poultry manure in 3 representative cleanout cycles. Data are by sample time for rows cleaned out initially in Normal houses (n = 12 for LO and HD and n = 8 for HAT) and those cleaned out initially in Alternate houses (n = 6 for LO and HD and n = 4 for HAT). Manure removal times indicated by arrows.

general, there was no significant difference between numbers of flies in Normal versus Alternate houses. Muscinae larvae were slightly more abundant in Normal houses in 7 of 10 cycles, and *M. domestica* adults were slightly more abundant in Normal houses in 6 of 10 cycles. However, differences were significant ($P < 0.1$) only for cycles HD5 and HAT1, and house fly adults actually were significantly more abundant in the Alternate houses in HAT1.

Fannia femoralis adults and *Fannia* larvae were about as likely to be at least slightly more abundant in Alternate houses (4 of 10 cycles) as in Normal houses (6 of 10 cycles); *F. canicularis* adults were slightly more abundant in Alternate houses in 7 of 10 cycles. Statistically significant ($P < 0.1$) differences favoring higher *Fannia* numbers in Normal houses occurred somewhat more often (5 of 7 cycles) than the reverse (2 of 7 cycles), but numbers of *F. canicularis* adults and *Fannia* larvae were markedly higher ($P < 0.02$) in Alternate houses for cycles HD1 and HD3, respectively.

Discussion

We did not gauge cleanout effects on parasitic Hymenoptera, the other key group of filth fly natural enemies. Monitoring these parasites requires an entirely different type of effort. We had hoped that the emergence traps would yield some insights, but the wasps seldom entered the collecting heads. Their presence, however, might have been reflected in the emergence trap results; similar numbers of flies regardless of cleanout pattern would suggest that alternate manure removal also does not particularly favor these pupal parasites. This should be tested separately, particularly be-

Table 3. Probability values (*P*) for the contrast between numbers of flies ($\log_{10}[n + 1]$-transformed) in poultry houses with normal versus alternate row manure removal patterns

Site	Cycle	*F. femoralis* adults	*F. canicularis* adults	*Fannia* larvae	*M. domestica* adults	Muscinae larvae
LO	1	0.32A[a]	0.87A	0.13A	0.86A	0.71A
	2	0.83A	0.57N	0.57A	0.35N	0.69A
	3	0.16N	0.52A	0.79N	0.67N	0.68N
	4	0.13N	0.01N**	0.90N	0.27N	0.31N
HD	1	0.03N**	0.01A**	0.05N**	0.86N	0.82N
	2	0.14N	0.34A	0.27N	0.50N	0.35N
	3	0.02A**	0.51A	0.18A	0.76A	0.27N
	4	0.06N**	0.21N	0.77N	0.95A	0.31A
	5	0.14A	0.52A	0.21A	0.10N**	0.24N
HAT	1	0.01N**	0.84A	0.12N	0.07A**	0.01N**

**, Contrasts with a P value ≤ 0.1.

[a] Sample times used were 0, 4 and 8 weeks after initial cleanout. Regardless of magnitude of difference, the larger number of flies for that site and cycle is noted by A (more in alternate row removal houses) or N (more in normal removal houses). Contrasts are based on df = 1, 95 for each cycle at sites LO and HD and df = 1, 63 for HAT.

cause fly pupation tends to occur away from the larval development sites we were sampling. Leaving a pad might be relatively effective for pteromalid preservation, because it is the drier manure near the base which is left and sometimes contains many fly pupae and parasites.

These experiments were imposed on normal producer manure cleanout schedules and methods and were done year-round, for multiple years and under highly variable field conditions. The scale, large number of possible comparisons, and inherently complex nature of the experimental design required us to present data selectively in order to avoid obscuring the important points.

Short-Term Effects of Cleanout on Key Predators and Pest Diptera. Despite the fact that manure cleanout would be expected to have profound effects on arthropod fauna, literature to document this is rare. Peck and Anderson (1970) confirmed that total poultry manure cleanout (small plots in houses over a single summer–fall season) reduced predator numbers while increasing pest flies, but proportional reduction caused by cleanout is difficult to derive from the figures in that article. The key predators, *M. muscaedomesticae* and adult Histeridae (probably mostly *C. pumilio*), required ≈4 and 6 wk, respectively, to achieve significant numbers after removal in those studies. Geden and Stoffolano (1987) supplied limited data from Massachusetts suggesting that poultry manure cleanout, where the producer was removing the manure in stages themselves, reduced but did not eliminate *M. muscaedomesticae* and *C. pumilio*. The authors hypothesized the beetles were moving back into the houses from manure piled outside, which also may have occurred in our studies. In some cleanout cycles we were on site while a cleanout was in progress. It was common to see adult *C. pumilio*, in particular, flying after the manure was disturbed. The disturbance itself therefore might aid dispersal of predators. Geden and Stoffolano (1988) followed *C. pumilio* and *M. muscaedomesticae* populations in a Massachusetts poultry house over a 2-mo summer period and confirmed the relatively low numbers of predators following a cleanout.

Our study examined in detail the arthropods remaining after a cleanout that leaves a residual pad of dry manure. The pad has been recommended as a means of providing both a natural enemy refugium and absorbant base for new manure (Legner 1971), and leaving a pad at cleanout is now standard practice for California poultry producers who allow manure to accumulate beneath the hens. Both pest flies and predators, however, have a surface distribution that predisposes them to catastrophic removal by a normal cleanout (Geden and Stoffolano 1988, Wills and Mullens 1991). The data presented here suggest that predators overall are drastically reduced by cleanout. The mite *M. muscaedomesticae* seems to be particularly susceptible to such effects, although the Coleoptera also usually are mostly removed. Larval Histeridae and Staphylinidae were particularly reduced at LO, where a smaller residual pad was left relative to HD and HAT.

Interestingly, not all cleanouts resulted in marked predator removal. Mite populations were reduced by <50% at 1 wk after the LO4 cleanout, for example, and predator numbers in general were actually higher after the HD4 cleanout than before (Table 1). In cycle HD4, however, cleanout time was extended, and the 1-wk period after cleanout actually was as long as 14–17 d. This allowed the arthropods more time to recover. There was some indication from our data that cool weather cleanouts resulted in less disruption to the predator complex than did summer cleanouts, which might indicate seasonal differences in distribution of arthropods relative to the manure surface. Variability was substantial and cool-weather predator numbers were generally lower, however. Further studies on this point are needed. Rather than functioning as an important predator refugium, the main role of the dry pad may be to elevate the fresh droppings, exposing them to more air flow

and reducing moisture and suitability for fly oviposition and development (unpublished data).

Pest Diptera also were removed by cleanout, but rapidly recolonized new droppings. In that regard the fly numbers in Table 2 do not accurately (relative to predator taxa) reflect the reduction following cleanout. The fly larvae (especially Muscinae) resulting from short-term oviposition in new manure deposits already were present after 1 wk in many cycles. The "fly rebound" following manure disturbance was clear in the current studies, in agreement with prior research (Peck and Anderson 1970, Geden and Stoffolano 1988). Increased fly utilization of new manure deposits also no doubt underpinned the inverse relationship between manure mass and fly emergence emphasized by Legner et al. (1973).

Fly resurgence tended to occur regardless of the time of year the manure was disturbed, but summer or fall disturbance tended to result in more house flies, while spring disturbance resulted in *Fannia* spp. Hot, dry weather substantially aids manure drying in summer in southern California, and *M. domestica* tends to be easier to control using integrated management. *Fannia canicularis* therefore is regarded as a more serious pest than is *M. domestica* on most southern California poultry ranches, and the presence of large numbers of *Fannia* spp. larvae often causes problems for poultry producers. *Fannia femoralis* is smaller, stays near developmental sites, and males do not form the conspicuous hovering swarms for which *F. canicularis* is well known. *F. femoralis* therefore is not a pestiferous fly relative to *F. canicularis*. However, the immatures of *F. femoralis* resemble those of *F. canicularis*, and inspectors often confuse the 2 species. Because *F. femoralis* outnumbers *canicularis* by over 30:1, an inspector could easily overestimate the potential *F. canicularis* problem based on detection of larval *Fannia* spp. alone.

Our studies were not designed specifically to address the question of seasonal removal versus fly populations. However, based on our observations, the optimal times to remove manure in our area to minimize fly resurgence appear to be approximately December (after house fly season but before *Fannia* adults are active in large numbers) and June (after *Fannia* season but before house flies are abundant).

Effects of Alternate Manure Removal on Predator Taxa. Numbers of different predator groups varied substantially by time and site. Even so, it is clear that the presence of undisturbed manure near new manure deposits usually made no difference in reestablishment of predators in these systems. In this respect our study agrees with smaller scale observations in Massachusetts (Geden and Stoffolano 1988) and northern California (Peck and Anderson 1970). In a summer study in 1 Massachusetts poultry house, Geden and Stoffolano (1988) noted that numbers of predator mites and beetles remained low for weeks in a disturbed manure row situated between 2 undisturbed rows with much higher predator numbers. They suggested that even the relatively mobile Coleoptera such as adult *C. pumilio* might be demonstrating a preference for older manure, despite the greater presence of fly prey in nearby disturbed habitat. Peck and Anderson (1970) used small plots (1–2 m) of several manure removal treatments (no removal, weekly removal, monthly removal, monthly removal with 0.1-m^2 "island") arranged in randomized complete block fashion within a poultry house. These studies showed that leaving a 0.1-m^2 island of undisturbed manure had no effect on numbers of predator taxa in manure in that plot following otherwise total cleanout. On the scale of an entire ranch, their experimental plots were small, but the general absence of predators in their removal treatments over time did suggest that presence of undisturbed manure only 1–2 m from disturbed manure might not result in substantial predator recolonization.

Our studies suggested that *M. muscaedomesticae* numbers increased sooner after disturbance if undisturbed manure was directly adjacent (HD), whereas undisturbed manure separated by a 1-m concrete walkway (LO) presented no advantage for recolonization. These predaceous mites will move phoretically (presumably quite some distance) on flies, although it is not known how important this is in recolonization compared with walking. In our studies, mites probably walked to new manure deposits, but movements were impeded by the concrete walkways.

It is notable that predator numbers in general rebounded more quickly in our studies than in those of Peck and Anderson (1970) and Geden and Stoffolano (1987, 1988). These prior studies indicated that numbers of both predaceous mites and beetles could be depressed for 4–6 wk or more after a total cleanout. The more rapid numerical increase in our studies could reflect the presence of the dry pad, which, in addition to elevating the fresh droppings for faster drying (unpublished data), could cause chemical changes making fresh droppings more attractive for recolonization (Geden and Stoffolano 1988). In general the number of predators persisting in the residual pad is small, but still might assist in predator recovery. Additionally, our observations indicate that producers do not conduct cleanouts as neatly as might be done by a researcher. They accomplish cleanouts as quickly as possible and scatter a considerable amount of small manure chunks, thereby likely seeding natural enemies into areas which later will receive new droppings.

Effects of Alternate Manure Removal on Pest Flies. Overall, presence of nearby undisturbed manure clearly did not significantly reduce numbers of flies following a manure cleanout. There did seem to be some advantage in certain cleanout cycles. Cycles HD1 and HAT1, for example, had lower numbers of *F. femoralis* or Muscinae larvae in

Alternate versus Normal removal treatments. However, it was possible for numbers of flies in the secondary cleanout to exceed those in the primary cleanout, and timing effects could outweigh any minor benefit of staggering the cleanout pattern.

An alternate row removal strategy could be of more benefit in a closed type of system, such as high-rise caged layers, particularly if total removal is practiced. Too few of these systems now exist in southern California for us to test them adequately.

Although the net time required for removal is not dramatically increased, an alternate removal pattern does have some disadvantages. These include possible complications with weather or selling or removing the manure for fertilizer, and the more frequent need to carry out what producers regard as a necessary but distasteful task. For such an alternating manure removal pattern to be worthwhile, there would need to be distinct benefits for fly control, which we were unable to detect. In these open poultry systems which already leave some residual dry manure pad, benefits of an alternate manure removal strategy are tenuous at best.

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