Evaluation of Surveillance Methods for Monitoring House Fly Abundance and Activity on Large Commercial Dairy Operations

ALEC C. GERRY,[1] G. E. HIGGINBOTHAM,[2] L. N. PERIERA,[3] A. LAM,[4] AND C. R. SHELTON[4]

J. Econ. Entomol. 104(3): 1093–1102 (2011); DOI: 10.1603/EC10393

ABSTRACT Relative house fly, *Musca domestica* L., activity at three large dairies in central California was monitored during the peak fly activity period from June to August 2005 by using spot cards, fly tapes, bait traps, and Alsynite traps. Counts for all monitoring methods were significantly related at two of three dairies; with spot card counts significantly related to fly tape counts recorded the same week, and both spot card counts and fly tape counts significantly related to bait trap counts 1–2 wk later. Mean fly counts differed significantly between dairies, but a significant interaction between dairies sampled and monitoring methods used demonstrates that between-dairy comparisons are unwise. Estimate precision was determined by the coefficient of variability (CV) (or SE/mean). Using a CV = 0.15 as a desired level of estimate precision and assuming an integrate pest management (IPM) action threshold near the peak house fly activity measured by each monitoring method, house fly monitoring at a large dairy would require 12 spot cards placed in midafternoon shaded fly resting sites near cattle or seven bait traps placed in open areas near cattle. Software (FlySpotter; http://ucanr.org/sites/FlySpotter/download/) using computer vision technology was developed to count fly spots on a scanned image of a spot card to dramatically reduce time invested in monitoring house flies. Counts provided by the FlySpotter software were highly correlated to visual counts. The use of spot cards for monitoring house flies is recommended for dairy IPM programs.

KEY WORDS house fly, monitoring, surveillance, dairy, IPM

House flies, *Musca domestica* L., are the number 1 nuisance pest associated with dairy and other confined animal facilities in the United States (Geden and Hogsette 1994, Hinkle and Hickle 1999). In addition to causing nuisance, these flies are capable of carrying several disease organisms that affect humans and animals, such as the virulent *Escherichia coli* strain O157:H7 (Sasaki et al. 2000, Talley et al. 2009). The presence of house flies is especially problematic for animal facilities bordering residential areas where fly management is often mandated by law, with failure to manage flies resulting in citations, fines, and costly lawsuits against facility operators (Thomas and Skoda 1993).

House flies breed in animal manure, wet animal feed, and other decaying organic material; all of which are plentiful on even the most sanitary of confined animal facilities. From an integrated pest management (IPM) perspective, confined animal facilities should strive to maintain adult house fly numbers below some measurable abundance threshold ("action threshold") above which nuisance or pathogen transmission to nearby humans and animals may occur. However, there are currently no standard methods for monitoring house fly abundance at confined animal facilities, and most facilities do not practice this necessary component of an IPM strategy. The lack of an established monitoring system and therefore an IPM program for house flies has several important consequences: 1) pest management measures for house flies are typically initiated only after an action threshold has been breached, resulting in nuisance complaints or pathogen transmission; 2) the main fly management strategy used by animal facilities is the application of pesticides to immediately reduce adult house fly abundance (Geden and Hogsette 1994), a management strategy that has led to widespread insecticide resistance in house fly populations (Keiding 1999; Kaufman et al. 2001, 2008; Butler et al. 2007; Gerry and Zhang 2009); and 3) applied pest management measures are not evaluated for effectiveness resulting in the continued use of ineffective measures such as the field application of baits to which flies are no longer susceptible (Mullens et al. 2010).

Methods for monitoring house fly abundance in enclosed poultry houses have been developed, to include sticky ribbons (Anderson and Poorbaugh 1964), spot cards (Axtell 1970), and baited traps (Burg and Axtell 1984). However, none of these methods have been evaluated for use on large dairy operations, where animals are not typically confined to enclosed

[1] Corresponding author: Department of Entomology, University of California, Riverside, CA 92521 (e-mail: alec.gerry@ucr.edu).
[2] University of California Cooperative Extension, Fresno, CA 93702.
[3] Department of Animal Science, California State University, Fresno, CA 93740.
[4] Department of Computer Science, University of California, Riverside, CA 92521.

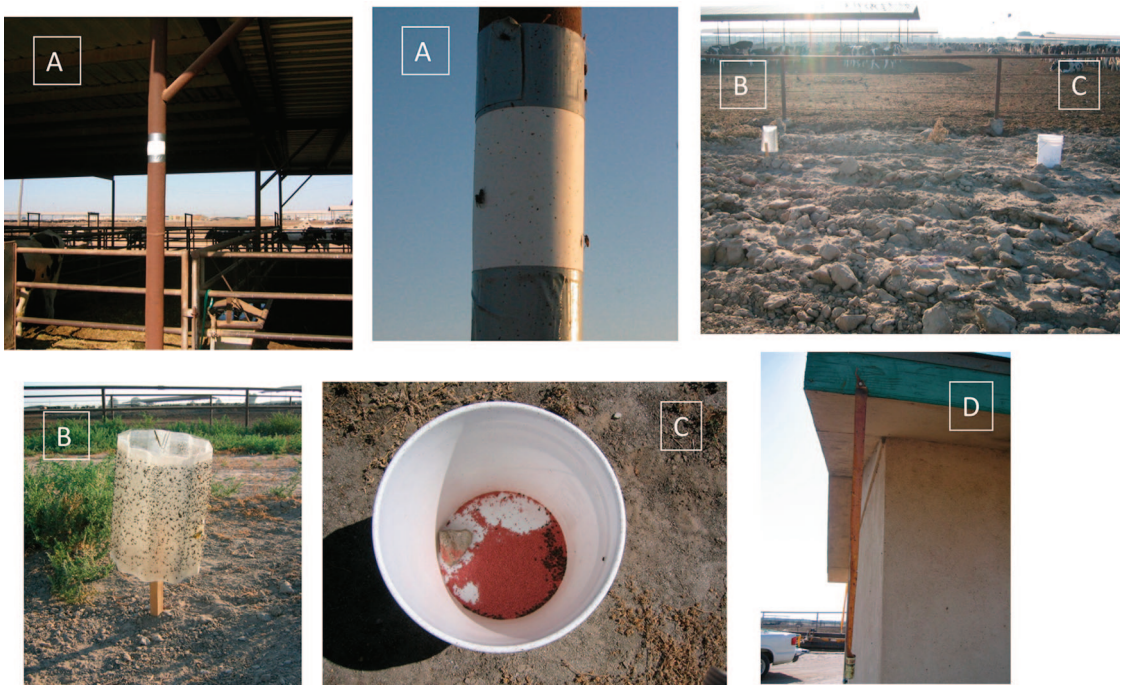

Fig. 1. Monitoring methods used in these studies included 10.2- by 15.4-cm white spot cards (A) placed on shade structure supports near cattle, Alsynite sticky traps (B) and baited pail traps containing a commercial fly bait (QuickBayt) (C) placed on the ground in open areas near cattle pens, and sticky fly ribbons (D) fixed to the eaves of structures near cattle pens. (Online figure in color.)

houses. The purpose of this study was to evaluate the performance of these methods as a means to monitor changes in house fly abundance and activity on large commercial dairy operations and to determine the density of monitoring devices for each method that would be needed to assure reasonable sampling precision by using the highest recorded counts as a surrogate for an unknown fly activity action threshold.

Materials and Methods

Relative changes in house fly abundance and activity at three large commercial dairy operations in the San Joaquin Valley of California were determined over a 10-wk period from 16 June to 25 August 2005 by simultaneous use of four different fly monitoring methods: spot cards, fly tapes, Alsynite traps, and bait traps (Fig. 1A–D). The dairies used in this study housed between 1,000 and 3,000 heifers and cows and were either dry lot (dairy MA and MS) or free stall with flush lane (dairy N) facilities. All dairies were within 48 km (30 miles) of each other, and monitoring devices were similarly placed at each of the dairies.

Spot cards, 10.2- by 15.4-cm (4- by 6-in.) unlined white index cards, were attached using tape onto shade structure support poles above cattle pen feed lanes, a common resting location for house flies (A.C.G., unpublished data), at a height of 1.8 m above ground. Flies resting on the spot cards deposit fecal and regurgitation spots that can be counted to provide a relative measure of house fly abundance and activity (Axtell 1970). All other monitoring devices resulted in the capture of adult house flies as a relative measure of house fly abundance and activity. Sticky fly tapes (Victor Fly Ribbon, Woodstream Corp., Litiz, PA) were placed to hang vertically from the eaves of a single story structure on each dairy (milk barn or equipment shed). Alsynite sticky fly traps (Biting Fly Trap, Olson Products, Medina, OH) and fly bait traps, 18.9-liter (5-gallon) white plastic buckets containing 85 g of commercial fly bait (QuickBayt, Bayer Animal Health, Shawnee Mission, KS), were paired and placed in the open on bare ground near cattle pens with the bottom of the Alsynite trap 0.5 m above the ground and a 2-m distance separating the Alsynite and bait traps. At each dairy, 10 spot cards, five Alsynite traps, and five bait traps were placed at sites providing coverage of the entire dairy, whereas five sticky fly tapes were concentrated on a single structure. All monitoring devices were replaced weekly on the same day. Captured flies were determined to species and sex. Spot cards were marked with a grid pattern to facilitate visual counting of all spots on the cards. If more than a few hundred flies were captured in a single bait trap, the captured flies were measured volumetrically to get a total count, and then 100 randomly selected flies were examined to determine the species and sex ratio.

Paired Alsynite traps and bait traps also were placed on bare ground ≈250 m to the north and south of each

dairy (off-dairy traps) twice per week from ≈0900 to 1500 hours to capture house flies dispersing from the dairies during this period. No obvious fly development sites were found in the area surrounding the study dairies, and it was presumed that captured flies would have originated from the nearby dairy.

Spot cards collected on three dates (15 June, 14 July, and 18 August 2005) from all 10 sampling sites at the MA and MS dairies were used for development of a software program (FlySpotter; A. C. Gerry and C. R. Shelton, University of California–Riverside [a trial version of this software is available for noncommercial use at http://ucanr.org/sites/FlySpotter/download/) using computer vision technology to count fly spots on a JPEG image of spot cards scanned using a flat bed scanner. Marked grids on these spot cards were randomly selected and all fly spots within the grids, up to a minimum of 100 spots per card, were evaluated for spot size, shape, and color. The three dates evaluated were selected to address potential variation in spot characteristics due to changing environmental conditions. For evaluating spot size, the diameter of each spot was measured and the typical range of spot sizes was found. For shape, we found determining the ratio of the spot's width to height was sufficient for capturing variation in shape and also determined the range of such ratios. For color, the red-green-blue values of the spot images were analyzed and 20 prototypical colors for spots were found using the K-Means clustering algorithm. All data of spot characteristics were then used to develop FlySpotter. FlySpotter scans each card and labels observed spots as valid if they fit the appropriate size, shape, and color criteria.

To test the sensitivity of the spot recognition software, spot cards were placed as above but at a separate dairy (dairy F) in the same region from 28 July to 29 September 2008. At dairy F, spot cards ($n = 3$) were placed on shade supports at three separate dry lot pens (total of nine spot cards) and replaced weekly in accordance with the monitoring study described above. After collection, spot cards were scanned on a flat bed scanner to acquire a JPEG image of the card, and then fly spots were visually counted by a single experienced laboratory technician. Separately, the number of spots on scanned card images was determined using the FlySpotter software with data recorded as spots/in^2.

General Data Analysis. Differences in the sex ratio of captured flies by monitoring method were examined using the Wilcoxon matched pairs signed ranks test, and the relationship between male and female flies of each species captured was determined by regression analysis with traps capturing no flies removed from the analysis. With strong correlation between male and female fly counts using all trap methods, remaining analyses used total flies captured. For each dairy and monitoring method, $\log_{10}(n + 1)$-transformed counts were compared for differences between placement sites by using Friedman nonparametric repeated measures analysis of variance (ANOVA) with Dunn's multiple comparisons test; and, in the absence of a controllable independent variable, for correlation by trap placement site using Pearson correlation. The relationship between monitoring methods at a single dairy or between dairies was determined using regression analysis of $\log_{10}(n + 1)$-transformed mean weekly counts. Mean weekly counts were lagged up to 2 wk for comparisons between monitoring methods to look for time-displaced relationships. Differences between the transformed mean counts for monitoring methods and dairies were evaluated using one-way ANOVA with Tukey's honestly significant difference (HSD) test. All analyses were conducted using Instat version 3.06 statistical analysis software (GraphPad Software, San Diego, CA).

Precision Analysis. For each monitoring method, statistical descriptors of the count data including the mean, sample variance, and coefficient of variability (CV) (or SE/mean) (Karandinos 1976) were calculated for each week at each test dairy. A CV of ≤0.25 is sufficient to detect a doubling of the fly population (Southwood and Henderson 2000). The weekly CV value was compared across all dairies using Kruskal–Wallis (KW) nonparametric ANOVA with Dunn's multiple comparisons test to determine significant differences in variability among the monitoring methods. The mean and variance of weekly counts was combined across all test dairies for each monitoring method and examined for significant correlation using regression analysis of the form $y = a + bx$; where y = log (variance +1) and x = log (mean +1). Given a significant positive relationship between the count mean and variance, the number of traps (or spot cards) required to obtain a fixed level of precision (CV = 0.25 and a more conservative CV = 0.15) for the week with the highest mean weekly count for each monitoring method was determined using the equation $n = s^2/[\bar{x}^2(\mathrm{CV})^2]$ where n is the sample size required to obtain the fixed CV for the highest count mean ($\bar{x}$) and using a variance estimate (s^2) derived from the mean-variance regression for the highest count mean (Karandinos 1976, Lysyk and Axtell 1985).

FlySpotter Software Analysis. Differences in fly spot size (diameter) on spot cards by dairy (MS and MA) and by month of collection (June–August) were evaluated using Kruskal–Wallis nonparametric test with Dunn's multiple comparisons test. Fly spot visual counts (total spots) for spot cards obtained from dairy F were transformed to spots per cm^2 and compared with the FlySpotter-generated count by using regression analysis.

Results

Spot card counts ranged from 35 to 5,940 spots per card per week across all dairies and weeks sampled, with mean weekly spot card counts of 1611, 461, and 174 per dairy (Table 1). Fly tape counts ranged from 0 to 464 house flies per tape per week across all dairies and weeks sampled, with mean weekly fly tape counts of 59, 147, and 127 house flies per dairy. Stable flies (*Stomoxys calcitrans* L.) also were collected on fly

Table 1. Mean, SE, and CV of house fly relative abundance counts recorded using three different abundance monitoring methods at three commercial dairies over a 10-wk summer sampling period

Abundance index	Dairy N		Dairy MS		Dairy MA	
	Mean (SE)[a]	CV[b]	Mean (SE)	CV	Mean (SE)	CV
Spot cards (n = 300)	1,611 (202.2)a	0.09	461 (40.4)b	0.06	174 (14.8)c	0.06
Fly tapes (n = 140)	59 (8.3)b	0.15	147 (16.0)a	0.11	127 (13.8)a	0.11
Bait traps (n = 148)	600 (45.8)b	0.08	1473 (121.3)a	0.08	2040 (184.0)a	0.09

[a] Means within rows followed by the same letter are not significantly different by Tukey's HSD test ($P \leq 0.05$).
[b] When examined across all dairies, the median weekly CV was significantly lower for spot cards and bait traps relative to fly tapes by Dunn's multiple comparisons test ($P < 0.001$), whereas the median CV for spot cards and bait traps was not different from each other ($P > 0.05$).

tapes and represented 7–20% of the total weekly catch depending upon the dairy. Fly tapes proved of limited value as 9/50 (18%) were lost due to high winds, and those lasting the week were often no longer adhesive due to the accumulation of dust. Bait trap counts ranged from 41 to 4,545 house flies per trap per week across all dairies and weeks sampled, with mean weekly bait trap counts of 600, 1,473, and 2,040 per dairy. Accumulations of dust on Alsynite traps coupled with removal of captured flies by wild birds prevented their use as a viable fly monitoring method on the dairies. Data from on-dairy Alsynite traps were not analyzed due to these limitations; however off-dairy Alsynite traps that were deployed for only 6 h twice per week were evaluated for fly sex ratio and relationship of fly capture to other monitoring methods.

The number of male and female house flies captured was significantly correlated at each dairy for fly tapes ($r^2 \geq 0.67$; df $\geq 1, 40$; $P < 0.0001$) and fly bait traps ($r^2 \geq 0.64$; df $\geq 1, 47$; $P < 0.0001$), but with more male than female house flies captured on fly tapes at all three dairies (W ≥ 817; df $\geq 1, 40$; $P < 0.0001$) and in bait traps at two of three dairies (W ≥ 740; df $\geq 1, 49$; $P \leq 0.0004$) (Table 2). Similarly, the number of male and female house flies captured was significantly correlated at off-dairy fly bait traps ($r^2 \geq 0.67$; df $\geq 1, 25$; $P < 0.0001$) and Alsynite traps ($r^2 \geq 0.55$; df = 1, 32; $P < 0.0001$), with more males than females captured by fly bait traps near two of three dairies (W ≥ 213; df $\geq 1, 33$; $P < 0.01$) and by Alsynite traps near all three dairies (W ≥ 317, df $\geq 1, 32$, $P \leq 0.002$). The number of male and female stable flies captured on fly tapes also was significantly correlated at all three dairies ($r^2 \geq 0.50$; df $\geq 1, 21$; $P < 0.0001$), but with male stable flies captured significantly more often than females at only one dairy (W = 451; df = 1, 33; $P < 0.0001$).

As would be expected, fly counts varied significantly by trap placement site for all monitoring methods (Fr ≥ 14.5; df $\geq 4, 49$; $P \leq 0.006$) and correlation between fly counts at each trap placement site varied considerably for all monitoring methods at each dairy. Spot card counts were significantly correlated ($r^2 > 0.41$; df = 1, 9; $P < 0.05$) for 15–45 of 45 placement site comparisons at each dairy, with counts significantly correlated for all sites at dairy N ($r^2 \geq 0.71$, $P < 0.005$) but only for proximate sites with similar midafternoon shading (shade or no shade on the spot card) at the remaining two dairies. Bait trap counts were significantly correlated ($r^2 > 0.56$; df = 1, 9; $P < 0.05$) for three to seven of 10 comparisons at each dairy, and fly tape counts were significantly correlated ($r^2 > 0.46$; df = 1, 9; $P < 0.05$) for only zero to five of 10 placement site comparisons, even though fly tapes were concentrated on a single dairy building. Mean weekly spot card counts were significantly related to same week mean weekly fly tape counts at dairy N ($P < 0.05$) and at dairy MA ($P < 0.0001$) (Fig. 2). Mean weekly bait trap counts were not significantly related to same week mean weekly counts of other

Table 2. Relationship between male and female flies captured by monitoring method and dairy

Fly species	Monitoring method	Dairy	Mean no. ♀ (SE)	Mean no. ♂ (SE)	Regression	df	r^2
M. domestica	Fly tapes	N	12.26 (1.81)b	46.76 (6.77)a	y = 3.20× + 7.71	40	0.73
		MS	34.73 (3.74)b	111.94 (12.85)a	y = 2.92× + 11.12	45	0.71
		MA	28.02 (3.09)b	99.04 (11.32)a	y = 3.00× + 15.17	48	0.67
	Bait traps	N	310.73 (23.44)a	294.42 (24.52)a	y = 0.90× + 14.00[a]	47	0.74
		MS	659.48 (54.65)b	813.34 (71.04)a	y = 1.07× + 109.22[a]	49	0.67
		MA	857.70 (67.82)b	1,182.08 (123.13)a	y = 1.46× − 67.57	49	0.64
	Off-dairy bait traps	N	3 (1.26)b	5.14 (2.08)a	y = 1.54× + 0.56	33	0.86
		MS	10.08 (2.30)b	17.31 (3.39)a	y = 1.33× + 4.17	33	0.82
		MA	2.53 (0.60)a	3.31 (0.91)a	y = 1.27× + 0.14[a]	25	0.67
	Off-dairy Alsynite traps	N	9.83 (2.13)b	18.14 (3.81)a	y = 1.62× + 2.44	32	0.83
		MS	10.28 (1.67)b	23.17 (3.87)a	y = 1.98× + 3.02	33	0.72
		MA	6.03 (1.76)b	7.86 (1.05)a	y = 0.44× + 5.18[a]	35	0.55
S. calcitrans	Fly tapes	N	1.86 (0.79)a	2.24 (0.66)a	y = 0.72× + 1.71	21	0.89
		MS	4.92 (1.94)a	4.90 (1.86)a	y = 0.92× + 0.78[a]	21	0.94
		MA	10.78 (3.07)b	14.26 (3.22)a	y = 0.71× + 9.69	33	0.50

Within a row, means followed by the same letter are not significantly different by Wilcoxon matched pairs signed ranks test ($P \geq 0.05$).
[a] Slope of the regression line is not different from m = 1.0 based upon the 95% CI. All correlations are significant at $P < 0.0001$.

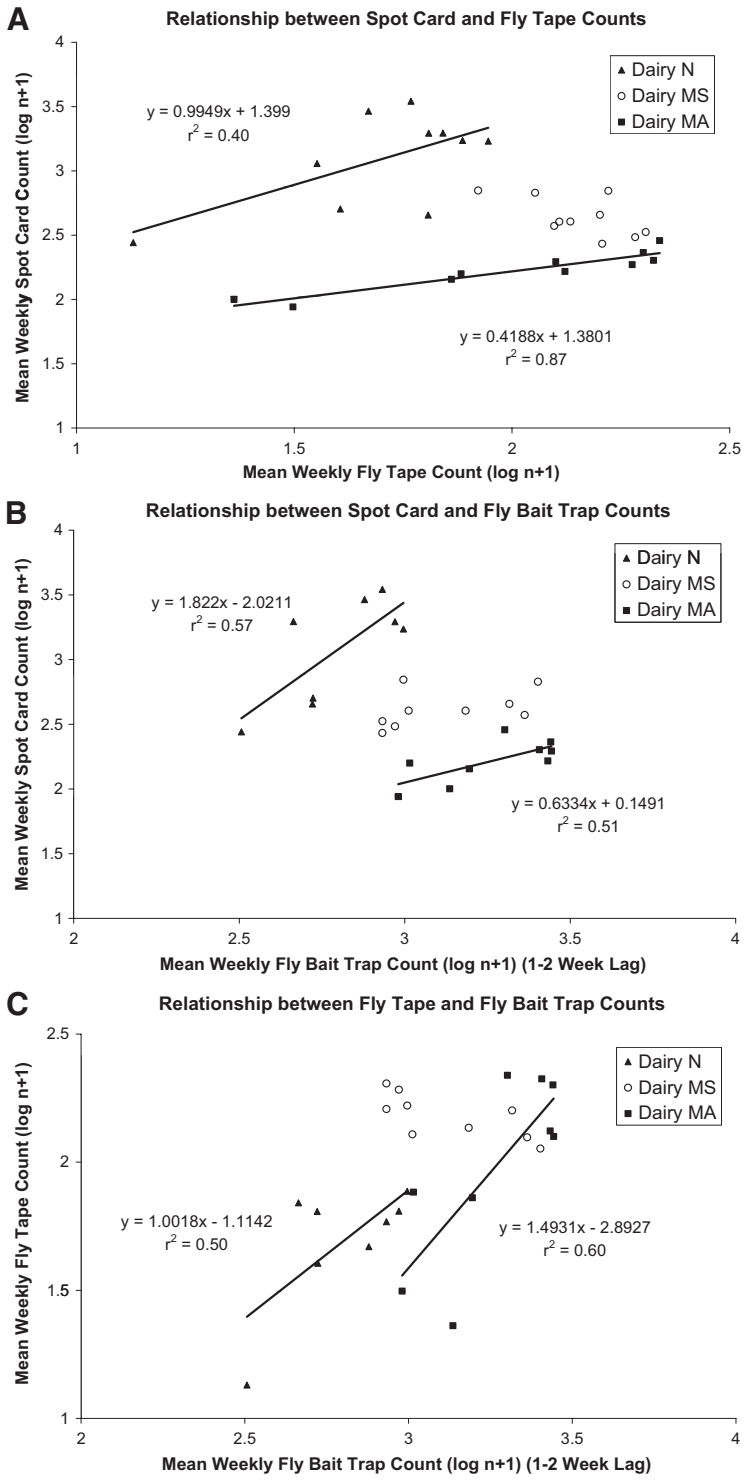

Fig. 2. Relationship between house fly counts by monitoring methods. Fly bait trap counts were lagged by 1 wk at dairies MS and MA and by 2 wk at dairy N, for best fit.

monitoring methods. However, mean weekly bait trap counts were significantly related to the previous week mean spot card and fly tape count at dairy MA ($P = 0.03$ and 0.01, respectively), and to the 2-wk previous mean spot card and fly tape count at dairy N ($P < 0.05$ and $P = 0.03$, respectively). There

Table 3. Regression of house fly count variance against the mean for each week of the study at all three test dairies combined and sampling effort (number of of monitoring devices) required to achieve a fixed level of precision given by CV for the highest weekly mean count recorded during the study

Monitoring method	Regression[a]	df	r^2	Highest mean ($\bar{x}$) count	Log_{10} (s^2)	Sampling effort required[b]	
						CV = 0.25	CV = 0.15
Spot cards	$y = 2.11x - 0.96$	29	0.94	3,485	6.51	4.28	11.90
Fly tapes	$y = 1.69x + 0.28$	29	0.67	217	4.22	5.68	15.77
Bait traps	$y = 2.47x - 2.43$	29	0.65	2,760	6.08	2.53	7.03

[a] For all regressions, $P < 0.0001$; y = log (variance +1) and x = log (mean +1).

[b] The sampling effort or number of traps (n) required to achieve a fixed precision (CV) value is determined using the equation $n = s^2/(\bar{x}^2(CV^2))$ following Karandinos (1976), where s^2 is calculated for each monitoring method from the mean-variance regression at the highest mean count ($\bar{x}$) recorded at any dairy for the monitoring method. The highest mean count is used as a surrogate estimate for an unknown IPM action threshold, where precision is most important.

were no significant correlations between monitoring methods used at dairy MS, even when counts were lagged up to 2 wk before analysis.

Between dairies, the mean weekly fly count varied significantly for each monitoring method ($F \geq 8.32$; df = 2, 27; $P \leq 0.0015$); however, there was a significant interaction between dairy and monitoring method. Spot card counts for dairy N were significantly higher than for dairy MS or MA, whereas fly tape and bait trap counts for dairy N were significantly lower than for dairy MS or MA (Table 1). Although actual counts were considerably different between the dairies, these counts were significantly related between dairy N and dairy MA by using either mean weekly spot card or bait trap counts ($r^2 \geq 0.49$; df = 1, 9; $P \leq 0.03$), but not fly tape counts. House fly counts at dairy MS were not related to house fly counts at the other two dairies by any monitoring method.

The mean weekly capture of house flies at off-dairy bait traps was significantly correlated with off-dairy Alsynite traps at two of three dairies (N and MS) ($r^2 \geq 0.50$, df = 1, 8; $P \leq 0.05$) and with same week on-dairy bait trap counts on two of three dairies (MS and MA) ($r^2 \geq 0.44$; df = 1, 8; $P < 0.05$). There were no other significant relationships between the house fly counts from off-dairy traps relative to any other monitoring method, even when counts were lagged up to 2 wk.

Precision of Monitoring Methods. Count variability was significantly different between trap methods (KW = 34.77; df = 2, 87; $P < 0.0001$); with variability being lowest for spot cards and bait traps relative to the significantly more variable fly tapes ($P < 0.001$) (Table 1). The relationship between weekly count mean and variance was significant for all monitoring methods ($P < 0.0001$) (Table 3). To achieve a sampling precision of CV = 0.15 (Lysyk and Axtell 1986) for the highest weekly mean count of each monitoring method, 12 spot cards, 16 fly tapes, or seven bait traps are required for the large commercial dairies used in this study.

FlySpotter Software. The diameter of a fly spot ranged from 0.1 to 1.5 mm for all spots examined (n = 1497), with a mean ± SD diameter of 0.56 ± 0.22. There were significant differences in fly spot size by dairy and collection month (KW = 37.19, $P = 0.0001$), with fly spots collected at dairy MS being larger in June (95% CI: 0.58–0.64 mm in diameter) than in July (0.53–0.56) or August (0.53–0.58) and fly spots collected at dairy MA being larger in July (0.59–0.65) than in August (0.48–0.53) but not different in June (0.50–0.61). When examined over all months, spot size was not different between dairies ($P > 0.05$). Fly spot size may be related to house fly body size or local environmental conditions (e.g., humidity), however this was not evaluated.

The number of fly spots on spot cards from dairy F was significantly related for visual and FlySpotter generated counts ($r^2 = 0.95$, df = 79, $P < 0.0001$). A regression equation of $y = 0.78x + 1.35$ (Fig. 3) indicated that the FlySpotter program slightly overcounted spots when visual counts were low and undercounted spots as spot density increased. Nevertheless, the FlySpotter program provided a reasonably accurate count of fly spots and changes in the visual spot card count were significantly reflected in the FlySpotter spot card count.

Discussion

Monitoring pest activity is a cornerstone requirement of an IPM program. Monitoring house fly activity is necessary to recognize increasing house fly activity at confined animal facilities due to changing environmental conditions or following engineering and management failures. A house fly monitoring program is also necessary to evaluate the usefulness of any fly control efforts applied and to provide evidence of current fly activity relative to past activity; an important consideration in the context of nuisance citations and litigation.

House fly monitoring methods that accumulate flies over time, such as traps or spot cards, provide a more reliable estimate of fly abundance and activity relative to instantaneous visual counts which are subject to diel variation and changing environmental conditions (Lysyk and Moon 1994). House fly activity measured by traps or spot cards is a product of house fly abundance and the variable expression of fly behaviors resulting in contact between flies and monitoring devices. At a given abundance level, house fly activity will increase or decrease with changes in house fly behavioral responses to environmental conditions and to the presence–absence of nearby stimuli (Lysyk and

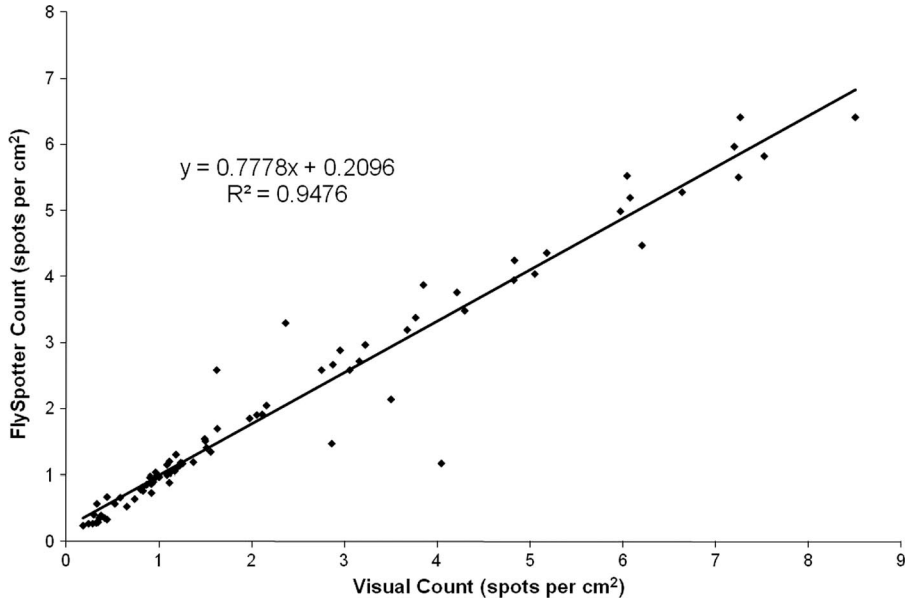

Fig. 3. Relationship between spot card counts using visual counting methods and the FlySpotter computer program to count spots on scanned spot card image files.

Axtell 1985). Therefore, actual fly density and measured fly activity may be unrelated (Beck and Turner 1985). Although true fly abundance may be more accurately measured, e.g., using mark–release–recapture methods, economic injury associated with house flies at a commercial animal operation is primarily due to nuisance or pathogen transmission, both of which are probably related to fly activity more than to simple abundance.

Trap Placement. Measured house fly activity varied significantly between trap and spot card locations with activity significantly correlated only for traps or spot cards placed in near proximity or at locations with similar environmental characteristics. This was expected given the heterogeneity of habitat and stimuli associated with a large dairy operation. At dairy N, spot card counts were correlated for all locations because all spot cards were placed on support poles in three large free-stall structures with covered roofs, providing full daytime shade and similar humidity characteristics at all locations. The spot counts were also relatively very high at this dairy because flies tended to congregate on the support poles in these shaded areas during the day to avoid the high summer daytime temperatures. In contrast, dairy MA and dairy MS had dry lot pens with narrow shade structures providing shade that shifted throughout the day, leaving some spot card locations in afternoon shade and others in full sun. Spot card locations in full midafternoon sun typically had the lowest spot counts.

Conventional wisdom is to monitor house fly activity on an animal facility by distributing traps evenly across the entire facility (Lysyk and Moon 1994). However, on a large open confined animal facility, such as the dairies used in this study, it may be better to place spot cards in areas that are shaded during midafternoon to more accurately measure changing fly activity during the hot summer when house fly activity is near a peak and the potential for pathogen transmission or nuisance is greatest. Placement of spot cards in locations with midafternoon sun may result in a decrease in the spot count with increasing temperature; even though fly abundance or activity is increasing at the facility. In poultry houses, Lysyk and Axtell (1985) found that as daytime temperatures and fly density were increasing, spot cards placed onto roof rafters showed decreasing fly activity; presumably due to the shift in daytime resting behavior of house flies to avoid the very hot roof rafters. In more sun-protected locations within the poultry house, activity measured by spot cards was most significantly influenced by fly density with temperature only somewhat influencing measured activity.

Comparison of Monitoring Methods. In agreement with this study, Lysyk and Axtell (1986) found that fly activity measured using spot cards was correlated with activity measured using fly tapes, but not bait traps, over the same period. These studies did not examine correlation between spot cards and lagged bait trap captures. Spot cards and fly tapes take advantage of the same fly resting behaviors and thus might be expected to provide a similar indication of changing activity. Fly baits contain volatiles that are variably attractive to house flies depending upon fly sex, age, nutritional status, or other physiological constraints. In the current study, spot card counts were significantly related to bait trap captures 1–2 wk later at two of the three dairies, perhaps indicating that younger (recently emerged) flies were less responsive to the bait traps than were older flies. This is an important point if the

purpose of the monitoring program is the early recognition of increasing fly activity so that control measures may be instituted before pathogen transmission or nuisance to facility animals and human neighbors. However, this finding should be confirmed with additional studies given the lack of correlation between spot card counts with lagged bait trap captures at one dairy.

The lack of any relatedness between monitoring methods at dairy MS is unexplained but may be due to the lower cattle density and greater geographic area at this facility relative to the other two dairies, or perhaps due to the presence of more limited shade structures resulting in a higher proportion of spot cards in variable or full midafternoon sun. This dairy also had the fewest correlations between spot card locations (only 15 of 45 site comparisons). Lysyk and Axtell (1986) reported that spot counts for cards placed in a confined poultry facility were influenced by the presence of other fly species, most notably the little house fly, *Fannia canicularis* (L.). However, at commercial dairies in California, only house flies and stable flies commonly rest on the vertical structures to which spot cards were attached in this study. However, stable flies are susceptible to high daytime temperature and are present in only limited numbers during the hot and dry California summer when house fly activity is at a peak and monitoring is most critical (Mullens and Meyer 1987, Gerry et al. 2007).

The significant correlation between male and female flies captured by all traps in this study means that the resting and feeding activity of the two sexes is related. Thus, even if one sex may be primarily responsible for causing disease or nuisance, the total fly count can be effectively used as a measure of activity for that sex. However, it is interesting that more male than female flies were captured using nearly all trap methods both on and off the dairy. If we assume a 1:1 male:female sex ratio of newly emerging house flies (Krafsur et al. 1985), then either male survival is greater or males are more likely to contact traps due to differences in behavior. With traps placed at some distance from cattle to prevent destruction of traps, it may be that male flies predominate in trap collections because females are more inclined to remain in the vicinity of animals to acquire the exogenous proteins needed for egg development (Goodman et al. 1968) or where manure for oviposition is plentiful. Geden (2005) also captured more male than female house flies at a dairy by using sticky traps and baited traps, whereas more female than male flies were captured in jug traps containing a fermenting liquid bait solution.

House fly activity counts at two of the dairies (MA and N) were significantly correlated using spot cards or bait traps, indicating similar change in house fly activity over time across the region. However, there was a lack of correlation between fly activity counts at dairy MS relative to the other two dairies, and a significant interaction between monitoring method and dairy sampled when counts were analyzed for differences between dairies. Therefore, house fly activity counts should not be compared across facilities. Instead, monitoring results obtained as they were in this study are only meaningful in the context of previous counts at the same facility by using the same monitoring method with an action threshold determined independently for each facility. Additional studies are needed to standardize trap locations and methodology to provide house fly activity data that can be directly compared between different dairy facilities.

Although off-dairy bait trap captures were correlated with same week on-dairy bait trap captures at two dairies, fly captures at off-dairy traps were otherwise not related, even with a time lag, with any other monitoring method used on the dairies. However, the 6-h sampling period used for off-dairy traps differed considerably from the multiday sampling period for the on-dairy traps. House fly activity measured by off-dairy traps may have proven more related to fly activity on the dairy if the trapping period was equivalent. Additional research is needed to examine monitoring methods to capture house flies dispersing away from animal facilities and to evaluate nuisance to humans so that action thresholds for fly management can be determined for on-dairy monitoring methods.

Precision of Monitoring Methods. Count variability between trap locations was lowest for spot cards and bait traps, relative to sticky ribbons. A sampling precision (CV) = 0.25 is considered sufficient to recognize a doubling of the house fly population (Southwood and Henderson 2000). Using the even more conservative CV = 0.15 used by Lysyk and Axtell (1986), an efficient house fly monitoring program could be implemented on a large dairy using only 12 spot cards or seven bait traps.

House Fly IPM Using Spot Cards. Spot cards are a simple, economical means of obtaining a relative estimate of house fly abundance and activity. Most other house fly monitoring methods require the preparation and placement of messy adhesive traps or the application of chemically treated baits. These other monitoring methods also require some limited taxonomic skill and considerable time as captured flies would require identification to species; a potentially difficult task for a nonentomologist when flies are covered in adhesive. Counting spots also can be very time-consuming, with a thousand or more spots per card. Even using a grid counting system, visual card counts averaged over 15 min per card in this study. A confined animal facility operator is not likely to adopt an IPM monitoring program for house flies that requires a substantial time commitment to identify captured flies or to visually count spot cards.

As part of this study, a spot card counting program using computer vision (FlySpotter; http://ucanr.org/sites/FlySpotter/download/) was developed that could count the fly spots on a scanned image of a spot card and that was very highly correlated with the visual spot card counts. Using the FlySpotter program, the time required to count spot cards was reduced to

under 30 s per card, essentially the time it took for a flatbed scanner to scan the spot card! By automating this time-consuming process, we now have a monitoring system suitable for use on dairies or other confined animal facilities.

An additional substantial benefit to using spot cards is that spot counts are not influenced by declining attractiveness of the cards over time, as is the case for some baited traps (Geden 2005). Baited traps using an insecticide have the additional significant limitation that the development of insecticide resistance by house flies is rapid (Keiding 1999; Kaufman et al. 2001, 2008; Butler et al. 2007) with behavioral mechanisms of resistance resulting in avoidance of house fly baits (Gerry and Zhang 2009, Mullens et al. 2010). Spot cards do not require destructive sampling of house flies; thus, there is no selection pressure placed on the house fly population to affect future use of this method.

It is recommended that an IPM monitoring program for house flies be instituted at large confined animal facilities. Based upon the results of these studies, it is recommended that spot cards be used with placement of cards onto vertical surfaces receiving midafternoon shade. House fly baits could continue to be used as a management tool to reduce adult fly numbers without compromising the monitoring value of spot cards.

Acknowledgments

We appreciate the willingness of four anonymous dairy operators in California to allow access to their facilities during the length of this study. We thank Diane Zhang (Department of Entomology, University of California–Riverside) for the tedious work of visually counting fly spots from all spot cards used in these studies and Curtis Yu (Department of Computer Science, University of California–Riverside) for developing the software user interface for the spot recognition program. Funding for this study was provided by University of California Agriculture and Natural Resources Core Issues grant CIG04-079 (to A.C.G. and G.E.H.) and University of California Cooperative Extension IPM demonstration grant 07DM003 (to A.C.G., G.E.H., and C.R.S.).

References Cited

Anderson, J. R., and J. H. Poorbaugh. 1964. Observations on the ethology and ecology of various Diptera associated with northern California poultry ranches. J. Med. Entomol. 1: 131–147.

Axtell, R. C. 1970. Integrated fly control program for caged-poultry houses. J. Econ. Entomol. 63: 400–405.

Beck, A. F., and E. C. Turner. 1985. A comparison of five house-fly (Diptera: Muscidae) population monitoring techniques. J. Med. Entomol. 22: 346–348.

Burg, J. G., and R. C. Axtell. 1984. Monitoring house fly, *Musca domestica* (Diptera: Muscidae), populations in caged-layer poultry houses using a baited jug-trap. J. Environ. Entomol. 13: 1083–1090.

Butler, S. M., A. C. Gerry, and B. A. Mullens. 2007. House fly (Diptera: Muscidae) activity near baits containing (Z)-9-tricosene and efficacy of commercial toxic fly baits on a southern California dairy. J. Econ. Entomol. 100: 1489–1495.

Geden, C. J. 2005. Methods for monitoring outdoor populations of house flies, *Musca domestica* L. (Diptera: Muscidae). J. Vector Ecol. 30: 244–250.

Geden, C. J. and J. A. Hogsette [eds.]. 1994. Research and extension needs for integrated pest management of arthropods of veterinary importance. *In* Proceedings of a Workshop, 12–14 April 1994, Lincoln, NE. USDA–ARS, Gainesville, FL.

Gerry, A. C., B. A. Mullens, and N. G. Peterson. 2007. Predicting and controlling stable flies on California dairies. Division of Agriculture and Natural Resources. Publication 8258, University of California, Oakland, CA.

Gerry, A., and D. Zhang. 2009. Behavioral resistance of house flies, *Musca domestica* (Diptera: Muscidae), to imidacloprid. Army Med. Dep. J. (July–September) 2009: 54–59.

Goodman, T., P. E. Morrison, and D. M. Davies. 1968. Cytological changes in the developing ovary of the house fly fed milk and other diets. Can. J. Zool. 46: 409–427.

Hinkle, N. C., and L. A. Hickle. 1999. California caged layer pest management evaluation. J. Appl. Poult. Res. 8: 327–338.

Karandinos, M. G. 1976. Optimum sample size and comments on some published formulae. Bull. Entomol. Soc. Am. 22: 417–421.

Kaufman, P. E., J. G. Scott, and D. A. Rutz. 2001. Monitoring insecticide resistance in house flies (Diptera: Muscidae) from New York dairies. Pest Manag. Sci. 57: 514–521.

Kaufman, P. E., A. C. Gerry, D. A. Rutz, and J. G. Scott. 2008. Monitoring susceptibility of house flies (*Musca domestica* L.) in the United States to imidacloprid. J. Agric. Urban Entomol. 23: 195–200.

Keiding, J. 1999. Review of the global status and recent development of insecticide resistance in field populations of the housefly, *Musca domestica* (Diptera: Muscidae). Bull. Entomol. Res. 89: 67.

Krafsur, E. S., W. C. Black, C. J. Church, and D. A. Barnes. 1985. Age structure and reproductive biology of a natural house fly (Diptera: Muscidae) population. Environ. Entomol. 14: 159–164.

Lysyk, T. L., and R. C. Axtell. 1985. Comparison of baited jug-trap and spot cards for sampling house fly, *Musca domestica* (Diptera: Muscidae), populations in poultry houses. Environ. Entomol. 2: 199–205.

Lysyk, T. L., and R. C. Axtell. 1986. Field evaluation of three methods for monitoring populations of house flies (*Musca domestica*) (Diptera: Muscidae) and other filth flies in three types of poultry housing systems. J. Econ. Entomol. 79: 144–151.

Lysyk, T. and R. D. Moon. 1994. Sampling arthropods in livestock management systems, pp. 515–538. *In* L. P. Pedigo and G. D. Buntin (eds.), Handbook of sampling methods for arthropods in agriculture. CRC, Boca Raton, FL.

Mullens, B. A., and J. A. Meyer. 1987. Seasonal abundance of stable flies (Diptera: Muscidae) on California dairies. J. Econ. Entomol. 80: 1039–1043.

Mullens, B. A., A. C. Gerry, and A. N. Diniz. 2010. Field and Laboratory trials of a novel metaflumizone house fly (Diptera: Muscidae) bait in California. J. Econ. Entomol. 103: 550–556.

Sasaki, T., M. Kobayashi, and N. Agui. 2000. Epidemiological potential of excretion and regurgitation by *Musca domestica* (Diptera: Muscidae) in the dissemination of *Escherichia coli* O157:H7 to food. J. Med. Entomol. 37: 945–949.

Southwood, T.R.E., and P. A. Henderson. 2000. Ecological methods, 3rd ed., Blackwell Ltd., Oxford, United Kingdom.

Talley, J. L., A. C. Wayadande, L. P. Wasala, A. C. Gerry, J. Fletcher, U. DeSilva, and S. E. Gilliland. 2009. Association of *Escherichia coli* O157:H7 with filth flies (Muscidae and Calliphoridae) captured in leafy greens fields and experimental transmission of *E. coli* O157:H7 to spinach leaves by house flies (Diptera: Muscidae). J. Food Prot. 72: 1547–1552.

Thomas, G. D., and S. R. Skoda. [eds.]. 1993. Rural flies in the urban environment? *In* Proceedings of a symposium presented at the Annual Meeting of the Entomological Society of America, December 1989, San Antonio, TX. Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska–Lincoln, Lincoln, NE.

Received 21 October 2010; accepted 26 January 2011.