A Preliminary Survey of Fly Breeding at Sanitary Landfills in Hawaii with an Evaluation of Landfill Practices and their Effect on Fly Breeding

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ABSTRACT

Fly population surveys were conducted weekly over a five-month period at 16 sanitary landfills on the islands of Oahu, Kauai, Maui, and Hawaii. Indices from flies captured on sticky traps made from commercial cockroach traps ranged from 0.78 ± 0.13 at a privately operated landfill to 106.76 ± 9.19 at a county landfill. Distinctly higher indices occurred at landfills having less than daily refuse compaction and twice a week soil cover frequencies.

Field and laboratory observations indicated that refuse compaction and soil covers did not prevent immature stages of flies already in buried incoming refuse from developing and emerging as adults. Results showed that flies were capable of emerging from refuse buried beneath 25 cm of moist (18.3% moisture content), bulldozer compacted soil cover. The failure of this thick soil cover in preventing fly emergence suggested that a cost-saving thinner layer of soil cover than presently required could be used to adequately maintain its other functions of reducing odors, preventing fires, and minimizing trash flyaway. The immediate consolidation and compaction of incoming refuse to deny ovipositional material to flies, and the application of a minimum twice a week soil cover to reduce odors that attract immigrant flies appeared to be major factors in fly control at landfills.

Observations made on any sanitary landfill operation in Hawaii will invariably show that the daily compaction and cover of refuse with the recommended 15 cm of soil (Johnson 1970) is seldom followed. This noncompliance is not a disregard of sound sanitation practices but a consequence of economics. The high cost of purchasing and hauling cover material from distant sites has compelled landfill operators to use only the minimum cover material necessary to prevent excessive fly nuisance. While such minimal fly control measures may have sufficed in the past, they may no longer be adequate because of the encroachment of residential developments close to existing landfills. The following studies were therefore conducted to evaluate current sanitary landfill practices to determine whether they could be improved to provide better fly control at less cost: (1) devise a standardized survey method to obtain fly population indices; (2) obtain fly population indices for all major landfills; and (3) determine the effectiveness of refuse compaction and soil covers in preventing fly breeding.

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MATERIALS AND METHODS

Fly Population Survey Methodology

Development of a new fly survey method became necessary when standard survey methods (Scott and Littig 1962) were found unsuitable for landfills. Tolerance of houseflies to insecticides made poison bait traps useless while screen cone traps (Scott and Littig 1962) were considered too cumbersome and expensive for large-scale surveys. The Scudder fly grill (Scott and Littig 1962) was also found too difficult to use because of the large, diverse, and highly-active fly populations at landfills. Difficulty in maintaining consistent attractiveness and competitiveness with natural attractants at landfills also precluded the use of bait attractants.

In my preliminary trials with various alternative traps, the most promising appeared to be an unbaited sticky cockroach trap converted to capture flies alighting on it. This commercially made cockroach trap was typical of several available brands in that it consisted of a 19 × 24 cm piece of cardboard that folded into an open-sided box. The 9 × 15 cm bottom of the trap is coated with tacky glue to entangle legs of insects that enter the trap.

Preliminary field testing indicated that longitudinal folding of the trap at a 90° angle (see Fig. 1) greatly enhanced its attractiveness as a landing site. To demonstrate this increased attractiveness, ten replicates of paired folded and unfolded traps were placed over natural fly attractants found on the landfill face. The traps were left exposed for 15 minutes. Testing showed that trap exposure for a minimum of 15 minutes was needed to

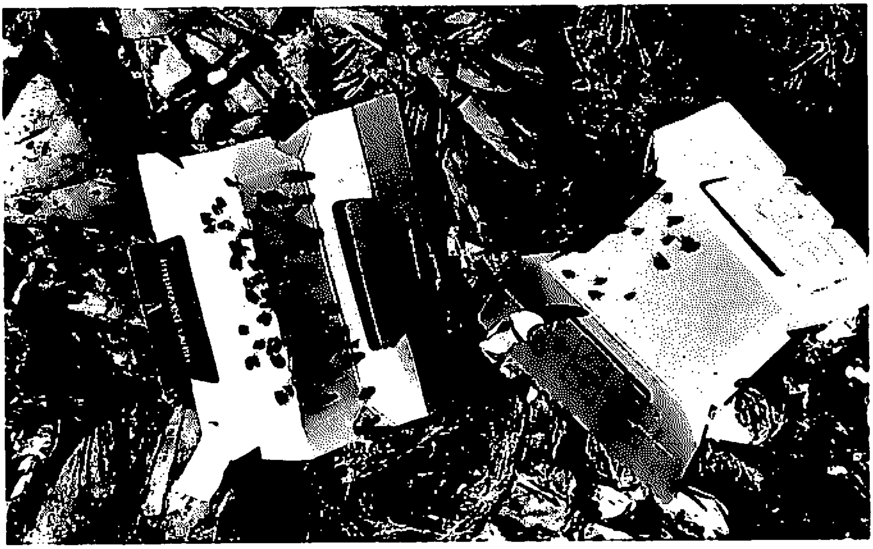

FIGURE 1. Difference in Flies Captured between Folded (left) and Unfolded (right) Commercial Sticky Cockroach Traps Exposed for 15 Minutes over Natural Attractant on Landfill Face

obtain catches that most accurately reflected the prevailing fly population at the trap site. Exposure for longer periods caused a bias when captured flies increased the attractiveness of the trap as a resting site.

The effectiveness of the sticky trap was tested by comparing it with the Scudder fly grill and the screen cone trap. The Scudder fly grill, screen cone trap, and folded sticky trap were used sequentially over exposed fly attractants on the landfill face. The screen cone trap and folded sticky trap were each exposed for 15 minutes between 10:00 and 12:00 A.M. at Kawailoa and Waianae landfills on Oahu. Fifty more samples were also taken with the screen cone trap and folded sticky trap to determine differences in numbers and species of flies captured with these traps.

Landfill Fly Survey

Weekly fly trapping by Vector Control Branch personnel on the islands of Hawaii, Maui, Kauai, and Oahu was conducted at all major landfills during the months of April-June and September-October. The indices obtained were used to compare fly populations between landfills with differing compaction and cover frequencies.

Ten sticky cockroach traps were prepared as previously described and exposed for 15 minutes between 10:00 and 12:00 A.M. on the landfill face of freshly compacted refuse. The length of the landfill face was paced off and divided into 10 equal segments. A trap was then placed in each segment over a natural attractant with the highest number of flies on it. Only five or less traps were exposed at a time to maintain accurate exposure periods. Traps were also taped down to prevent overturning by winds.

Development of Buried Housefly Eggs

Housefly egg clusters of approximately equal size were buried with breeding media under 15 cm of soil to determine whether they would be capable of completing development under such conditions. The egg clusters were placed on 573 ml (by volume) of fresh cow dung and put at the bottom of 3.8 liter glass jars. The egg clusters and cow dung were then covered with 15 cm of soil and kept in a room with an average ambient temperature of 25.6°C.. The soil, from sugar mill mud basins containing approximately 18% moisture, was compacted by hand before covering the jars with organdy cloth to trap emerging flies. There were six test and two control replicates that were not covered with soil.

Emergence Rates of Buried Housefly Larvae and Puparia

Five hundred each of housefly puparia and 4th instar larvae were buried under 61 cm of soil in straight-sided glass jars and kept in a room with an average ambient temperature of 26.3°C. to determine whether flies could emerge. The soil cover, from sugar mill mud basins containing approximately 18% moisture, was compacted by hand before covering the jars with organdy cloth to trap emerging flies. Testing was done only once for puparia and larvae.

Influence of Soil Compaction on Fly Emergence

Four pairs of fly emergence traps were placed on freshly compacted and covered refuse to capture emerging flies. The traps were 30 × 30 × 15 cm wooden boxes with a 2.5 cm hole in the covered top of the box. An inverted baby food jar with a similar 2.5 cm hole was nailed over the hole on the top of the box. The baby food jar containing an inverted screen cone was screwed onto the cover to trap emerging flies attracted to the light from the hole in the box. Two replicates of paired boxes were placed over compacted soil of 15 and 25 cm depths. One box of each pair, placed over soil dug up and loosened to the level of the buried refuse, acted as controls. The test boxes were placed at Kawailoa landfill seven days after the refuse was covered and left for five days. The soil cover, from Waialua Sugar Mill mud basins containing 18.3% moisture, was compacted by being run over repeatedly with a D-8 Caterpillar Bulldozer.

RESULTS

Fly Population Survey Methodology

Results clearly indicated that folded sticky traps were superior to flat unfolded traps (Fig. 1) in attracting flies as a resting site. The mean ± S.D. of flies captured for 10 samples were: folded trap, 59.16 ± 7.14; unfolded trap, 3.15 ± 1.10.Comparison of the different trapping methods indicated that the folded sticky trap and the screen cone were comparable in effectiveness and also easier to use than the Scudder fly grill. The large numbers of highly active flies at landfills made counting of flies difficult even when using only a quarter section of the grill. The mean ± S.D. of flies captured were: Scudder fly grill, 14.25 ± 1.58; screen cone trap, 44.4 ± 6.45; and folded sticky trap, 59.16 ± 7.74. The mean ± 2.S.D. (50 samples) of fly species captured by the screen cone trap and sticky trap respectively were: *Musca domestica* L., 11.82 ± 4.10 and 15.80 ± 3.78; *Phaenicia cuprina* (Wiedemann), 17.70 ± 7.30 and 16.16 ± 7.66; *Chrysomya megacephala* (Fabricius), 14.82 ± 8.16 and 26.82 ± 9.16. The lack of any apparent difference in the indices of fly species captured between the screen cone trap and sticky trap indicated that the effectiveness of the sticky trap was comparable to the screen cone trap in both numbers and species captured.

Observations made during this trap comparison study corroborated earlier observations that 15 minutes exposure of the sticky traps resulted in catches that most accurately reflected the prevailing fly populations at the trap site.

Landfill Fly Survey

In general, a comparison of fly populations (Table 1) of landfills not periodically treated with insecticides, showed notably higher indices at landfills with less than daily compaction and twice a week cover frequencies.

Table 1. Results of Landfill Survey with Sticky Traps in Hawaii

Island Landfill	Compaction Frequency	Cover Frequency	Cover Material	Flies per Trap ($\bar{x}$ ± S.D.)[a]	
				(n = 90) April-June	(n = 40) Sept.-Oct.
Oahu					
Kawailoa[b]	many ×/daily	2×/week	soil	28.57 ± 2.91	32.22 ± 5.64
Waianae	many ×/daily	2×/week	soil	7.94 ± 0.90	17.17 ± 5.69
Kapaa	many ×/daily	daily	soil	10.09 ± 2.45	4.42 ± 1.69
Puu Palailai[c]	many ×/daily	daily	soil	0.78 ± 0.13	1.70 ± 0.34
Kauai					
Kekaha[d]	many ×/daily	2×/week	sand	14.97 ± 1.69	10.82 ± 2.17
Hanalei[d]	1×/week	1×/week	soil	6.34 ± 1.42	9.42 ± 2.04
Kapaa[d]	3 ×/week	1×/week	soil	5.98 ± 1.40	13.20 ± 3.04
Halehaka[d]	many ×/daily	2×/week	soil	13.04 ± 1.74	16.15 ± 4.06
Maui					
Waikapu	many ×/daily	daily	sand	7.28 ± 1.54	2.52 ± 0.84
Olowalu	many ×/daily	daily	cinders	10.96 ± 2.64	0.67 ± 0.15
Makani	many ×/daily	daily	soil	12.44 ± 2.59	8.32 ± 2.27
Hawaii					
Waiohinu	2×/week	2×/week	soil	30.62 ± 4.57	23.55 ± 3.30
Kailua	many ×/daily	1×/week	cinders	23.96 ± 3.66	23.55 ± 5.72
Kohala	2×/week	none	none	106.76 ± 9.19	72.75 ± 9.97
Waimea	1×/daily	none	none	72.06 ± 7.17	67.35 ± 8.69
Hilo[d]	many ×/daily	1×/week	cinders	19.88 ± 2.56	12.07 ± 2.80

[a] Fly species: *M. domestica, P. cuprina, C. megacephala*
[b] Covered 4 times in 13 weeks because of non-delivery of soil & equipment breakdown.
[c] Private landfill for commercial refuse.
[d] Periodically treated with insecticide.

The large differences in means between the first and second samplings of many landfills also showed that large fluctuations in fly populations occurred at landfills. These large fluctuations indicated that baseline indices of fly populations for landfills can be obtained only by continuous samplings throughout the year to account for all variables that cause changes in fly populations.

Development of Buried Housefly Eggs

The means of emerging adults from the six buried and two unburied housefly egg clusters were: buried, 479.3; and unburied, 549.0. These results confirmed that housefly eggs buried under 15 cm of soil were capable of developing into adults without any adverse effects.

Emergence Rates of Buried Larvae and Puparia

Larvae and puparia buried under soil at the optimum recommended depth of 61 cm appeared to suppress fly emergence from puparia but not larvae. Flies emerging from 4th instar larvae and puparia buried under 61 cm of soil were: larvae, 72.0%; and puparia, 24.8%. Emergence from unburied control samples were: larvae, 88.2%; and puparia, 91.0%.

Influence of Soil Compaction on Fly Emergence

The numbers of houseflies captured in the fly emergence traps from moist soil compacted with a bulldozer were: 15 cm depth, six houseflies; 25 cm depth, two houseflies. Control traps with loosened soil captured: 15 cm depth, one housefly; 25 cm depth, none.

DISCUSSION

Consistency of the trapping methodology in reflecting sanitary conditions at landfills not treated with insecticides was demonstrated by the nearly similar rankings of landfills between the first and second fly population survey (Table 2).

The marked increase in fly indices of landfills ranked above six in Table 2 pointed to a relationship between cover and compaction frequencies and increased fly populations. Those landfills ranked above six differed from others in that they all had either less than daily compaction or twice a week cover frequencies (Table 1). The degree that other factors such as elevation of landfills above sea level, refuse composition, and climatic factors had an effect on fly indices was not determined in this preliminary survey. However, during my weekly inspections of landfills on Oahu over a three-year period, I have usually observed a noticeable increase in fly populations whenever the minimum twice a week soil cover frequency was disrupted. The data in Table 1 showing low indices for landfills using volcanic cinders and sand as cover material suggested that the type of material was not as important as the cover frequencies.

Comparison of indices between the first and second samplings (Table 1) showed large fluctuations in fly populations occurring at landfills. Observations of landfill operations over several years showed that these

Table 2. Ranking of Landfills by Increase in Mean Number of Flies ($\bar{x}$ ± S.D.)[a]

Sept.-Oct. Landfill	Compaction/Cover	Frequency (n = 90)	April-June Landfill	(n = 40)
1. Puu Palailai	many × daily/soil daily	0.78 ± 0.13	Olowalu	0.67 ± 0.15
2. Waikapu	many × daily/sand daily	7.28 ± 1.54	Puu Palailai	1.70 ± 0.34
3. Waianae	many × daily/soil 2× wk	7.94 ± 0.90	Waikapu	2.52 ± 0.84
4. Kapaa	many × daily/soil daily	10.09 ± 2.45	Kapaa	4.42 ± 1.69
5. Olowalu	many × daily/cinders daily	10.96 ± 2.64	Makani	8.32 ± 2.27
6. Makani	many × daily/soil daily	12.44 ± 2.59	Waianae	17.17 ± 5.69
7. Kailua	many × daily/cinders 1 × wk	23.96 ± 3.66	Kailua	23.55 ± 5.72
8. Kawailoa[b]	many × daily/soil 2 × wk	28.57 ± 2.91	Waiohinu	23.55 ± 3.30
9. Waiohinu	2 × wk/soil 2 × wk	30.62 ± 4.57	Kawailoa	32.22 ± 5.64
10. Waimea	1 × daily/none	72.06 ± 7.17	Waimea	67.35 ± 8.69
11. Kohala	2 × wk/none	106.76 ± 9.19	Kohala	72.75 ± 9.97

[a] Landfills treated with insecticides not included.

[b] Covered 4 times in 13 weeks because of non-delivery of soil/equipment breakdown.

large population changes usually occurred when compaction and cover frequencies were disrupted by equipment breakdown, non-delivery of cover material, or prolonged periods of rainfall. Of these three factors, landfill operators questioned generally agreed that prolonged periods of rainfall caused the greatest increase in fly populations. Wetting of refuse apparently increased and prolonged its fly breeding potential.

The higher emergence rates of adults from larvae buried beneath 61 cm of soil was attributed to the tendency of larvae to tunnel toward the surface before pupating. These tunnelings were visible along the side of the glass jar in which they were buried. The lower emergence rate from buried puparia was apparently caused by adults being trapped in the many air pockets visible in the soil along the side of the glass jar. It is suspected that these trapped flies stopped tunneling after reaching these air pockets because they were fooled into thinking that they had reached the surface. The practical value of using non-homogeneous soil covers with many air pockets to prevent fly emergence from buried puparia at landfills is probably minimal since few puparia would be found in refuse collected on twice a week schedules.

The emergence of flies from below 25 cm of moist soil that was compacted by a bulldozer disagreed with Black and Barnes' (1956) conclusion that 7.5 cm to 15 cm of compacted soil containing 6.5% to 12.5% moisture would prevent fly emergence under field conditions. Their observation of dead adults remaining in the space at the bottom of the plastic tubes containing compacted soil suggested the existence of a gap between the food medium and compacted soil that had prevented the larvae from migrating toward the surface to pupate. The difficulty in maintaining adequate moisture in the compacted soil because of our warm climate may have contributed to the failure of the soil cover in preventing fly emergence at the test site.

Although the efficacy of a minimum twice a week soil cover frequency in reducing fly populations was evident from the indices in Table 1, the question of how it actually reduced fly populations was not clear. The unhindered development of buried fly eggs and the emergence of flies from refuse beneath compacted soil covers clearly demonstrated that prevention of fly emergence was not the primary function of soil covers. The beneficial effect of soil covers in reducing adult fly populations was frequently observed during my three years of weekly inspections of sanitary landfills on Oahu. During these inspections, I have often observed landfill operators apply their sometimes limited supply of soil cover in very thin layers over the compacted refuse. Applications of this thin soil cover in which refuse could be seen protruding usually resulted in striking reductions in fly populations. This sudden reduction in fly populations suggested that soil covers affected fly populations by reducing odors that attracted immigrant flies.

Observations on several occasions of large differences in the amount of fly larvae found on compacted and uncompacted refuse when left uncovered for several weeks stressed the importance of the consolidation and compaction frequency at landfills. Immediate consolidation and compaction not only buries most fly breeding material before oviposition occurs but also flattens and dries exposed organic material to make them unfit for breeding. This denial of ovipositional material to flies should also include dead animals at landfills. Burying carcasses immediately with incoming refuse at the landfill face may be a more practical method of fly control than the use of dead animal pits. Dead animal pits would be ineffective because the eggs deposited on exposed carcasses during the day would still be capable of developing after being buried at the end of the day.

It is evident from this study that the key to fly control at sanitary landfills is to minimize fly oviposition on incoming refuse. To achieve this, it is necessary that flies already breeding in incoming refuse be kept to a minimum by adhering to a twice a week refuse collection schedule. Less than this frequency will greatly increase fly breeding in residential refuse before it is brought to landfills (Ikeda et al 1972). Minimizing oviposition on refuse after it arrives at landfills can be accomplished by the immediate consolidation and compacting of all incoming refuse and the application of a minimum twice a week soil cover. The failure of thick soil covers in preventing fly emergence suggested that a cost-saving thinner layer of soil cover than presently recommended could be used to adequately maintain its other functions of reducing odors, preventing fires, and minimizing trash flyaway.

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