Bionomics of the Dog Dung Fly, *Musca sorbens* Wiedemann, in Hawaii [1, 2]

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Musca sorbens Wiedemann (Diptera: Muscidae) is a dung breeding fly which occurs in the Ethiopian, Oriental, and some tropical and subtropical areas of the Palearctic region. The fly has also been recorded from many Pacific islands among which are Guam, Kwajalein, Ebeye, Aitutaki, Samoa, Solomon Islands, and Hawaii.

The larvae develop in various types of animal feces. Human, dog, pig, horse, cattle, and water buffalo dung are common breeding sources. In Hawaii, larval habitats include dog, cat, bovine, horse, goat, and pig dung (Yu 1971). Dog and cat dung were reported to be excellent sources for larval development when compared with cattle dung (Mau 1978).

The dog dung fly was discovered in Hawaii in 1949 (Joyce 1950). Wilton (1963) reported that there were many complaints about annoying flies where *M. sorbens* was present. By 1970, complaints about flies were widespread and numerous, and subsequent surveys by Department of Health entomologists indicated that much of the problem was directly attributable to activities of the dog dung fly.

In order to develop and implement control procedures, detailed information on the biology and seasonal abundance was needed. This paper presents the results of biological studies.

Materials and Methods

Rearing. A laboratory culture was established from field collections of adults from several locations on Oahu and maintained using the following procedures. Flies were provided daily with sliced beef liver beginning the second day following emergence and continuing for 3 days thereafter. When gravid, the females were allowed to oviposit for a 24 hour period in ca. 100cc of fresh dog dung. Eggs (ca. 200-300) were transferred to cups containing approximately 150 cc fresh dog dung. On the third day after addition of the eggs, the cups were placed in a tray of sand. The prepupal stage larvae migrated from the feces into the sand during the next 2 days and pupated. The puparia were sifted from the sand using a 12 mesh sieve and were placed (ca. 500/cage) into 25.4 cm cubical aluminum framed screen cages. Sugar cubes and water were provided at this time. Laboratory conditions were 26.7 ±2.2°C, 60% relative humidity and 10 to 12-hour photophase.

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Ovarian development and fecundity. Flies were collected as they emerged during a 12-14 hour period and were held in standard rearing cages. Sugar and water were placed in the cages and were available at all times. Sliced liver and dog feces were provided each morning.

Ovaries were dissected from 10 or 20 females at daily intervals. Each pair of ovaries was placed in insect saline in a cell of a Boerner slide. Measurements of size were taken using the width of each female's head as an indicator, since fly size directly affected fecundity. Ovaries were examined with a dissecting microscope to determine the stage of ovarian development. The egg stage classification method described by Tyndale-Biscoe and Hughes (1969) was used. In addition, Anderson's (1964) methods for distinguishing nulliparous from parous flies and for determining age of cyclorrhaphous Diptera were utilized. The number of stage 4 or 5 ova was determined and used to estimate fecundity. The study was replicated 4 times.

Pupal eclosion. Prepupal stage larvae were collected as they left the feces during a 12- to 14-hour period. Approximately 2 days after pupation, the puparia were sifted out of the sand and separated into replicate groups at random. Each group of puparia was held in an emergence cage as described by Mau (1975). A 9- to 10-hour photophase was maintained during the study. Puparia from 2 different fly generations were utilized. The study included 6 replicates from the first generation and 5 from the second.

Longevity. Longevity of flies were determined under laboratory conditions of 26.7 ±2.2°C, 60% RH, and 10- to 12-hour photophase. Two studies were conducted. The first involved flies that were provided with food and water. The second involved flies deprived of food and water.

Longevity of mated and unmated flies was investigated in the first study. Each replication of the mated group consisted of 10 males and 10 females which were held in a 500 cc paper container with a clear plastic lid. In the unmated group, each replication consisted of 20 males and 20 females which were placed in separate containers. The newly emerged flies were anesthesized with carbon dioxide to facilitate sexing, counting and placement in cages. Ten replicates were used in the mated group and 5 replicates in the unmated group. Sugar and water were placed in each cage, and fresh dog feces and sliced liver were provided daily. Mortality data were taken at 2-day intervals.

In the group without food, flies were held in the top half of the emergence cage used in pupa eclosion studies. Each cage contained the flies that emerged during a 2-hour period. Mortality data were taken at hourly intervals. A total of 368 females and 480 males was used in 4 replicates.

Daily adult activity. Daily activity of adults was determined from observations made during 12 months of field abundance studies and from specific trapping conducted at the Ala Wai Boat Harbor study area. Steiner fruit fly traps which were modified for live catch were used (Mau 1975). Fresh dog feces were used as the standard attractant. Trapping was conducted 5 times each day. The first trapping period was at sunrise, and thereafter trapping was done at ca. 3-hour intervals ceasing at sunset. Traps were allowed to catch flies for only 15 minutes during each period. Information on nocturnal behavior was derived from observations made an hour prior to sunrise and an hour after sunset.

Dispersal. A dispersal study was conducted to: (1) determine if populations were always high in certain areas because the flies did not disperse from these areas; (2) determine the relative rate of dispersal from fly emergence sites, and (3) determine the importance of dispersal in community fly problems.

Two releases of 0- to 1-day old flies marked with Tinopal SFG were made; 3517 and 2522 marked flies were released at the Ala Wai Boat Harbor and a residential area of Manoa, respectively. Seasonal and relative abundance trapping studies had shown that *M. sorbens* was consistently more abundant at the Ala Wai Boat Harbor than at Manoa.

Results and Discussion

Life history. Eggs were deposited in dung in clusters of several to more than a hundred. The females oviposited in cracks and crevices in the surface of the dung. Large clusters were formed by oviposition of several females. Eggs hatched within 9.5- to 11-hours and 90 ±7.6% hatched under laboratory conditions.

First instar larvae penetrated the surface of the dung within a few minutes after hatching. All 3 larval instars developed in the dung. Larval development was completed in 4-5 days. The duration of each instar did not deviate significantly from that presented by Okada (1973).

Mature larvae left the dung during the 4th or 5th night, and pupation occurred within a day. The duration of the pupal stage was 4-6 days. Adult emergence averaged 90%.

The majority of the adults emerged from the puparium during the night and early morning hours. Feeding did not occur for several hours following emergence. Earliest mating occurred approximately 3 days after emergence and mating activity was high during the 4th to 7th day. Oviposition began approximately 6 days after emergence.

Pupal eclosion. A diel-like periodicity was observed in studying pupal eclosion. Although replicates varied as to the proportion of flies that emerged daily, a general adult emergence rhythm was observed (Fig. 1A). Emergence began during the late afternoon or early evening, peaked during the morning, and practically ceased by noon. A similar emergence rhythm occurred during the second night. An average of 92% emerged during the 2-day period. Of this 51% and 49% emerged during the 1st and 2nd cyclic periods, respectively. The emergence period in Hawaii differed somewhat from that in Egypt. Hafez and Attia (1958) reported that maximum emergence of adults in Egypt occurred between 4 a.m. and 8 a.m., with peak emergence occurring between 6-7 a.m. Although our time of peak emergence was approximately the same as in Egypt, the daily emergence period was longer in Hawaii. These differences could have been due to differences in photoperiod or day-night laboratory temperatures.

A higher proportion of females emerged during the 1st night, and a higher proportion of males emerged during the second. Forty-four percent

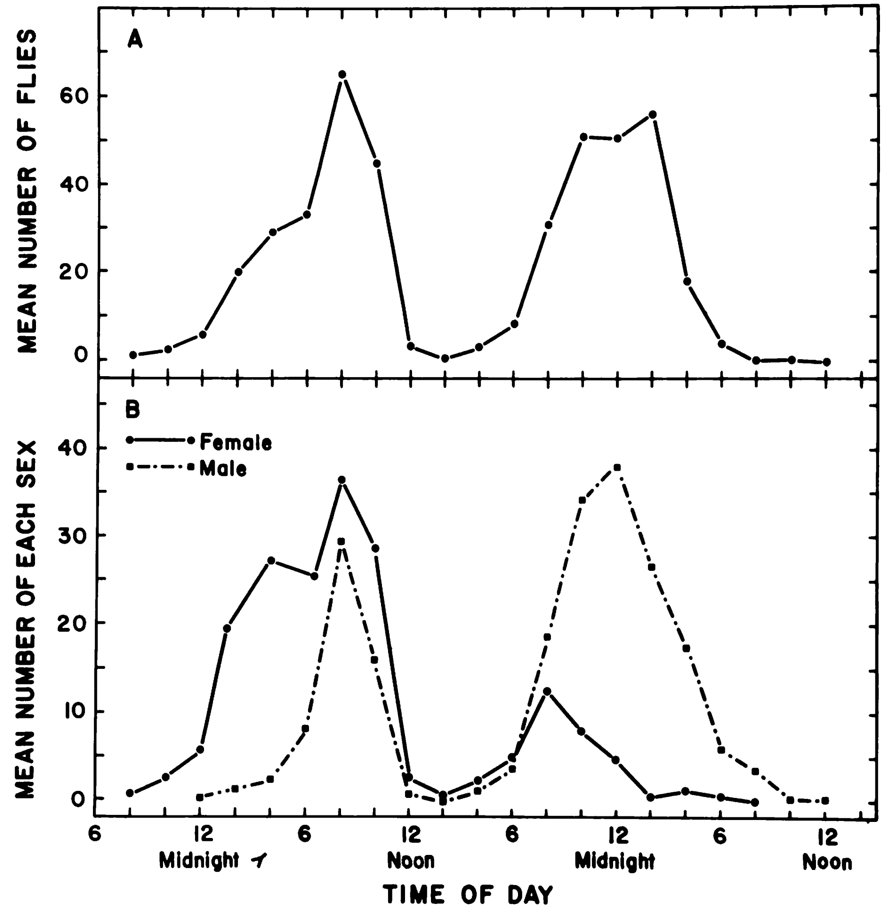

FIGURE 1. *Musca sorbens* adult emergence rates. A—Mean emergence of adult flies; B—Mean emergence of each sex.

more females than males emerged during the 1st period and 52% more males than females during the second. Since all prepupal stage larvae were collected during a 12- to 14-hour period, the differences in daily emergence of each sex strongly suggested that there was a differential rate of development between the sexes during the pupal stage. Similar observations were reported for *Musca vetustissima* Walker by Hughes et al. (1972); the developmental rate of females was slightly faster in the larval stage and was more pronounced during the pupal stage.

Sex ratio. Field trapping with dog dung as bait resulted in catches composed of significantly ($P < 0.01$) more females than males. Similar results were obtained when trapping was done during the various times of the day (Fig. 5) or when trapping was done at biweekly intervals for ca. 1 year (Fig. 2). Since previous evidence supported a 1:1 sex ratio, the sex ratio of the adults in the pupal eclosion studies was analyzed to determine whether the sex ratio in our population differed significantly from those of Hafez and

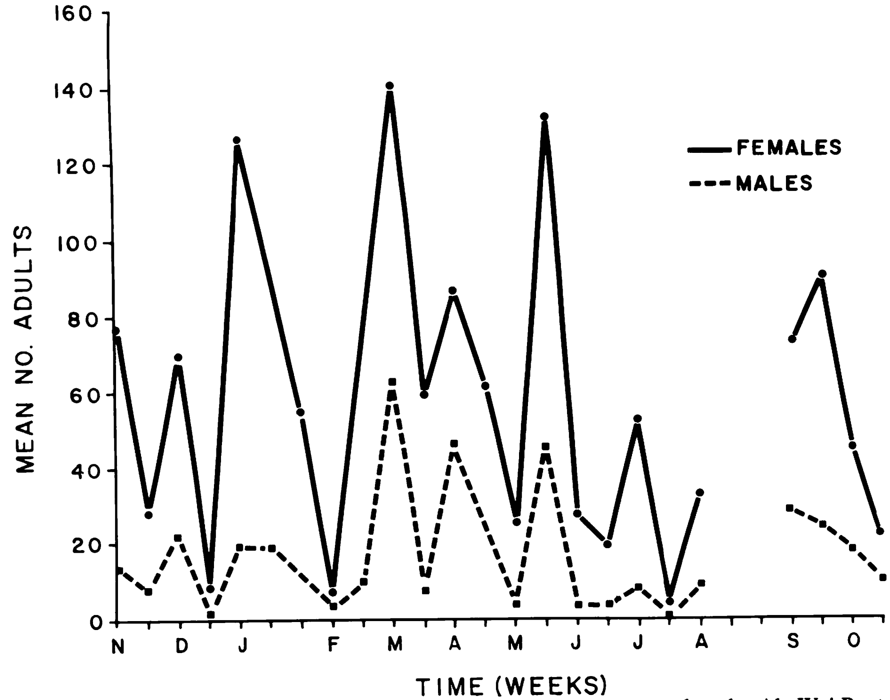

FIGURE 2. Relative numbers of male and female *Musca sorbens* trapped at the Ala Wai Boat Harbor study area during the period November 1971 through October 1972.

Attia (1958) and Yu (1971). These data revealed that the sex ratio in our population, 1 female to 1.1 males (983 females; 1040 males), did not differ from those of the previous workers.

Therefore, the great deviations from a 1:1 sex ratio in trap catches were a reflection of the differential attractiveness of the bait and were not due to a different sex ratio of flies produced under field conditions. Since dog feces, the normal ovipositional medium, was the standard attractant used in our traps, it is apparent that the females were much more attracted to this bait than were the males. Females used dog feces for food, moisture, and oviposition, whereas, males were probably only attracted for food and moisture. Moreover, results of trap efficiency studies showed that females of almost every physiological age group were attracted to dog feces (Fig. 3). It is likely that flies in age groups 0-1, 2, 3, and 4 were attracted for moisture and nutrients required for ovarian development, and females of group 5 were attracted for moisture and oviposition. Results of a study by Tyndale-Biscoe (1971) showed that *M. vetustissima* males only casually fed on protein (blood or feces), and that such feeding did not increase the number of matings, mating success, sexual activity, or longevity.

Further analysis of the results presented in Fig. 3 showed that there was a significant ($P < 0.01$) correlation (in the ratio) of females and males which were trapped. These results are significant for the following reason. Monitoring of fly populations could use either male or female numbers as a relative estimate of abundance; the use of male counts would save a tremendous amount of time in such a program.

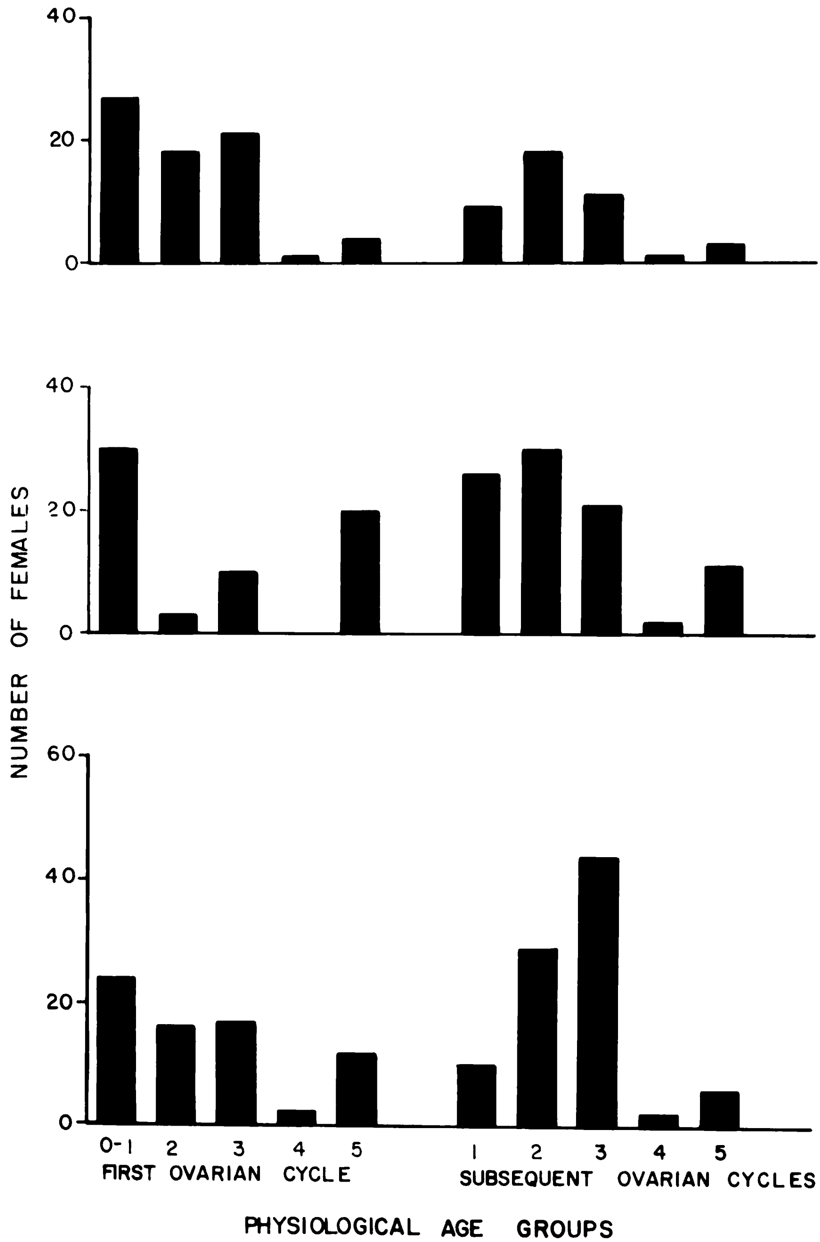

FIGURE 3. Relative numbers of *Musca sorbens* females or different physiological ages collected using modified Steiner traps and dog feces bait. Trapping was conducted during 3 different periods.

These studies also showed that females are probably more likely to be involved in mechanical transmission of fecal-borne diseases because of their close association with feces. Furthermore, because of this close association, dog feces should be closely analyzed to determine the component which is responsible for its great attractiveness. Identification and synthesis of the attractant may provide a useful tool for managing the obnoxious species.

Reproductive potential. Three factors which could affect the number of eggs produced were female size, food quality, and fly longevity. Female size could determine the maximum number of eggs which are developed. Food quality could affect the number of eggs developed and the rate of ovarian development. Longevity could determine the total number of eggs each female develops in her lifespan.

TABLE 1. *Mean fecundity per ovarian cycle of laboratory reared* Musca sorbens.

Ovarian Cycle	No. of Flies Examined	Head Width (mm) $\bar{x}$	s	No. of Eggs per Fly $\bar{x}$	s
1	169	2.15	0.116	41.4	5.5
2	55	2.17	0.095	42.3	5.3
3	49	2.17	0.093	43.1	4.1

TABLE 2. *Comparative ovarian developmental rates of* Musca sorbens *in response to different sources of protein.*

Diet	Dissection Age (Days)	No. Flies	No. of Flies in Ovarian Cycle I	II	III
Liver	9	40	0	13	27
Dog feces	8-10	40	40	0	0
*Field protein (Unknown Source)	9	23	2	21	0

*Marked laboratory reared flies released at Ala Wai Boat Harbor in February 1972 and recaptured 9 days later.

Females were multiparous and completed 3 ovarian cycles within the 2 week period following emergence. The first cycle was completed in 4-6 days, and the 2nd and 3rd each in 2-3 days. An average of 42 eggs was produced during each egg cycle (Table 1). Not surprisingly, in this experiment differences in egg production and adult size were not significant ($P > 0.01$). Since these flies were reared at almost optimal conditions, the size variations in the flies were not large and the data probably was an expression of the maximum ovarian development and egg production rates.

Since dog feces appeared to be a major food source in the field, studies were conducted to determine the nutritional quality of dog feces as it affects ovarian development rate and fecundity. For comparison, a second group of flies was provided with the standard laboratory food, steer liver. In addition, a third group of flies, which was laboratory-reared, released in the field, and recaptured, was examined. These flies were 9-days old when recaptured and had ostensibly fed on proteins in the field. The data from the dissections of the 9-day old flies are presented in Table 2. As expected, the females fed liver exhibited the most rapid rate of ovarian development. Nine-day old flies from this group had already oviposited twice and were developing the 3rd complement of eggs.

The rate of ovarian and egg development in females of the dog feces group was significantly slower. They had not oviposited at all. Subsequent observations with other flies to confirm these data revealed that the last stage ova of the first ovarian cycle were present in 9-day old flies in one replication and in 15-day old flies in two other replications. Although these flies had not yet oviposited, they were within a day or two of the initiation of oviposition. Other studies (Mau 1975) have shown that the flies oviposited one or two days after the appearance of last stage ova.

Females that had been released in the field and recaptured showed that they had oviposited once and were developing second clutches of eggs.

These results showed that food quality affected the rates of ovarian development. Liver was superior to dog feces for rapid egg production. The ovarian development of recaptured females suggested that dog feces were probably not the only source of proteinaceous food in the field. This was most surprising since no other food sources were observed and the flies were always found in the vicinity of fresh dog feces.

We also found that food quality also affected fecundity of *M. sorbens.* Females of the dog feces group produced fewer eggs than those of the liver group (Table 3). Two paired tests were conducted, and the differences in egg production were significant ($P < 0.01$). Each female in the dog feces group produced an average of 22 eggs per ovarian cycle compared with 36 for females in the liver group.

Although dog feces are obviously inferior to liver as a protein source, they still must be considered an important protein source in the field because of their availability and high attractiveness to females. It is apparent, however, that other proteinaceous foods are utilized by *M. sorbens.* A conclusive assessment of the importance of dog feces for egg production in the field cannot be made without identifying these additional foods. Total fecundity of *M. sorbens* was not ascertained since it was extremely difficult

TABLE 3. *Comparison of food quality of beef liver and dog feces for* Musca sorbens *Wiedemann ovarian development.*

Test Number	Food	Head Width (mm) $\bar{x}$	s	Student's t-test Value	Eggs per Ovarian Cycle $\bar{x}$	s	Student's t-test Value
1	Liver	1.91	0.069	0.823 NS 38df	30.4	4.5	8.91** 38df
	Dog Feces	1.89	0.060		14.7	1.9	
2	Liver	2.10	0.068	0.950 NS 31df	40.5	6.7	3.68** 31df
	Dog Feces	2.12	0.062		29.8	9.3	

NS = no significant difference at 0.05 level.
** = significant difference at 0.01 level.

to determine total fecundity from dissections, and it was not practical to determine fecundity from eggs deposited in media.

Longevity. With adequate food and water, the maximum lifespan of adults was ca. 2 months (Fig. 4A). Fifty percent of the adults lived for 4-5 weeks and 10 percent as long as 7-8 weeks. Differences in the longevity of unmated and mated adults and between males and females were not significant ($P > 0.01$).

In the absence of food and water, *M. sorbens* adults did not survive more than 45 hours. Accelerated mortality began ca. 18 hours after emergence

(Fig. 4B). Fifty percent of the flies died within 27 hours after emerging.

Behavior. Flight was confined to the period between sunrise and sunset. The results of trapping showed that daily activity began at or soon after sunrise and ceased a few minutes before sunset (Fig. 5). Females were more active than males during these transitional periods. For example, 83 and 100 percent of the adults trapped at sunrise and sunset, respectively, were females. In lowland areas where the studies were conducted, sunlight appeared to be the major stimulus which triggered the beginning and ending of diurnal activity. Temperature may have influenced activity during the morning hours, but it did not inhibit activity totally.

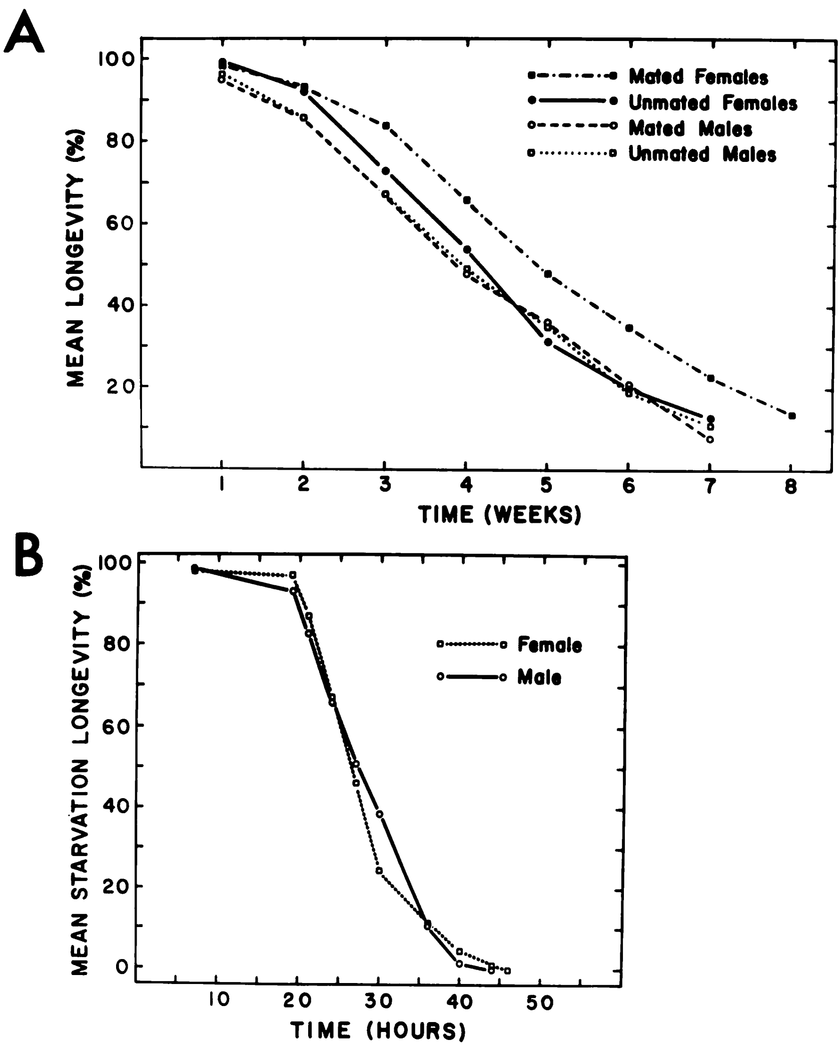

FIGURE 4. Longevity of *Musca sorbens.* A—With adequate food and water. B—Without food and water.

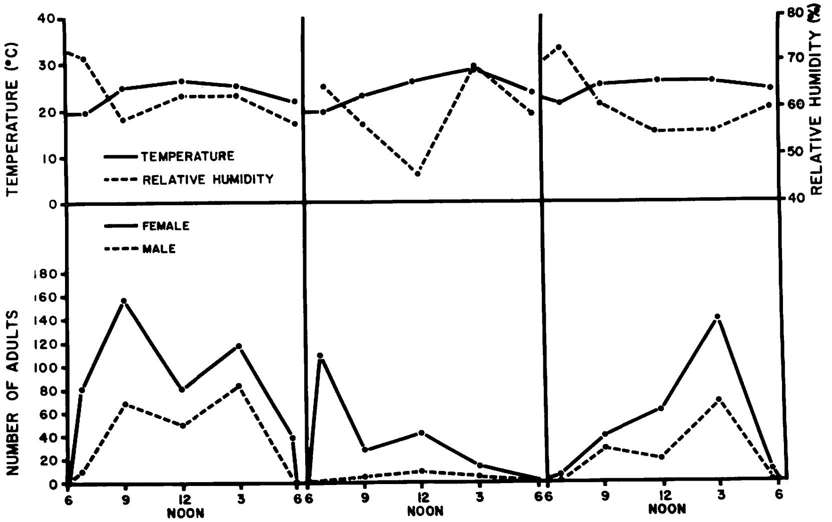

FIGURE 5. Diurnal activity of *Musca sorbens* adults as measured by bait trapping.

However, there was no consistant diurnal pattern of activity that could be detected in the flies. In three days of trapping conducted at one location (Fig. 5), one showed a biomodal curve and two had a unimodal curve. On the first day activity peaked at 9:00 a.m. and 3 p.m., on the second day at 7:00 a.m. and on the third day at 3:00 p.m. These results differed from those presented by Yu (1971), who indicated that *M. sorbens* followed a unimodal activity curve in Hawaii.

Peak activity apparently can occur almost any time of the day in Hawaii. Since there are definite peaks in activity, it is apparent that there are factors affecting the flies. Whether these factors are extrinsic (i.e., temperature, humidity, light, etc.) or intrinsic (i.e., physiological, reproductive, nutritional, etc.) or combinations of these factors is not known. The extrinsic factors, however, are generally within the activity range of the flies.

At night adults were found on blades of grass, grass flower spikes, and on leaves of shrubs. Flies were not observed on the trunks or fronds of young coconut trees in the study area. In general, the flies were found close to the ground (ca. 1 m). They were found throughout the study area but were most numerous near the trapping site where abundance studies showed populations to be highest. No sexual preference for resting sites was observed.

Flower spikes of graminaceous plants were the preferred resting sites in the study area. Those flies which were observed on grass blades were usually found on those which were 7-13 cm above the ground; no flies were found at ground level. On shrubbery such as beach naupaka, *Scaevola sericea* Vahl, the flies were always found on the exposed leaves and rarely deep in the foliage.

The results of the dispersal study indicated that the flies dispersed more slowly from the Ala Wai area than from Manoa. Five percent and 0.3 percent of the flies were recaptured 1 day after release at the high and low abundance sites, respectively. Eight days after release, 0.3 percent of the flies was recaptured at the Ala Wai site and none was trapped at the Manoa release site.

Although most of the flies apparently left the release sites, the total number trapped in adjacent areas was surprisingly few. At the boat harbor area only 6 (3 females, 3 males), 2 (2 females), 10 (9 females, 1 male), and 3 (3 females) flies were caught at 7 adjacent trapping sites 1, 3, 8 and 15 days after release, respectively. At the Manoa study area 89 (72 females, 17 males), 17 (1 female, 16 males), and 4 (4 females) flies were caught at 3 adjacent trapping sites 1-hour, 1 day, and 8 days after release, respectively. These results suggested that the majority of the flies rapidly moved out of the study areas. The flies seemed to disperse at random from the release sites.

The results indicate that a community-wide effort at controlling *M. sorbens* must be made to reduce or eliminate the problem. Random dispersal from fly breeding areas within a community is likely to affect the entire community; thus, a community effort is important in managing dog dung fly numbers.

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