

THE EFFECTS OF POULTRY HOUSE DESIGN ON THE PRODUCTION OF
FANNIA CANICULARIS AND F. FEMORALIS LARVAL AND PUPAL POPULATIONS

by

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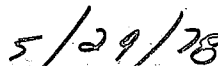


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ABSTRACT

A study of the seasonal abundance of Fannia canicularis (Linnaeus) and F. femoralis (Stein) pupal and larval populations was conducted from mid-March through late August, 1976, at the University of Arizona Poultry Research Center, Tucson, Arizona. Larvae, sampled by Berlese funnel extraction, and pupae, sampled by water flotation, were collected from four laying houses, each being of a different design. Data were compared and results indicated significantly lower populations in one of the four houses, demonstrating a construction design which suppresses Fannia populations. Factors such as competition, moisture content of manure and temperature, and their effects of Fannia populations are discussed.

In addition, data on percent pupal parasitism and the identification of pupal parasite species are presented and discussed.

INTRODUCTION

High humidity and chemical stimuli produced by amassed poultry manure attract females of both Fannia canicularis (Linnaeus) and Fannia femoralis (Stein). This is especially true in semi-arid areas such as southern Arizona, where there are few acceptable oviposition sites. F. canicularis and F. femoralis, as well as Musca domestica Linnaeus, have been identified as the major dipteran pests breeding in poultry manure (Peck and Anderson 1969a; Wicht and Rodriguez 1970; Legner and Brydon 1966). Although both species of Fannia are most frequently reported as being associated with poultry manure, they are not restricted to this substrate. These species have been reared from a wide variety of plant and animal organic matter, including dog feces (Poorbaugh and Linsdale 1971), cattle manure (Ogden and Kilpatrick 1958), lawn clippings (St. Germaine 1956), decaying tomatoes (Nelson 1938), decaying plums, peas, corn and onions (Chillcott 1960), highly fertilized soil (Eastwood and Tuff 1957), mammalian corpses (Illingsworth 1926), and from the nests of a number of bird species (Nordberg 1936).

It is in amassed poultry manure, however, that populations of Fannia species reach extremely high numbers. Smith (1954) reports a chicken farm with 17,560 F. canicularis larvae per square foot of surface under cages. When populations of these flies build, adults often invade homes of nearby residential areas, causing annoyance and

posing a possible threat to human health. Cases of intestinal and urinary myiasis in man have been attributed to F. canicularis (Hewitt 1912; James 1947), and Greenberg (1971) provides long lists of pathogens associated with both F. canicularis and F. femoralis. Both species have been reported to carry the virus of Newcastle's disease, and thereby pose a threat to the chickens with which they are associated (Rogoff et al. 1975). In addition, F. canicularis serves as the intermediate host of the nematode parasite Thelazia californiensis Price, which infects the eyes of a number of wild and domestic mammals, including man (Burnett et al. 1957).

Much work has been done in the area of fly control in poultry manure. Natural control is responsible for 90% mortality of Fannia larvae in poultry manure (Legner, Bay and White 1967). Legner and Brydon (1966) report that, aside from physical factors, predatory arthropods appear to have the greatest impact on total numbers of dung-inhabiting flies. These predators attack the egg and larval stages of the flies, but rarely attack the pupal stage (Legner 1971). Since predators are ultimately responsible for such a significant reduction in the fly population, treatment of manure with insecticide is generally discouraged (Axtell 1970; Anderson and Poorbaugh 1964). However, Stone and Brydon (1965) report satisfactory (99.1% mortality) control of immature Fannia by stirring Diazinon (0-0-Diethyl-0-(2-isopropyl-6-methyl-5-pyrimidinyl) phosphorothioate) and gypsum dust into manure. In laboratory studies using first instar larvae of F. canicularis, Eversole, Lilly and Shaw (1965a) report greater than 90%

control using Diazinon, Dimethoate (0,0-Dimethyl S-(N-methylcarbamomyl-methyl) phosphorodithioate) and Coumaphos (0,0-Diethyl O-(3-chloro-4-methyl-2-oxo-2H-1-Benzopyran-7-yl) phosphorothioate), applied in separate tests to poultry manure. When Coumaphos was applied as a feed additive, however, its effectiveness decreased by about seventy-fold (Eversole, Lilly and Shaw 1965b).

Variable outcomes have resulted from treatment of manure with Bacillus thuringiensis Berliner. Dose levels found to be most effective when fed to caged layers resulted in some reduction of feed consumption and egg production (Briggs 1959). This was an unacceptable side effect. Hall, Dulmage and Arakawa (1972) could achieve only 40-60% mortality of F. canicularis larvae using B. thuringiensis, in an integrated program in conjunction with two species of predator mites, Macrocheles muscaedomesticae (Scopoli) and Fuscuropoda vegetans (DeGeer). Their result was a significant decrease in dipteran larval populations. Rodriguez, Singh and Taylor (1970) later found that using these acarine species alone, they could achieve 86-99% control of house flies, under semi-field conditions.

Laboratory tests on the possible role of the fungus Beauveria bassiana (Balsamo) Vuillemin as a biological control agent for Fannia species have shown promise, giving up to 87% mortality in the larvae of F. femoralis (Hall et al. 1972).

Considerable research has been conducted on the arthropod predators of fly species in poultry feces. Field studies to identify species and determine seasonal abundance of predators have been

conducted by Peck and Anderson (1969a), Legner et al. (1975) and Steve (1959).

Laboratory studies on the feeding behavior and predatory potential of certain larval and pupal predator species have been conducted by Peck and Anderson (1969b). Legner et al. (1975) concluded from their studies that different predator species are important in different seasons, and that natural enemy complexes, rather than individual species, are required for optimal control.

In addition to predators, parasites, which infect the pupae, are important in the suppression of fly populations. Arthropod parasites are the only organisms that seem to be important in destroying final-instar larvae and pupae (Legner and Brydon 1966). Studies to identify species and determine seasonal abundance of pupal parasites have been conducted by Legner (1966), Legner and Olton (1971), and Legner et al. (1975). Pupating larvae of Fannia species represent only 10% of the total number of deposited eggs (Legner et al. 1967). This surviving 10% is responsible for the total adult population. A reduction in numbers of individuals at this point in the life cycle would, therefore, have the most direct impact on adult populations.

Attempts to utilize pupal parasites as a biological control agent have resulted in only marginal success (Legner and Brydon 1966; Olton and Legner 1975). Legner and Dietrick (1972) mass-released parasites and achieved an almost twofold increase in the percent parasitization of fly pupae.

The construction of laying houses and management of manure play a significant role in the suppression of fly populations. Eastwood et al. (1967) report that, by composting, manure can be rendered unsatisfactory for the development of dipterous larvae. Rodriguez et al. (1970) report that dry manure does not produce flies, and they mention other cultural methods, such as the repair of faulty watering systems, as a means of controlling fly populations. Legner and Brydon (1966) suggest that certain modifications of housing structure might improve the environment to favor parasite activity.

This study was initiated to investigate the effects of laying house design on the production of larval and pupal populations of Fannia canicularis and F. femoralis.

METHODS AND MATERIALS

Location and Description of Study Area

The study was conducted at the Poultry Research Center, at the University of Arizona Casa Grande Highway Farm (Fig. 1). The center is located 7 km northwest of the U. of A. main campus on Interstate Highway 10, at $111^{\circ} 00' 10''$ east longitude, $32^{\circ} 15' 30''$ north latitude, at an elevation of 698 meters. The entire facility occupies 42.8 hectares and, in addition to the poultry center, it houses a cattle feedlot, a small alfalfa field and an installation operated by the Water Resources Department.

The Poultry Resource Center was bordered to the north by Interstate Highway 10, to the east and south by a large undeveloped area consisting of desert vegetation, and to the west by a small pecan orchard. Total rainfall during the sampling period (mid-March to late August) was 12.8 cm. The mean high temperature was 31° C, the mean low temperature 13.22° C (Fig. 2).

Of the twelve poultry houses at the research center, four were selected for sampling, each being of a different design (Fig. 3). House 1 had a total area of 836.1 m^2 , and an 11,004 bird capacity. One half of the house consisted of floor pens, which were not sampled. The other half consisted of suspended cages arranged in three rows, with concrete aisles separating each. Birds were held in $45.7 \text{ cm} \times 61 \text{ cm}$ cages, four birds per cage, suspended 1.37 m above a

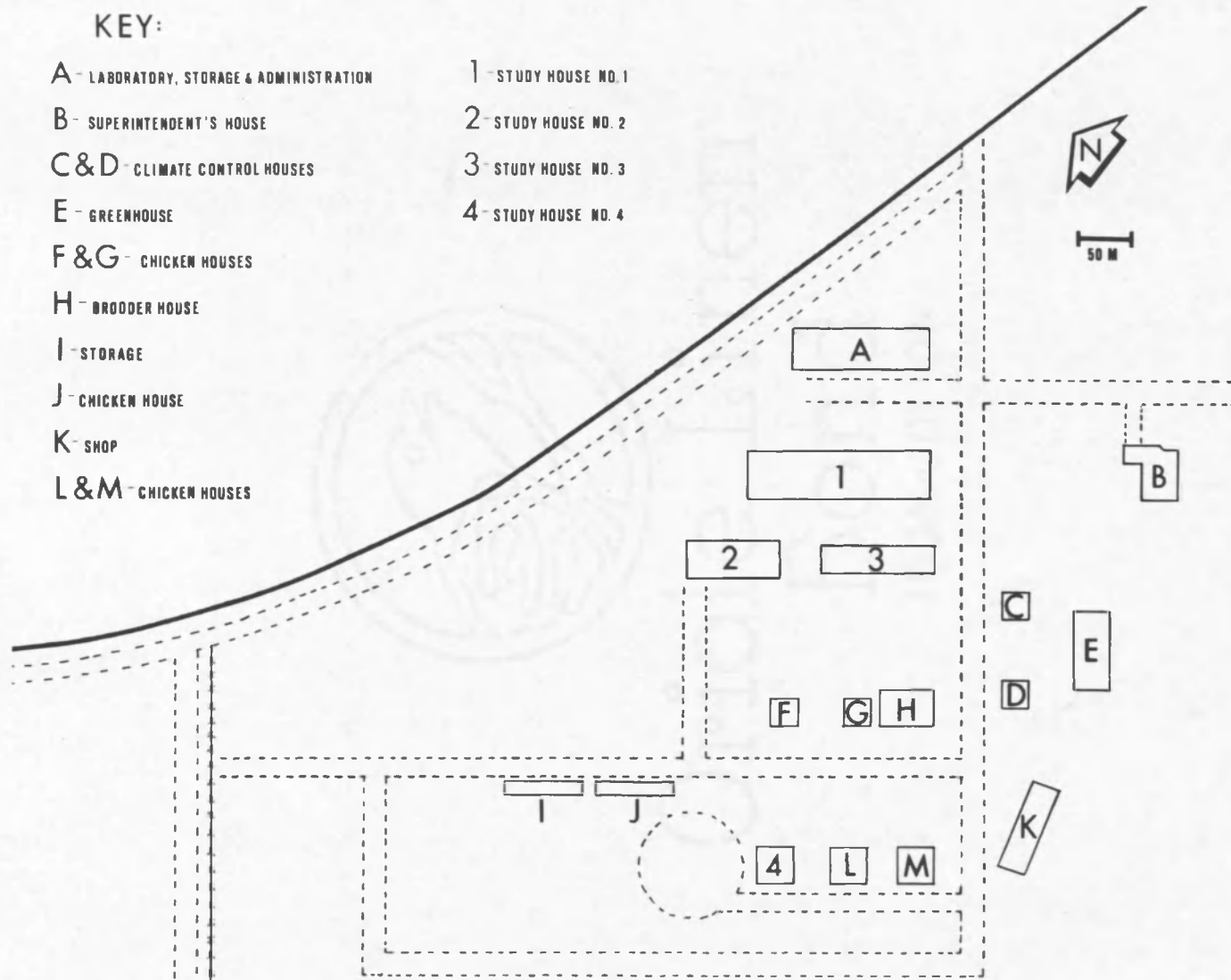


Figure 1. Overall layout of the Casa Grande Highway Farm, Poultry Research Center, showing relative positions of the four study houses.

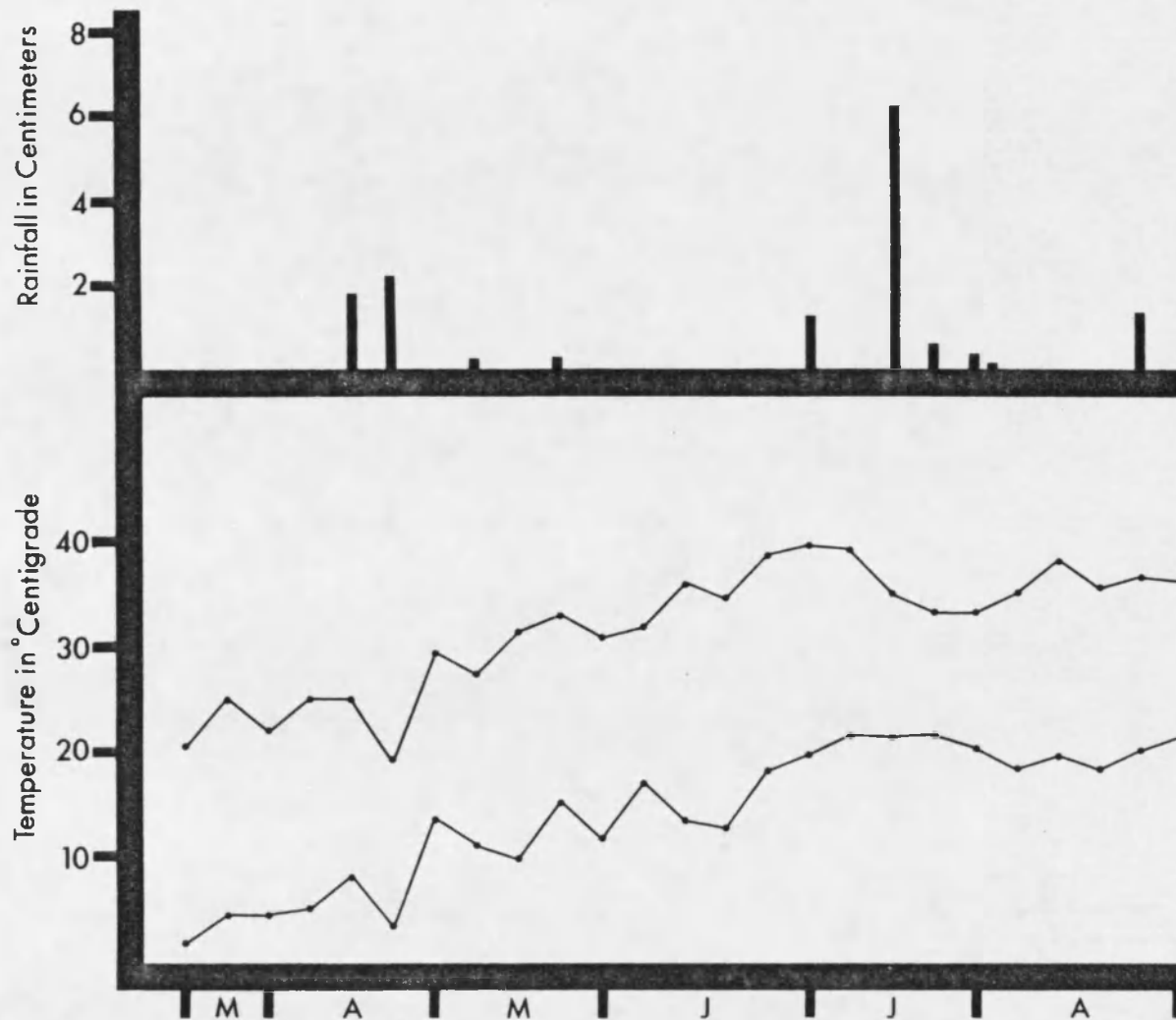
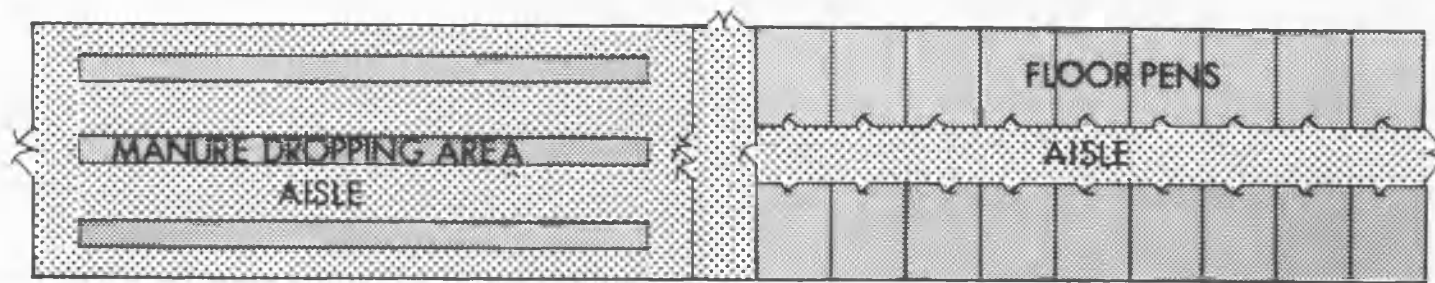
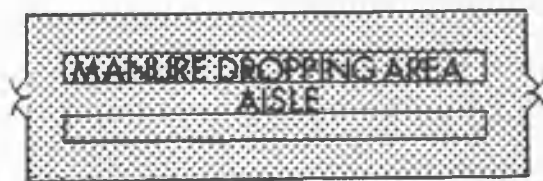


Figure 2. Maximum and minimum temperatures and precipitation at the Casa Grande Highway Farm during the 1976 study period (beginning with the week of March 12).



HOUSE NO.1



HOUSE NO.2



HOUSE NO.3

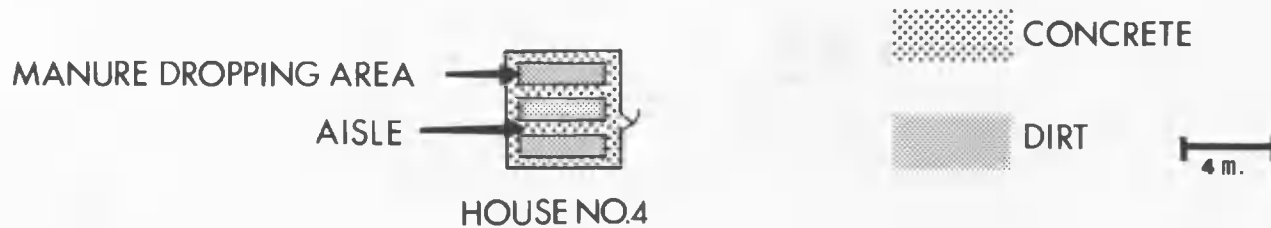


Figure 3. Floor plans of the four poultry houses sampled.

dirt-bottomed manure dropping area. This dropping area was 5 cm deep, 1.35 m wide and 28 m long.

House 2 had an area of 193.2 m², with a 544 bird capacity. This house contained suspended cages arranged in two rows, separated by concrete aisles. Cages were of the same dimensions as those in House 1, and also housed four birds each. Each cage was held 86.6 cm above a manure dropping area. The dropping area was 8.9 cm deep, 1.03 m wide and 20.78 m long. Unlike House 1, the dropping area in House 2 had a concrete bottom.

House 3 had the capacity of holding 520 birds, with a total area of 223.5 m². The birds were housed in cages measuring 22.9 cm x 45.7 cm, with one bird per cage. The cages were arranged in three rows separated by concrete aisles and suspended 81.3 cm above the dirt floor. The manure dropping area was 11.4 cm deep, 1.05 m wide and 29.87 m long.

House 4 was a constant temperature cage house. This house was constructed with corrugated sheet metal so that it was completely closed, in contrast with Houses 1, 2 and 3, which had open sides permitting fresh air and sunlight to enter. House 4 was also equipped with an evaporative cooling system, while the other houses were not. House 4 was the smallest of the four study houses, with a total area of 30.1 m² and a capacity of 240 birds. The cages, measuring 61 cm x 45.7 cm, each held 4 birds and were suspended 82.6 cm above a dirt floor manure dropping area, which measured 12.7 cm deep, 91.4 cm wide, and 6.2 m long.

Sampling Methods

Sampling was conducted between mid-March and late August, 1976. Larval samples were taken once a week and pupal samples on alternate weeks. Two sampling methods were employed, Berlese funnel extraction for larvae, and water flotation for pupae.

Berlese Funnel Extraction

Five one-liter manure samples were taken from each of the four study houses. Each one-liter sample was collected using a sheet metal trough, measuring 55 x 13 x 8 cm, and a trowel. The trough was inserted into the manure at a 45° angle, and each sample was obtained by "back hoeing" the manure into a one liter container. The sample was then placed in a brown paper bag. When all the samples had been collected, they were placed in individual Berlese funnels and larvae extracted with forty watt incandescent lights for forty-eight hours. Larvae were collected in vials containing 70% ethanol, placed at the bottom of each funnel, and returned to the laboratory for processing. The content of each vial was placed in a large petri dish which was manipulated to evenly distribute the material over its bottom surface. The bottom surface was divided into fourths and counts of all Fannia spp. larvae in one quadrant were made. This number was multiplied by four and recorded for each sample. The samples were then placed in coded vials and preserved in 70% ethanol.

Species composition of the samples was determined as follows:

Twenty Fannia larvae were subsampled from each vial and the number

of F. canicularis and F. femoralis specimens in each subsample was recorded. This provided a ratio on which the total number of each species was estimated. Identification of larvae was made using the characters described by Chillcott (1960).

Water Flotation

Five one-liter manure samples were taken randomly from each of the four houses in the same manner as described for the larval samples. The samples were placed in plastic buckets (9.4 liter) which were then filled to approximately one-half capacity with water. The contents were stirred, causing pupae and debris to be floated to the surface. This floating material was placed through a series of sieves and rinsed until only the pupae remained. The pupae thus collected were then transferred to bags made of plastic screen (6.6 msh/cm) and transported to the laboratory for processing.

At the laboratory, the pupae were placed into a candling device to separate the viable individuals from empty pupal cases. The device consisted of a glass petri dish set atop an overturned translucent plastic container, with a forty watt incandescent light bulb inside. The device provided backlighting in such a way that viable pupae would appear dark whereas empty pupal cases appeared bright. The viable pupae were then placed in individual gelatin capsules (size 000) and held at 25° C for adult and parasite emergence.

Following emergence, adults were pinned, labeled and identified. Numbers of F. canicularis and F. femoralis adults were recorded and the specimens placed in Schmitt boxes for storage. Each capsule observed

to contain an emerged parasite(s) was set aside. The parasitized pupae were removed and identified. Data for total numbers and percent parasitization were thus obtained.

Moisture Content of Manure

Manure samples were taken on March 15, April 17 and May 17, 1977, to determine moisture content. On each date five small samples (approximately 10 grams) were taken from each house. These were returned to the laboratory, weighed, and then dried in a vacuum oven to constant weight. This provided data on percent moisture by weight for manure in each of the study houses.

RESULTS AND DISCUSSION

Seasonal Abundance of Larvae

Seasonal abundance data are presented in Figures 4 through 7, each figure representing the population in one of the four test houses. Houses 1 and 2 had similar manure management systems and yielded the largest larval populations. In these houses, manure accumulated in a mass of uniform height below the cages. Each cage contained four birds and the cages were suspended about 1 m. above the manure dropping area. This arrangement provided an ideal larval habitat in that the manure accumulated rapidly, evenly and retained a high moisture content.

In House 1, the floor of the dropping area was composed of dirt, whereas in House 2, the dropping area was composed of concrete. This difference seems to have little affected the populations of Fannia larvae. In both houses the larvae of F. canicularis far outnumbered those of F. femoralis. In House 1 (Fig. 4) the mean population density of F. canicularis peaked on April 14 (House 1 \bar{X} = 583.5 larvae/liter; House 2 \bar{X} = 591.8 larvae/liter), followed by a rather drastic decline on the next sample date, April 20 (House 1 \bar{X} = 379.5 larvae/liter; House 2 \bar{X} = 299.3 larvae/liter). This decline was apparently due to a drop in temperature during that week.

The mean low temperature for the week of April 8 was 8.16° C. This dropped to a mean low of 2.88° C for the week of April 15. Nieschulz (1935) reports that F. canicularis is inactive below the

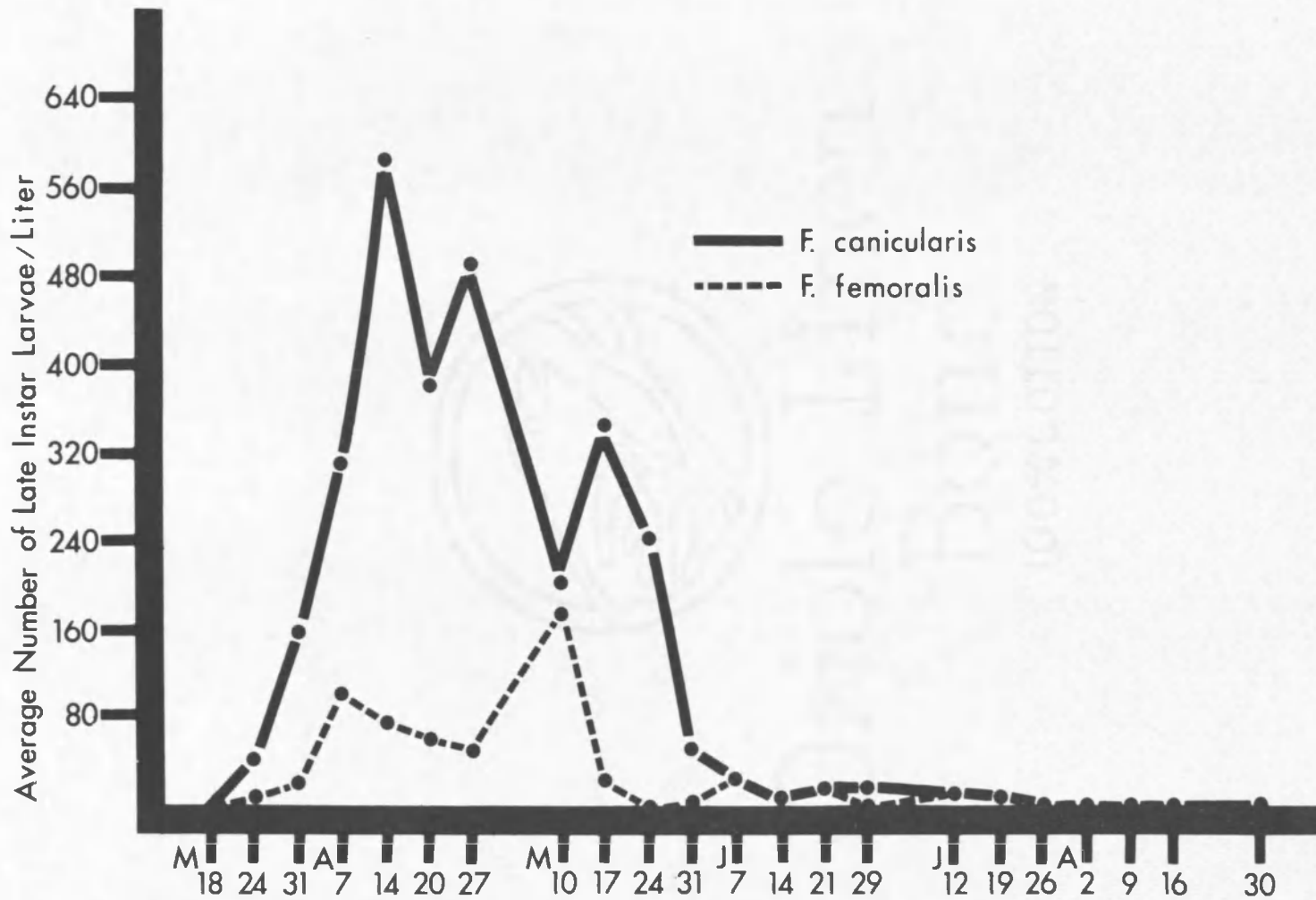


Figure 4. Seasonal abundance of second and third instar *Fannia femoralis* and *F. canicularis* larvae in House No. 1.

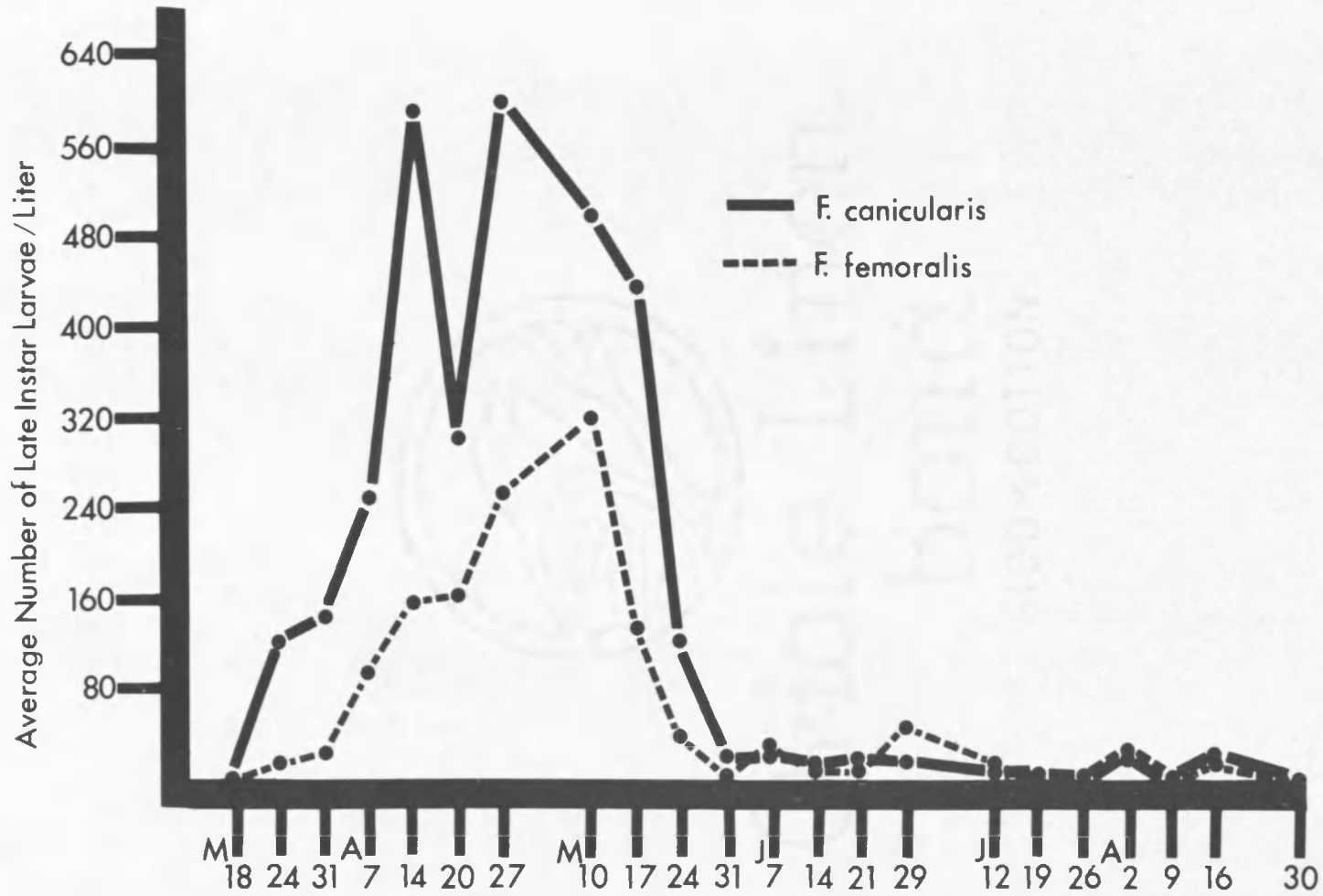


Figure 5. Seasonal abundance of second and third instar *Fannia femoralis* and *F. canicularis* larvae in House No. 2.

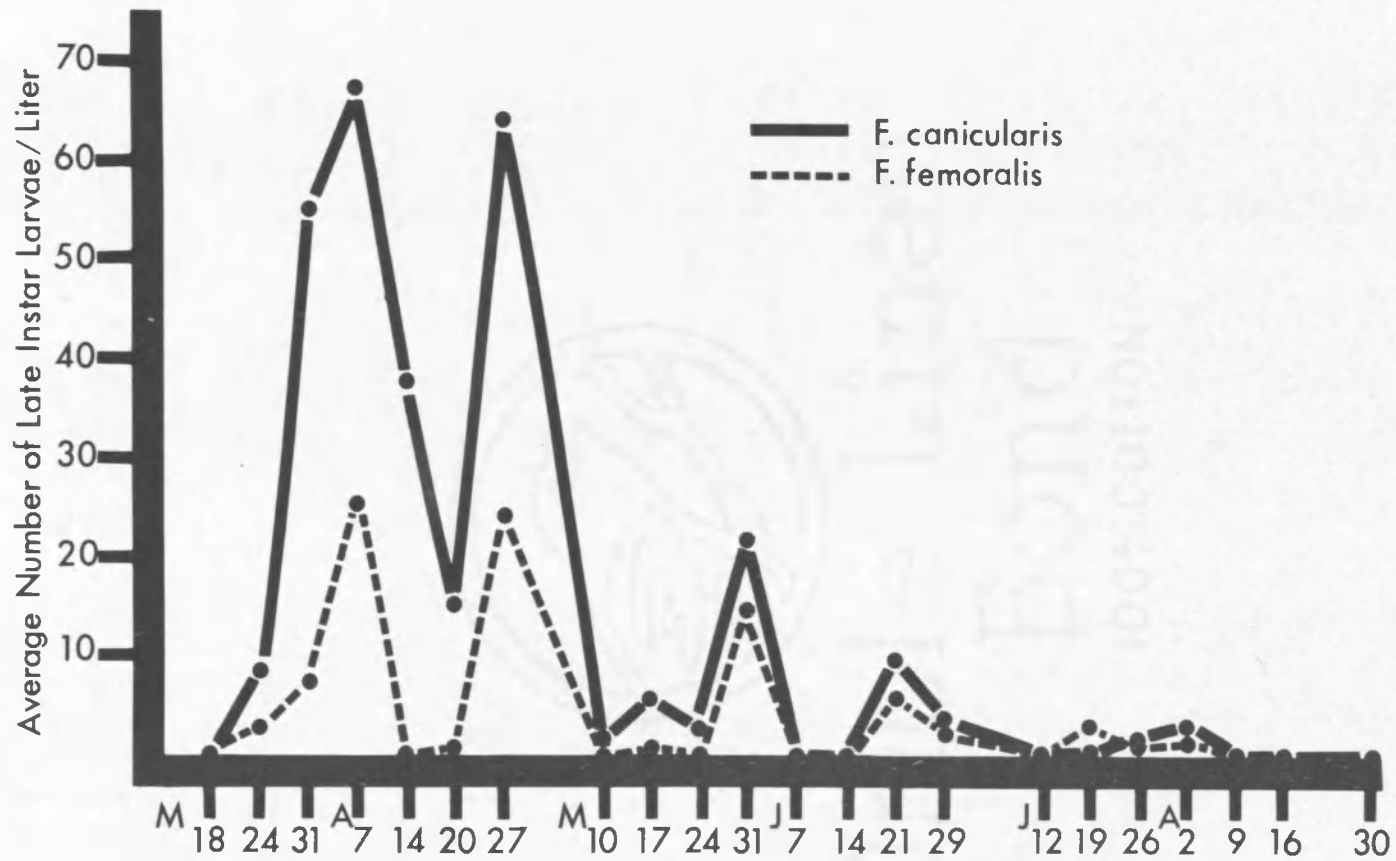


Figure 6. Seasonal abundance of second and third instar *Fannia femoralis* and *F. canicularis* larvae in House No. 3.

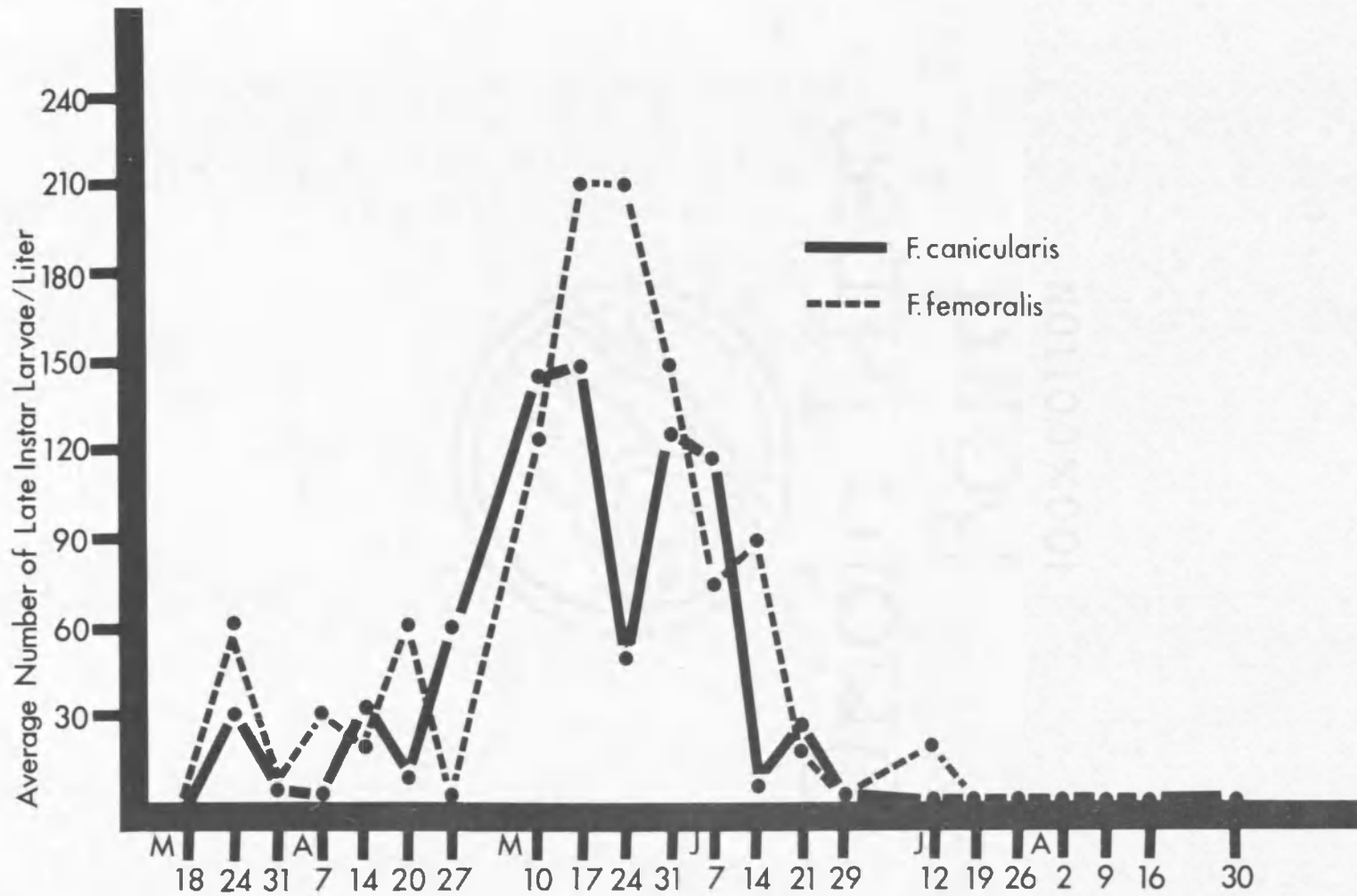


Figure 7. Seasonal abundance of second and third instar Fannia femoralis and F. canicularis larvae in House No. 4.

temperature of 4.5° C. The following week (April 22-28), the mean low temperature rose to 13.92° C. This rise in temperature was accompanied by a rise in the populations of F. canicularis. In House 1, the population rose to a mean of 490.1 larvae/liter, somewhat lower than the peak of April 14. In House 2, the population rose to 597.4 larvae/liter, slightly higher than the peak of April 14. The F. canicularis population in House 1 declined again on May 10 to a mean of 202.0 larvae/liter. A much less severe decline of the F. canicularis population of House 2 was observed, to a mean of 496.5 larvae/liter.

The F. femoralis populations in these two houses were, as previously mentioned, considerably smaller throughout the study. The decrease in temperature during the week of April 15 had a much smaller effect on F. femoralis. The population in House 1 dropped from 72.9 larvae/liter on April 14 to 60.0 larvae/liter on April 20. In House 2 there was actually a slight increase from 157.0 larvae/liter on April 14 to 161.5 larvae/liter on April 20, indicating a greater cold tolerance in this species. The F. femoralis populations peaked on May 10, four weeks after the initial population peaks of F. canicularis.

In comparing the population curves of both species within each house, there is some indication of competition between the two species. In House 1 there is a decline of F. canicularis from a mean of 490.1 larvae/liter on April 27 to 202.0 larvae/liter on May 10, accompanied by a sharp increase in the F. femoralis population from a mean of 250.7 larvae/liter (April 27) to a mean of 176.4 larvae/liter (May 10). On the following sample date, May 17, the F. canicularis population

increased to a mean of 345.2 larvae/liter and the F. femoralis population dropped to 22.8 larvae/liter. In House 2, the F. canicularis population declined from a 597.4 larvae/liter mean on April 27 to a mean of 496.5 larvae/liter on May 10 and continued to decline to a mean of 40.3 larvae/liter on May 31. The F. femoralis population in House 2 increased between April 27 and May 10 from a mean of 252.6 larvae/liter to 317.9 larvae/liter and then rapidly decreased to a mean of 34.6 larvae/liter on May 24. Competition in this case is probably for suitable microhabitat, specifically areas of high moisture content in the manure, rather than for food. Valiela (1974) reports that competition for food does not appear to be a limiting factor among dung-feeding arthropods.

After May 17, the Fannia populations in both Houses 1 and 2 crashed, and did not reach appreciable levels again. This event was apparently a response to summer temperature extremes. The mean high temperature, from May 17 to the last sample date (August 30), was 35.6° C; Nieschulz (1935) reports that F. canicularis experiences heat stress at 34.3° C.

The overall mean larval density of Fannia spp. in House 3, 17.15 larvae/liter, was far below the overall means produced in either House 1 (206.24 larvae/liter) or House 2 (164.76 larvae/liter). The system utilized in House 3 was drastically different from that employed in Houses 1 and 2. In House 3 birds were held in individual cages. This resulted in a slower accumulation of manure, and thereby provided time for the manure to dry. In addition, the manure formed individual

isolated cones beneath each cage. This also facilitated drying. In contrast with manure samples taken from Houses 1 and 2, which contained 49.0% (SD = 14.76) and 52.37% (SD = 8.94) water by weight, samples from House 3 were found to contain 15.97% (SD = 18.34) water by weight.

The first population peak of F. canicularis in House 3 (\bar{X} = 55.1 larvae/liter) occurred two weeks earlier (Fig. 6), March 31, than the peaks observed in Houses 1 and 2. A possible explanation for this is that the coned manure absorbed heat more rapidly because of its relatively larger surface/volume ratio. The manure received direct sunlight for at least part of each day. The same depression of the F. canicularis population on April 20 was observed. This decline first became evident on April 14, when the density dropped from 69.08 larvae/liter on April 7 to 37.6 larvae/liter on April 14 and continued to drop to a density of 14.8 larvae/liter by April 20. This event was due to the previously mentioned drop in temperature which occurred at this time. The population decline was far more drastic in House 3 than in Houses 1 and 2; again this was probably the result of the larger surface/volume ratio of the manure in this house, allowing a greater heat loss from the manure.

The second peak in House 3 occurred on April 27 (\bar{X} = 62 larvae/liter); this coincides both with the increase in temperature and with peaks observed in Houses 1 and 2. By May 10, the F. canicularis population dropped to a mean of 1.6 larvae/liter and, with the exception of small increases on May 31, to a mean of 22.1 larvae/liter, and on June 21, to a mean of 9.6 larvae/liter, remained near zero for

the remainder of the study. The population of F. femoralis was, as in Houses 1 and 2, considerably smaller than that of F. canicularis. The peaks and troughs of the F. femoralis population paralleled those observed for F. canicularis in this house. Peaks occurred on April 7 ($\bar{X} = 18.9$ larvae/liter), April 27 ($\bar{X} = 24.5$ larvae/liter), May 31 ($\bar{X} = 14.7$ larvae/liter) and June 21 ($\bar{X} = 6.4$ larvae/liter). The population data for House 3 show no indication of competition between the two species of Fannia. It is possible that at the lower larval densities found in this house, resources (e.g., larval microhabitats) were not limited.

House 4 was a temperature control house. Temperature in this house was regulated by heating and evaporative cooling systems. The manure was almost in a liquid state; samples taken had a mean water content of 77.51% by weight (SD = 2.96). This was, at least in part, the result of a lack of exposure to sunlight and air, since this house was enclosed.

The mean population density of F. canicularis in House 4 was 48.69 larvae/liter, this being significantly lower than the means reported for Houses 1 and 2; however, this density is higher than that reported for House 3. Unlike the situations found in Houses 1, 2 and 3, the F. femoralis population in House 4 (Fig. 7) was larger (overall $\bar{X} = 68.22$ larvae/liter) than the F. canicularis population. In fact, the population density of F. femoralis was higher in House 4 than in any of the other houses sampled, indicating that F. femoralis can tolerate, and even prefers, a substrate with high moisture content.

The first population peak in House 4 occurred on March 24, much earlier than in the other houses. This was apparently due to the fact that a higher temperature was maintained in this house. The outside temperature for the two-week period, from March 11 to March 24, had a mean low of 3.16° C, whereas inside House 4 for the same period, the mean low was 16.52° C. In addition, the populations remained at their highest levels for a much longer period, from April 27 to June 7. Again, this is probably attributable to temperature maintenance in this house. The populations dropped on June 14 and remained at zero (except for an increase in F. femoralis on June 12) for the remainder of the study. The reason for this population crash appears to be the fact that the populations in neighboring houses (including Houses 1, 2 and 3 of this study) crashed at this time. Although House 4 produced a substantial number of larvae, there were essentially no adult flies being produced in this house (as is indicated by data on pupal populations, discussed separately). Therefore, larval populations in House 4 were being produced by adult flies immigrating into this house from surrounding houses. When the populations in these houses crashed, the populations in House 4 likewise crashed.

Seasonal Abundance of Pupae

Figures 8 through 11 illustrate the seasonal abundance of pupae in Houses 1, 2, 3 and 4, respectively. Houses 1 and 2, which produced the largest number of larvae, not surprisingly also yielded the largest pupal populations.

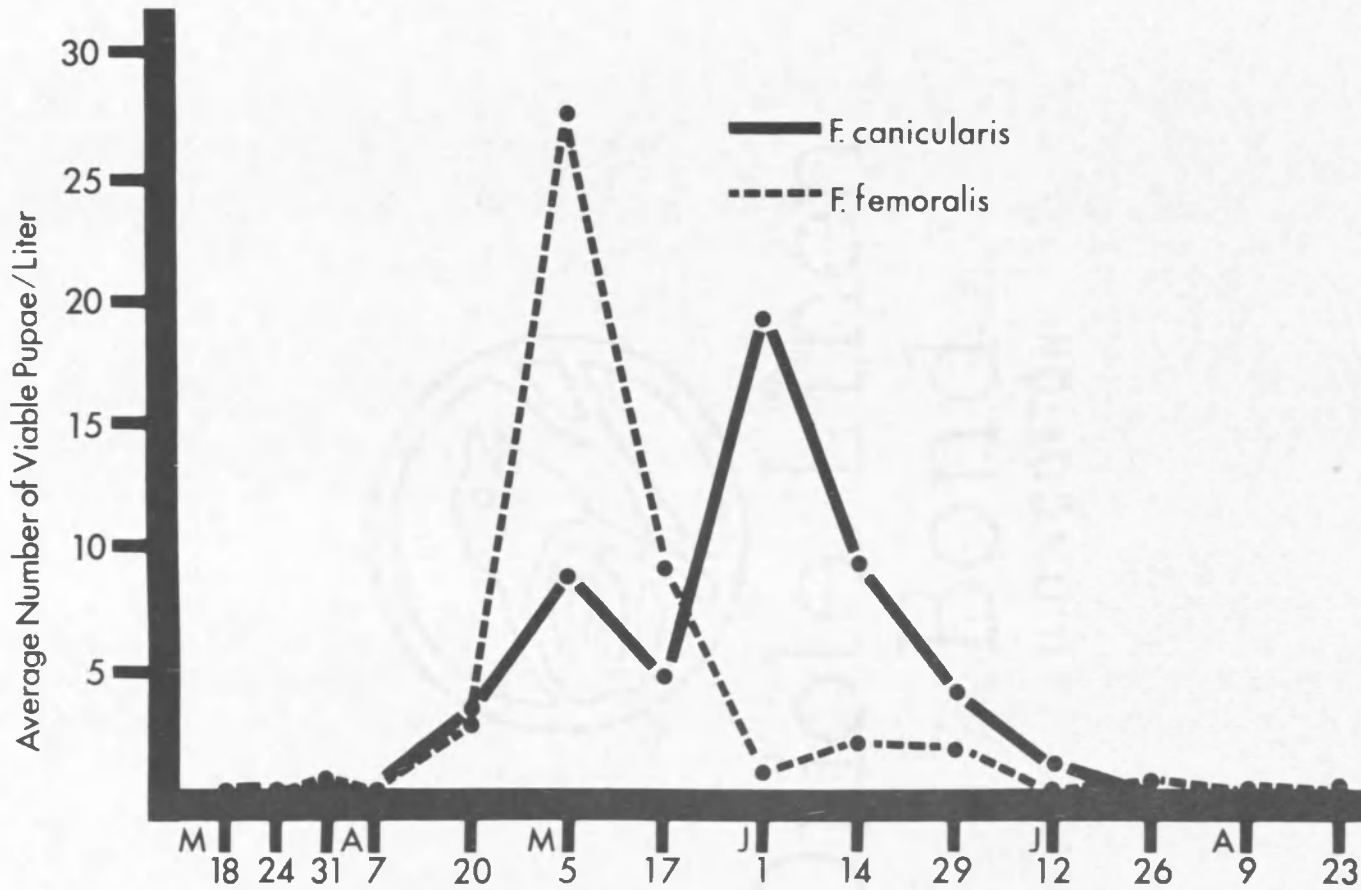


Figure 8. Seasonal abundance of *Fannia femoralis* and *F. canicularis* pupae in House No. 1.

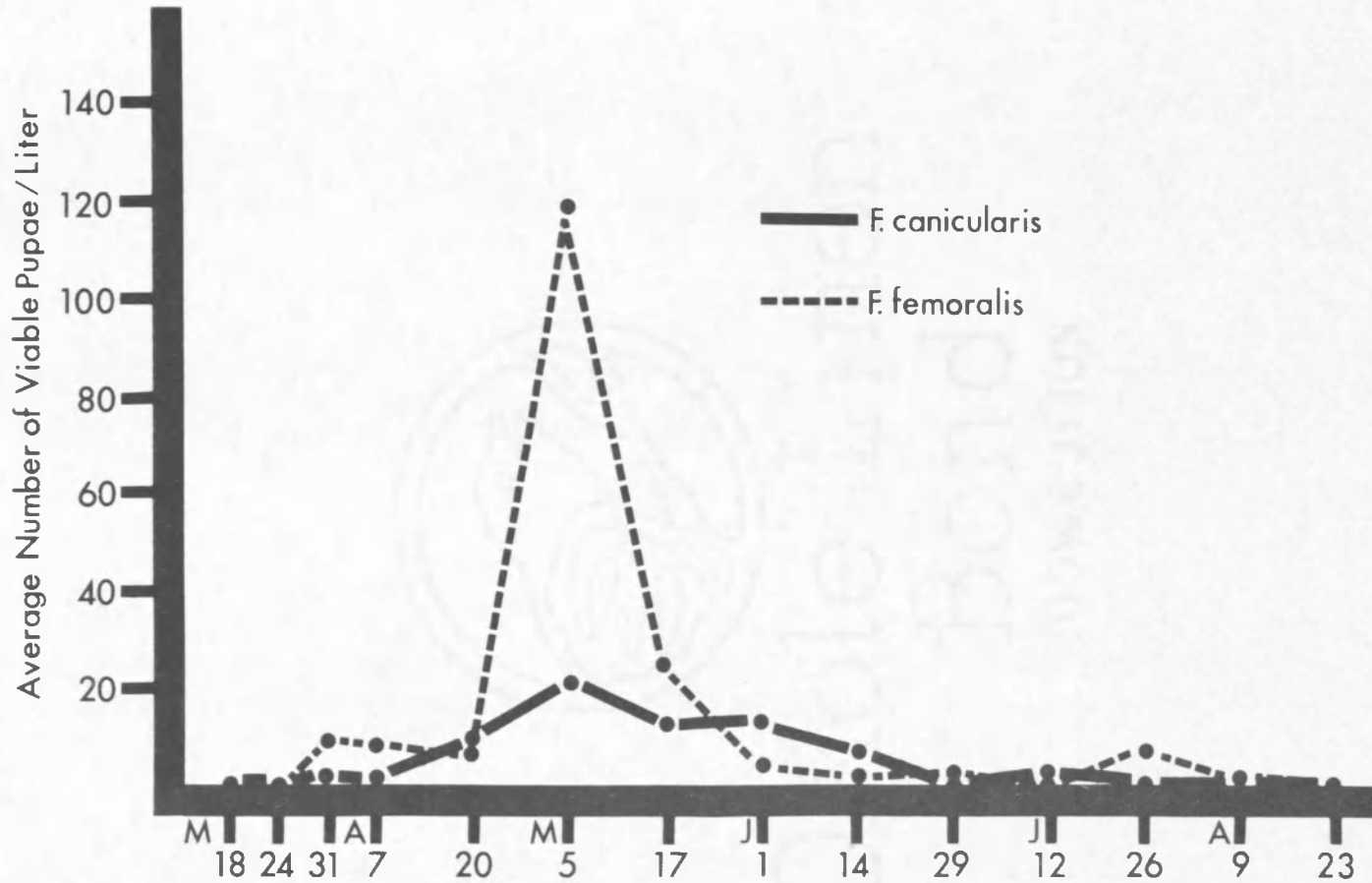


Figure 9. Seasonal abundance of *Fannia femoralis* and *F. canicularis* pupae in House No. 2.

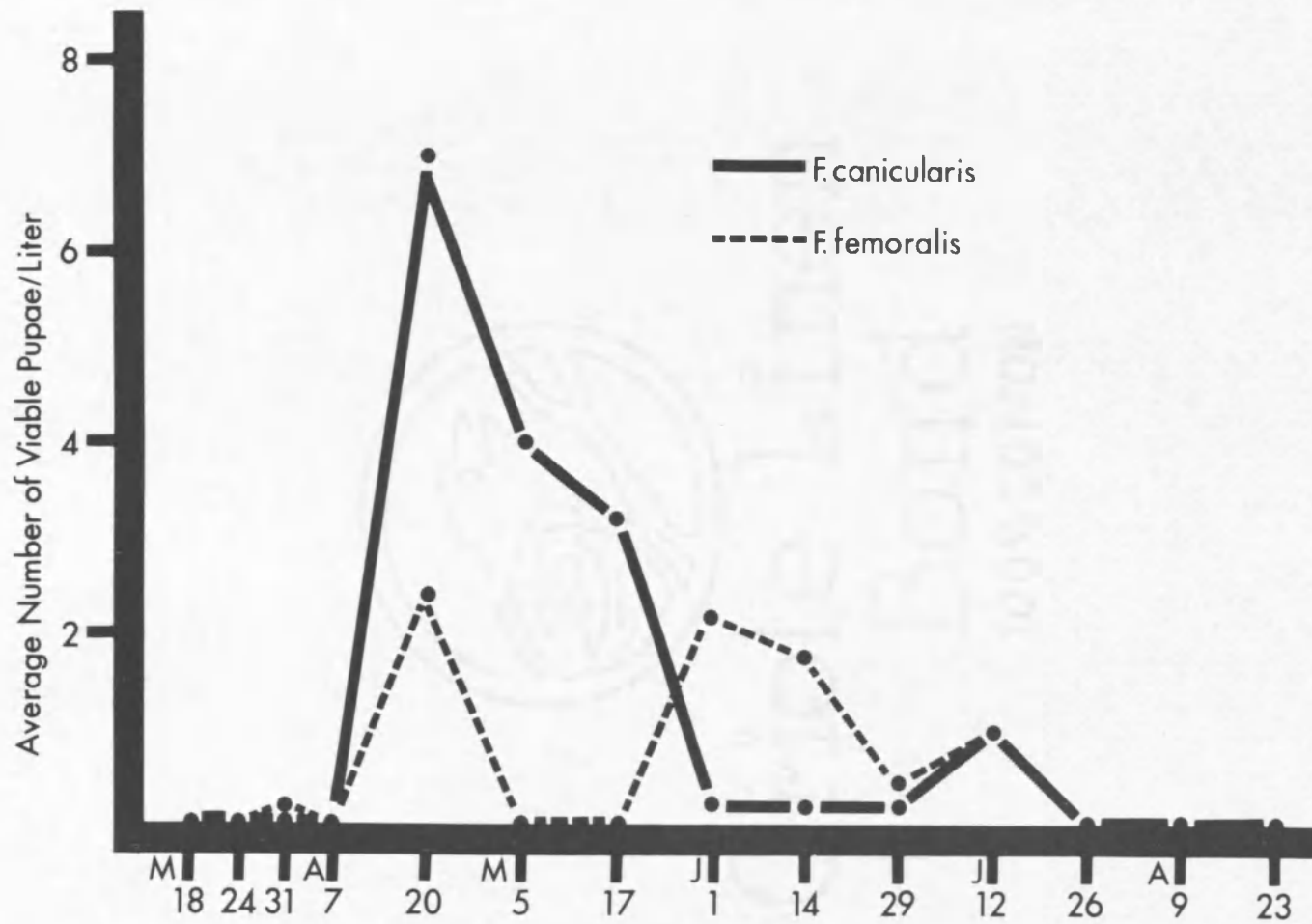


Figure 10. Seasonal abundance of *Fannia femoralis* and *F. canicularis* pupae in House No. 3.

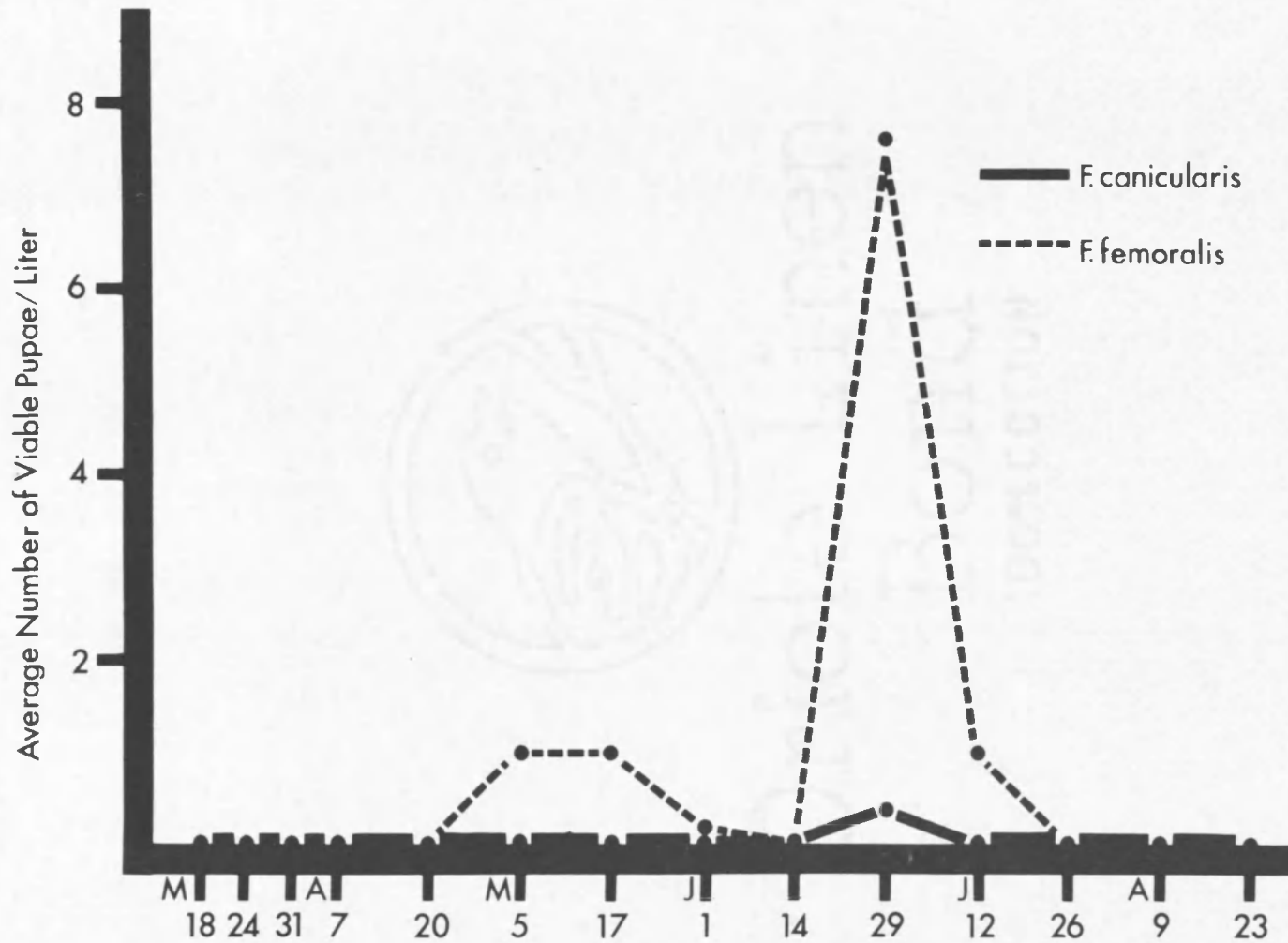


Figure 11. Seasonal abundance of *Fannia femoralis* and *F. canicularis* pupae in House No. 4.

House 1 produced an overall mean of 3.243 F. femoralis pupae/liter and an almost equal number of F. canicularis pupae, 3.586 pupae/liter. The F. femoralis population shows one peak, on May 5, with a density of 27.6 pupae/liter (Fig. 8). The F. canicularis population shows two peaks, the first also occurring on May 5, with a density of 8.8 pupae/liter; and a second, larger peak, occurring on June 1, with a density of 19.4 pupae/liter. This second peak appears to be in response to the decline in the F. femoralis pupal population (from 27.6 pupae/liter on May 5 to 9.0 and 0.8 pupae/liter on May 17 and June 1). This may represent competition for suitable pupation sites, which were probably at a premium. Brydon, Kada and Fuller (1967) report that Fannia pupae prefer a substrate with a 40.5% moisture content. Samples taken from this house revealed that the manure contained 49.0% (SD = 14.76) water by weight.

Both F. femoralis and F. canicularis populations in House 1 began to decline by June 14 and were down to near zero on July 12, this probably in response to temperature extremes (mean high temperature for the period of June 10 to July 16 was 37.2° C).

House 2 produced the largest pupal populations (Fig. 9) of the four houses, with an overall mean of 13.89 F. femoralis pupae/liter and 4.86 F. canicularis pupae/liter. Both populations reached one peak during the study, which occurred, as in House 1, on May 5. The F. femoralis population reached a density of 118.8 pupae/liter on this date; whereas the F. canicularis density was a much lower 21.4 pupae/liter. The F. femoralis population declined to a density of 25.0

pupae/liter on May 17, and continued to decline to near zero. The population remained at zero, with the exception of a small peak on July 26 (7.6 pupae/liter), for the remainder of the study. The F. canicularis population dropped to a density of 12.4 pupae/liter on May 17, but then had a small increase to 13.4 pupae/liter on June 1, followed by a decline to 7.2 pupae/liter on June 14. The F. canicularis population was below the level of the F. femoralis population for the entire study period, except for the two sample dates after May 17, the time at which the F. femoralis population crashed. This may be the result of the same type of competition for pupation sites as was observed in House 1.

Houses 3 and 4 produced very small populations of pupae; however, certain population peaks are evident and are worthy of consideration. House 3 was the only house in which the number of F. canicularis pupae (overall $\bar{X} = 1.1$ pupae/liter) outnumbered the F. femoralis pupae (overall $\bar{X} = 0.6$ pupae/liter). As previously mentioned, the manure in House 3 was the lowest in moisture content (15.97% by weight). This fact is apparently responsible for the lower numbers of F. femoralis pupae, which seem to have higher moisture requirements than F. canicularis. The population of F. femoralis pupae in House 3 (Fig. 10) shows two major peaks of equal magnitude. The first of these occurred on April 20, when the density rose to 2.4 pupae/liter. The population then fell to zero on May 5 and remained at zero on the following sample date, May 17. On June 1 the population rose again, to a density of 2.2 pupae/liter, dropped slightly on

June 14, to 1.8 pupae/liter, and then fell to a density of 0.4 pupae/liter on June 29. A small increase to 1 pupa/liter was observed on July 12, followed by a drop to zero on the next sample date (July 26). The pupal population of F. canicularis in House 3 peaked only once, on April 20, to a density of 7.2 pupae/liter. The population then declined, over the next three sample dates, to near zero, where, with the exception of a small increase on July 12, it remained. The Fannia pupal populations in House 3 showed their first peaks two weeks earlier than the populations in Houses 1 and 2; this was probably due to the way in which the manure in this house accumulated. As described earlier, the manure formed cones, and as mentioned, the larger surface/volume ratio probably resulted in heating of the manure, favoring an increase in developmental rates of the flies.

House 4 produced the fewest Fannia pupae, with overall means of 0.8 F. femoralis pupae/liter and 0.03 F. canicularis pupae/liter. The F. femoralis population first appeared on May 5 (Fig. 11), with a density of 1 pupa/liter; the same density was present on the following sample date (May 17). The largest peak occurred late, on June 29, with a density of 7.4 pupae/liter. F. canicularis pupae were recovered on only one sample day from House 4, June 29, at a density of 0.4 pupa/liter. The apparent reason for the small pupal population in House 4 was the very high moisture content of the manure, 77.5% (SD = 2.96).

Pupal Parasitization

Parasitized pupae first began to appear on April 20; on this date parasitized F. canicularis pupae were recovered from Houses 2 and

3. Table 1 summarizes pupal parasitization data for both Fannia species in each house. Overall, F. canicularis were more heavily parasitized (40% of recovered pupae) than F. femoralis (27.8% of recovered pupae). Legner and Brydon (1966) report that Fannia spp. pupae are more heavily parasitized than those of Musca domestica Linnaeus because they do not pupate as deeply in the manure. Perhaps this same behavioral difference exists between F. femoralis and F. canicularis, resulting in the latter being more heavily parasitized. House 2 had the highest percent parasitization of Fannia spp. pupae, at 37.57%, possibly due to the fact that the floors of the dropping areas were composed of concrete. Concrete prevents the larvae from pupating in the soil and therefore exposes them to parasitization (Legner and Brydon 1966).

House 1 had the lowest combined percent of Fannia pupal parasitization, 23.1%. House 1 was quite similar in construction to House 2; apparently the critical difference was that the floors of the dropping areas in House 1 were composed of dirt.

Three species of pupal parasites were identified from the four study houses: Spalangia endius Walker, Muscidifurax raptor Gerault and Sanders, and a Eurytoma species. The percent of the total parasitized pupae attributable to each of these species, in each house, is presented in Table 2. S. endius and M. raptor were responsible for the majority of the observed pupal parasitization. M. raptor showed a marked preference for the pupae of F. canicularis, having been responsible for parasitizing 71.38% of all the parasitized F.

Table 1. Mean percent parasitization of F. femoralis and F. canicularis pupae in each of the test houses for the study period (March 18 - August 23, 1976).

House No.	\bar{X} % <u>F. canicularis</u> parasitized	\bar{X} % <u>F. femoralis</u> parasitized	Combined \bar{X} %
1	35.86	10.39	23.13
2	37.83	37.30	37.57
3	46.35	4.17	25.26
4	-	59.21	-

Table 2. Percent of total parasitized pupae attributable to each parasite species.

House No.	Host Pupa	% Parasitized by		
		<u>S. endius</u>	<u>M. raptor</u>	<u>Eurytoma</u> spp.
1	<u>F. femoralis</u>	55.72	44.28	0
	<u>F. canicularis</u>	20.84	76.50	2.64
2	<u>F. femoralis</u>	67.14	24.39	8.47
	<u>F. canicularis</u>	39.52	60.00	0.48
3	<u>F. femoralis</u>	66.67	33.33	0
	<u>F. canicularis</u>	22.36	77.64	0
4	<u>F. femoralis</u>	83.35	16.65	0
	<u>F. canicularis</u>	0	0	0

canicularis pupae. S. endius, on the other hand, appeared to prefer F. femoralis pupae, having parasitized 68.22% of all the parasitized F. femoralis pupae.

The highest levels of parasitization occurred in mid-June for F. canicularis and in late July for F. femoralis (Table 3). Unfortunately, these peaks of parasitization did not coincide, temporally, with the population peaks of the two Fannia species, decreasing the impact of parasitization on natural control. The parasite species seem to require higher temperatures than the fly species can tolerate.

Results of Statistical Analysis

The mean numbers of F. femoralis and F. canicularis larvae produced in each study house were compared using Duncan's Multiple Range Test (LeClerc et al. 1962) to identify statistically significant differences. Results are presented in Table 4 and in Appendix, Table I. Significant differences in the numbers of F. femoralis larvae produced were found between Houses 2 and 3 and Houses 4 and 3, with House 3 producing the fewest. The numbers of F. canicularis larvae produced were found to be significantly different between Houses 1 and 3, Houses 2 and 3, Houses 1 and 4, and Houses 2 and 4.

Data on the mean number of F. femoralis and F. canicularis pupae were likewise compared using Duncan's Multiple Range Test. Results are presented in Table 4 and in Appendix, Table II. Significant differences in the numbers of F. femoralis pupae produced were found between Houses 2 and 3 and Houses 2 and 4. No significant

Table 3. Seasonal occurrence of pupal parasitization in the four study houses, beginning on April 20 (no pupae were collected prior to April 20).

Date	% <i>F. femoralis</i> parasitized								% <i>F. canicularis</i> parasitized							
	by <i>S. endius</i> in				by <i>M. raptor</i> in				by <i>S. endius</i> in				by <i>M. raptor</i> in			
	House 1	House 2	House 3	House 4	House 1	House 2	House 3	House 4	House 1	House 2	House 3	House 4	House 1	House 2	House 3	House 4
4/20	-	-	-	-	-	-	-	-	-	20.0	11.8	-	-	80.0	88.2	-
5/5	100	100	-	100	0	0	-	-	66.7	0	0	-	33.3	100	100	-
5/17	100	93.3	100	-	0	6.7	0	-	0	37.9	0	-	100	62.1	100	-
6/1	0	59.5	0	-	100	40.5	100	-	4.5	49.1	-	-	95.5	50.9	-	-
6/14	28.6	76.5	100	-	71.4	23.5	-	-	15.8	41.2	100	-	71.1	55.9	0	-
6/29	20.0	-	-	100	50.0	-	-	0	38.9	-	-	100	55.6	-	-	-
7/12	-	33.3	-	66.7	-	66.7	-	33.3	20.0	88.9	0	-	80.0	11.1	100	-
7/26	-	7.4	-	66.7	-	33.3	-	33.3	-	-	-	-	-	-	-	-
8/9	-	-	-	-	-	-	-	-	0	-	-	-	100	-	-	-
8/23	-	100	-	-	-	0	-	-	-	-	-	-	-	-	-	-

\bar{x} = 55.72 67.14 66.67 0 44.28 24.39 33.33 16.65 20.84 39.52 22.36 100 76.50 60.00 77.64 0

Table 4. Mean values for numbers of larvae, pupae and percent pupal parasitization for F. femoralis and F. canicularis in the four study houses, with statistical differences between values indicated.

House No.	<u>F. femoralis</u>			<u>F. canicularis</u>		
	Larvae	Pupae	% Pupal Parasitization	Larvae	Pupae	% Pupal Parasitization
1	24.76AB	3.42AB	10.39A	140.00A	3.59A	35.86A
2	59.44A	13.89A	37.30B	146.80A	4.86A	37.83A
3	3.79B	0.57B	4.17A	13.36B	1.14A	46.35A
4	68.22A	0.76B	59.21B	48.69B	0.03	-

Any two means, within houses for each life stage, followed by different letters are significantly different at the 0.05 levels. Duncan's Multiple Range Test.

differences were found in the populations of F. canicularis between any of the houses.

Percent pupal parasitization was likewise analyzed by Duncan's Multiple Range Test, and results are presented in Table 4 and in Appendix, Table III. Differences in percent parasitization of F. femoralis pupae were found to be significant between Houses 2 and 3, Houses 4 and 3, Houses 2 and 1, and Houses 4 and 1. The differences between percent parasitization of F. canicularis pupae were not significant in any of the houses. Because the number of F. canicularis pupae recovered in House 4 was so small, data on percent parasitization could not be analyzed.

Conclusions

The construction design employed in House 3 resulted in the smallest larval populations of both Fannia species (8.6 larvae/liter), and the smallest population of F. femoralis pupae (0.4 pupae/liter). House 4 produced smaller numbers of F. canicularis pupae (0.1 pupae/liter); however, the difference between the means of F. canicularis pupae in Houses 4 and 3 were not found to be significant. Parasitization of F. canicularis pupae was highest in House 3 (46.35%); however, parasitization of F. femoralis pupae was lowest (4.17%). Overall, the design of the type exemplified by House 3 is the most successful in suppressing populations of F. femoralis and F. canicularis.

The manure in House 3 was the driest (15.97% water by weight). It is this fact which seems to be responsible for the low production of Fannia in this house. The fact that House 3 was found to produce the

fewest larvae indicates that the manure within it was least attractive as an oviposition site. Kliever and Boreham (1964) report that a substrate with a moisture content of 33.3% had little or no attractancy to ovipositing females of F. canicularis. In addition, the low moisture content leads to high larval mortality, as indicated by the small numbers of pupae recovered. Pupal parasitization in this house could have been enhanced by constructing the bottom of the manure dropping areas out of concrete rather than dirt.

In conclusion, the construction design of House 3, which resulted in the formation of manure cones having a low moisture content, is the most effective in suppressing populations of F. canicularis and F. femoralis.

APPENDIX

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST
FOR LARVAE, PUPAE, AND PERCENT PARASITIZATION
OF F. CANICULARIS AND F. FEMORALIS

Table 1. Results of Duncan's Multiple Range Test for larvae of F. canicularis and F. femoralis in the four study houses.

Mean Differences (larvae/liter)	0.05 Confidence Level rp	0.05 Confidence Level Rp	0.01 Confidence Level rp	0.01 Confidence Level Rp
<u>femoralis</u>				
H1-H3 = 20.97	2.772	47.063	3.643	61.851
H2-H3 = 55.65*	2.918	49.542	3.796	64.448
H4-H3 = 64.43*	3.017	51.223	3.900	66.214
H2-H1 = 34.68	2.772	47.063	3.643	61.851
H4-H1 = 43.46	2.918	49.542	3.796	64.448
H4-H2 = 8.78	2.772	47.063	3.643	61.851
<u>canicularis</u>				
H4-H3 = 35.33	2.772	69.114	3.643	90.831
H1-H3 = 126.64**	2.918	72.755	3.796	94.646
H2-H3 = 133.44**	3.017	75.223	3.900	97.239
H1-H4 = 91.31**	2.772	69.114	3.643	90.831
H2-H4 = 98.11**	2.918	72.755	3.796	94.646
H2-H1 = 6.8	2.772	69.114	3.643	90.831

rp = significant studentized range, Rp = shortest significant range.

H1 = mean number of larvae in House 1, H2 = mean number of larvae in House 2, etc.

* significant at 0.05 level of confidence.

**significant at 0.01 level of confidence.

significant if mean difference Rp.

Table II. Results of Duncan's Multiple Range Test for pupae of F. canicularis and F. femoralis in the four study houses.

Mean Differences (pupae/liter)	0.05 Confidence Level		0.01 Confidence Level	
	rp	Rp	rp	Rp
<u>femoralis</u>				
H4-H3 = 0.13	2.772	10.925	3.643	14.358
H1-H3 = 3.05	2.918	11.501	3.796	14.961
H2-H3 = 12.36*	3.017	11.891	3.900	15.371
H1-H4 = 2.917	2.772	10.925	3.643	14.358
H2-H4 = 12.23*	2.918	11.501	3.796	14.961
H2-H1 = 9.31	2.772	10.925	3.643	14.358
<u>canicularis</u>				
H3-H4 = .467	2.772	3.745	3.643	4.922
H1-H4 = 1.40	2.918	3.943	3.796	5.129
H2-H4 = 3.50	3.017	4.076	3.900	5.269
H1-H3 = .933	2.772	3.745	3.643	4.922
H2-H3 = 3.03	2.918	3.943	3.796	5.129
H2-H1 = 2.10	2.772	3.745	3.643	4.922

rp = significant studentized range, Rp = shortest significant range.

H4 = mean number of pupae in House 4, H3 = mean number of pupae in House 3, etc.

* significant at 0.05 level of confidence (significant if mean difference \geq Rp).

Table III. Results of Duncan's Multiple Range Test for percent parasitization of Fannia pupae in the four study houses.

Mean Differences (% parasitization)	0.05 Confidence Level rp	0.01 Confidence Level Rp	0.01 Confidence Level rp	0.05 Confidence Level Rp
<u>femoralis</u>				
H1-H3 = 6.223	2.858	26.210	3.825	35.079
H2-H3 = 33.133*	3.006	26.250	3.988	34.825
H4-H3 = 55.043**	3.102	35.462	4.098	46.849
H2-H1 = 26.91*	2.858	22.555	3.825	30.186
H4-H1 = 48.82**	3.006	32.475	3.988	43.084
H4-H2 = 21.91	2.858	29.820	3.825	39.910
<u>canicularis</u>				
H2-H1 = 1.97	2.858	22.276	3.825	29.813
H3-H1 = 10.49	3.006	27.226	3.988	36.121
H3-H2 = 8.52	2.858	24.487	3.825	33.515

rp = significant studentized range, Rp = shortest significant range.

H1 = mean percent parasitized pupae in House 1, H2 = mean percent parasitized pupae in House 2, etc.

* significant at 0.05 level of confidence.

**significant at 0.01 level of confidence.

significant if mean differences Rp.

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