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Project No. 88-F13 - Pollination

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Objectives: To develop information on pollination by bees which will result in increased production and greater grower returns.

Interpretive Summary:

Most of our effort in spring 1988 was devoted to gathering data for the almond pollination model ALMPOL in an orchard near Davis, CA with 5 cultivars: Mission, NePlus, Nonpareil, Peerless and Price.

Blossoms per meter--As a basis for comparison, blossoms per cluster and spurs per meter were counted on four sides of 36 trees per cultivar. Mission had the greatest bloom density, NePlus the least.

Nectar & pollen production--No significant differences were found among the 5 cultivars. However, when converted to nectar produced per meter of branch, Mission produced significantly more nectar than all other cultivars and Peerless produced significantly more than the remaining three cultivars. Mission and Peerless also produced significantly more pollen due to their greater densities of bloom.

Bee per tree--Counts of bee visitation to each cultivar were made throughout the season. Bee activity was significantly greater at Mission and Peerless than at the other three cultivars, Price had the least visitation.

Hand pollinations--Flowers of different ages of each cultivar were hand pollinated to determine potential set and the importance of flower age on success of pollination. Peerless and Mission gave the poorest sets (ca 39 & 47%). The remaining 3 cultivars set between 68-78%. [Price X NePlus is reported to be incompatible].

Pollen vs. nectar foraging--No differences were found in time spent per blossom by pollen versus nectar foragers on any cultivar and AM and PM. Bees spent more time collecting nectar than pollen throughout the bloom season.

Nut set--Potential set as determined by hand pollinations and actual nut set from open pollinations were not in total agreement. Peerless and Mission had the lowest set as predicted from hand pollinations despite having the highest nectar and pollen production. However, the actual nut set of Price was significantly higher than any other cultivar despite having only moderate amounts of blossoms per meter and pollen production as well as low nectar production and bee visitation. Price was also the highest yielder in this orchard last year.

Bloom progression and predictions--Predictions of full bloom were reasonably close, but rates of change preceding and following full bloom often differed considerably from predictions during this unusually warm dry pollination season.

Colony strength--Entrance flight activities were correlated with cluster counts to enlarge our data base. Preseason tests were conducted to determine the most suitable screen design for use in our entrance activity counts. Costs of various strength evaluations were also analyzed. Colonies with 8 frames of bees produced significantly higher flight than those with fewer or more bees.

Almond Pollination Model

In 1988 research was conducted to determine bloom progression as a function of temperature, cultivar attractiveness (i.e., available pollen and nectar), honey bee foraging activity per tree, and blossom quality (i.e., the probability that cross-pollination will lead to nut set) as a function of blossom age. This information was incorporated into the ALMOPOL pollination and nut set prediction model. Nut set predictions generated by ALMOPOL were compared to actual set in an orchard planted to 'NePlus, 'Nonpareil', 'Price', 'Peerless', and 'Mission'. Results and discussion of this research are presented below.

Bloom Progression as a Function of Temperature

In the ALMOPOL program bloom progression is predicted as a function of bloom period temperatures using accumulated degree days (DD). With this method we can simulate chronologically shorter bloom periods when temperatures are high (DD accumulate faster), and longer bloom periods when they are low. The bloom phenology of five almond cultivars ('NePlus, 'Nonpareil', 'Price', 'Peerless', and 'Mission') are mathematically described in ALMOPOL, but other cultivars can be added to the program as data become available. Separate equations have been derived for pre- and post-peak bloom intervals. The correlation coefficients for actual and predicted bloom using these equations are shown in Table 1. Correlation coefficients indicate that bloom progression equations for the pre-peak bloom interval of 'NePlus' and 'Price' need modification. This will be accomplished by incorporating 1988 bloom progression data into these cultivars' overall bloom data base, and re-fitting the pre-peak bloom curves.

Floral Density, Cultivar Attractiveness, and Honey Bee Foraging Activity per Cultivar

In 1988 the amount of nectar and pollen per blossom was measured throughout bloom. Blossom density (i.e., the number of blossoms per meter of branch) was also measured so that floral rewards could be expressed as pollen and nectar per meter. Throughout bloom the number of honey bees foraging five trees of each cultivar was counted at least twice a day (AM and PM) when weather was suitable for flight. The nectar/m, pollen/m, and honey bees per tree are shown in Table 2. An analysis of variance was performed on the data to determine if any of the means were significantly different. When means did differ, a Scheffe's S multiple comparison test was conducted.

Nectar and pollen data was first analyzed to determine the average amount of pollen and nectar per blossom, and an analysis of variance was performed to determine if any of the cultivars were significantly different with regards to floral rewards. No significant differences were found among cultivars concerning the average amount of nectar or pollen per blossom. However, when the average amount of nectar and pollen per blossom was multiplied by the average number of blossoms/m some cultivars were found to have significantly more floral rewards than others. 'NePlus', 'Nonpareil', and 'Price' had the least amount of nectar/m, and 'Mission' the most. 'NePlus' and 'Nonpareil' had the least amount of pollen and 'Peerless' and 'Mission' the most. These differences in rewards per meter were reflected in honey bee foraging activity. Throughout bloom 'Peerless' and 'Mission' had the highest average number of bees per tree, and 'NePlus', 'Nonpareil', and 'Price' the least.

Blossom Quality as a Function of Blossom Age in Each Cultivar

Throughout bloom in 1988 blossoms of each cultivar were hand-pollinated after first being grouped according to their age (i.e., the DD's accumulated since anthesis). Blossoms were hand-pollinated only once either on their day of anthesis or on subsequent days. The age of the blossoms was determined by the state of their petals, anthers and pistil. Blossom stages were characterized from 'A' to 'D' with 'AB' being blossoms that had just opened, with the pistil below or just at the lowest anthers, and no anthers dehisced, 'C' being petals fully separated with some anthers dehisced, the stigma above the lowest anthers, and the corolla base either pink or red, and 'D' being blossoms with petals fully separated, all anthers dehisced or missing, stigma above the anthers, and the corolla base either pink or red. Blossoms were bagged in nylon mesh until pollination to exclude bees. These bags were not 100% effective in excluding bees though. The pistils of blossoms were exposed outside the bags in some instances. We will modify our techniques for bagging blossoms during the 1989 season to avoid this problem.

Results of hand-pollinations are shown in Table 3. In 'NePlus', blossoms pollinated in the 'AB' stage did not have significantly higher probabilities of nut set than those pollinated in the 'C' or 'D' stages. In 'Nonpareil', blossoms pollinated in the 'AB' or 'C' stage had significantly lower probabilities of setting nuts than those in the 'D' stage. These results may reflect the delay in embryo sac maturation that is characteristic of 'Nonpareil'. In this cultivar embryo sacs do not mature until 7-8 days after anthesis, and pollen tubes may not be attracted to the embryo sac until maturation occurs.

The probability that cross-pollination would lead to nut set was highest in the 'AB' stage for 'Price' and 'Mission' and declined significantly by the 'C' and 'D' stages. In 'Peerless', blossoms in the 'C' stage had the greatest probability of setting nuts. Comparing all cultivars tested, 'NePlus', 'Nonpareil', and 'Price' had the highest overall nut set probabilities throughout a blossom's life, and 'Peerless' and 'Mission' had the lowest.

Comparisons of Actual and Predicted Nut Set Using the ALMOPOL Model

Data on orchard parameters including tree height and width, trunk height, average number of blossom clusters per meter of branch, blossom viability, and number of trees of each cultivar per acre were collected at a commercial orchard site located near Davis, CA, and were entered into the ALMOPOL model. Weather data (temperature, wind velocity, solar radiation and rainfall) were collected hourly throughout bloom. These weather data were also entered into the ALMOPOL program. Initial nut set was determined by counting blossoms during bloom, and then counting the number setting nuts 6-8 weeks after petal fall to estimate the percentage of blossoms setting nuts. Comparisons of actual and ALMOPOL predicted nut set at the site are shown in Table 4.

ALMOPOL nut set predictions were not significantly different from actual nut set for 'NePlus', 'Peerless', and 'Mission'. The prediction for 'Nonpareil' set was slightly lower than the actual set for this cultivar. The ALMOPOL nut set prediction for 'Price' set was considerably lower than actual set indicating that some of the model's assumptions for nut set are not applicable for this cultivar. This is the second year that 'Price' set has been considerably higher than ALMOPOL predictions. Data on honey bee foraging activity and blossom quality indicate that 'Price' is not exceptionally high for either of these parameters compared to the other cultivars. The ALMOPOL model assumes all cultivars are self-incompatible and require cross-pollination for nut set. We will hand-pollinate 'Price' blossoms with self-pollen during the 1989 bloom season to determine if this cultivar is at least partially self-compatible which would account for the higher sets.

Honey Bee Colony Strength and Flight

Most of our research in almonds this year was concerned with validating the Almond Pollination Model to predict yield (see previous section). However, we did conduct observations at the colony with the hope of eventually being able to develop a model that will help growers determine the number and size of colonies needed for optimal pollination under their particular orchard conditions.

Materials and Methods: Cluster estimates of strength were made as described in previous Almond Board Reports on colonies in place for almond pollination in the 30-acre orchard being used to validate the Almond Pollination Model. On February 16, near the beginning of almond bloom, 71 colonies were assessed, and on March 4, near the end of the bloom, 62 colonies were assessed. Some colonies were moved into the orchard after the February assessment, and some colonies evaluated in February were moved out prior to the March assessment. A total of 52 colonies had both initial and final assessments made on them, and these were used for calculating the percent change in colony strength during the period of almond pollination.

Counts of incoming pollen and non-pollen foragers (as described in previous reports) were made on all 71 colonies on February 16. On February 17, 5 colonies in each of four strength groups (4, 6, 8, and 11 frames of bees [FOB]) were selected from the 71 colonies to be evaluated for incoming flight for the remainder of the bloom period. Normally, at least one morning count (usually about 11 a.m.) and one afternoon count (usually around 2 p.m.) were made at each hive.

Results: The lower strength categories had the largest percent increases in strength between the beginning and ending evaluations (Table 5). The higher strength categories showed decreases in colony strength between the beginning and ending evaluations (Table 5).

The 8-frame category gave significantly higher pollen, non-pollen and total flight than the 4 FOB category (P = 0.02) and significantly higher non-pollen and total flight than 6 and 11 FOB (P = 0.0001) (Table 6 and Figure 1).

Discussion: As in previous years, the lower strength categories have the highest percent increase in strength while the upper strength categories show a decrease in strength. However, it must be borne in mind that these are percent changes so that a two frame colony increasing by 150% will still not be as strong as a four frame colony increasing by only 50%. Also, as in past years, the 8 frames of bees appear to be the optimal strength category for producing maximum flight. For further discussion, see the Multiyear Comparisons section of this report.

Cost Analyses of Colony Strength Evaluations

As in 1987, we recorded the times required to perform the flight counts at colony entrances in order to give the grower an idea of the cost involved.

Materials and Methods: As in previous years, a screen was placed over the colony entrance for 30 seconds thus forcing incoming honey bees to either land on the screen or hover in front of the colony. At the end of 30 seconds, the number of bees on the screen were recorded. Starting and ending times for counting sessions were recorded. A bee veil (about $10), bee gloves (about $5), a clipboard with paper, pen or pencil, and a watch which will measure in seconds are necessary for making counts.

Results: Our measures of time to conduct colony evaluations are as follows:

Location	Number of Colonies Being Counted	Number of times each Colony Counted	Average time Per Colony (Min.)
Bee Biology Facility UC Davis	24	48	1.40 ± 0.15
Almond Orchard Dixon, CA	20	31	1.75 ± 0.18

Figured on the basis of $7.00 per hour labor, it would have cost 20 cents per colony to do the counts at Dixon.

Discussion: The time required per colony for counts at Bee Biology was close to that for Dixon in 1987 (1.44 min. per colony). Probably, the longer time required for counting bees at Dixon this year is due to increased time walking between colony drops. (There were colonies in six different drops to count this year versus only four last year). If a grower were to inspect 10% of the colonies in a 40-acre orchard with 2 hives per acre, the cost for labor would be $16 plus possibly transportation to and from orchard.

Entrance Excluders for Measuring Incoming Flight

We have noted especially on clear days that substantial numbers of bees do not land on hive entrance excluders for determining incoming flight and ratio of pollen foragers. Painting the galvanized hardware cloth used to make these excluders to match the predominant hive color helps, but does not completely solve this problem. In 1987, several devices for blocking hive entrances to count incoming flight activity were tested to determine which gave the highest counts. The best two from 1987 were selected for comparisons with two additional flight count models (FCM) in tests prior to bloom in 1988.

Materials & Methods: On February 2, cluster counts were made on 26 colonies at the Bee Biology Facility at the University of California, Davis. Of these, 24 were selected for the study. A morning and an afternoon count were made on each colony on 5 and 8-12 Feb. There were 11 and 13 colonies in two yards separated by about a city block. Each of two observers counted different yards, and then switched yards to allow bees to "settle down" between counts. On any single day, each observer tested two FCM by placing one of them over the colony entrance to block incoming flight for 30 seconds. At the end of 30 seconds the number of bees with and without visible pollen loads that had alit on or near the FCM were counted. After all 24 colonies had been counted using one FCM, the second FCM was tested.

Bee yard #1 fortuitously turned out to be different from yard #2 in amount of shading which allowed us to test the effects of different lighting conditions on the FCM. Yard #1 had several large sycamore and English walnut trees. Some hives in yard #1 were facing north. Yard #2 had no trees, and all hives were facing south. These differences allowed us to test possible effects of hive entrance orientation on our flight measurements.

Descriptions of the 4 FCMs are as follows:

#5 consists of a 2 1/4 X 16 1/2" strip of 8 mesh hardware cloth with a 1 1/2 X 16 1/2" strip of 1/8" wood paneling stapled on one edge. The screen was sprayed with flat black paint to match the hive entrance hole. The wood paneling was painted to match the predominant hive color (white in 1988 and yellow in 1987). On both ends of the strip were 1X1X3/4" hardware cloth protrusions with holes opening to the side of the hive and serving as escapes for exiting bees.

#6 was similar to #5 except the hardware cloth over the 3/4" colony entrance slit was bent out 1" horizontal to the hive body and then bent vertically down to cover the entrance and yet allow outgoing bees to escape on either end of the cloth. Hardware cloth legs of 1 1/4 X 7/8" protruded on each end of the FCM. No paneling was placed on top of this FCM, but the top 2" of the cloth was painted (white in 1988 and yellow in 1987), and the bottom flat black.

#15 was a 14 3/8 X 1 1/2" strip of 8 mesh hardware cloth bent at right angles lengthwise in the middle to form an L-shaped strip with two 3/4" legs. A metal strip was rivited on one end to serve as a handle. The whole FCM was painted flat black.

#16 consisted of a 16 3/8 X 2 3/16" piece of 1/8" plexiglass with a strip of 1/8" holes on 1/4" centers drilled about 1/8" from one of the lengthwise edges. Legs of 3/4 X 1 1/2" of the plexiglass were glued one inch from either end of the strip to serve as supports. The FCM was sprayed with Krylon^R No. 1311 matte finish to reduce reflections.

Results: No significant differences between the FCMs were found for bees returning with pollen, but numbers of bees without pollen were significantly higher with FCM 15 and 16 while FCM 6 generally had the lowest numbers of returning bees alighting:

Means of returning bees

FCM	N	Pollen	Non-pollen	Total
5	252	1.21 A*	8.31 AB	9.52 AB
6	252	0.88 A	7.02 B	7.89 B
15	252	1.23 A	9.05 A	10.27 A
16	251	1.09 A	9.68 A	10.73 A

*Means with the same letter are not significantly different

General linear model procedure did not show any significant interactions between FCM and colony strength or lighting. However, there is a consistant pattern of higher counts with FCM 15 and 16 (Figs. 2-5).

Significantly higher counts were obtained with FCM 15 and 16 under sunny conditions:

Means of returning bees

FCM	N	Pollen	Non-pollen	Total
5	25	0.7±0.9 A	4.8±3.6 B	5.6±3.5 B
6	21	0.3±0.6 A	3.8±3.1 B	4.2±3.1 B
15	20	0.4±0.5 A	7.6±5.6 AB	8.1±5.7 AB
16	21	1.0±1.3 A	9.0±7.1 A	10.0±7.4 A

When colonies with 2 and 4 FOB were compared by north and south facing entrances, no significant differences were found in the 4 FOB strength group, but pollen collectors and total incoming flight were significantly higher when entrances faced south:

Flight means ± S.D.

Direction	N	Pollen	Non-pollen	Total
South	48	1.54±1.50 A	8.67±6.21 A	10.21±6.48 A
North	192	0.83±1.10 B	7.07±5.98 A	7.89±6.22 B

As with previous experiments, we found significantly higher flight as colony strength increased (Fig. 5).

Discussion: Although extra variables such as lighting and colony orientation were encountered making the results more difficult to interpret, the differences did allow more detailed evaluations of the FCMs. On the basis of producing the highest counts of returning bees under most conditions FCM 16 was the best whereas FCM 15 performed as well or better under shady conditions. FCM 6 gave the lowest readings in general and will be excluded from further testing. Future evaluations to determine the best flight count model should include measures of lighting at the hive entrance with a light meter.

Bee Flight Relative to Weather and Time of Day

In a continuing effort to determine which colony strength group produces the best flight under varying conditions of weather and resource (pollen and nectar) availability during almond bloom, the flight data described in the section on Strength and Flight were compared with corresponding weather, time and date information.

Materials and Methods: Flight counts and corresponding, time, date and weather data were analyzed using regression analysis and analysis of variance.

Results: No significant differences were found in pollen, non-pollen, or total incoming flight between morning and afternoon counts by Tukey's or LSD tests ($P=0.05$, $n=340$ for days with both AM and PM counts).

We expected that incoming flight of pollen, non-pollen and total foragers would increase directly as temperature increased. However, we found less flight during the middle temperature category than during the lowest category (Table 7 and Figures 6-8). To determine whether different periods during the season could account for this discrepancy, we analyzed the AM (no PM counts were taken in late season) count data for early (Feb. 16-20), middle (Feb. 22-27) and late (Mar. 1-4) bloom as follows:

Day Group	N	Pollen	Non-pollen	Total
Feb 16-20	100	4.0±4.3 A	7.7±7.4 B	11.7±11.3 B
Feb 22-27	159	2.4±2.1 B	17.9±9.4 A	20.4±10.4 A
Mar 1-4	118	1.0±1.3 C	9.5±7.1 B	10.5± 7.7 B

Pollen collectors significantly decreased as the season progressed, while non-pollen bees increased mid-season and decreased late season. Flight increased with temperature during early season for both pollen and non-pollen bees. During mid-season flight dipped slightly and then rose again with temperature for pollen collectors, but decreased for non-pollen bees as temperature rose. The general linear model procedure showed the following relationships between the variables:

Flight	Time of Season	Temperature Group	Temperature X Season Interaction
Pollen	0.0001	0.007	0.0001
Non-pollen	0.0001	N.S.	0.0001
Total	0.0001	N.S.	0.0001

The P-values confirm the influence of period within the bloom season on flight actvity of bees and the interaction between temperature and seasonal period.

Another general linear model comparing flight with strength group and temperature gave the following results for days with both AM and PM counts (n=340):

Flight	Strength Group	Temperature Group	Strength X Temp. Interaction
Pollen	0.07	N.S.	N.S.
Non-pollen	0.003	0.0001	N.S.
Total	0.004	0.0001	N.S.

This model shows only a marginal effect of temperature on pollen flight, highly significant effects of temperature and strength on non-pollen bees, and no interaction between strength and temperature.

Discussion: Although temperatures were higher in general, mid-season flight was not always so especially for pollen collectors. These results appear to indicate that flight was being heavily influenced by other factors, (e.g., nectar and pollen availability) which masked effects of temperature. Other factors such as overcast periods and increasing colony strengths may also have obscured trends. More counts were taken during mid-season when temperature was not so influential. This may be the reason for the apparent dip in flight at the middle temperature category when early, middle and late counts were pooled.

Total flight is often more greatly influenced by the non-pollen bees because they are often much more numerous than are pollen collecting bees.

These observations need to be repeated with greater numbers of counts per day. In a year with a more varied temperature regime, especially more inclement weather, differences between flight by different strength groups might be more striking.

Yield Estimates by Nut and Pedicel Counts

In the past we have obtained percent nut set for determining yield estimates of pollinating efficiency of various research treatments. We counted initial buds and/or flowers on a number of limbs. In mid-April (after initial fruit drop has occurred) and again just prior to harvest we returned to count the numbers of nuts set on these limbs. This year early harvest of one cultivar prior to our final nut counts forced us to seek additional evidence of nut set. We counted nut sets of the remaining 4 cultivars and compared the numbers of pedicels, to which the nuts were attached, remaining on their test limbs after harvest to determine whether pedicel counts would be accurate enough to serve as an alternative or supplement to actual nut set counts.

Materials and Methods: On September 1, two observers independently counted nuts on four cultivars in the transect that had been counted daily for bloom progression data. This transect consisted of 5 trees per cultivar and 4 limbs per tree (N=20 limbs per cultivar). On September 6 and 7, the same two observers returned, removed all nuts from the previously counted limbs and counted pedicels that showed recent abscission. The tips of recently abscissed pedicels were easily distinguished by their "corky" brown color from pedicels of previous years which were gray and pedicels from spring drop which were smaller in diameter. T-tests and regression analyses were used to compare counts of pedicels versus nut set.

Results: There were no significant differences between pedicel and nut counts by T-tests. Correlation coefficients were in general high as listed below:

Cultivar	Observer	Nut Count* & S.D.		Pedicel Count* & S.D.		T-test	R2 at P=	
Mission	1	18.4	10.5	16.0	8.8	N.S.	.89	.000
Mission	2	18.1	15.4	15.4	8.5	N.S.	.96	.000
NePlus	1	25.8	11.1	27.2	12.5	N.S.	.76	.000
NePlus	2	25.0	11.9	25.6	11.6	N.S.	.43	.001
Peerless	1	15.0	8.6	14.3	10.0	N.S.	.90	.000
Peerless	2	14.8	8.8	14.2	8.5	N.S.	.28	.01
Price	1	37.0	17.9	38.9	19.0	N.S.	.88	.000
Price	2	37.8	19.8	39.2	19.6	N.S.	.81	.000

Discussion: Based on these results, counting pedicels appears to be a viable alternative to counting nuts. Pedicel counts have the advantage that they can be done after harvest. Also, pedicel counts include nuts that may have been knocked off accidently by equipment moving through the orchard, predators, wind, etc. Natural harvest drop that might have occurred prior to counting would also be picked up in pedicel counts. Depending on how long the nuts retain their brown color, pedicels could possibly be counted after leaf drop which would make observation easier. Disadvantages of counting pedicels might be that they are smaller and more difficult to see. However, in cultivars such as Price, where the nuts occur in dense clusters making accurate counts difficult, pedicels might be easier to count. Also, if an absolute estimate of yield of nuts actually being harvested is desired, pedicel counts would include nuts eaten by predators and lost to other causes prior to harvest.

Multiyear Comparison of Intensive vs. Cluster Bee Counts

This year we concluded our experiment to develop a quick, less disruptive method to evaluate colony strength. Data collected between 1983-1987 during the almond bloom season were analyzed. A regression equation was derived to compare intensive count estimates of colony strength by number of frames covered by bees on both sides (IC) with the cluster count method (CC). The relationship between CC and IC estimates of colony strength and brood area were also calculated. In addition, cost analyses and economics of using CC are discussed.

Materials and Methods: Data collected from examining 631 colonies during the almond bloom seasons of 1983-87 were used for analyses. Data were analyzed for each year separately and for the five years combined. Simple regression and correlation analyses were performed. The homogeneity of the correlation coefficients of the five year data were tested. To cross test the derived regression equation in predicting the IC from CC, the strength of 50 randomly selected colonies was estimated using their CC count. The predicted IC and the actual IC were compared using a T-test. Similar correlation and regression analyses were performed on brood area, CC and IC data.

Results: All correlations between CC and IC were highly significant at $P>.0001$ (Table 8). No significant differences were found among the correlations of the tested years. For the five year combined data, correlation between CC and IC was .743. In colonies with CC less than 2.5 ($N=11$) and more than 9 frames of bees ($N=220$) the correlation coefficients with IC are .492 and .435, respectively. Bee colonies with CC between 3 and 9 frames ($N=400$) had a higher correlation ($r=.600$).

The relationship between CC and IC is shown in the fitted regression line (Fig. 9). The regression equation was $Y= 2.07 + .65 X$ where: $Y=$ IC; $X=$CC. T-test for slope $=0$ was significant at $P <.0001$. The r^2 indicated that CC explained about 56.2% of the total variation in IC.

Cross testing the derived equation showed that the predicted IC was not significantly different from the actual IC for the 50 tested colonies ($t= .93$, $P< .35$, $N=98$).

In most years, estimates of colony strength (IC and CC) when compared with brood area showed low correlation except for 1985 when the correlation coefficient between CC and brood area was .74 ($P>.001$).

Discussion: Data analyses of CC and IC suggested that evaluation of colony strength can be estimated using CC. CC predicted between 48 and 78% of the variation in colony strength for the five years of data. The improvement in correlation over the course of five years (Table 8) suggests that there may have been a reduction in variability possibly due to improved methodology or learning by observers. Colonies with a CC less than 3 frames are under-estimated while colonies with more than 9 frames are over-estimated. This pattern may possibly be explained by the following facts: 1. clusters with less than 3 frames are small and may not cover the tops of the frames; 2. clusters of 9 frames and above are more often split into two boxes causing an over-estimation of cluster size; and 3. colonies with clusters under 9 frames usually form a tight cluster in one hive box facilitating accuracy in estimating their size. Despite this limitation in cases of colonies with less than 3 or more than 9 frames, calculating the

FOB using CC in the predictive regression equation has shown no significant differences between the estimated values of FOB and those obtained in the field. This may be related to large percentage of the numbers of colonies (63.4%) with 3 to 9 frames. The most important category according to our flight activity studies is 8 FOB.

Brood data analyses have shown little evidence that estimates of colony strength by CC or IC can predict BA especially during early spring when egg laying activity has not yet begun. Low correlation between the BA and CC and IC is presumably due to many factors such as time of initiation and rate of egg laying by queens, feeding, and seasonal variability. However, data in 1985 showed that brood area had a high correlation with CC and IC. This high correlation can be explained by early egg laying activity (one or two weeks) prior to estimation of colony strength and BA measurement.

Economics of Cluster and Intensive Counts

We kept track of the person hours to make the strength evaluations by each method to determine the savings in conducting the simpler cluster counts in contrast to the intensive counts.

Materials and Methods: Cost analyses of colony strength evaluations using IC and CC were made in order to give potential users an idea of the comparative economics of using the two methods. Time spent in making the CC and IC for each colony was recorded for 80 colonies. In making the CC, one person counted while another recorded. In making the IC, two groups were tested. Group A consisted of two persons counting and one person recording. Group B consisted of one person counting and one recording. The average times for CC or IC per colony for Group A and B were calculated. The cost of estimating colony strength by CC or IC was determined by multiplying these figures by an hourly wage rate of seven dollars per hour based on consultation with experienced beekeepers.

Results: The average amount of time per hive required to perform CC was 0.9±0.2 while IC group A and B required 5.7±1.6 and 7.4±3.8 minutes, respectively. Based on the number of persons performing the CC and IC and the average time required per colony, the calculated cost per colony for CC, IC group A and B was 0.21±0.05, 2.00±0.56 and 1.73±0.88 dollars respectively. Thus, CC is 6 to 10 times less expensive than IC.

Discussion: The CC method is simple and easy to perform. Two examiners and one recorder can perform CC in 1/6 of the time needed to perform IC. This time can be reduced by increasing the number of examiners. For CC, estimating colony strength takes only 0.9 minutes per colony. In addition, CC does not vary significantly from person to person, and is less disruptive to colonies than previoulsy described methods. Even though the CC method does not provide information about the brood and queen quality, this method can be recommended to beekeepers and growers for evaluating colony strength. CC's that are made prior to or early in bloom will allow enough time to replace colonies with strength less than that recommended for pollination and/or specified in a contract. Thus, this method represents an advantage to beekeepers and growers practicing pollination services.

Table 1. Correlation coefficients for actual and predicted bloom progression for five almond cultivars. Bloom progression for each cultivar is defined mathematically by separate pre- and post-peak bloom equations.

Cultivar	Correlation Coefficient	
	Pre-peak bloom	Post-peak bloom
'NePlus'	0.71	0.97
'Nonpareil'	0.94	0.96
'Price'	0.86	0.96
'Peerless'	0.93	0.95
'Mission'	0.97	0.95

Table 2. The average amount of nectar and pollen per meter of branch, and honey bees per tree throughout bloom in five almond cultivars.

Cultivar	Nectar/m (ul)	Pollen Grains/m	Honey Bees/ Tree
'NePlus'	11.0 a	238,233 a	5.6 a
'Nonpareil'	15.3 a	384,359 ac	5.2 a
'Price'	12.2 a	464,757 bc	4.2 a
'Peerless'	27.0 b	628,699 b	8.6 b
'Mission'	32.7 c	651,861 b	10.6 b

Means followed by the same letter are not significantly different at the 0.05 level as determined by Scheffe's S test.

Table 3. The percentage of blossoms of various ages ('A' are the most newly open blossoms and 'D' are blossoms opened the longest amount of time) setting nuts from hand-pollinations of blossoms throughout bloom in five almond cultivars.

Cultivar	Blossom Stage	Blossoms Pollinated	% Nut Set
'NePlus'	AB	7	57.0 a
	C	9	78.0 a
	D	100	72.5 a
'Nonpareil'	AB	27	70.3 a
	C	26	65.4 a
	D	36	97.2 b
'Price'	AB	26	73.0 a
	C	20	62.5 b
	D	50	68.0 b
'Peerless'	AB	25	32.0 a
	C	26	46.0 b
	D	55	38.0 c
'Mission'	AB	78	51.0 a
	C	78	46.0 b
	D	67	45.0 b

Means followed by the same letter within a cultivar are not significantly different at the 0.05 level as determined by binomial approximations of 95% confidence intervals around the means.

Table 4. Comparisons of actual nut set and predictions from the ALMOPOL cross-pollination and nut set prediction model for five alomnd cultivars.

Cultivar	Actual % Nut Set + SE	Predicted % Nut Set
'NePlus'	52.7 ± 10.4	62.7
'Nonpareil'	36.0 ± 6.0	26.4
'Price'	76.2 ± 8.8	29.5
'Peerless'	27.3 ± 7.4	29.5
'Mission'	23.7 ± 5.8	25.8

Table 5. Percent change in colony strength during the almond bloom period - 1988.

All Colonies Assessed			Colonies counted for flight	
Strength Group (Frames of Bees) [FOB] by Cluster Technique	Number of Colonies	Mean % Change	Number of Colonies	Mean % Change
2	10	159.2 ± 169.6		
4	19	52.0 ± 69.4	5	102.5 ± 70.9
6	8	30.8 ± 49.2	5	33.3 ± 44.8
8	5	25.3 ± 32.4	5	22.0 ± 29.6
10	4	-6.1 ± 35.4		
11-12	6	-49.0 + 48.2	5	-41.5 + 49.9
TOTAL	52	50.7 + 106.5	20	29.1 ± 70.3

Table 6. Honey bees returning to colonies of different strength (bees alighted on screen blocking entrance at the end of 30 seconds).

Strength Group (FOB) by Cluster Technique	Number of 30 Second Counts	Bees with Pollen	Bees without Pollen	Total
4	330	2.0±2.2 B[*]	12.3±13.9 B	14.4±14.4 B
6	330	2.9±2.7 A	11.8± 6.8 B	14.7± 8.1 B
8	330	2.9±3.0 A	16.0±10.0 A	18.9±11.5 A
11	330	2.4±3.5 AB	12.9±13.6 B	15.3±16.0 B

[*] Groups followed by the same letter are not significantly different (P = 0.0002, 0.0001, 0.0001 for the three columns, respectively).

Table 7. Mean Incoming Flight by Strength and Temperature Group.

Strength (FOB)	Temperature (^{o}F)	Sample Size	Pollen Mean S.D.	Non-pollen Mean S.D.	Total Mean S.D.
4	55-59	29	2.89±2.54	13.69± 7.77	16.59± 8.69
4	60-65	21	2.38±2.80	5.71± 5.60	8.09± 6.88
4	66-70	35	3.26±2.09	14.23± 5.97	17.49± 7.00
6	55-59	27	3.96±3.18	13.22± 8.05	17.18± 9.06
6	60-65	23	3.56±3.49	8.35± 6.32	11.91± 9.03
6	66-70	35	4.23±2.62	15.54± 5.63	19.77± 7.24
8	55-59	28	3.61±3.06	16.78±11.10	20.39±11.89
8	60-65	22	3.82±3.77	11.04± 8.63	14.86±11.60
8	66-70	35	4.60±3.25	21.06± 7.97	25.66± 9.60
11	55-59	26	3.38±4.66	14.46±15.92	17.85±18.54
11	60-65	24	2.87±4.00	7.79± 9.95	10.67±13.61
11	66-70	35	3.48±4.17	15.88±14.23	19.37±17.75

Table 8. Correlation between cluster and intensive colony strength estimates.

Year	Number of colony estimated	R^{*}	R^{2}
1983	211	0.70	0.49
1984	105	0.70	0.48
1985	182	0.80	0.64
1986	87	0.84	0.64
1987	46	0.88	0.78
1983-1987	631	0.75	0.55

* All R values are significant at $P<0.0001$.

Figure Captions

Figure 1. Relationship between strength and incoming flight in honey bee colonies during almond bloom.

Figure 2. Comparison of four flight count models (FCM) for evaluating incoming activity at all honey bee colonies in both apiaries.

Figure 3. Comparison of four flight count models (FCM) for evaluating incoming activity at colonies with 2 frames of bees (FOB).

Figure 4. Comparison of four flight count models (FCM) for evaluating incoming activity at colonies with 4 frames of bees (FOB).

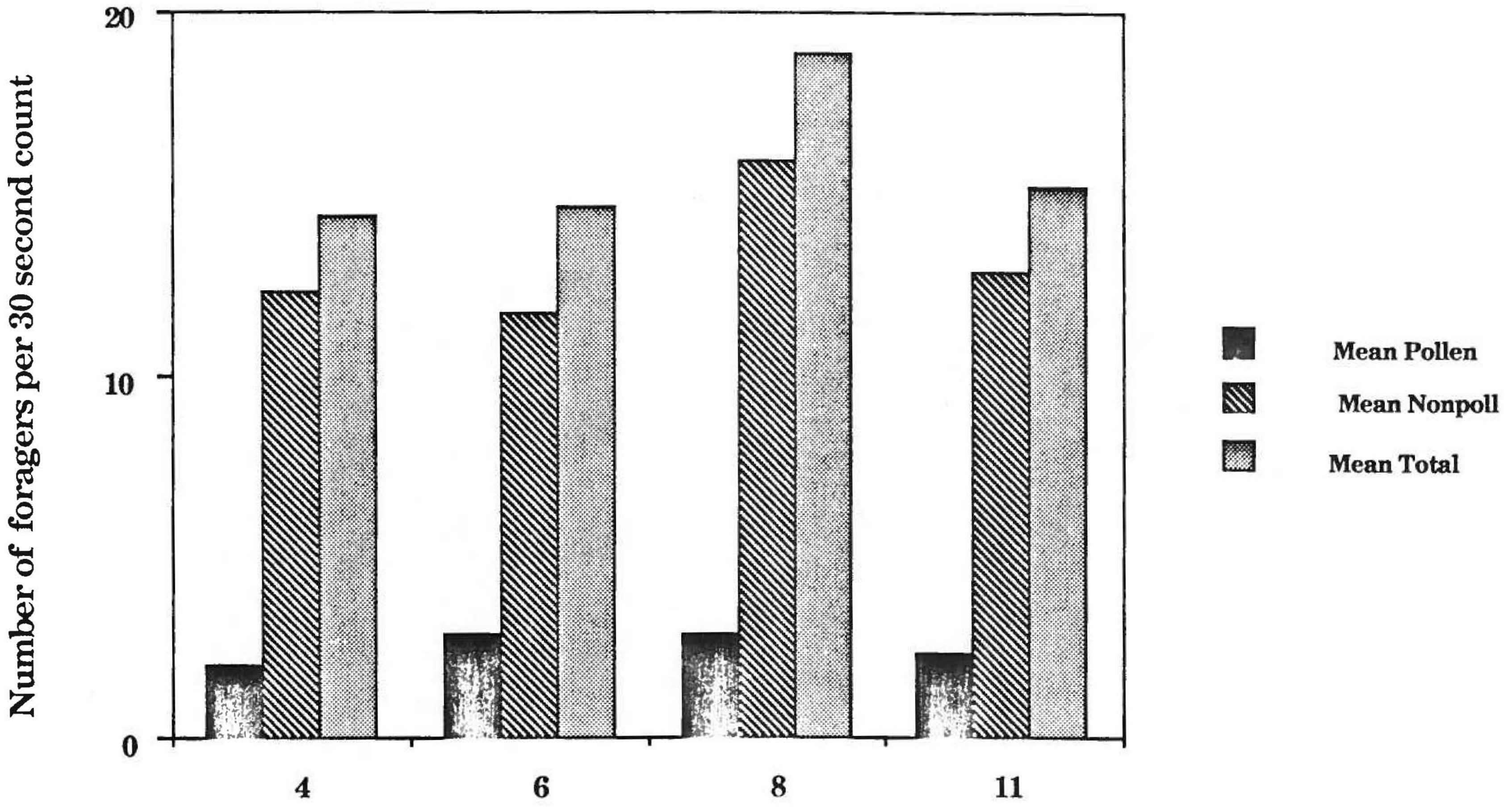
Figure 5. Comparison of incoming flight activity at colonies with 2 or 4 FOB.

Figure 6. Mean of returning pollen foragers vs. temperature and colony strength during almond bloom (n = 340 counts).

Figure 7. Mean of foragers returning without pollen vs. temperature and colony strength during almond bloom (n = 340 counts).

Figure 8. Mean of total foragers returning vs. temperature and colony strength during almond bloom (n = 340 counts).

Figure 9. Regression of colony strength evaluations by cluster size vs. intensive frames of bees counts.

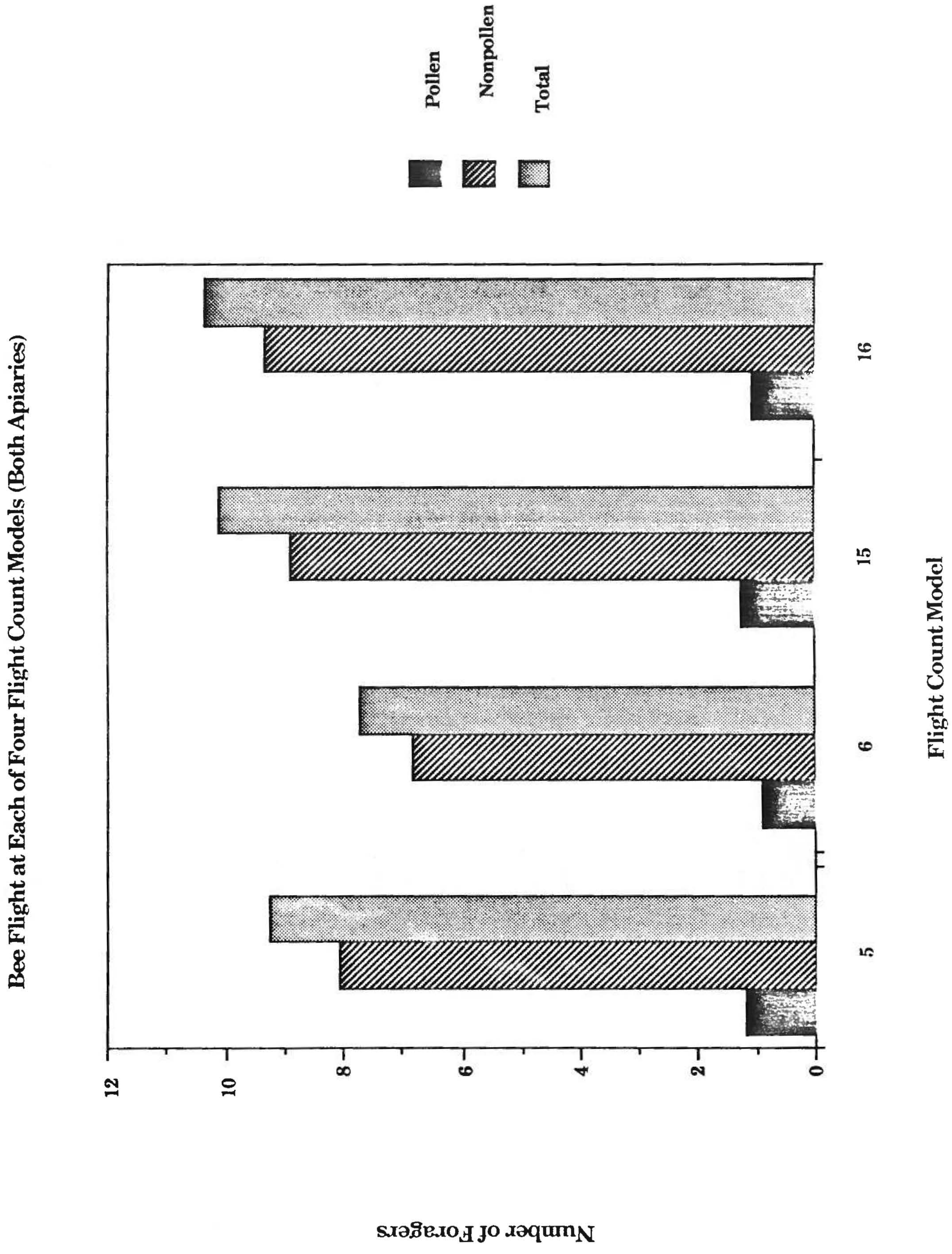


Foragers with and without pollen loads returning to 5 colonies in each of 4 strength categories (4, 6, 8 or 11 FOB* by Quick Cluster Technique) over the 1988 almond bloom season near Dixon, California

*Frames of Bees

Figure 1

Figure 2



Bee Flight at Each of Four Flight Count Models (Both Apiaries)

Effect of Flight Count Model on Foragers Counted at 2 FOB Colonies

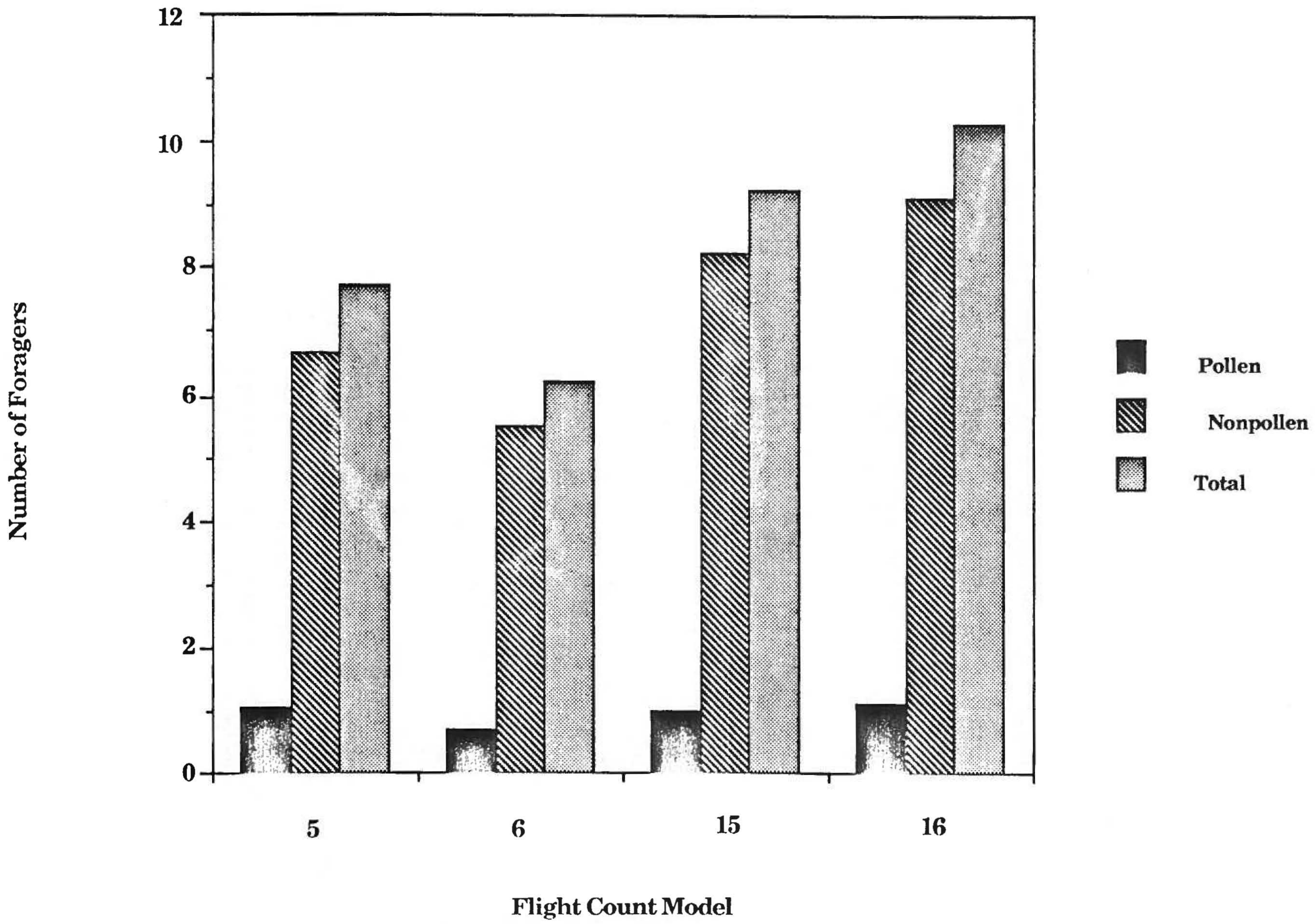


Figure 3

Effect of Flight Count Model on Foragers Counted at 4 FOB Colonies

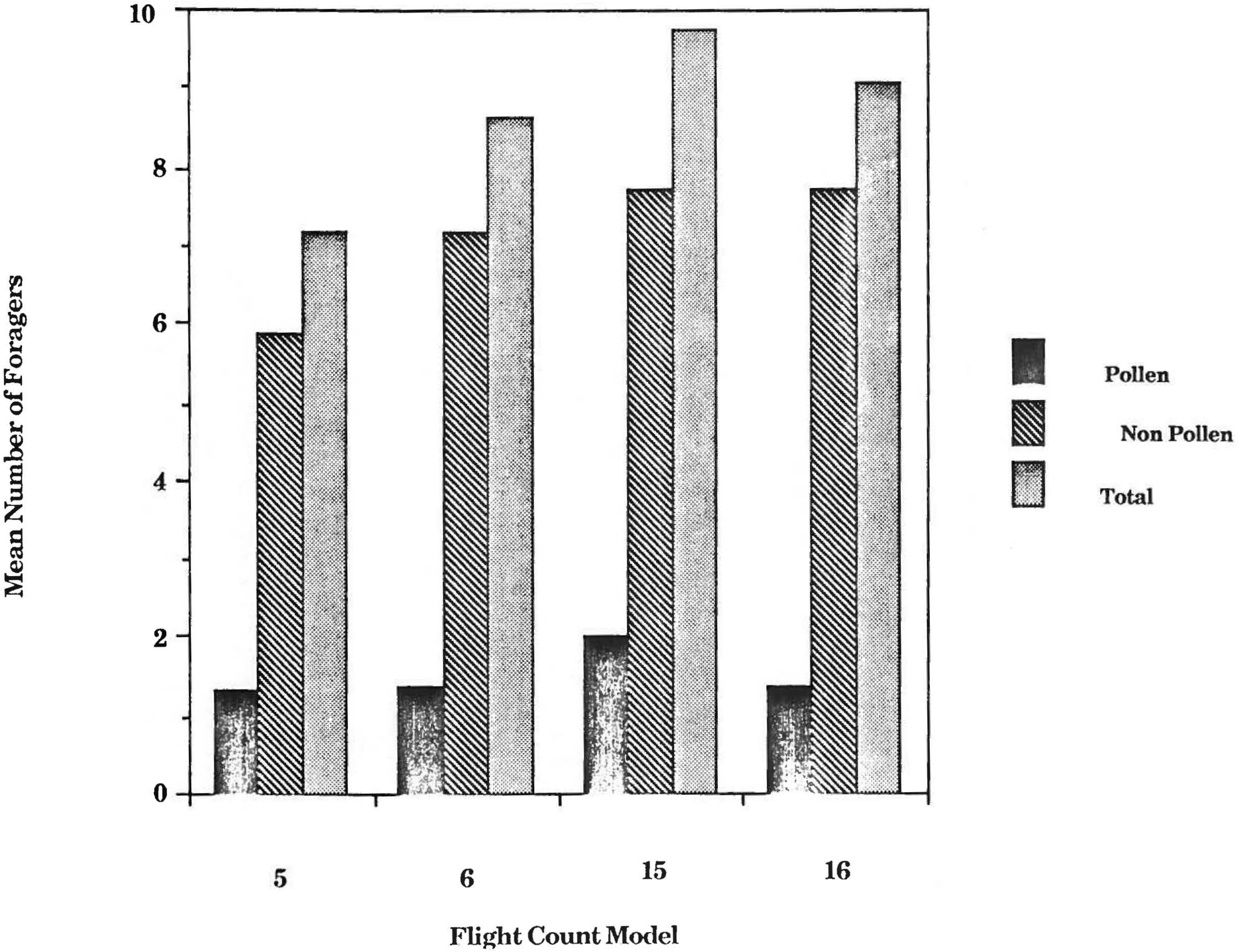


Figure 4

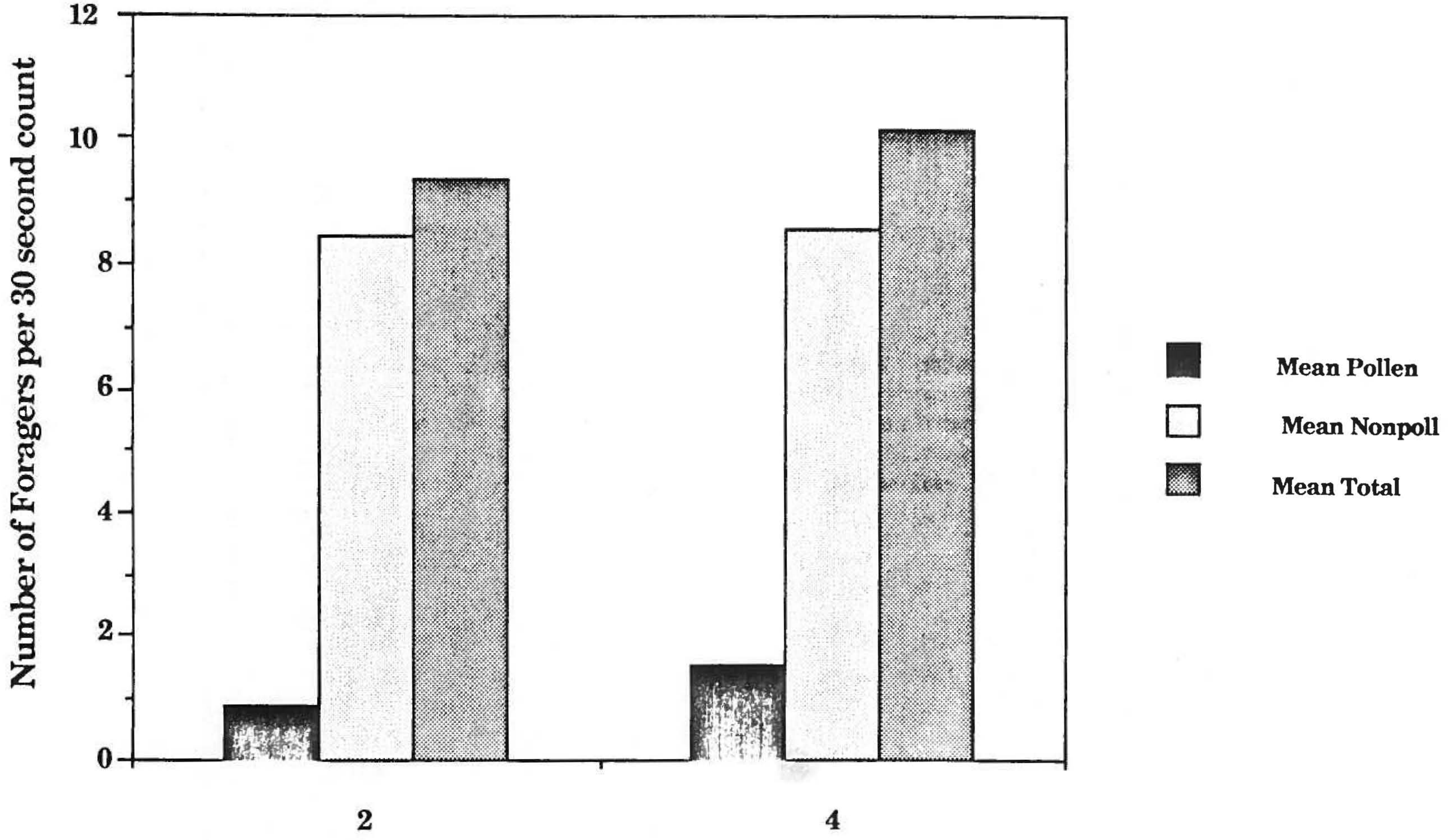
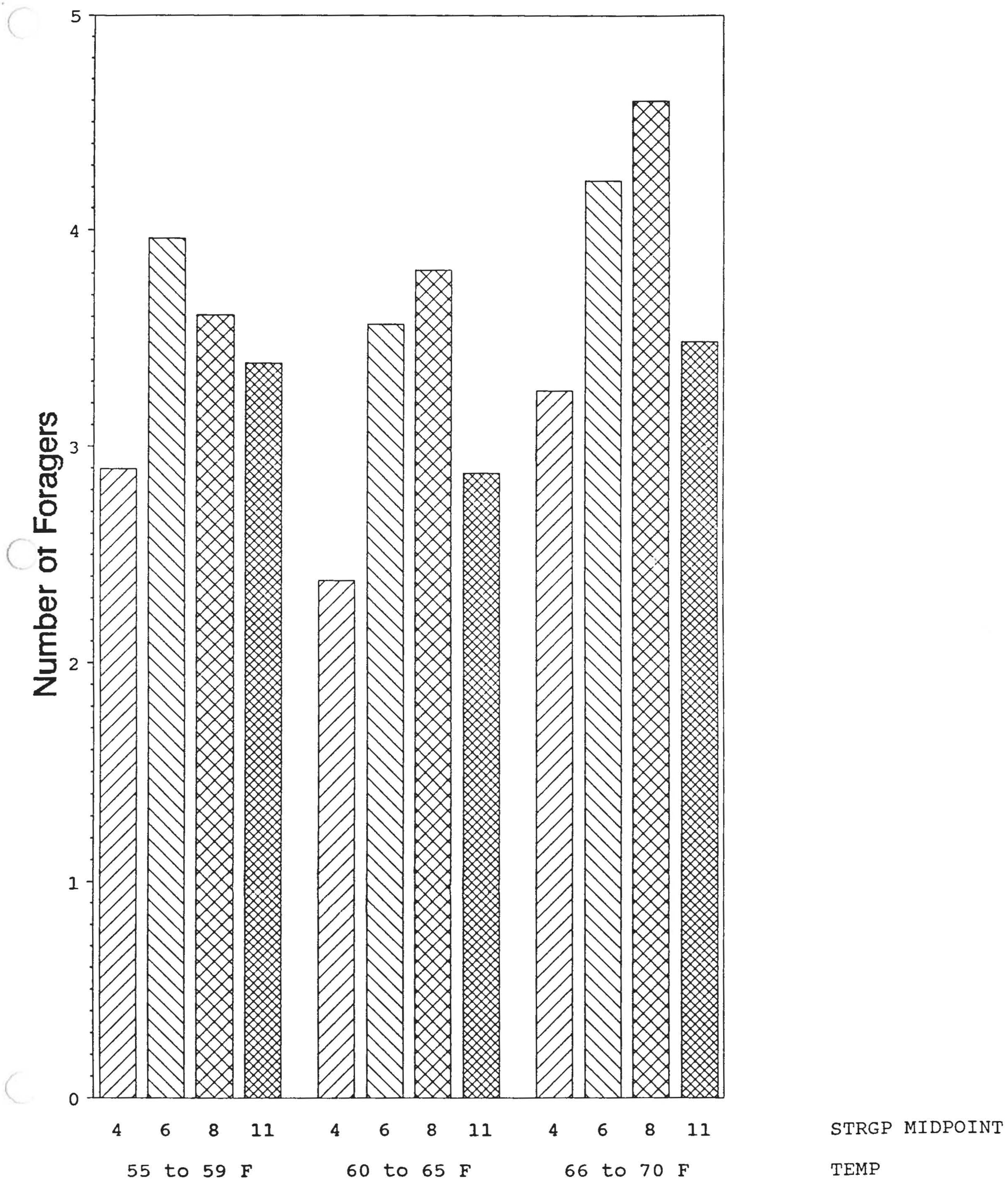


Figure 5

Foragers with and without pollen loads returning to colonies in 2 strength categories (2 or 4 FOB* by Quick Cluster Technique) just prior to the 1988 almond bloom season near Davis, California

* Frames of Bees

Mean Pollen Flight vs Temperature and Colony Strength During Almond Bloom



Mean Non Pollen Flight vs Temperature and Colony Strength During Almond Bloom

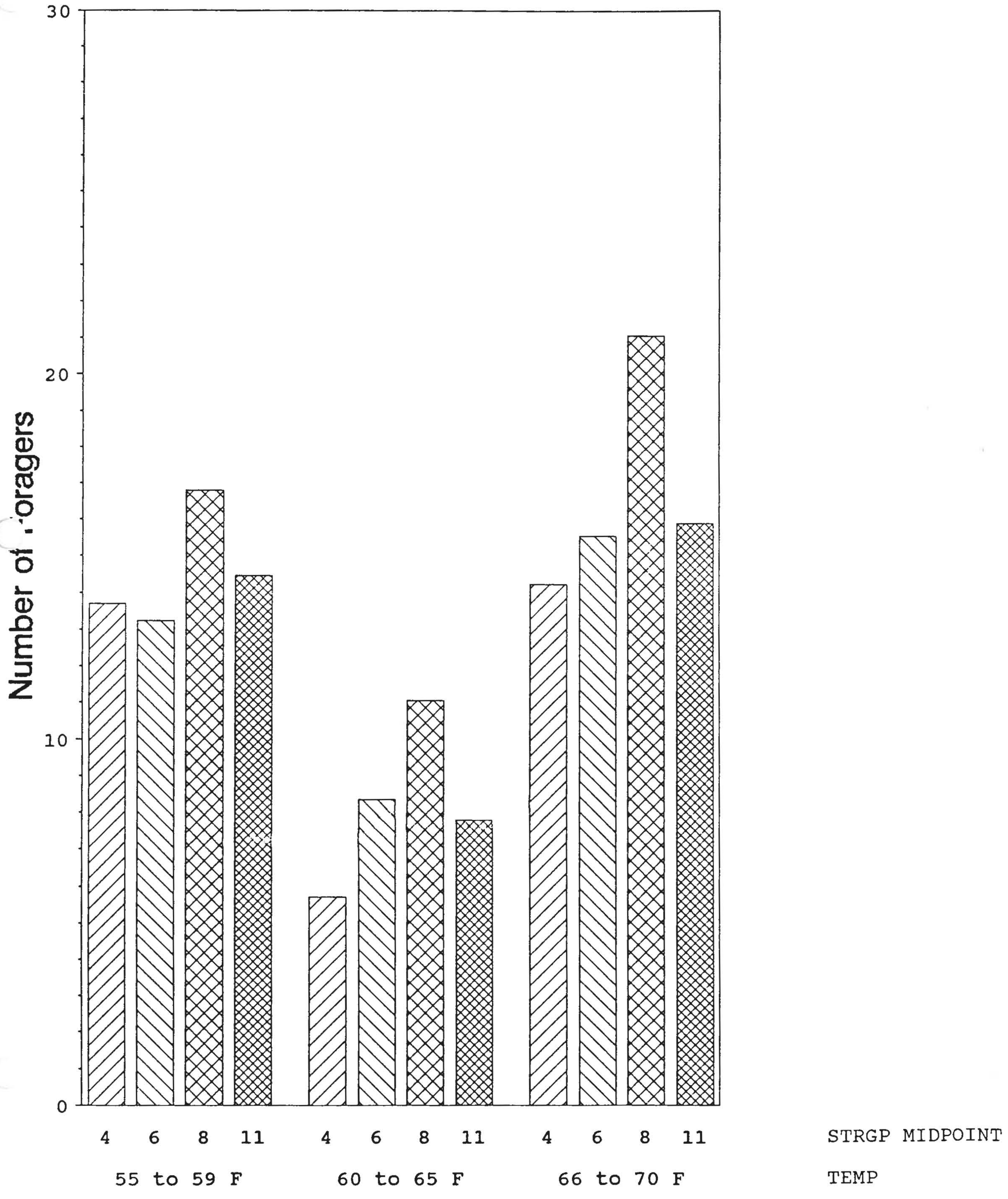
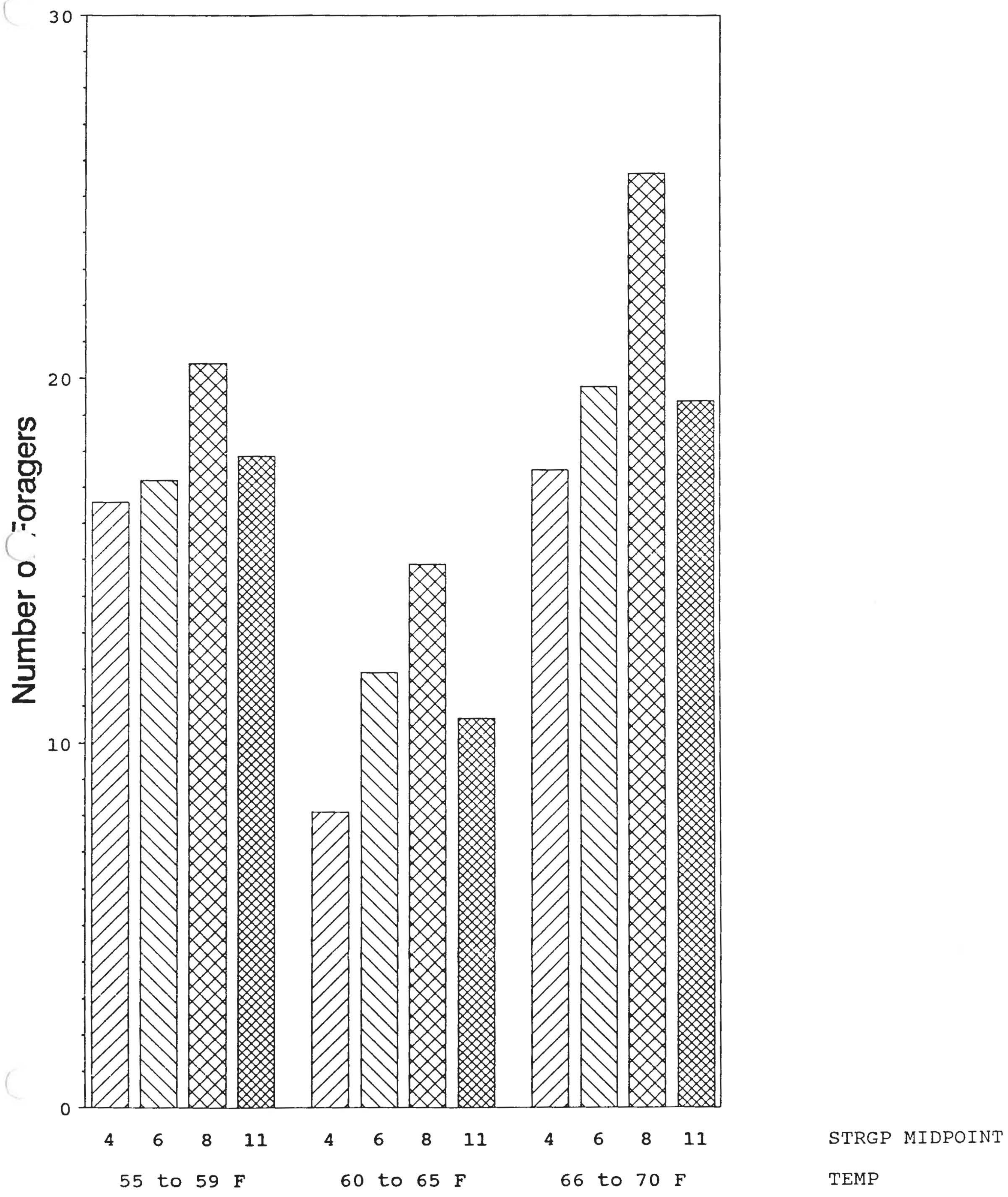
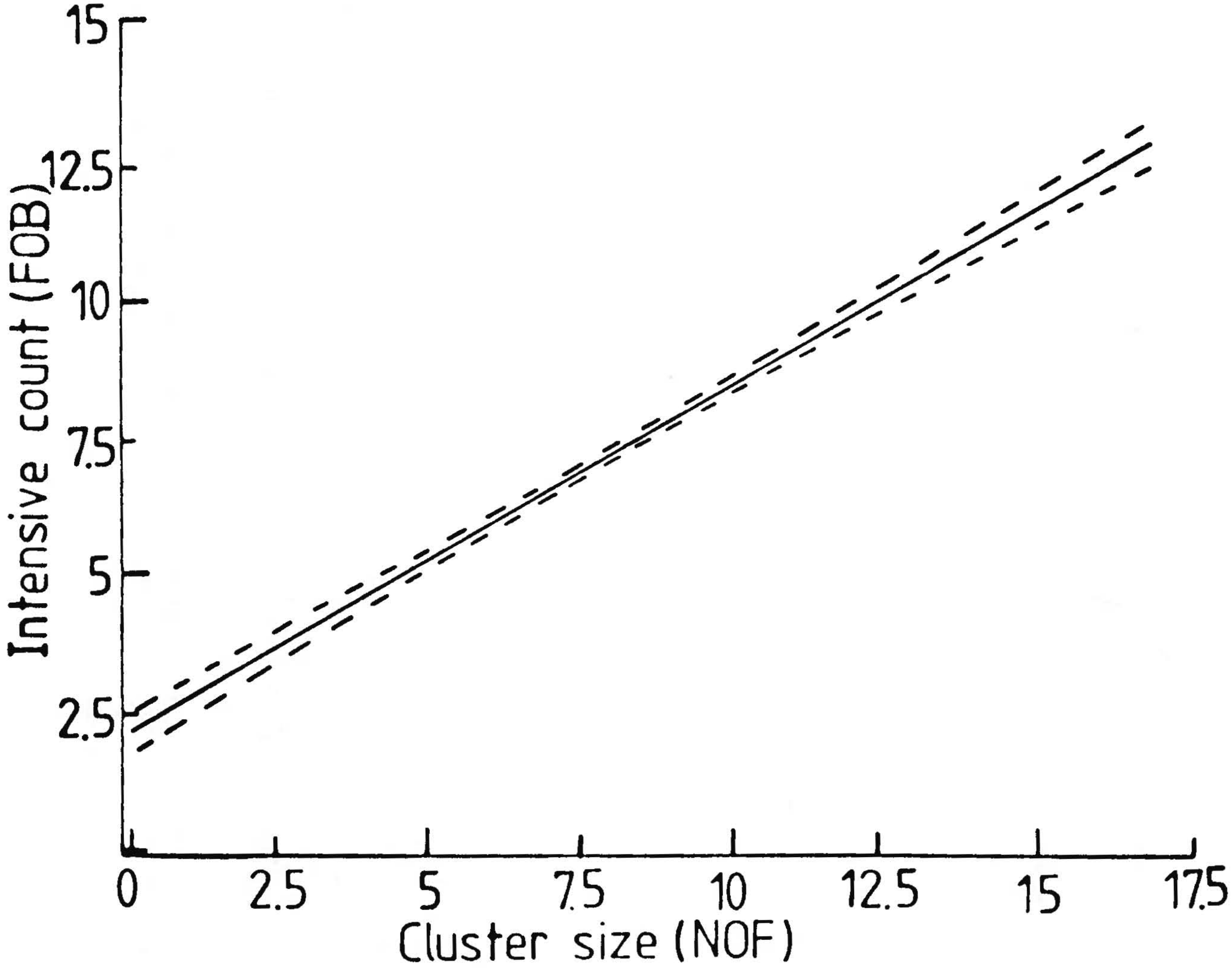


Figure 8

Mean Total Flight vs Temperature and Colony Strength During Almond Bloom





Regression of colony strength estimates: intensive count by frames of bees (FOB) on cluster size by number of frames (NOF). Regression equation is:
Intensive count (FOB) = 2.07 + 0.659*[Cluster size (NOF)].
Slope is significant at $P < 0.001$ ($R^2 = 56.2\ \%$, $N = 631$).

Figure 9