1987 ANNUAL REPORT TO ALMOND BOARD OF CALIFORNIA

Project No. 87-M12 - Tree and Crop Research
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: Colony strength correlations--We increased our database for comparisons between cluster and frame by frame counts of worker bees by 99 hives. Another 127 hives with only cluster estimates were used to calculate bee population available to the orchard used for the pollination model validation. As in previous years, correlation between two methods was high. There was no significant difference among estimates by two experienced and one inexperienced observers indicating that the methods can be easily learned. Cost analysis shows that the intensive counts are about 8 times as expensive as cluster counts.

Hive strength and flight correlations--The 4-frame hives had significantly less flight than larger hives did. This affirms the importance of strong hives. Multi-year comparisons of flight activity showed considerable variation probably due to weather and confirms less flight from lower strength groups. Use of flight counts seems promising for strength evaluation, but more data are needed.

Floral biology--Height of the stigma above anthers at dehiscence differed between cultivars. Abortive flowers increased through the season. Nectar production increased after rain and irrigation.

Fruit drop by cultivar--Of 5 cultivars, only Price showed a significantly lower final than initial fruit set. However, it had the highest set so the percent drop relative to initial nuts was significantly less than for other cultivars.

Moving bees in waves--All hives had about 98% almond pollen in traps regardless of time of introduction. This was a small sample, but, unless there is strong competition from other plants, introducing hives in waves may not improve pollination in almonds as it seems to do in other crops.

Osmia cornuta--Emergence from nearly 60 nests from last year started in synchrony with almond bloom. Emergence was poor. Only 4 nests were provisioned.

Almond pollination model--A computer program that predicts the rate of cross-pollination and nut set during bloom in almond is being developed. Potential nut set, at the end of bloom, can be used to estimate crop value. This can then serve as the economic basis for crop management decisions that year. The goal is to develop a program that will be accessible to growers via software for personal computers.

Nut set predictions are based upon: 1) weather conditions during bloom, 2) cultivars present, and 3) honey bee foraging population size. During 1987, blossom counts were taken throughout bloom to validate bloom progression estimates. Bees at almond flowers were counted to test the accuracy of the program's estimates of foraging population size throughout bloom. Nut set was counted about one month after petalfall and just prior to harvest to compare actual set with the program's estimates.

21 December 1987

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Tree Research: Pollination (Project No. 87-M12)
R. W. Thorp, U. C. Davis

Honey Bee Colony Strength Correlations

We continued to gather data comparing intensive frame by frame counts of bees and brood with the quicker, less disruptive cluster estimates of bee populations. These data were collected during the process of selecting colonies for experiments on the relationship of colony strength and returning flight activity at the hive entrance and on the effects of moving colonies into the orchard in waves.

Materials and Methods: All colonies in the 30 acre test orchard were evaluated. A sample of colonies from neighboring orchards were evaluated by cluster estimates during cool mornings prior to the initiation of flight. All colonies in the test orchard and a portion of those from nearby orchards previously evaluated by cluster estimates were examined intensively frame by frame as follows:

	Date	No.	Eval.	Orchard	Comments
Feb.	12	25	Cl	Test	Moved in Feb. 9
	16	24	Cl	Test	Moved in Feb. 9
	16	49	In	Test	Moved in Feb. 9
	16	12	Cl/In	Nearby	Moved in Feb. 9
	19	37	Cl	Nearby	--
	20	41	Cl	Nearby	--
	20	47	In	Nearby	--
	27	12	Cl/In	Test	Moved in Feb. 20
	27	5	Cl/In	Test	Moved in Feb. 27
Mar.	4	96	Cl	Nearby	--

	Orchard:	Test	Nearby
Totals:	Cluster	66	186
	Intensive	66	59

Ending strength counts were made only on the 66 colonies in the test orchard. Of the 459 colonies in and near the test orchard, 99 of those evaluated on 12, 16 and 20 February were selected for comparisons of cluster versus intensive count methods. Some colonies measured during this period were not included because they were from another beekeeper using different depth hive boxes from those in our test orchard.

Results: There were no significant differences among the 3 observers in their estimates of cluster sizes ($F_{2,180}$= 1.287, P<.279) (Table 1). A series of T-tests between cluster estimates and intensive counts for each observer showed no significant differences (P<.001).

All strength categories for 20 colonies showed increases in strength over the season (Table 2). These were significant increases only for the 4 and 10 frames of bees groups. Although no significant increase was found in the 6 frames of bees category, the percent of change was highest in this group. This may be due to the high variability in the group (2 colonies eincreased by 83.34% while the rest only increased by 6.62%).

Cluster measures underestimate smallest colonies and overestimate larger colonies when compared to intensive frame by frame counts for 1987 (Table 3).

Discussion: The best correlations are the initial intensive and cluster counts (Table 1) which are the ones needed by the grower for early evaluation of the bees rented. The relationship between initial cluster estimates and intensive frame by frame counts for 1987 (Table 3) is similar to those of our previous studies with underestimates of smallest colonies and overestimates of larger colonies. However, cluster counts continue to show promise as a rapid, less disruptive means of determining colony strength in the range which is most meaningful to growers (6-10 FOB). Fuller discussions of these measures appears in Almond Facts Sept/Oct 1986 pp 30-31 and in the following section on cost analyses.

Cost Analyses of Colony Strength Evaluations

We made a cost analysis in order to give the grower an idea of the costs involved to perform or pay some third party to conduct strength assessments of colonies.

Materials and Methods: The amount of time needed to perform cluster counts, intensive frame by frame measures, and counts of flight activities at hive entrances were recorded during the bloom season. The average amount of time per hive needed to perform each of these operations was calculated. After talking to people knowledgeable about farm and beekeeping labor costs, a $7.00 per hour figure was used to calculate cost per hive. Beekeeping supplies needed and their approximate costs include:

Bee veil	8.00 - 12.00
Coveralls	22.00
Hive tool	3.00
Smoker	15.00
Gloves	5.00
	53.00 - 57.00

The coveralls, hive tool, smoker, and gloves might not be necessary for the entrance flight counts (unless colonies were very aggressive), but a screen to block the entrance, and a watch with the capability for measuring seconds would be needed. There are currently no manufacturers of flight screens, but a screen could probably be made for no more than $5 - $10 including labor.

Results: The results of these calculations are:

	No. Counts	Hours	Cost/hive
Beginning Intensive	107	5.4	1.05
Ending Intensive	97	3.0	0.90
Beginning Cluster	32	0.6	0.13
Ending Cluster	39	1.1	0.11
Flight Counts	1456	35.0	0.10

There were two people counting and one person recording the intensive counts so the cost per colony includes the times of three workers.

Discussion: All the beekeeping supplies are reusable. Their costs may be amortized over many years. Since the grower probably would only be concerned with beginning intensive and cluster counts, the intensive counts are 8 times as expensive to conduct as the cluster estimates ($1.05/0.13= 8.08) as well as being much more disruptive to the colony. One should be aware that the cluster estimates do not give any indication as to the presence of brood or a viable queen. For further discussion of other factors to consider in comparing the two methods see

Almond Board of California Research Update (August 1986) or Almond Facts (Sept/Oct 1986): 30-31. Amount of pollen income to pollen traps (see 1985 Almond Board of California Report) and on strips of carpeting (See 1986 Almond Board Report) could also be used to gauge colony fitness for pollination. Determining the amount of pollen collected has the advantage that it incorporates the number of bees flying and the proportion collecting pollen. We have not yet made a cost analysis on using pollen traps to collect pollen, but it would probably be more costly than the above mentioned methods.

Colony Strength and Bee Flight Correlations

As in previous years, research was conducted to determine which hive strength groups produce the greatest flight activity and presumably the best pollination.

As can be seen by comparing tables 6 and 7 of the "Multiyear Analyses" section of this report, counts of incoming flight are considerably lower than those of outgoing flight. Since incoming and outgoing flight should be about equal, we decided to try to increase incoming counts by improving our flight screens.

Materials and Methods: Flight counts were made on 61 colonies in the 30 acre test orchard from 23-27 February. Five more colonies were moved into the orchard on 27 February and counts were made on them on 2 and 3 March. Due to time constraints, counts on 6, 9-13, 16 and 18-19 March were made only on 5 hives from each of four strength groups.

Counts were made, as in previous years, by blocking the hive entrance with a screen and counting the numbers of bees landing on the screen after 30 seconds. We have had some problems in previous years in getting bees to land on the screens, especially on clear days. Apparently bees could more readily detect a change in the hive entrance because of reflections from the screens on clear, but not overcast days. Therefore, we tested several different types of wire mesh and wood paneling "screens" this year. Screen 3 is made of 8-mesh hardware cloth, painted on top to match the hive color and black where the screen covers the colony entrance. Screen 2 was slightly shorter than 3 and not painted black to reduce reflection where it covered the entrance. Screen 5 is the same except the top of the screen above the entrance is covered with a slat of 1/8" wood painted to match the color of the hive. This probably gave #5 a solid, unbroken pattern better simulating the hive body. Screen 6 is identical to #3 except the screen over the entrance hole is stepped out about 1." Screen 7 is an "L" shaped piece of 8-mesh hardware cloth painted completely black.

In counts done prior to 6 March, different observers counted with different types of screens. Since we had more time after cutting the number of hives from 66 to 20, we decided each observer should use two screens, one a "standard" screen used by all observers, and one of several different screens for comparison. On 6, 9,10, and the morning of 11 March, each hive was counted using two different screens in quick succession. In the remainder of the counts for the season, all hives in a group were counted with one screen then the observer returned to the first hive of the group to begin counting with the second screen so that several minutes elapsed between first and second counts of each hive. There were 4-6 treatment hives per location so that this procedure seemed to allow the colonies time to settle and accurate counts could be obtained.

Results: There were significant differences among pollen foragers ($F_{3,236}$= 4.939, P<.0002) and non-pollen foragers ($F_{3,236}$= 7.606, P<.001) (Table 4). Six frame colonies had significantly more pollen and non-pollen foragers than 4 frame colonies (67.7% and 168.2% more, respectively)(Fig. 1). There were no significant differences among means for pollen foragers or non-pollen foragers in 6, 8, and 10 frame colonies.

Analyses of strength versus bee flight at hive entrances for 20 colonies for the entire season are listed below:

1. Regression summaries for incoming flights:

			R^2	S.E.	F_{18}	P
Pollen	=	2.162 + 0.291 X I(I)	0.262	1.023	7.739	0.012
Pollen	=	2.477 + 0.197 X C(I)	0.255	1.028	7.514	0.013

			R^2	S.E.	F_{18}	P
Non-Pollen	=	8.497 + 1.145 X I(F)	0.206	4.597	5.931	0.026
Non-Pollen	=	11.298 + 0.592 X C(F)	0.094	4.910	2.981	0.101

I= intensive; C= cluster; (I)= initial; (F)= final

2. Correlation coefficients for strength vs. incoming bee flight

Pearson Correlation Coefficient Matrix

	Initial Intens.	Final Intens.	Initial Cluster	Final Cluster	Pollen Flight
Final Intensive	.776	----			
Initial Cluster	.802	.594	----		
Final Cluster	.582	.775	.421	----	
Pollen Flight	.548	.640	.543	.645	----
Non-Pollen Flight	.498	.755	.377	.628	.745

Spearman Rank Correlation Coefficient Matrix

	Initial Intens.	Final Intens.	Initial Cluster	Final Cluster	Pollen Flight
Final Intensive	.794	----			
Initial Cluster	.742	.545	----		
Final Cluster	.577	.781	.357	----	
Pollen Flight	.492	.538	.476	.571	----
Non-Pollen Flight	.606	.755	.475	.627	.606

There were no significant differences between early and late season pollen flights, but non-pollen flights were significantly greater late versus early in the season for 20 hives overall flights (Table 5). More detailed analyses of the flight data by early versus late season show that the significantly lower flights for 4 FOB colonies (Table 4) are due to early season pollen flights and late season non-pollen flights.

Because of potential observer bias and differences in count methodology on those days before 11 March, only those dates after 10 March (11, 13, 16 and 19 March) were used in the analyses of screen types. The only significant differences were: screen 5 had significantly higher pollen and non-pollen foragers than did screens 2 or 3 on 11 March; and screen 6 had significantly higher non-pollen flight than did screen 7 on 13 March (P= .05 in both cases).

Discussion: As in past years the 4 frames of bees [FOB] category had significantly lower flight than greater strength categories reaffirming the need to contract for strong colonies. The leveling off in flight and apparent slight dip in flight at the 8 frame category may be due to the fact that this year (Table 4, Fig. 1) and also in 1986, the colonies in the 6 frame category had the highest rate of growth for the season (in 1986, 4 FOB= 18.1%, 6FOB= 63.3%, 8FOB= 34.1%, 10FOB= 16.7%), and thus the flight counts toward the end of the season would reflect higher forager populations than might be expected (see Multiyear analysis section of this report for related discussion).

Analyses of colony flights of early versus late season, showed that early season pollen and late season non-pollen flights were primarily responsible for the significantly lower flights noted for 4FOB hives. The slower growth of the 4FOB colonies and the general trend toward less pollen and more non-pollen flight (perhaps due to lower pollen resources at the end of the season) accounts for both of these.

The pilot experiment to find a more suitable flight screen needs to be repeated using those screens that showed the most promise in 1987, especially screens 5 and 6. The black color and/or the rough surface of the bottom of the "L" extending over the landing board probably caused #7 to be less acceptable than #6.

Multiyear Analyses of Hive Strength and Flight Activities

In order to attempt to answer the question qrowers frequently ask about what is the optimal colony strength to use for almond pollination, an analysis of several years of data was conducted.

Materials and Methods: Data from our previous studies are being analyzed to determine the relationship of flight to colony strength in almonds, especially for comparing flight activities of 4 and 8 FOB colonies. These findings are only preliminary since different methods were used in different years. In some years only brood area was used to measure strength. In some years only outgoing flight was used to evaluate entrance activity. We have modified our incoming flight count methods in attempting to improve them.

Results: In 1965-66, square inches of brood was used as a measure of strength. In 1970-72 strength was based on intensive counts of frames of bees. The outgoing flight was very well predicted by FOB.

Strong and medium categories of FOB did not produce as much incoming flight as might have been expected based solely on FOB strength in the years with comparable data for the three categories from 1983-87. In 1972, the only year with data for both incoming and outgoing flight, both showed less flight for the medium category than would have been expected. A large variation occurred between years.

The differences between colony strength groups in flight in years with different weather regimes and resultant crop sizes are shown in Figure 2.

Discussion: Preliminary analyses of our multiyear data show that there is much variation from year to year and between incoming and outgoing flight counts. There seems to be some correlation between low bee flight counts and years that had generally poor weather and crop size. This evidence reinforces the recommendation for strong colonies, especially in years with poor weather. In years with especially poor weather, 1982-83, the lower size colony strength categories gave disproportionately lower flight than the medium strength size category. Because of rain in early and mid-bloom in 1986, there was very little bloom remaining in our test orchard by the time bees could forage. This may be the reason the 1986 flight counts were high, but yields were low (Fig. 2).

Incoming flight counts do not appear to be as high or as well correlated to strength categories as do outgoing flight counts. This seems mostly due to our methodology. We are continuing to improve our incoming flight count methods. Incoming flight counts are necessary if one is interested in determining the pollen to non-pollen forager ratios.

As time allows, we hope to refine these analyses comparing pollen to non-pollen forager ratios, flight response to weather, colony size increase over the bloom season, amount of pollen collected, etc. Based on these criteria we should be able to rate the different colony strength categories and make recommendations on the optimum strength category to use for almond pollination.

Floral Biology

Several aspects of the biology of almond flowers were examined to better understand their relation to pollination and yield including: stigma height in relation to anther position at time of dehiscence and possible self deposition of pollen; numbers of abnormal or abortive flowers; and nectar production. These data were gathered primarily by Dr. Azhar Phoon, visiting scientist from Malaysia in cooperation with our studies.

Materials and Methods: Flowers of each cultivar were examined throughout the day and season to determine: anthesis; anther dehiscence; stigma height in relation to anther position at time of dehiscence and possible self deposition of pollen; numbers of abnormal or abortive flowers; and nectar production.

Nectar measurements were taken by two methods first working on the early-blooming cultivar, NePlus, then Nonpareil and later on the late-blooming cultivars, Mission and Thompson. Method I involved the measurement of nectar in tagged and bagged flowers, removing the nectar by using micropipettes at fixed intervals (continuous sampling of each flower). Method II involved removal of many flowers at various stages of anther dehiscence at each time interval. The flowers were divided into 12 stages from zero anther dehiscence (stage 1) to total dehiscence and where the color pattern at the base of the petals had darkened (stage 12). Each flower was split open to expose the nectaries for nectar removal (destructive sampling method).

Results: The almond flower retained its petals for 3-7 days depending on weather conditions. Almond cultivars with long styles include: Peerless, Mission, Thompson while short-styled cultivars include: NePlus Ultra, Price, Nonpareil. Each almond cultivar has a certain percentage of flowers with abortive ovaries. The ovary of the almond flower has two ovules but generally only one developed into seed. Some almond cultivars such as Mission, Nonpareil, Peerless, Price and Thompson have hair on the nectaries, while NePlus has relatively smooth nectaries.

Almond flowers anthesed throughout the day. Flowers at all stages of anthesis were present at any time, but the proportion of receptive flowers tended to be highest during the first few hours of good weather, during the morning of each day and during peak flowering period of the flowering season. Dehiscence of the more than 30 anthers per flower was completed within 2 days during warm weather, but took up to 6 days during cool weather at early flowering. Pollen grains were collected by honey bees throughout the day and were most abundant during the morning period of each day (good weather) and during the peak flowering season. Prolonged rain killed the anthers which failed to dehisce.

Method I: Nectar secretion in the almond flower is a continuous process. The nectar accumulates in the cup-shaped flower over the night and early morning, so that at the first visit by a bee, a large volume is available. Nectar replenishment is slow and hairs on the nectary would likely prevent its complete removal and thereby encourage more bee visits. Total weight of sugars (assumed to be volume X concentration) per flower ranged from approximately 34-270 mg (Table 6). The nectaries were damaged to various degrees during repeated nectar removal and this could account for the lower total sugars per flower than that obtained by Method II. Apart from this, it also appeared that less nectar per flower was secreted near the end of the flowering season, easily noticed by the size of the micropipette that could be used for withdrawing nectar.

Method II: This method confirms that nectar secretion is continuous. The accumulated nectar did not affect further secretion in the flower and reabsorption was detected. Larger quantities of sugar per flower were obtained (approximately 74-350 mg/flower) partly because the nectaries were not damaged. There was an obvious increase in nectar flow (volume and weight of sugars) after irrigation (1 March) and with onset of wet weather (see NePlus, Table 6). Prior to irrigation the nectar was more concentrated (range 15-70%). Nectar was more dilute when water was available to the plants (range 4-40%).

During cold weather, nectar flow was noticed when the first anther dehisced, but during warm weather it occurred prior to anther dehiscence. Fresh nectar was dilute (4-10% sugars), but became highly concentrated (>80% sugars) on subsequent days in bagged flowers. Fresh nectar was watery, but appeared mucilaginous on subsequent days, especially during wet weather when the nectar remained dilute.

During mornings, when weather permitted (this range from 09:00-11:00 hours), bees visited almond flowers mainly for pollen. Early in the day, abundant pollen was available, having been released during the evening to early morning when no bees were flying. The bees collected large pollen loads. Few bees visited flowers for nectar in the morning hours because the nectar was dilute, except in older flowers. The proportion of nectar foragers was observed to increase towards afternoon and foraging activities ceased at between 16:00-18:00 hours depending on the weather.

Discussion: Flowers devoid of petals were visited by honey bees but would not set fruit even after successful pollination because pollen tubes require 3-5 days to reach the ovules for fertilization. Pollination should be effected as soon as possible after the flower opens and its success is highly dependent on good weather conditions for bee flight and anther dehiscence.

Several differences in flower morphology among cultivars may affect pollination effectiveness and could be reflected by yield characteristics of the cultivar. Almond cultivars with long styles (e.g., Peerless, Mission, Thompson) may have a greater tendency to receive pollen from other cultivars and fewer pollen grains per stigma compared to short-styled cultivars (e.g., NePlus Ultra, Price, Nonpareil). Flowers with short styles might fail to be cross-pollinated if too many of their own pollen grains covered over their stigmas. Some almond cultivars have hair on the nectaries (e.g. Mission, Nonpareil, Peerless, Price, Thompson). These hairs trap the nectar preventing complete removal by bees and may encourage more visits to the flower as the remaining nectar becomes concentrated with evaporation. NePlus has relatively smooth nectaries and might not have such an advantage. Each almond cultivar has a certain percentage of flowers with abortive ovaries. These flowers were males functionally and therefore would not set fruit. Almond cultivars with a high proportion of such flowers would be poor yielders. The ovary of the almond flower has two ovules but generally only one developed into seed (which is commercially desirable). It is important to know whether increased visits by bees would result in both ovules developing into seeds.

The advantage in Method I was that it simulated bee visits to flowers and this might stimulate nectar secretion. The advantage in Method II was more thorough removal of nectar, especially when the nectar volume was very small. Method I has the disadvantage that nectaries were damaged with repeated handling and not all the nectar may be removed. Method II required large numbers of bagged flowers and it was difficult to place the flowers into the various stages of dehiscence, especially during wet weather. Besides, the mucilaginous condition of nectar in bagged flowers after day one suggests nectar constituents might undergo some changes while in bagged flowers. Bags may also alter reabsorption and subsequent secretion.

Successful pollination of almonds to produce an optimum crop primarily depended on fair weather conditions which allow bee flight and nectar and pollen production in the flowers. When the weather was too cold for bees to fly, it not only prevented pollen transfer, but also affected pollen viability and pollen tube growth after pollination which adversely affected fruit-set. Both pollen and nectar foragers are capable of pollinating almond flowers, although the former is generally considered more efficient. In almond flowers which have short styles, the pollen forager would tend to smudge self-pollen over the stigmatal surface possibly reducing set. Alternating compatible rows of long- and short-styled varieties might be beneficial.

The points discussed are based on scanty data and observations which need further clarification. It is obvious that good weather conditions appear to be the critical factor in almond pollination.

Moving Bees into Almonds in Waves

Research in other crops such as alfalfa and kiwifruit has revealed that colonies newly moved into a crop will sometimes forage more on it than will bees from hives that have been on the crop for some time. Whenever a hive is moved into a new situation, the foragers must orient and locate food sources in the new location. Foragers usually start by visiting flowers nearest to the new hive location and thus their initial foraging should be greater on the target crop. After hives have been in place for several days, more distant resources within a 2 to 3 mile radius are located. If some of these other resources are more attractive than the target crop, increasing numbers of bees from resident hives will forage on them. In order to reduce the effects of losses of bees to competing crops, it may be beneficial to introduce hives in successive waves rather than all at once. We conducted a small test to determine whether this would be beneficial in almonds.

Materials and Methods: Bees were moved into the 30 acre test orchard on 9, 20 and 27 February. Three hives in the 9 February group and 2 hives in the 20 February group were paired by strength with 5 hives in the 27 February group. We considered that the 9 and 20 February groups had been in the orchard long enough to be considered as resident hives and could be pooled together. Pollen traps were placed on these 10 colonies on 28 February. Pollen was collected from these hives on 10 days between 1 and 16 March. Subsamples of two hundred pellets (or the total sample if less than 200) were sorted by color. Microscope slides were made from samples of each of the colors. These slides were examined under a compound microscope and the amount of almond versus other pollen was determined.

Results: There were no significant differences between the two waves in weight of pollen collected nor in percent of almond pollen included as the following data show.

Wave	Pollen Weight (gm/hive/day)			Percent Almond Pollen		
	N	Mean	S.D.	N	Mean	S.D.
Early	52	13.2	20.3	52	98.4%	3.26
Late	54	12.4	16.3	58	97.9	3.98

Discussion: This was admittedly a small sample, but it may be that unless there is strong competition from orchard ground cover or other plants surrounding the orchard, introducing colonies in waves may not improve pollination in almonds. This experiment should be repeated in an orchard with a high proportion of attractive plants (e.g. fiddleneck) in bloom at the same time as almonds.

Fruit Drop by Cultivar

In conjunction with getting fruit set counts for the almond pollination model, information was obtained on the percent fruit drop occurring between the initial and final fruit set counts.

Materials and Methods: Bud counts were taken prior to bloom, 12-13 February along the transect described in the "Bee in Tree Count" section. Buds were recounted on 16 February to confirm the previous count made partly in the rain. Bloom counts were made in adjoining trees in the same row along the transect to develop bloom curves. Initial fruit set was counted on 28 April, and final counts were made on 13 August just prior to harvest.

Results: There were no significant differences in percent drop among the 5 cultivars (Table 7). However, there were significant differences in fruit set among the cultivars in both early and late counts.

Discussion: As might be expected, those cultivars with the highest set had the greatest drop. However, the percent of the remaining crop that dropped was actually smaller in the cultivars with high set (<10%) than with low set (>10%). The fact that the earliest blooming cultivar, NePlus Ultra, had the lowest set may be due to the fact that there were not as many flowers with compatible pollen available to it early in the bloom season. Also the weather is generally poorer early in the season. Why Price had such high set is difficult to explain since its bloom came about the same time as Peerless and Nonpareil. Possibly, some genetic factor may be responsible. Price had large sets at other sites and exhibited the same high drop with overall high yield (Dr. Dale Kester, personal communication).

Bee in Tree Count Cost Analysis

In conjunction with work on the almond pollination model, counts were made of bees along a transect through the orchard. A cost analysis was made so that growers might compare the cost with that of counts made at or in the colony and decide whether to use one or both types of counts.

Materials and Methods: Bee in tree counts were made diagonally across the roughly rectangular 30 acre almond orchard mentioned elsewhere in this report. The orchard is planted with rows running east-west with every other row being Nonpareil alternated with NePlus Ultra, Price, Peerless, and Mission. Starting near the SW corner and going diagonally NE every fifth row of Nonpareil and every row of the other cultivars were counted for bees in trees. Five replicates of each cultivar were counted making a total of 25 trees. The orchard was 48 rows wide and since only every 5th row of Nonpareil was counted a total of 40 rows was transected. This was to obtain a representative sample across the entire orchard.

Three methods of counting bees were tried:

1) the observer stood on the south side of the tree and counted every bee observed in the canopy during 15 seconds;

2) the observer walked around the tree counting every bee observed in the canopy during a 15 second circuit; and

3) The observer walked along the south edge of the tree and counted every bee observed in the canopy in 15 seconds.

Method 3 was only used from 23-27 February. It did not appear to offer any advantage over the other two and some observers felt it was more difficult to see the movement of bees in trees when the observer was also moving. This was a problem with method 2 also. Method 2 was hard on the neck and on the eyes on that portion of the circuit where the observer faced the sun.

Results: The cost analysis is as follows:

No. trees/ observer	Time (min) total	Time (min) per tree	Trees/hour
425	836	1.96	30.50
410	836	2.04	29.42
100	266	2.66	22.56
660	1409	2.13	28.10
25	67	2.68	22.38
135	290	2.15	27.93
1755	3704	2.11	28.43

The average cost per count of each tree figuring the labor cost at $7.00 per hour is $0.25.

Discussion: These counts have advantages over strength assessments at the hive in that: 1) they are the sum of many variables (e.g., colony strength, hive number, flight from colonies, bloom density, weather, etc.); 2) they are closer to the actual act of pollination; 3) there is not as much chance of getting stung by the bees; 4) these counts may not require as much skill and subjective judgment; 5) cost would be less than 1/4 of that of doing intensive frame by frame counts, but would be slightly higher than doing cluster estimates; 6) when done on a transect, these counts give information on how bees are distributing themselves across the orchard and thus whether hive drops need to be modified as suggested by Loper et al. (Calif. Agric. 1985, 39 (11 & 12):19-20); 7) these counts give information needed in the model being developed by Dr. Gloria DeGrandi-Hoffman to predict yield. Labor costs were based on $7.00 per hour, but since bee in tree counts do not require working with bees, labor costs could be less. Also, two types of counts were made per tree. Possibly, further research may show that only one type is needed, thus cutting time almost in half.

Disadvantages of using only bee in tree counts include: 1) they do not necessarily indicate whether the grower is getting the colony strength that is specified in the contract with the beekeeper; 2) data may vary with size of trees, cultivar, stage of bloom, pollen and nectar rewards, competition from other flowers, etc.

Hopefully, when enough data have been accumulated, it will be possible to make up a table or computer program from which the grower can determine whether more bees need to be added after plugging in bee in tree counts. Whether these data will be available early enough during the same season to make adjustments or whether they will only be useful in making estimates of how many colonies will be needed the following year is yet to be determined.

Osmia cornuta

A small population of the Spanish Orchard Bee, *Osmia cornuta*, which had been reared in California almond orchards in 1986 was released in our test orchard to determine its emergence in relation to almond bloom and ability to reproduce under conditions during almond bloom in California.

Materials and Methods: Sixty nests of *Osmia cornuta* were produced from populations managed in almonds in the Dixon area in 1986. These were sent to Logan, Utah in June for evaluation of nesting success and returned to California in December for overwintering. They were installed in nest boxes each with 13-18 empty holes for renesting and set up in our test orchard in February 1987. Boxes containing bee nests were surrounded by boxes with empty straws to trap any dispersing females.

Results: Emergence started by 12 February in synchrony with almond bloom as had been observed in previous years. Nests were monitored frequently but no nesting activity was noted and there were few sightings of adult bees in or around the nests. Overall emergence was poor. Many nests still had their original plugs at the end of the season. Only 4 nests were partially provisioned. The 4 nests provisioned in 1987 contained 14 brood cells with 12 live bees. Pollen provisions in each cell were entirely from almonds.

Discussion: The Spanish orchard bee, *Osmia cornuta*, continued to show energence in synchrony with almond bloom. The pollen provisions show that they forage on almonds as long as they are in bloom. However, populations have decreased over the three years they were tested in almonds in California. We need to find ways to increase their populations under our growing conditions if they are to become commercially useful as pollinators of almonds.

Almond Pollination Model

Most of our research effort this year was devoted to cooperation with Dr. Gloria DeGrandi-Hoffman in attempting to gather data to validate her almond pollination model, ALMOPOL Cross-Pollination and Nut Set Simulation Model. This model is a computer program being developed to predict the rate of cross-pollination and nut set during bloom in almonds. Potential nut set, at the end of bloom, can be used to estimate crop value. This can then serve as the economic basis for crop management decisions that year. The goal is to develop a program that will be accessible to growers via software for personal computers.

Pollination and nut set in almonds are the result of interactions among weather, bloom, and honey bee foraging activity. These factors change over time throughout bloom and differ from site to site and year to year. Consequently, pollination and nut set rates are variables that can be predicted only when changes in the factors that affect them are updated over time.

The purpose of this research is to predict cross-pollination and nut set rates in almond, so that initial and potential final nut set can be predicted at petal fall. Predictions will be made by mathematically defining the interactions among weather, bloom progression, and honey bee foraging activity throughout bloom. This will be accomplished by constructing a computer simulation model (ALMOPOL). In 1987 data were collected in California orchards to begin the validation of the

ALMOPOL model's nut set predictions. This report contains a summary of the results.

Materials and Methods: Orchard sites in Dixon and Bakersfield, CA were used for this research. Weather (temperature, solar radiation, wind velocity, and rainfall) was monitored hourly throughout the bloom. Counts of open blossoms on NePlus, Nonpareil, Price, Peerless, and Mission trees were made daily at the Dixon site, and at least once a week at the Bakersfield site. Four limbs on five trees of each cultivar selected on a diagonal across the orchards were chosen. These data were used to validate existing almond bloom progression equations, and develop others for cultivars not included in the original ALMOPOL program. Equations were derived by expressing the progression of bloom as a function of accumulated degree days (Baskerville and Emins 1969 Ecology 50:514-517; DeGrandi-Hoffman, et al. 1987 Environ. Entomol. 16: 309-318).

The number of honey bees foraging trees of each cultivar was determined throughout bloom, by counting bees per tree at least twice daily. Some of the bees per tree estimates were used to determine the potential foraging population (i.e., the total number of bees that would forager per hectare if flight weather conditions were non-limiting) at the site. The remainder of the data were used to validate equations predicting honey bee foraging responses to temperature, wind velocity, solar radiation, and number of open almond blossoms (i.e., state of bloom) all at time (t). This was accomplished by comparing the actual number of almond foragers/acre with predictions using the estimated potential foraging population and the foraging response equations.

Data required to run an ALMOPOL simulation were collected at the Dixon site. This included tree height, width, and blossom spurs/m of branch. Four limbs on five trees/cultivar were selected for counts of blossom spurs/m of branch, and resulting nut set. The percentage of blossoms setting nuts and pounds of nuts/acre were compared with ALMOPOL predictions.

Results: Bloom progression equations for Nonpareil and Price required adjustments to more accurately predict bloom phenology. Equations for NePlus, Peerless, and Mission were derived by non-linear least squares analysis of the data. The degree day base for each cultivar was estimated using two biofix points: accumulated degree days for full bloom and for the entire bloom period. The number of degree days required to reach these biofix points was compared for the Bakersfield and Dixon sites using various base temperatures. The base temperature that minimized the error between sites for both biofix points was assumed to be the base temperature for the cultivar.

As in apple (DeGrandi-Hoffman, et al. 1987 Environ. Entomol. 16: 309-318), early blooming cultivars were found to have lower base temperatures than those blooming later. Base temperatures were estimated to be 2.22°C for NePlus and Nonpareil, 4.44°C for Price and Peerless, and 7.78°C for Mission. Actual and predicted bloom progression are shown in Figures 3-14.

Based on counts of honey bees per tree under monitored weather and bloom conditions, the potential foraging population at the site was estimated to be 1426 bees/acre (577 bees/ha) from Feb. 19 until March 2. From March 2 until the end of bloom the potential foraging population increased to 3349 bees/acre (1355 bees/ha). The potential foraging population was estimated using the equation: (B / T * W * S * F), where: B= the number of bees foraging almond at time (t) as estimated from counts of bees/tree of each cultivar and trees of each cultivar/ha; T= the reduction in the foraging population due to temperature using the temperature foraging response equation; W= the reduction in the foraging population due to wind velocity using the wind velocity foraging response equation; S= the reduction in the foraging population due to solar radiation using the solar radiation foraging response equation, and F= the reduction in the foraging population on almond due to the number of open almond blossoms (i.e., the bloom response equation). The number of bees foraging almond/acre was predicted from the estimated potential foraging population using the equation: PFP * T * W * S * F= A, where A= predicted almond foragers/acre; PFP= potential foraging population/acre; and T,W,S and F= reductions in the PFP due to temperature, wind velocity, solar radiation, and bloom respectively. The correlation coefficient between actual and predicted almond foragers is 0.855 (Fig. 15).

The percentage of blossoms setting nuts at the Dixon site and ALMOPOL nut set predictions are shown in Table 8. Actual nut set ranged from 10.2% (NePlus) to 54.0% (Price), while predicted set ranged between 11.7% (NePlus) to 36.1% (Price).

Discussion: Although equations describing the progression of bloom fit well for all cultivars, at least another year's data collected under different weather conditions will be needed to test their validity in predicting bloom progression. Equations predicting the foraging population's response to weather and almond bloom estimated the number of bees actually foraging almond/acre consistently well in the pre-peak bloom period (sample periods 1-5). More error was involved in some of the post-peak bloom predictions.

The ALMOPOL model predicted the general nut set trends in the orchard with reasonable accuracy, and estimates of the percentage of blossoms setting nuts for NePlus, Peerless and Mission did not differ significantly from actual set. However, predictions for Nonpareil and Price were significantly lower than actual set as was the average number of lbs/acre. The ALMOPOL model assumes that all cultivars of almond are equally attractive, and perhaps the low nut set estimates may be that the number of blossoms on Nonpareil and Price trees may have been overestimated which would result in lower predicted blossom to nut set ratios than what actually occurred.

The percentage of blossoms setting nuts on NePlus for the Dixon site appeared low, because there were nine NePlus trees to 36 Nonpareil. NePlus bloomed about three days before Nonpareil, but when Nonpareil bloomed there was predominantly compatible pollen for NePlus so set should have been higher than the average of 10.2%. In simulations, NePlus set could be made much higher if blossom viability and quality was made equivalent to the other four cultivars. The 11.7% prediction was obtained by lowering these bloom related factors.

Results of this first field season involving validation of the ALMOPOL model has directed our research to areas that need further study. These include the relative attractiveness of cultivars to honey bees, blossom quality and the probability of cross-pollination leading to nut set for each cultivar, and enlarging the data base for validation of bloom and foraging response equations.

Publications

Torchio, P. F., E. Asensio and R. W. Thorp. 1987. Introduction of the European bee, *Osmia cornuta*, into California almond orchards (Hymenoptera: Megachilidae). Environ. Entomol. 16:664-667.

Table 1. Correlation and regression analyses of cluster versus intensive counts for initial and final strength evaluations of honey bee colonies for three observers in 1987.

Intensive Count	N cols	Observer 1 r	Observer 1 R^2	Cluster Count Observer 2 r	Observer 2 R^2	Observer 3 r	Observer 3 R^2
Initial							
Pearson	99	.883	.780	.840	.706	.901	.812
Spearman	99	.885	.783	.851	.724	.906	.821
Final							
Pearson	49	.817	.759	----	----	.850	.723
Spearman	49	.701	.492	----	----	.772	.596

Regression equations for all 3 observers:

with R^2= .815 Intensive= 1.635 + .576 X Cluster

ANOVA on regression $F_{1,97}$= 433.419; P=0.000

Pearson Correlation Coefficient = .904

Spearman Rank Correlation Coefficient = .911

Table 2. Changes in honey bee colony strength during the 1987 almond pollination season (N= 5 hives for each FOB).

FOB	Initial $\bar{x}$	Initial S.D.	Final $\bar{x}$	Final S.D.	Percent $\bar{x}$	Percent S.D.	t-test P<.05
4	4.03	.30	5.40	.54	32.76	10.34	s.
6	5.88	.20	8.13	2.85	37.31	44.17	n.s.
8	7.83	.17	8.26	.88	5.66	13.12	n.s.
10	9.86	.40	10.83	.98	10.14	12.23	s.

Table 3. Relationship between colony strength (number of frames of bees= FOB) determined by measuring clusters versus intensive frame by frame counts (1987).

Cluster estimate (FOB)	N	$\bar{x}$ FOB Intensive	S.D.
0-2	16	2.44	.77
3-4	9	3.83	.92
5-6	19	5.08	1.12
7-8	10	5.26	.99
9-10	16	6.70	1.72
11-12	12	8.32	1.46
13-14	10	9.75	1.625
15-16	6	10.73	1.73

Table 4. Numbers of pollen and non-pollen foragers returning to the hive entrance during 30 second periods for 20 hives for the entire 1987 bloom season (N= 5 colonies per strength group).

FOB	Pollen Bees $\bar{x}$ ± S.D.		Non-pollen Bees $\bar{x}$ ± S.D.	
4	2.809±2.43	A	6.892± .89	A
6	4.709±3.33	B	18.480±11.24	B
8	4.413±3.63	B	16.399± 9.50	B
10	4.747±3.31	B	19.311±11.67	B

Means followed by the same letter are not significantly different at P>.05 using the Tukey range test.

Table 5. Overall flight means for honey bees returning to 20 colonies during the 1987 almond bloom season.

Period	Pollen or not	$\bar{x}$ S.D.
Early <3 Mar.	Pollen	4.408±1.575
	No Pollen	12.344±5.012
Late >2 Mar.	Pollen	4.036±1.227
	No Pollen	18.434±5.385

Pollen early vs. late: N.S. t= 1.227; P= 0.235
Non-Pollen early vs. late: Signif. t= 11.207; P> 0.000

Table 6. Mean sugars per flower of the almond as measured by two methods (see text).

Date	$\bar{x}$ S.D.	n	Cultivar	Method
2/23 - 2/25	34.19 ± 10.31	7	NePlus	I
2/25	105.22 ± 21.56	7	NePlus	II
2/26	73.98 ± 11.83	14	NePlus	II
2/27	128.35 ± 22.87	12	NePlus	II
3/2	331.68 ± 34.49	10	NePlus	II
3/4	308.07 ± 33.28	12	Nonpareil	II
3/6	349.55 ± 34.29	9	Nonpareil	II
3/9	197.07 ± 22.78	9	Mission	II
3/10	221.01 ± 19.14	32	Mission	II
3/11 - 3/13	161.89 ± 33.10	9	Thompson (bagged)	I
3/11 - 3/13	269.90 ± 57.63	5	Mission (unbagged)	I
3/11 - 3/13	150.45 ± 33.31	10	Mission (bagged)	I
3/11 - 3/13	94.84 ± 25.23	5	Thompson (unbagged)	I
3/16 - 3/17	55.84 ± 10.61	4	Mission (bagged)	I
3/16 - 3/17	122.78 ± 58.63	2	Thompson (bagged)	I

Table 7. Summary of percent fruit set (fruits in April or August/initial buds X 100) and percent fruit drop (relative to initial buds and initial fruit set) for 5 cultivars of almonds in 1987 (based on 4 limbs per each of 5 trees per cultivar).

Cultivar Early to Late	% Fruit Set Initial $\bar{x}$ S.D.	% Fruit Set Final $\bar{x}$ S.D.	% Fruit Drop Initial $\bar{x}$ S.D.	% Fruit Drop Final $\bar{x}$ S.D.
NePlus	9.92±1.90 C	8.78±1.47 C	1.14± .90 A	10.90±7.91 A
Nonpareil	26.17±8.16 B	22.36±7.42 B	3.80±1.86 A	14.43±7.35 A
Price	53.41±7.74 A	48.94±8.22 A	4.47±3.55 A	8.41±6.41 A
Peerless	18.44±7.44 BC	14.83±6.68 BC	3.61±1.62 A	20.73±9.05 A
Mission	26.70±6.48 B	23.96±4.84 B	2.74±2.11 A	9.60±5.21 A

Cultivar means followed by the same letter are not significantly different (Tukey test, P= .05)

Table 8. Actual and predicted almond yields.

Cultivar	% Blossoms Setting Nuts Actual	% Blossoms Setting Nuts Predicted	Lbs/Acre Actual	Lbs/Acre Predicted
NePlus	10.2 ± 1.4	11.7		
Nonpareil	27.0 ± 4.7	20.6		
Price	54.0 ± 8.7	36.1		
Peerless	19.7 ± 4.5	20.3		
Mission	26.0 ± 4.9	25.3	2950	2017

Figure Captions

Figure 1. Foragers with or without pollen loads returning to 5 hives each of four strength categories (4, 6, 8, or 10 FOB) over the 1987 almond bloom season.

Figure 2. Comparison between incoming flight at colonies of different strengths and total California almond crop from 1982-87.

Figure 3. Actual and predicted bloom progression for five almond cultivars based on sampling periods with proportion of bloom plotted relative to peak bloom. Open symbols represent predicted values, closed symbols are actually measured values.

Figure 4. Actual and predicted bloom progression for five almond cultivars with proportion of bloom based on degree days and given in relation to peak bloom. Open symbols represent predicted values, closed symbols are actually measured values.

Figures 5-14. Actual and predicted bloom progression for each cultivar based on sampling period or degree days with proportion of bloom plotted relative to peak bloom. Open square with central dot symbols represent predicted values, closed diamond symbols are actually measured values. Figures 5-6: NePlus. Figures 7-8: Nonpareil. Figures 9-10: Price. Figures 11-12: Peerless. Figures 13-14: Mission

Figure 15. Actual and predicted almond foragers per acre at the Dixon orchard site. Black bar is actual numbers counted, cross hatched bar is predicted value.

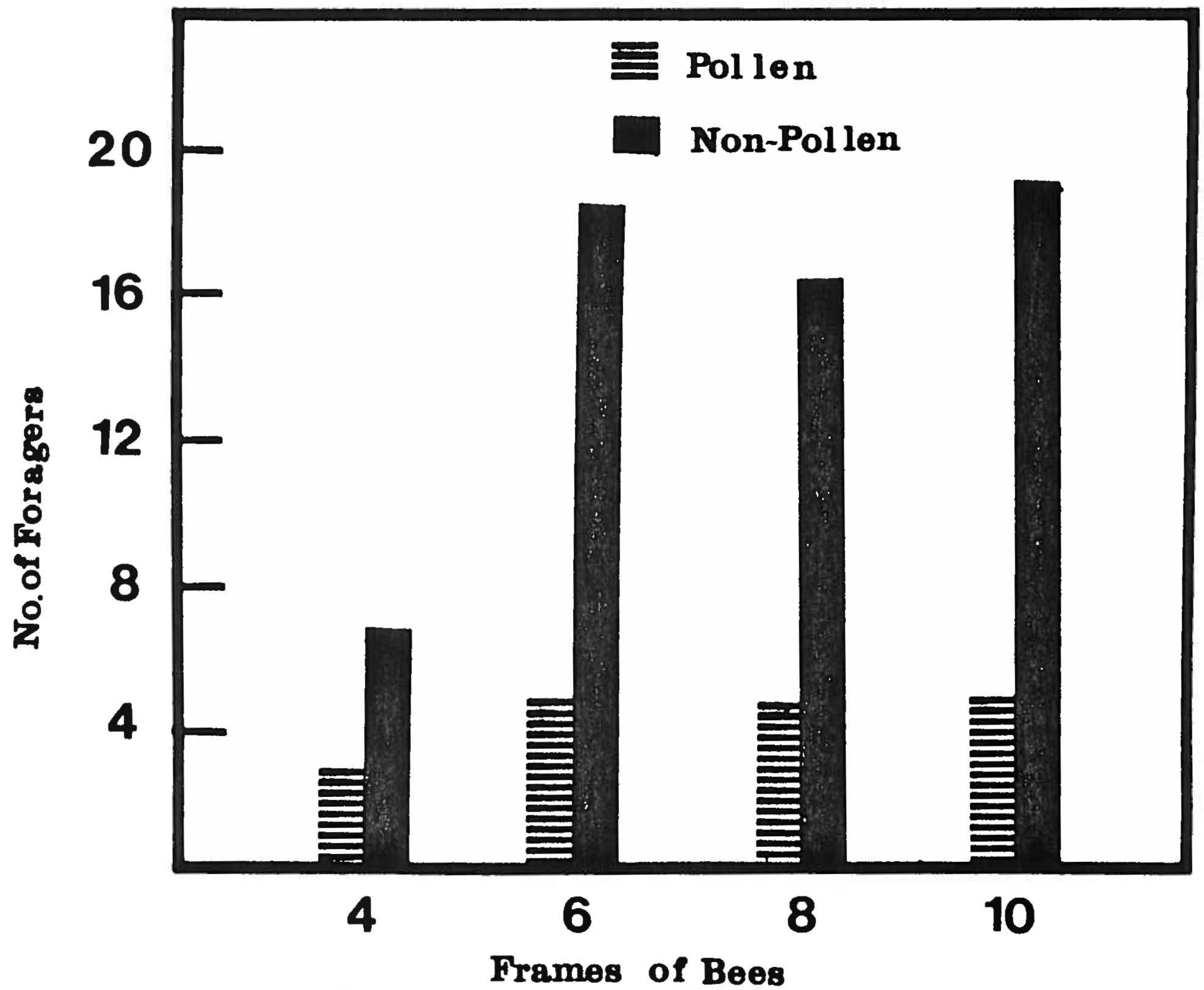
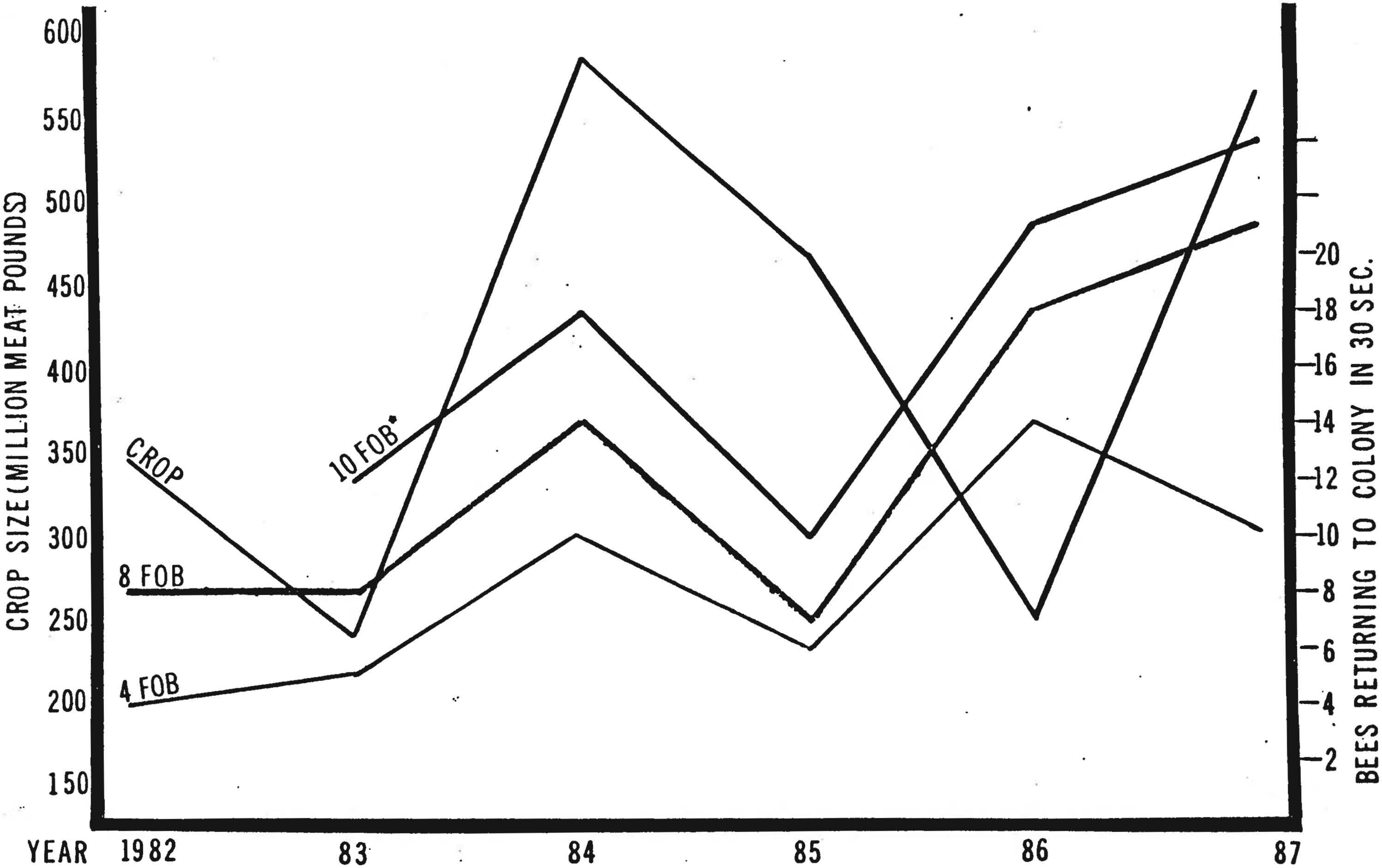

Pollen
Non-Pollen
20
16
12
8
4
No. of Foragers
4
6
8
10
Frames of Bees

Fig. 1



COMPARISON BETWEEN INCOMING FLIGHT AT COLONIES OF DIFFERENT STRENGTHS AND TOTAL CALIFORNIA ALMOND CROP

*FRAMES OF BEES

F 2

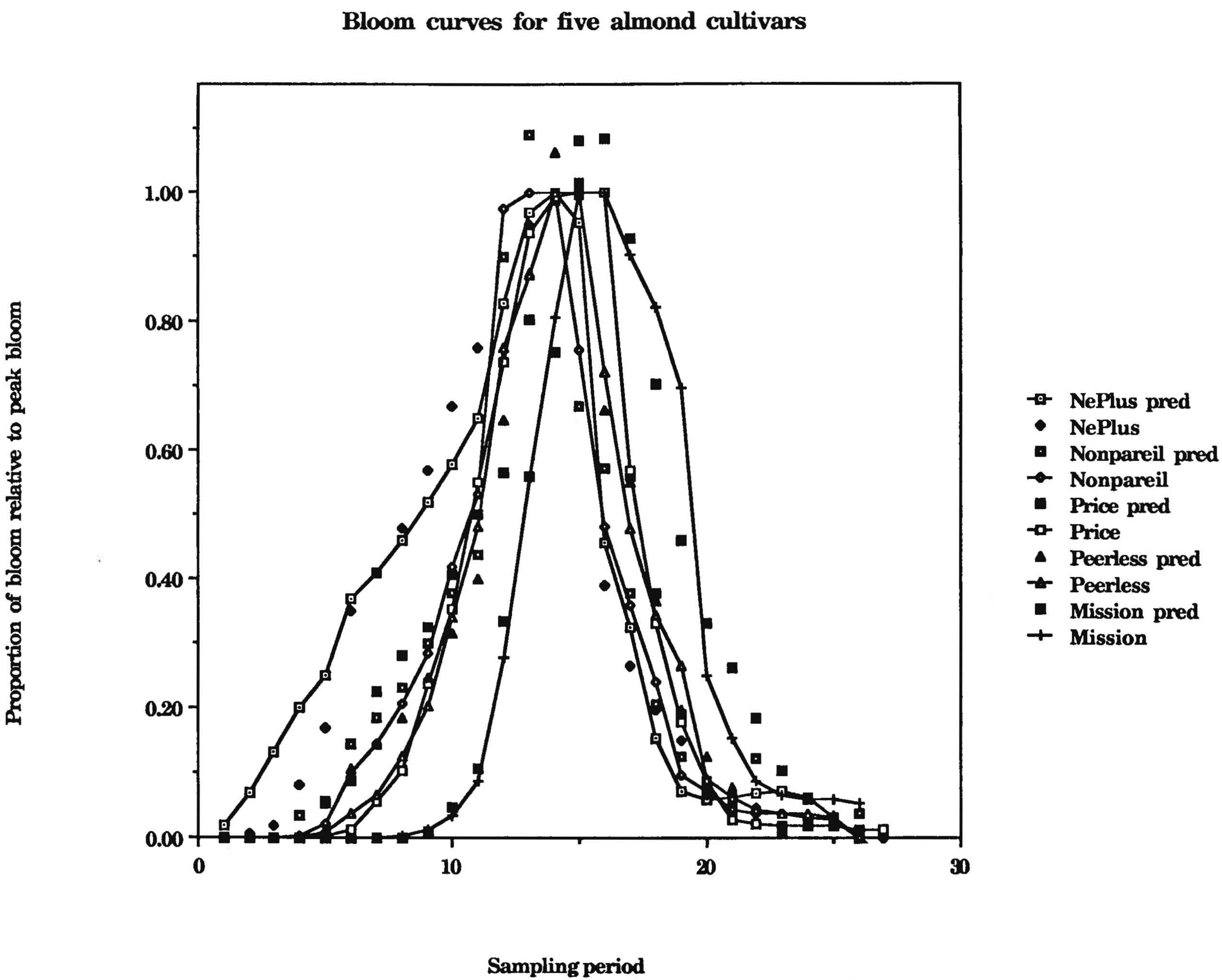
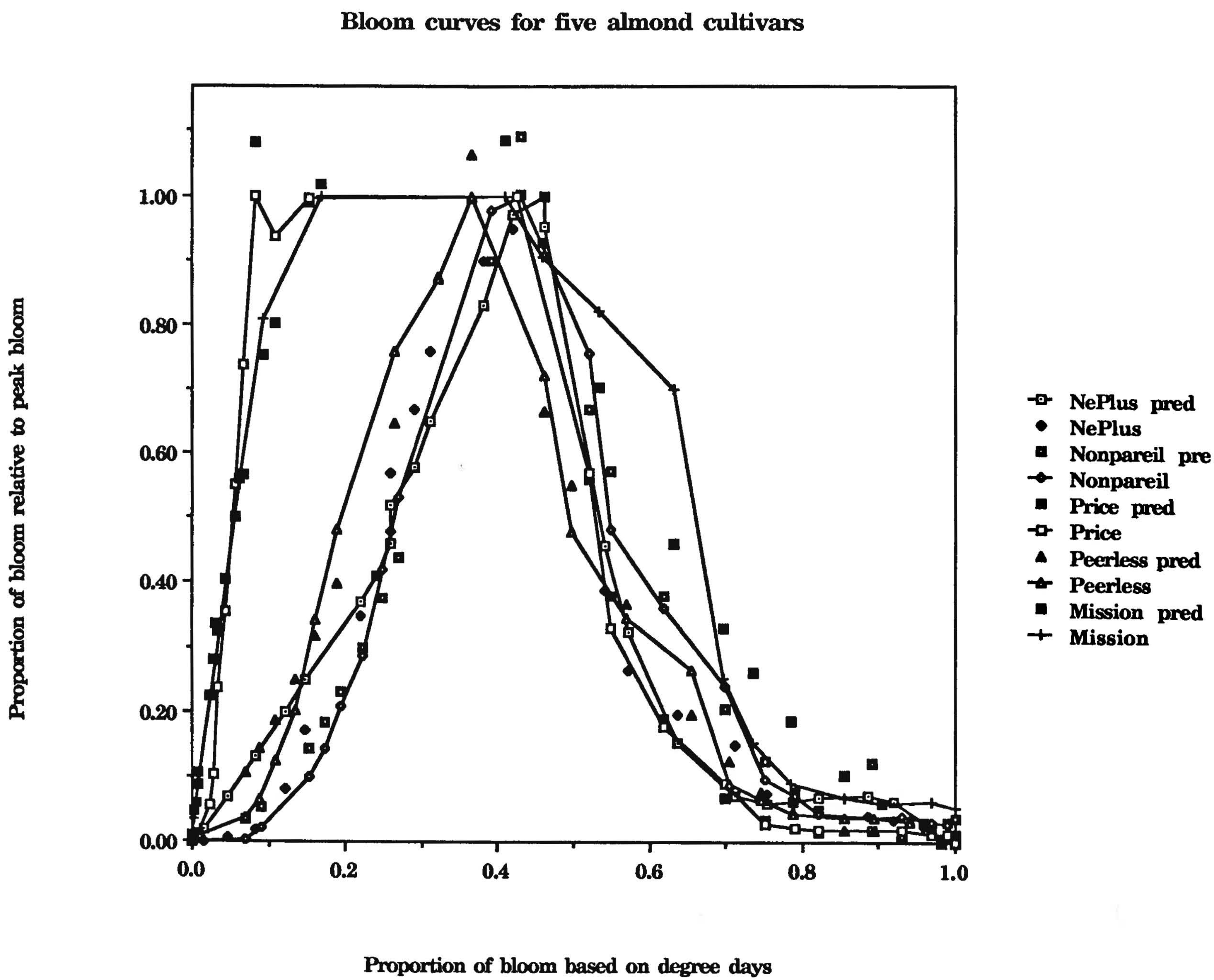

Bloom curves for five almond cultivars
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
Sampling period
NePlus pred
NePlus
Nonpareil pred
Nonpareil
Price pred
Price
Peerless pred
Peerless
Mission pred
Mission

Fig. 3



Bloom curves for five almond cultivars
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of bloom based on degree days
NePlus pred
NePlus
Nonpareil pre
Nonpareil
Price pred
Price
Peerless pred
Peerless
Mission pred
Mission

Fig. 4

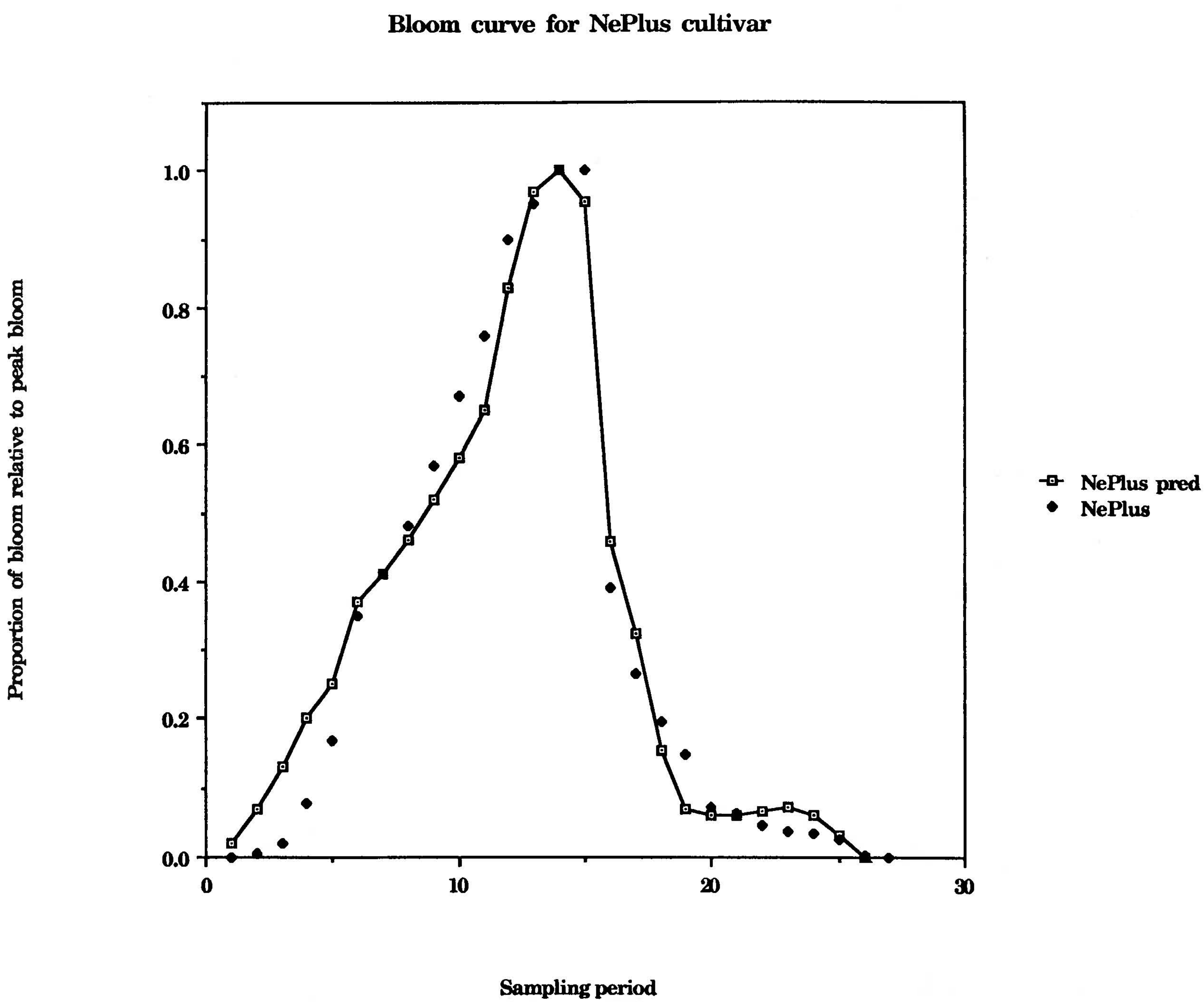

Bloom curve for NePlus cultivar
Proportion of bloom relative to peak bloom
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
Sampling period
NePlus pred
NePlus

Fig. 5

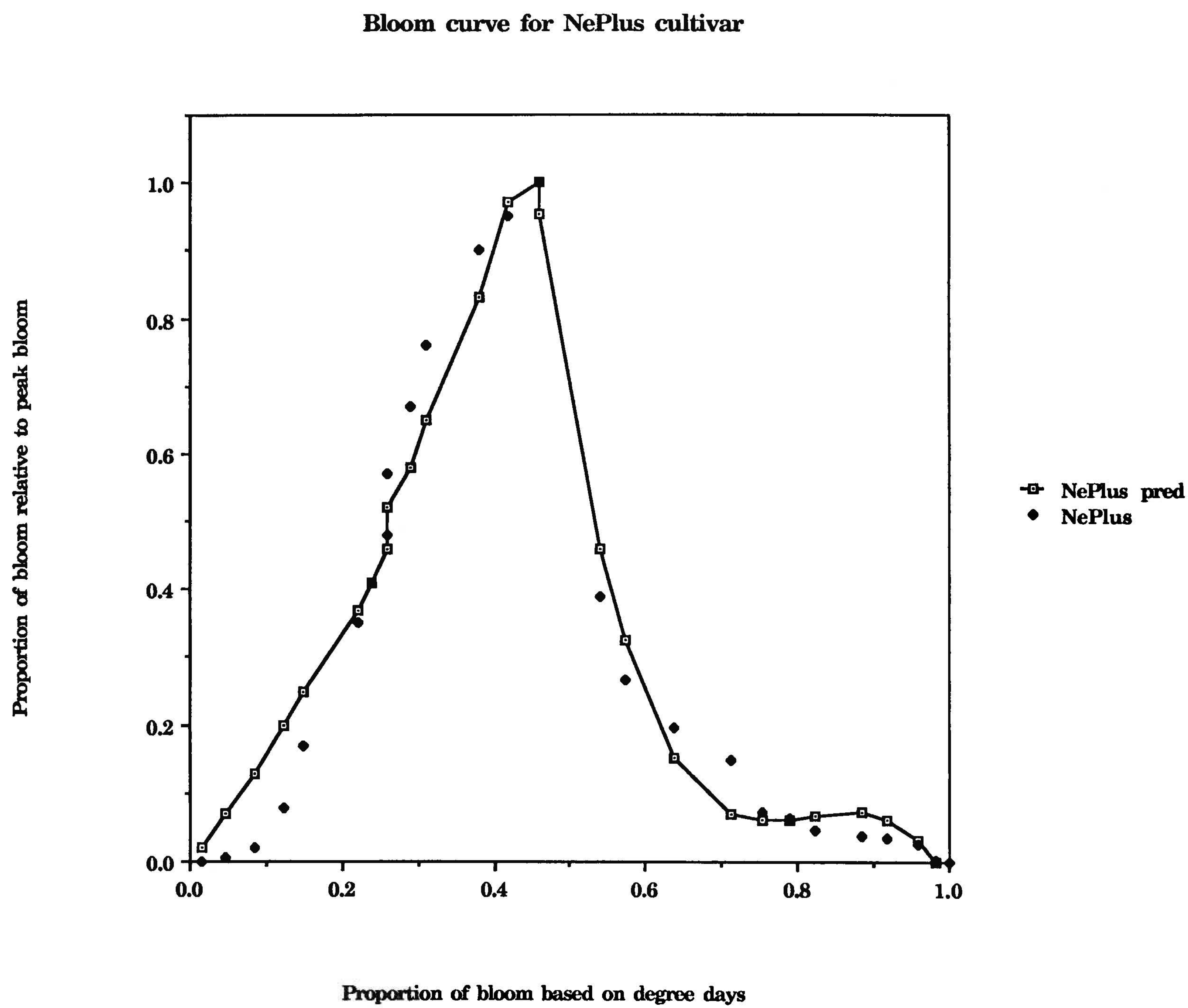

Bloom curve for NePlus cultivar
Proportion of bloom relative to peak bloom
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of bloom based on degree days
NePlus pred
NePlus

Fig. 6

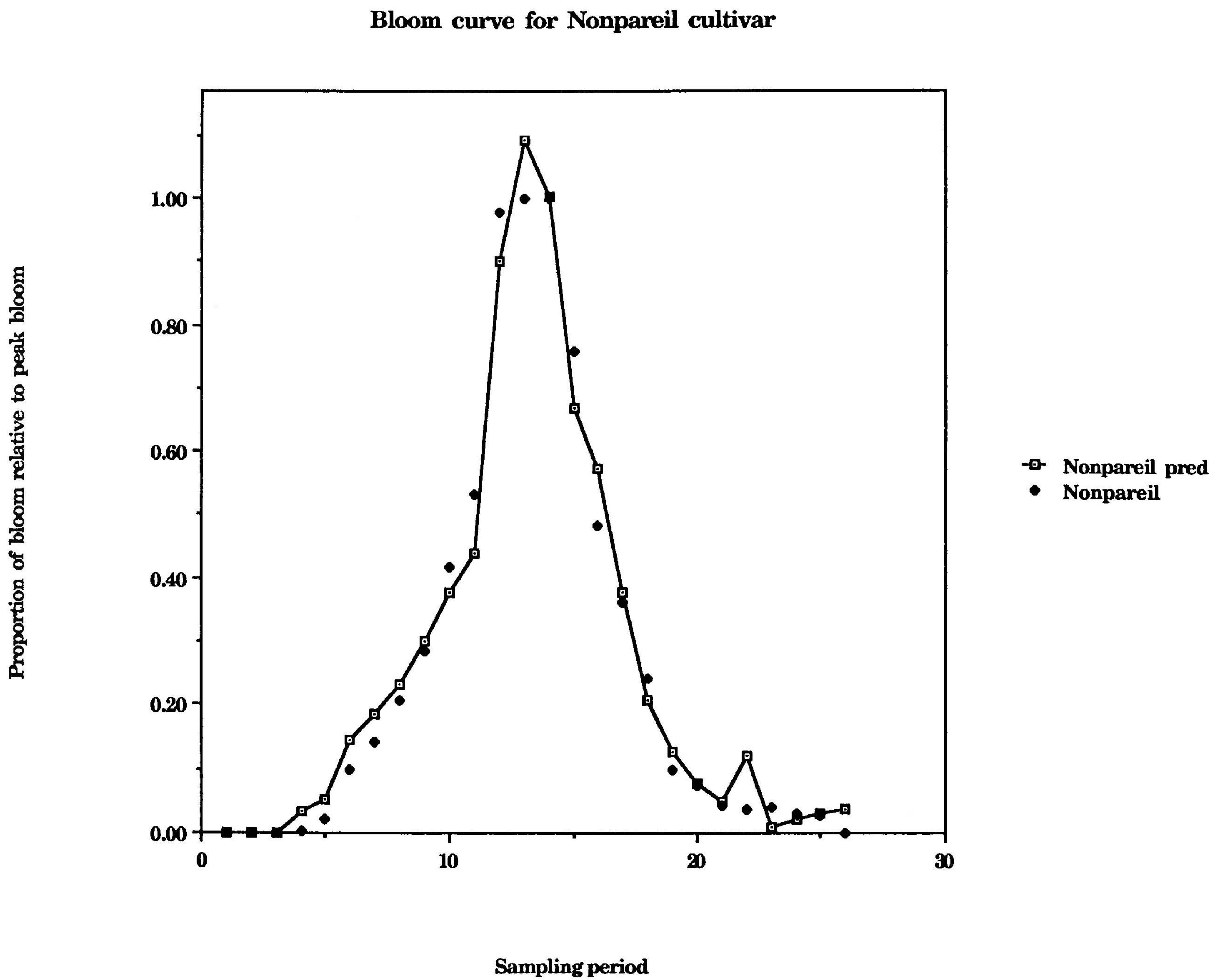
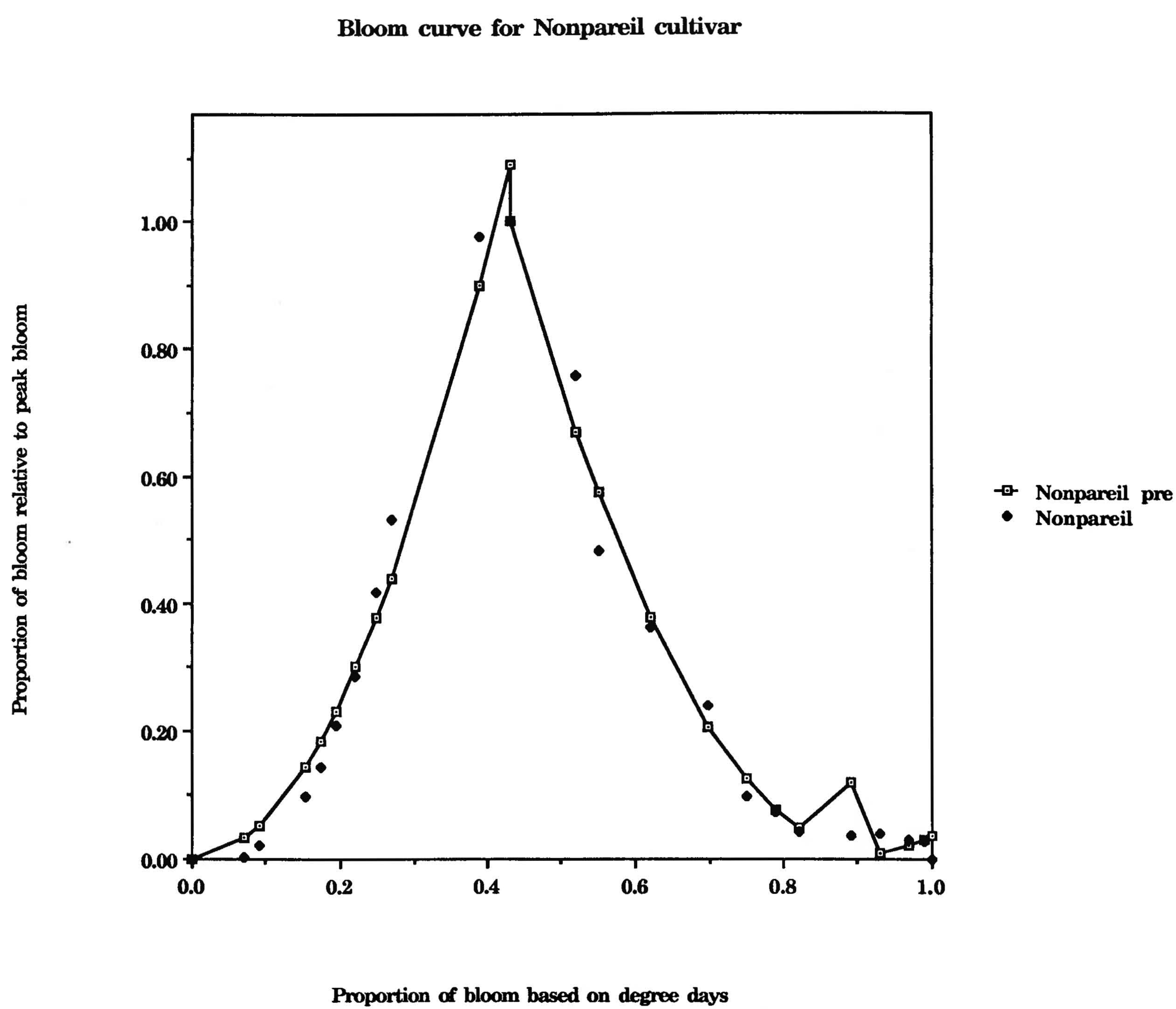

Bloom curve for Nonpareil cultivar
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
Sampling period
Nonpareil pred
Nonpareil

Fig. 7



Bloom curve for Nonpareil cultivar
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of bloom based on degree days
Nonpareil pre
Nonpareil

Fig. 8

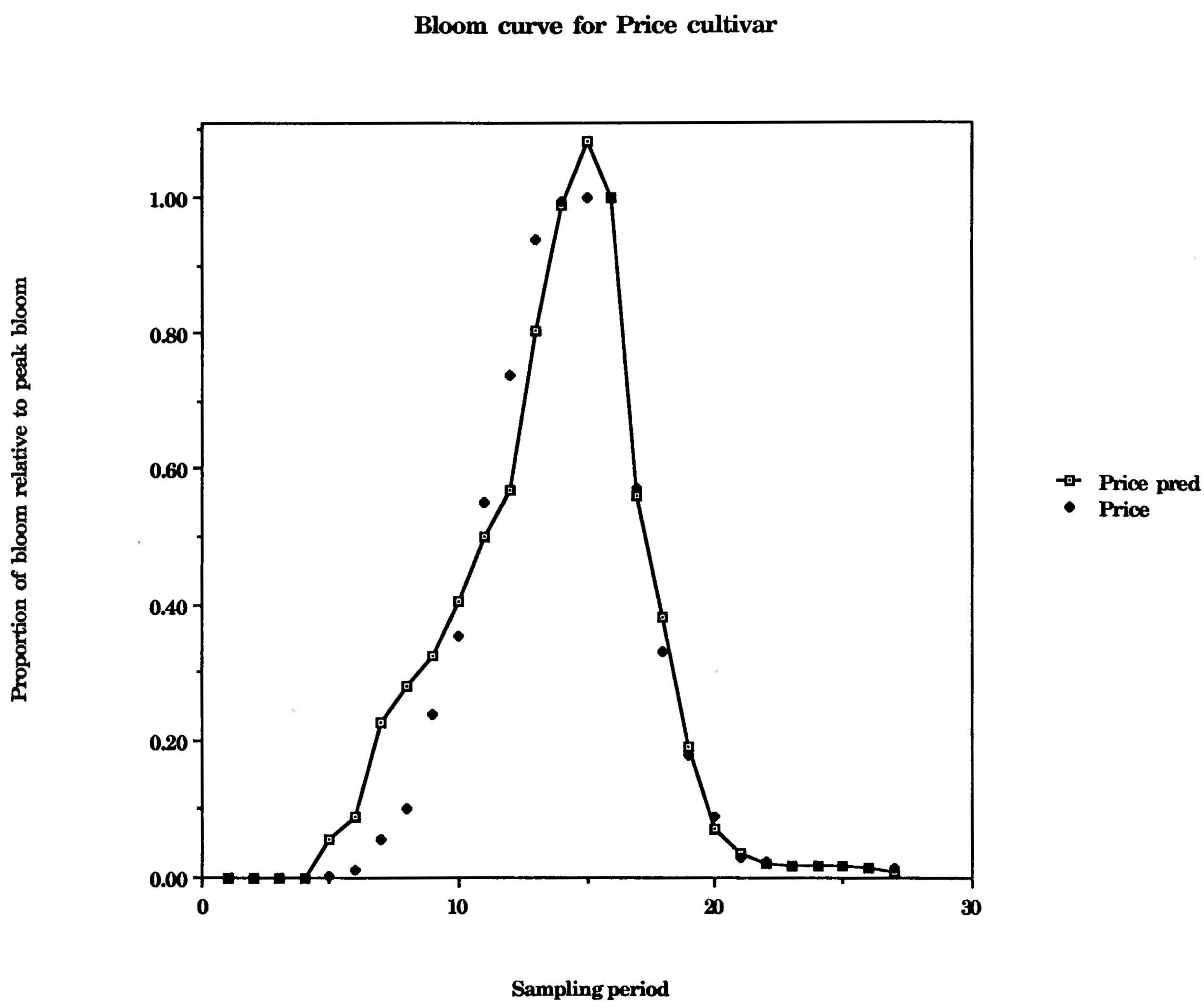

Bloom curve for Price cultivar
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
Sampling period
Price pred
Price

Fig. 9

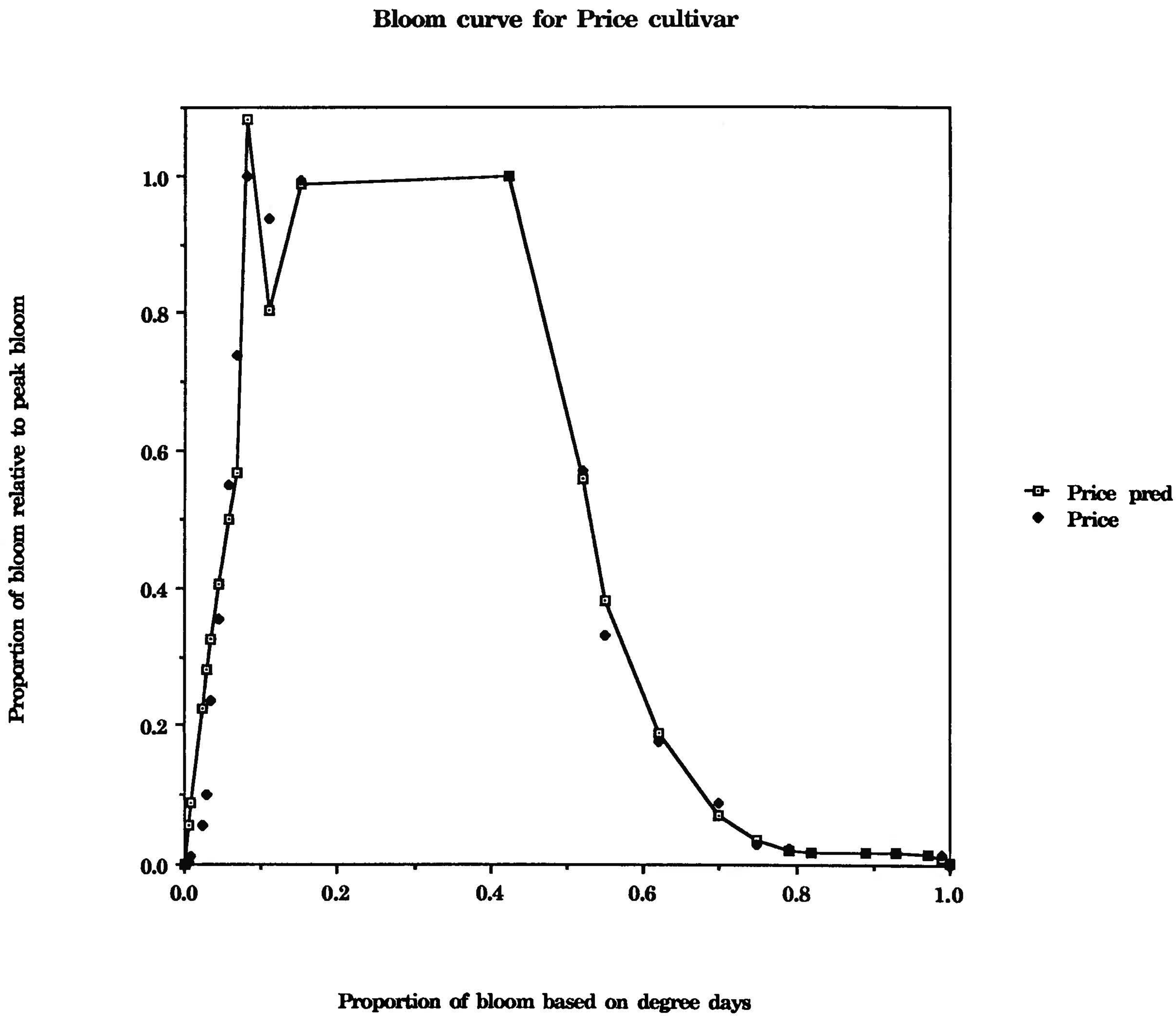

Bloom curve for Price cultivar
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of bloom relative to peak bloom
Proportion of bloom based on degree days
Price pred
Price

Fig. 10

Bloom curve for Peerless cultivar

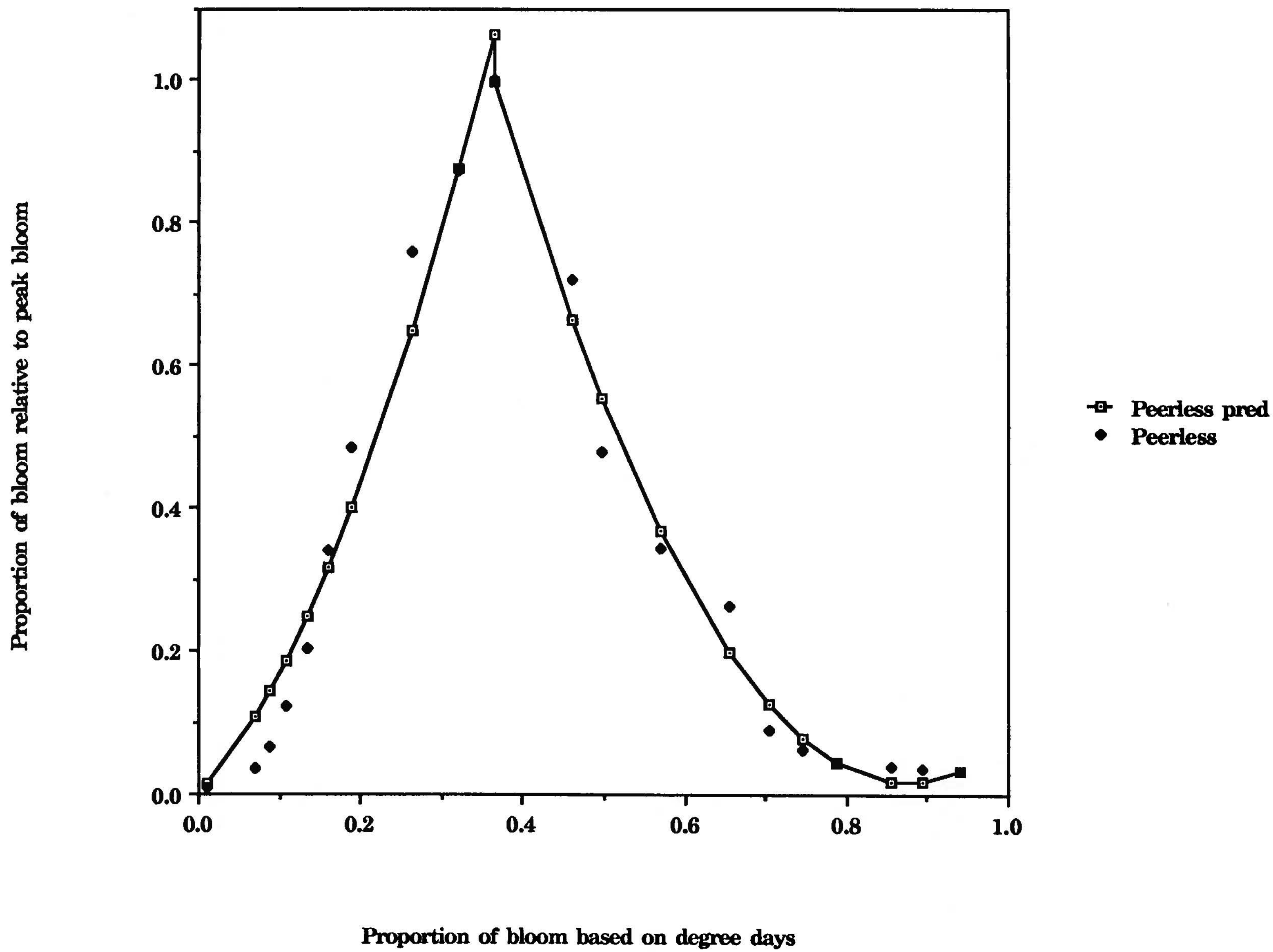
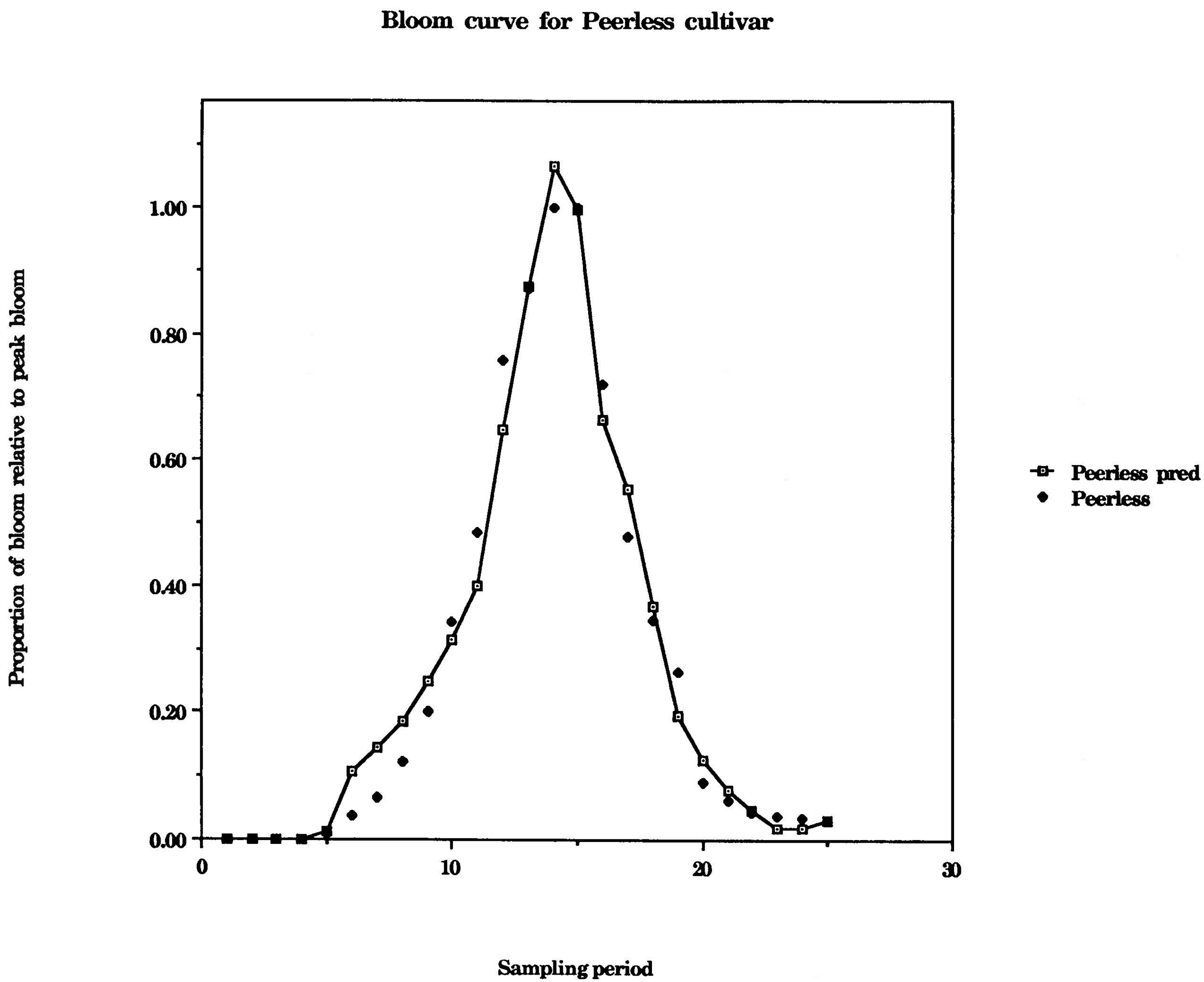
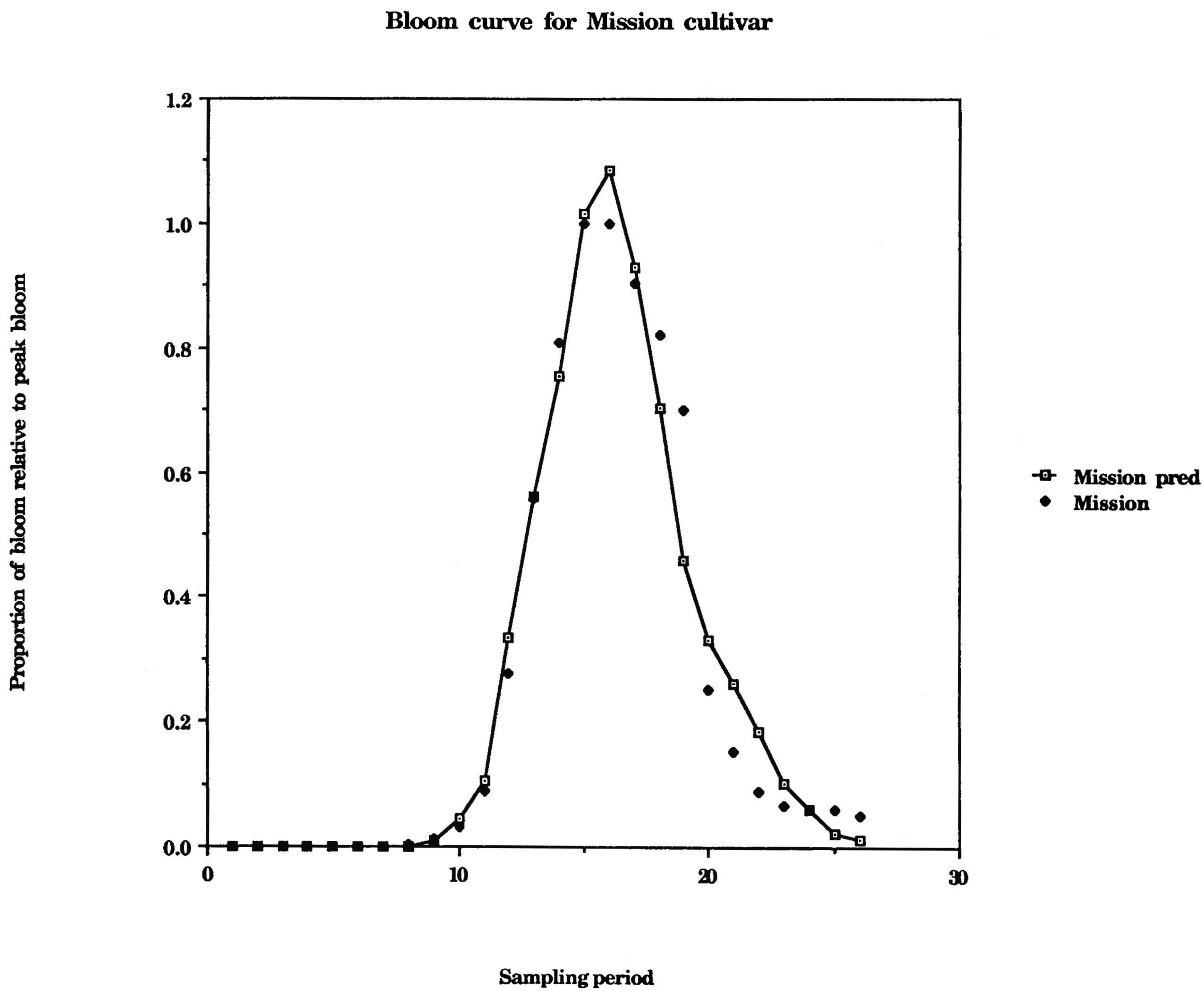


Fig. 11



Bloom curve for Peerless cultivar
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
Sampling period
Peerless pred
Peerless

Fig. 12



Bloom curve for Mission cultivar
Proportion of bloom relative to peak bloom
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
Sampling period
Mission pred
Mission

Fig. 13

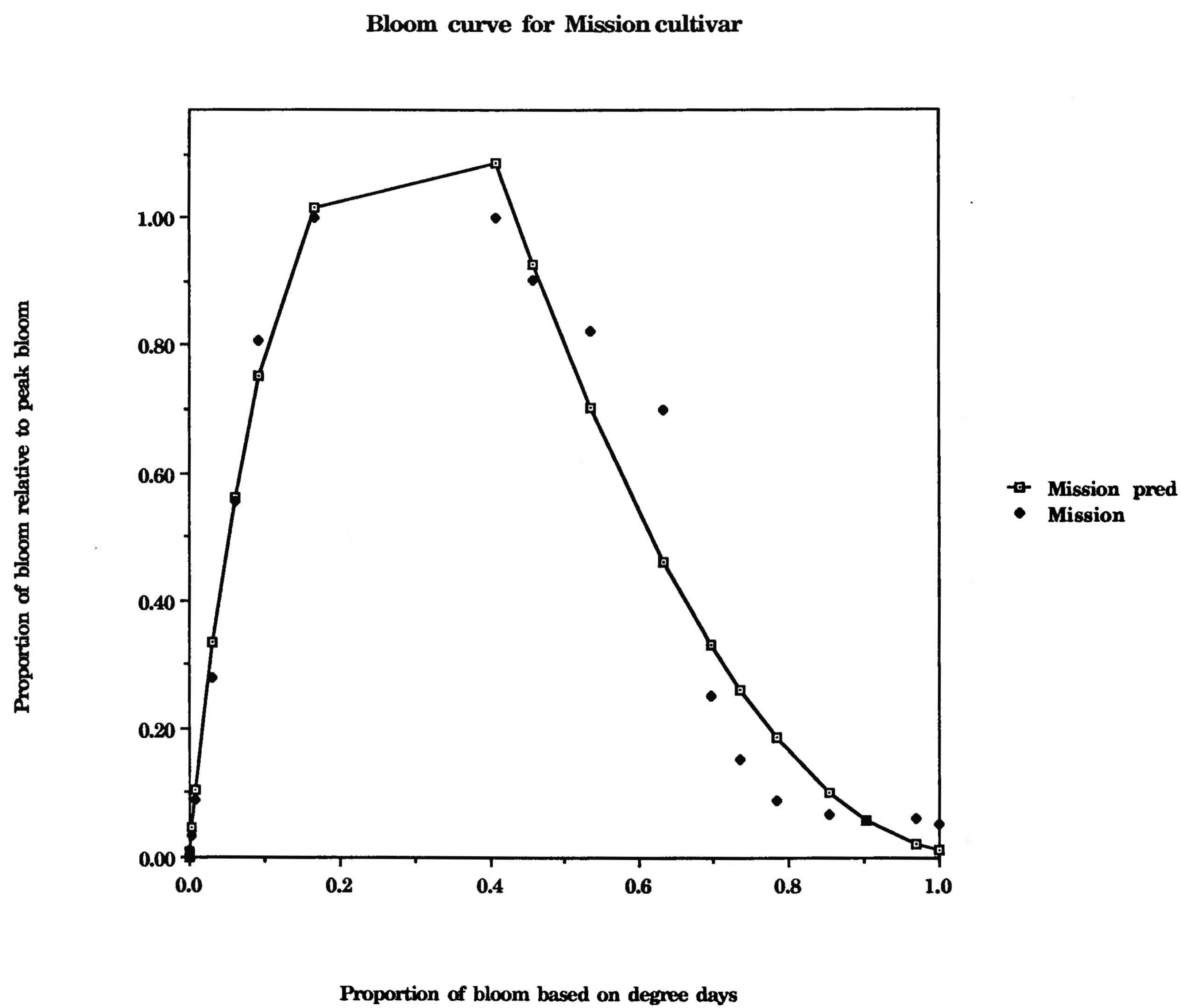

Bloom curve for Mission cultivar
Proportion of bloom relative to peak bloom
1.00
0.80
0.60
0.40
0.20
0.00
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of bloom based on degree days
Mission pred
Mission

Fig. 14

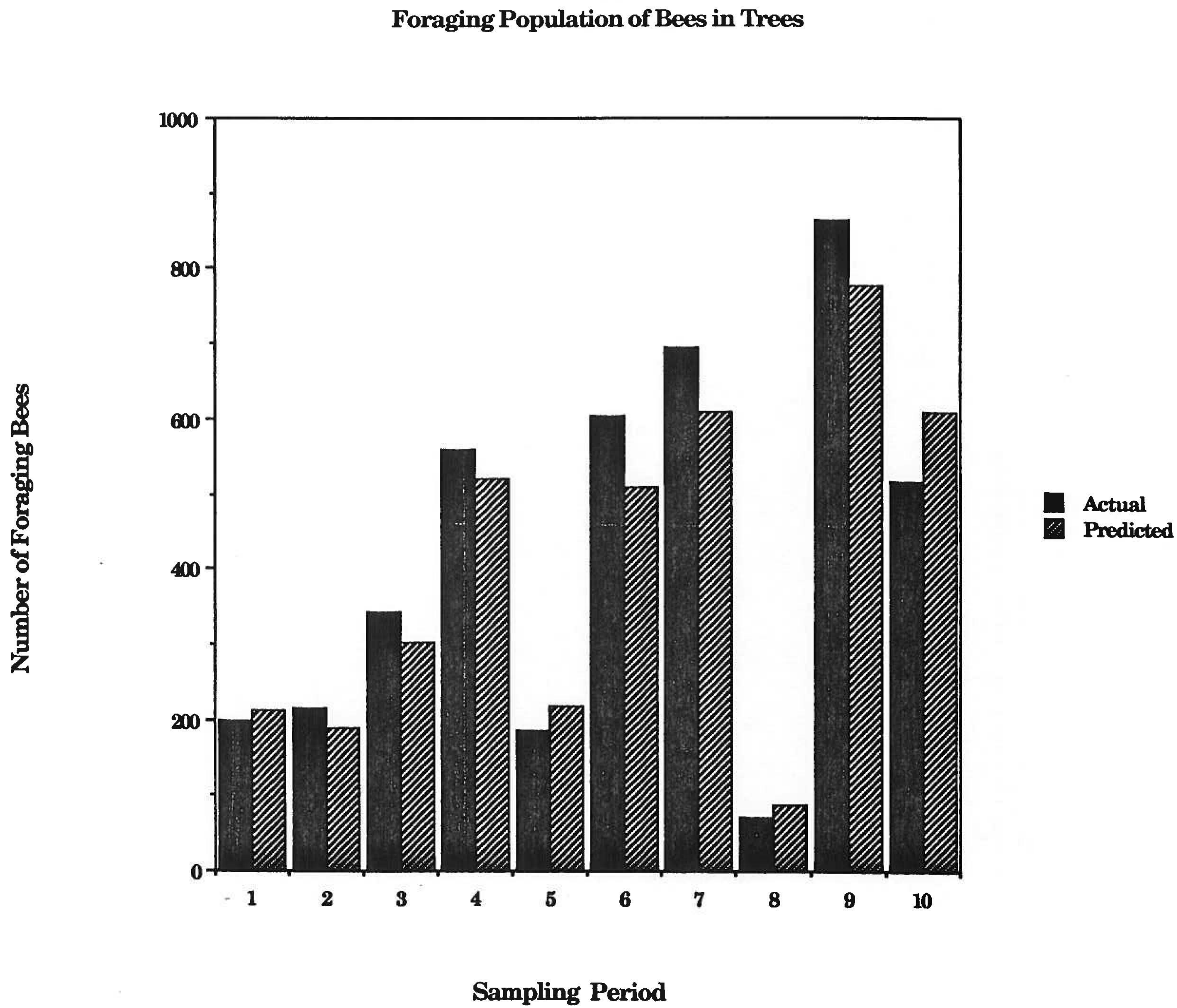

Foraging Population of Bees in Trees
Number of Foraging Bees
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
Sampling Period
Actual
Predicted

Fig. 15