1998 FINAL FINAL REPORT TO ALMOND BOARD OF CALIFORNIA

Project No. 97-RT-o0 Pollination

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Objectives:

1. Develop information on pollination by bees that will result in increased efficiency and greater grower returns
2. Improve pollination efficiency of rented honey bee colonies.
3. Evaluate and improve management of alternative pollinators.

Summary

Weather- El Niño wet conditions prevailed into mid February, especially through early bloom of NePlus. Intermittent rains occurred through early March including parts of Nonpareil and Mission bloom. Temperatures during peak Nonpareil bloom were above threshold for honey bee flight. Temperatures were below threshold for honey bee flight during peak of bloom for NePlus, Peerless and part of Mission bloom.

Bloom progression- Bloom of four cultivars in a test orchard near Dixon in 1998 started by 17 February and progressed slowly to 16 March. NePlus and Peerless overlapped well, but were declining when Nonpareil peaked. Mission did not have significant bloom until early March when Nonpareil was declining. Price was not measured in 1998.

Buds per meter- Buds per meter were counted on four cultivars as part of a long-term study initiated in 1990. In 1998, we found light bud production on all cultivars except Nonpareil. Price was not counted. Percent fruit set did not conform to earlier patterns.

Fruit set and stage of bloom- Early, mid, and late blooming flower cohorts of NePlus, Nonpareil, and Mission were measured for fruit set success. The best production was from the mid flower cohort of Nonpareil and the earliest cohort of Mission, the poorest was from early NePlus flowers. Mid cohort flowers of Nonpareil seem to have compensated for lack of pollination of the early cohort which suffered from rain.

Pollination efficiency of honey bees- More loose pollen was found on bodies of honey bees foraging for pollen on almond than on bees foraging for nectar. Pollen foragers visited younger more viable flowers more frequently, contacted stigmas more frequently, and spent more time in contact with stigmas during foraging than nectar foragers did. These data add support for our hypothesis that pollen foraging honey bees are the more efficient pollinators of almond.

Bloom progression & weather since 1990- Bloom periods and pollination by bees are strongly influenced by weather, especially temperature and rainfall. Patterns from 1990 through 1996 are reinterpreted in relation to temperature and rainfall during bloom. In most high production years bloom started late and was accompanied by warm dry conditions.

Ratios: fruit set/m- We calculated fruit set per meter to reflect yield to compare years and cultivars and to search for a possible predictor of broader patterns of yield. Nonpareil in an orchard near Dixon proved a good estimator of statewide production and per acre yields from 1990-91 through 1996-97, but not for 1997-98 or the current year.

Orchard mason bees- Too few *Osmia lignaria* were trapped in spring 1997 to use in tests in almond in 1998. They were returned to augment the population at the original site. Nesting activity at the trap site increased in spring 1998 following the El Niño wet conditions.

Introduction

The 1998 bloom season in the Sacramento Valley started by mid February (Fig. 1). El Niño wet conditions prevailed into mid February, especially through early bloom of NePlus and Peerless (Fig. 2). Intermittent rains occurred through early March including parts of Nonpareil and Mission bloom, but there were windows of good bee flight weather during peak bloom of Nonpareil and most of Mission bloom (Fig. 2). Temperatures during peak Nonpareil bloom were above the threshold [55°F (=13°C)] for honey bee flight (Fig. 1). Temperatures were below threshold for honey bee flight during peak of bloom for NePlus, Peerless and part of Mission bloom (Fig. 1). There was good overlap of bloom, except for early NePlus and late Mission (Figs. 1 & 4).

Bloom Progression

Bloom of four cultivars in our test orchard near Dixon started in mid February and progressed steadily to mid March (the cultivar, Price, was not measured in 1998). The early and mid blooming cultivars started during a rainy period. At the peak of Mission bloom, only Nonpareil had significant bloom remaining.

Methods: Bloom progression counts were made every 2 to 4 days along a diagonal (NE-SW) transect across the orchard using one limb on each of five trees for each of the four cultivars. More than 100 buds per limb per tree were counted from the tip and a color coded flagging tape was placed at the base of the section of initial buds counted. Bloom units were classified into three categories: bud (small buds through popcorn stage with petals showing but not separating); flower (from anthesis with petals just opening enough so that a bee can enter and contact the stigma = "cup-shaped," through initial petal drop); and senescent flower (with most petals gone, anthers empty, and stigma and style tip darkened. The cultivar, Price, was eliminated from the study this year due to the scarcity of buds on branches within reach.

Results: The 1998 bloom season started by mid February and progressed steadily until mid March. There was good overlap of bloom, except for early NePlus and late Mission (Figs. 3-5). There was a window of warm dry weather during peak Nonpareil and early Mission bloom (cf. Figs 1 & 2).

Discussion: Wet cool weather during early NePlus and Peerless bloom reduced the opportunities for bees to fly and pollinate almond. Also many early NePlus flowers appeared brown and withered during our bloom progression counts. The best window of warm dry weather for bee activity and pollination was during peak Nonpareil and early Mission bloom (cf. Figs 1 & 2).

Buds Per Meter and Fruit Set

In our test orchard near Dixon, buds per meter counts were made among four cultivars as part of a long-term study initiated in 1990 (Price was not measured in 1998). Bud production in 1998 was generally less than in 1997, except for Nonpareil and did not follow patterns of previous years. Only Nonpareil continued to exhibit a pattern of alternate bearing over the past nine year period. Percent fruit set did not continue to show an inverse relation to bud production in most cultivars.

Methods: This is a continuation of a long-term study started in 1990. Buds per meter were counted on five limbs of each of 10 trees in one row of each cultivar. Starting at the tip of each branch, a meter tape was run toward the base, measuring along each major spur and branch until one meter was reached. A clothes pin was clamped to the branch at that point and all buds were counted from the apex of each limb to obtain bud production in terms of buds per meter.

About 100 buds were counted on one limb on each of 10 trees of the four cultivars and flagged early in the bloom season and these were used as a base for calculating percent fruit set. These trees were the next 10 to the west in the same rows used for our buds per meter data set. Fruits set were counted on 29 April 1997 about 7-8 weeks after bloom ended. Percent fruit set was calculated by dividing the number of large fruits produced by the numbers of original buds and multiplying by 100.

The cultivar, Price, was eliminated from the study this year due to the scarcity of buds on branches within reach.

Results: Bud production was less in 1998 than in 1997 for most cultivars, except Nonpareil (Fig. 6). Only Nonpareil has continued to show a pattern of biennial bud production (Fig. 7). The general inverse relationship of fruit set to bud production in most cultivars noted in most previous years did not hold for 1998 (Figs. 8 & 9).

Discussion: Only Nonpareil continued to show a pattern of biennial bud production over the past nine years (Figs. 6 & 7). The lack of the previously noted inverse relationship between fruit set and bud production in most cultivars in 1998 was probably weather related (Figs. 8 & 9). Wet cool weather inhibited pollination of early bloom of NePlus (see Fig. 10).

Variation in bud/flower production may influence the bee/flower ratio and thus the percent fruit set. In low bud production years, percent fruit set often increases. This may be reversed in years of high bud production and often accompanied by increased fruit drop in about June. This suggests that trees with low bud production can compensate somewhat by devoting more resources to retain developing fruit. Trees with low bud and subsequent flower densities may also be more effectively pollinated due to more bees per flower producing more rapid depletion of pollen and nectar resources each day. This could cause increased bee flights between trees and therefore better movement of out-cross pollen in the orchard. It suggests that growers should ensure that they have adequate numbers of strong bee colonies during years of high bud densities. Increased bee activity during these years is needed to ensure an adequate bee/flower ratio and to obtain the best fruit set in years of heavy flowering.

Fruit Set and Stage of Bloom (Bloom Cohorts)

Some of our previous research has indicated that the earliest flowers to bloom on a tree produce more fruit set than do later blooming flowers. We tested this by dividing the bloom into early, mid, and late cohorts of flowers on each of three cultivars: NePlus, Nonpareil, and Mission. The hypothesis that earliest opening flowers produce the highest set was confirmed for mid and late blooming cultivars since the best production was from the earliest flower cohorts of Nonpareil and Mission in 1997, but not supported by our data in 1998. Early flowers of NePlus, the earliest blooming cultivar, bloomed during rainy weather and were not able to remain viable long enough to overlap with cultivars with cross-compatible pollen. Mid Nonpareil cohort seemed to compensate for lack of adequate pollination of early cohort due to rain.

Methods: As each of the three cohorts of flowers (early, mid, and late) came into bloom, ten flowers per tree on ten trees of each of three cultivars: NePlus Ultra, Nonpareil, and Mission were flagged with colored yarn. Each age cohort of flowers was flagged with a different color of yarn: red (early), purple (mid), and blue (late). Yarn was tied at the base of a flower peduncle or usually on a spur and other flowers or buds on the spur were removed. In late April 1998, fruits set for each flower was measured.

Results: There was no fruit set of the earliest cohort of flowers of NePlus. In Nonpareil, fruit set of the middle cohort was greatest while in Mission fruit set of the earliest cohort was much higher than for later cohorts (Fig. 10 Top). Fruit set was not much different among the last two age cohorts of NePlus Ultra and Mission, and the earliest and latest cohorts of Nonpareil. Most, but not all flags were found. Where flags were not found they are represented as missing data at the tops of the histogram bars concerned.

Discussion: The hypothesis that earliest opening flowers produce the highest set is only supported by our data from Mission for 1998. Early NePlus blooms lacked sufficient cross-compatible pollen to have significant fruit set (Fig. 10 Bottom) and bee flight activity was inhibited by the wet cool weather (cf. Figs. 1 & 2). Early bloom in Nonpareil was also during the wet cool conditions, but increased set and maturation of middle cohort flowers that bloomed during a warm dry window for good bee activity compensated for the loss of early fruit set. The best production was from the earliest flower cohort of Mission (Fig. 10 Top) which overlapped well with Nonpareil and late flowers of the other cultivars and which bloomed during the best window of warm dry weather for bee flight (cf. Figs. 1 & 2).

Pollination Efficiency of Honey Bees

Our previous data provided circumstantial evidence that pollen foragers are more efficient in pollen transfer in almond than are nectar foragers. In 1998, we repeated pollen counts on bees foraging at flowers using more fine grained measures than in 1997. We also made observations on age categories of flowers visited and frequencies and durations of stigma contacts by pollen versus nectar foragers. These data sets add support to our hypothesis that pollen foragers are more efficient at transferring pollen in almond and suggest the need for finding ways to increase pollen foraging from colonies rented for almond pollination.

Methods: Honey bee workers were collected by net at almond flowers while foraging for pollen or nectar. They were put in different kill vials depending on their foraging behavior. They were then transferred to plastic vials either individually or in pairs and put on ice until returned to the lab where they were placed in a freezer until they could be examined for pollen counts.

Detailed counts of pollen grains were made on parts of the body. Bees were examined under a dissecting scope at 36X magnification. Efforts were made to count all pollen grains visible on body parts. We examinied the head and ventral body surfaces that were most likely to come into contact with floral stigmas while bees forage on almond flowers.

Observations were also made on the behavior of honey bees on flowers, especially frequency of stigma contact during foraging. Bees visiting flowers were categorized as pollen or nectar foragers, based on the presence or absence of pollen in the corbiculae of the hind legs and their behavior while foraging on the flowers. Their foraging behavior on flowers was timed and the time of stigma contact was also measured. Pollen foraging (scrabbling on anthers) and nectar foraging (probing nectar reservoirs with the proboscis extended) and the age of the flower: predehiscent, early and late dehiscent (with pollen), post-dehiscent (without pollen) were recorded.

Results: Significantly more loose pollen available for pollination was found on most parts of honey bees foraging for pollen on flowers of almond (Fig. 11). Only the parts with the fewest pollen grains and those least likely to come into contact with the stigmas, the eyes and venter of the prothorax, showed no significant differences (Fig. 11).

Pollen foragers tended to visit almond flowers during early bloom when they were most receptive more frequently, while nectar foragers tended to visit almond flowers in later stages of bloom more frequently (Fig. 12). A higher percentage of pollen foragers contacted stigmas of almond flowers than did nectar foragers (Fig. 13). Of those bees that contacted stigmas, pollen foragers spent more time in contact with stigmas than did nectar foragers (Fig. 13).

Discussion: Evidence gathered in 1998 showed that pollen foragers at flowers of almond consistently had more loose pollen on their body parts that would be available for cross-pollination than did nectar foragers. Our data also show a significantly greater tendency of pollen foragers to visit younger more viable flowers, and their higher frequency and greater duration of stigma contact. These data give further support to our hypothesis that pollen foraging honey bees are more efficient pollinators of almond than are nectar foragers.

This is part of a long-term study to determine the relative efficiency of pollen versus nectar foraging honey bees as pollinators of almond. Our previous data provided us with circumstantial evidence that pollen foragers are more efficient in pollen transfer in this crop and that they represent only a small percent of bees returning to colonies. These findings have been the basis for studies to increase pollen foraging by honey bees rented for almond pollination. These include our studies on effects of syrup feeding, pollen traps, and thermal covers over hives. They are also the basis for the selections of high pollen hoarding strains of honey bees by Dr. Robert Page, U. C. Davis and our cooperative unpublished foraging studies of his selections in almond.

Our results suggest that it is important to continue studies to find ways to increase the ratios and numbers of pollen foragers in honey bee colonies rented for almond pollination. These may include management procedures and genetic selections already mentioned, and use of pheromones (e.g., queen mandibular pheromone and/or brood pheromone) to modify foraging behavior.

Ratios: fruit set/m

As part of our long-term data sets since 1990 in our test orchard near Dixon, CA, we have measured buds per meter production and percent fruit set for five cultivars: NePlus Ultra, Nonpareil, Peerless, Price (except 1998), and Mission. To summarize our data set we multiplied the two to determine the percent fruit set per meter as a reflection of yield for each cultivar. In order to determine whether pairs of cultivars covary with respect to yield from year to year, a ratio of percent fruit set per meter was calculated for each year. This analysis was performed to test the assertion that different cultivars covary over time. This assumption has been used to test whether pollen inserts were effective at increasing yield.

Methods: For each year that we have data from our test orchard near Dixon, CA (1990 - 1998), percent fruit set for each cultivar was multiplied by number of buds per meter to give percent fruit set per meter (Fig 14). This value is used as an estimator of yield for each cultivar.

In order to determine whether cultivars covary with respect to each other from year to year, we calculated ratios of percent fruit set per meter for each of four cultivars for each year compared to the fifth (Figs. 15-19). For example, a value of one for a particular year and for a particular pair of cultivars would indicate that the two cultivars had the same product during that year. Even if ratios deviate from unity, if they remain constant over years, the cultivars would be considered to covary.

Also for each cultivar, we calculated the ratio of percent fruit set per meter compared to the mean for all years (1990 - 1998) excluding the comparison year (Fig. 20). This was done to determine in which years the different cultivars had higher than mean production.

To determine whether any of the ratios might be predictive of production on a broader scale we compared the ratios for each of the cultivars over the years 1990-1998 in Figure 20 to data provided in the 1997 Almond Almanac produced by the Almond Board of California supplemented by calculations based on 1998 updates in the July issue of the Board's "California Almond News" (Fig. 21).

Results: Percent fruit set per meter of the five cultivars in our test orchard near Dixon, CA shows considerable variation between years and among cultivars with each year (Fig. 14).

Comparisons of each cultivar with all four other cultivars over the years show that they do not covary in the same pattern from year to year (Figs. 15-19).

Statewide figures for total almond production in millions of pounds correspond closely to those for bearing acre yields in pounds (Fig. 21 a & c). However, fluctuations in bearing acres seem to show little influence on these data (cf. Fig. 21 b vs. 21 a & c).

From the ratio of fruit set per meter data from our test orchard (Fig. 20), we find that Nonpareil shows the best fit with Statewide figures for total almond production in millions of pounds and for bearing acre yields in pounds (Fig. 21 a & c) from 1990 through 1996, but not for 1997 (too low) nor 1998 (too high).

Discussion: In order to determine whether pairs of cultivars covary with respect to production from year to year, a ratio of percent fruit set per meter was calculated and one cultivar was compared to the four others for each year. This analysis was performed to test the assertion that the yield from different cultivars covary over time. For example, even NePlus and Peerless (Figs 15, 16) seem to fit each other fairly closely except for 1995. This may be due to their early bloom and overall low productivity. None of the data for the other cultivars show much resemblance to one another over the years (Figs. 15-19). These data demonstrate that different cultivars in one orchard tend not to covary over time in ratios of bud production and fruit set per meter and suggest the same may be true for yield data. Comparisons of the ratio of percent fruit set per meter to the mean for all years (1990 - 1998) excluding the comparison year also show considerable variation between years and between cultivars within years (Fig. 20). Thus, measures of effectiveness of pollination techniques (e.g., applications of pollen, bee pheromones, bee food attractants) based on ratios of long-term production of any two cultivars in an orchard compared with a ratio of treated versus non-treated in the year of treatment must be interpreted with caution. Such estimates may over or under estimate the effects of treatment.

Statewide figures for total almond production in millions of pounds correspond most closely to those for bearing acre yields in pounds (Fig. 21 a & c). It is not clear why annual total production data do not correlate more closely with fluctuations in numbers of bearing acres (cf. Fig. 21 b vs. 21 a & c), except perhaps for the years of greatest production (e.g., 1990, 1994, 1997). It may be that the decline in acreage in 1992-93 kept production from attaining a higher level that year. If subsequent declines in acreage have been primarily removal of older less productive trees/orchards in the north and these have been replaced mainly by younger more vigorous orchards in the south where weather during bloom is on average better for pollination these could strongly influence correlations between our test orchard and the statewide data. There are also discrepancies between the figures on the bearing acres for 1997-98. We used the more conservative figure of 410,000 bearing acres as reported in "California Almond News" in July 1998, but the same source in July 1997 gave 420,000 bearing acres as the basis for the objective forecast. If the latter acreage were used, a greater influence of increase in bearing acreage in combination with ideal weather conditions for pollination would seem reasonable.

In considering statewide figures for almond production, the dominance of Nonpareil must be taken into account. About 44% of the almond crop in California is Nonpareil. This may be one of the reasons that our data for Nonpareil compare so well with the statewide data for the total crop at least through 1996-97. Our data for Nonpareil near Dixon grossly underestimate the state wide production figures for 1997-98 and overestimate the 1998-99 subjective estimate. The latter may be due to variable effects of El Niño since there was a break in the weather allowing for good pollination at peak bloom in the Dixon area in spring 1998.

Bloom progression & weather since 1990

In our reports for 1997 and 1998 (current), we incorporated temperature curves and bee flight threshold lines with our bloom progression graphs. We also produced graphs of temperature and rainfall during bloom. Both were attempts to better understand the influence of weather on pollination. We have gone back and added the same types of weather data to our bloom progression curves since 1990 and provide these weather summaries with this final report.

Methods: Bloom progression curves have been produced over the years since 1990 (except for 1991). This year we gathered historical weather data: daily maximum temperatures and rainfall for the periods bracketing bloom. We superimposed temperature on the bloom progression curves with a base line at 55°F which is considered the threshold for honey bee flight activity. We produced another graph for each year showing the combination of temperature, bee flight threshold, and rainfall.

Results: 1990 (Figs. 22 & 23): bloom initiated at end February; good overlap; little rain early; maximum temperatures above bee flight threshold most of bloom; increasing during bloom; Nonpareil ratio >1; bearing acre yields >1300 lbs statewide.

1991 (Fig. 24): bloom initiated mid February; by 27 February when rains started: NePlus past peak, Nonpareil, Price and Peerless at peak, and Mission starting; rain frequent from late February through most of March; maximum temperatures above bee flight threshold until rains started, then fluctuated around threshold through March; Nonpareil ratio <1; bearing acre yields <1300 lbs statewide.

1992 (Figs. 25 & 26): bloom initiated at end of February; good overlap except for early NePlus; rains during peak of Mission bloom and early bloom of Nonpareil, Price and Peerless; maximum temperatures above threshold for bee flight throughout bloom; Nonpareil ratio >1; bearing acre yields >1300 lbs statewide.

1993 (Figs. 27 & 28): bloom initiated near end of February; good overlap except for early NePlus; some rain during early NePlus bloom; maximum temperatures below flight threshold into peak bloom of NePlus, but above for peak of other cultivars; Nonpareil ratio <1; bearing acre yields <1300 lbs statewide.

1994 (Figs. 29 & 30): bloom initiated at end of February: good overlap (compact season); a little rain during early bloom of all cultivars except Mission; maximum temperatures above threshold for bee flight throughout bloom; Nonpareil ratio >1; bearing acre yields much >1300 lbs statewide (a record year to date).

1995 (Figs. 31& 32): bloom initiated in early-mid February; good overlap for most cultivars except Mission; rain insignificant; maximum temperatures below or only slightly above threshold for bee flight during early bloom of all except Mission, above threshold during peak bloom of Nonpareil and Peerless and all of Mission; Nonpareil ratio <1; bearing acre yields much <1300 lbs statewide.

1996 (Figs. 33 & 34): bloom initiated in mid February; good overlap of most cultivars, except Mission; rain during early and declining bloom of all cultivars; maximum temperatures above bee flight threshold during early bloom of all cultivars except Mission, slightly above during peak bloom periods, and below flight threshold during late bloom of all except Mission; Nonpareil ratio >1; bearing acre yields slightly <1300 lbs statewide.

Discussion: Re-examination of our long-term data sets on bloom phenology with the addition of weather data reveals a fairly close fit of the ratio of fruit set per meter for Nonpareil in our test orchard with the pattern of annual production and bearing acre yields statewide at least from 1990 through 1996 bloom years with the 1990-91 through 1996-97 almond yield reporting years. However, our data from 1997 and 1998 bloom years do not show a good fit between Nonpareil data from Dixon with statewide production for 1997-98 and estimates for 1998-99.

1997 [see 1997 report (Figs. 1 & 2)]: bloom initiated in early February; good overlap for most cultivars except Mission; rain insignificant; maximum temperatures above threshold for bee flight throughout bloom; Nonpareil ratio <1; bearing acre yields much >1300 lbs the record yield to date (750 million pounds over 410,000 acres) statewide.

1998 [see this report (Figs. 1 & 2)]: bloom initiated in mid February; poor overlap of bloom; much rain through peak bloom of NePlus and Peerless, during early bloom of Nonpareil, and some during late Nonpareil, peak Mission and late Mission bloom; maximum temperatures above bee flight threshold during peak Nonpareil, early Mission and late Mission bloom; Nonpareil ratio >1; bearing acre yields slightly <1300 lbs statewide (based on subjective estimate of 550 million pounds over 425,000 acres).

Discrepancies between patterns for our fruit set per meter data for bloom years 1997 and 1998 versus statewide production and bearing acre yields may be due to combinations of 1) weather during bloom at our single locality versus statewide averages, 2) increase in statrewide acreage in 1997, and 3) variable effects of El Niño in 1998.

Years of high yield statewide were best characterized in our data by combinations of late initial bloom, warm dry weather during bloom, and high buds per meter in Nonpareil.

Orchard Mason Bees

Populations of the orchard mason bee, *Osmia lignariapropinqua*, trapped in spring 1997 in the southern Sierra Nevada foothills were far fewer than in the previous two years. Since such small numbers of *Osmia lignariapropinqua* cocoons were available from nests provisioned in spring 1997 and collected in fall 1997, I returned them to the trap site to augment the original population. More bee nests were trapped in spring 1998.

Methods: Trap-nests of straws in wood or Styrofoam blocks containing *Osmia* trapped at a site about 20 miles ENE of Madera in spring 1997 were brought to UC Davis on 1 November 1997. Straws were X-rayed to determine the number of potentially viable brood cells and the presence of any parasites or nest destroyers and then placed in a cold room (at about 40°F = 5°C) by early November for the winter. Nests were dissected during the winter and viable cocoons were put back in cold storage. Mortality factors and their frequencies were assessed. Bees in cocoons were put into cold storage in late November 1997. Cocoons extracted from nests in straws were returned to the trap site in the southern Sierra Nevada foothills in mid March 1998.

Results: Over 155 nests were initiated at the source site in spring 1998 (144 capped nests). Seasonal pattern of fill was about two weeks later than for previous years.

Discussion: *Osmia* nesting activity at the source site was greater and peaked later in the season due to El Niño contidions in 1998 compared to previous years. Over twice as many nests were provisioned in straw trap-nests spring 1998 as in 1997. The number of nests provisioned in spring 1998 is comparable to 1995, but less than 1996. Data on viable brood cells with cocoons and mortality by natural enemies are not available for 1998.

Figure Captions:

Fig. 1. Bloom progression in an orchard near Dixon, CA for February and March 1998 and daily maximum temperatures during bloom based on weather data from Davis, CA.

Fig. 2. Daily maximum temperatures and rainfall during almond bloom 1998 based on weather data from Davis, CA.

Fig. 3. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Buds.

Fig. 4. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Flowers.

Fig. 5. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Senescent Flowers.

Fig. 6. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

Fig. 7. Buds per meter produced by three of five cultivars showing the strongest biennial patterns in an orchard near Dixon, CA measured over nine years: 1990 through 1998 (a subset of data shown in Fig. 6). (Price not measured in 1998).

Fig. 8. Fruit set for five cultivars in an orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

Fig. 9. Fruit set for three of five cultivars showing the strongest biennial patterns of bud production in an orchard near Dixon, CA measured over nine years: 1990 through 1998 (a subset of data shown in Fig. 8). (Price not measured in 1998).

Fig. 10. Top Graph: Fruit set by early, mid, and late blooming cohort flowers for each of three cultivars: NePlus Ultra, Nonpareil, and Mission in an orchard near Dixon, CA in 1998. Based on 100 flowers per cohort per cultivar. Bottom Graph: Flower progression for the three cultivars measured for cohort fruit set in 1998.

Fig. 11. Amount of pollen on various body parts of honey bees foraging for pollen or nectar from almond flowers.

Fig. 12. Pollen vs. nectar foragers relative to age (phenological stage of bloom) of almond flowers.

Fig. 13. Stigma contacts in almond flowers by pollen versus nectar foraging honey bees: Top Graph: Percent of pollen vs. nectar foragers that contact stigmas of almond flowers. Bottom Graph: Duration of stigma contact on almond flowers by pollen vs. nectar foragers. (Excludes bees that did not contact the stigma).

Fig. 14. Percent fruit set per meter in an almond orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

Fig. 15. Ratio of fruit set per meter for each cultivar compared to NePlus for 1990-1998 in an almond orchard near Dixon, CA.

Fig. 16. Ratio of fruit set per meter for each cultivar compared to Peerless for 1990-1998 in an almond orchard near Dixon, CA.

Fig. 17. Ratio of fruit set per meter for each cultivar compared to Price for 1990-1997 in an almond orchard near Dixon, CA.

Fig. 18. Ratio of fruit set per meter for each cultivar compared to Nonpareil for 1990-1998 in an almond orchard near Dixon, CA.

Fig. 19. Ratio of fruit set per meter for each cultivar compared to Mission for 1990-1998 in an almond orchard near Dixon, CA.

Fig. 20. Ratio of fruit set per meter for each year from 1990 through 1998 in an almond orchard near Dixon, CA compared to the mean of all years excluding the year being compared.

Fig. 21. Statewide figures for almond production, bearing acreage, and per acre yield. For reporting years, the top number is the year of bloom and pollination, the bottom year is the year when the yield is finally determined from processing. Values for 1998-99 are based on the subjective estimate. Left: Total production per year; Middle: Bearing acreage per year; Right: Bearing acre yield per year.

Fig. 22. Flower progression for 1990 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 23. Daily maximum temperatures and rainfall during almond bloom 1990 for an orchard near Dixon, CA.

Fig. 24. Daily maximum temperatures and rainfall during almond bloom 1991 for an orchard near Dixon, CA.

Fig. 25. Flower progression for 1992 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 26. Daily maximum temperatures and rainfall during almond bloom 1992 for an orchard near Dixon, CA.

Fig. 27. Flower progression for 1993 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 28. Daily maximum temperatures and rainfall during almond bloom 1993 for an orchard near Dixon, CA.

Fig. 29. Flower progression for 1994 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 30. Daily maximum temperatures and rainfall during almond bloom 1994 for an orchard near Dixon, CA.

Fig. 31. Flower progression for 1995 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 32. Daily maximum temperatures and rainfall during almond bloom 1995 for an orchard near Dixon, CA.

Fig. 33. Flower progression for 1996 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

Fig. 34. Daily maximum temperatures and rainfall during almond bloom 1996 for an orchard near Dixon, CA.

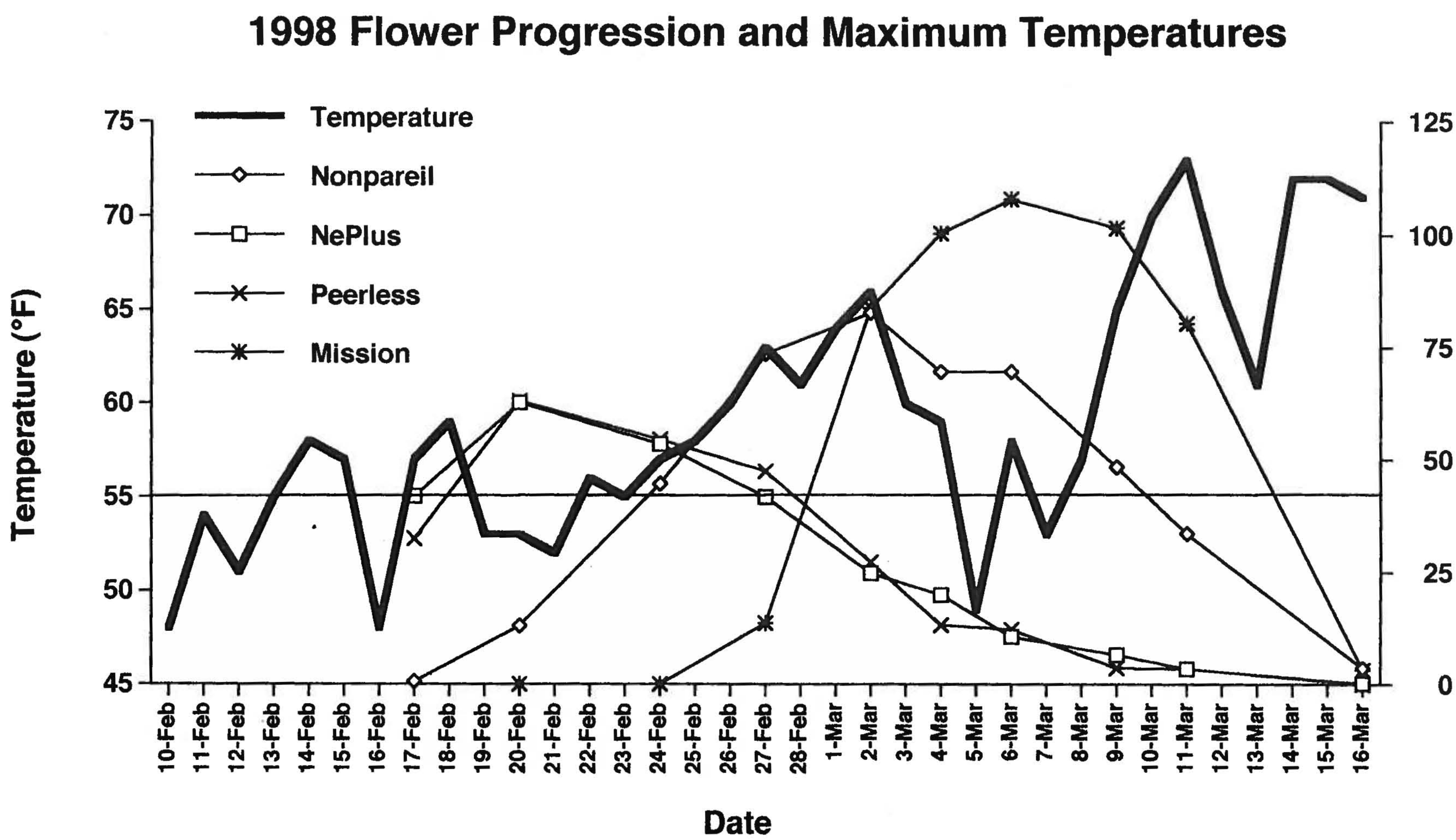


Fig. 1. Bloom progression in an orchard near Dixon, CA for February and March 1998 and daily maximum temperatures during bloom based on weather data from Davis, CA.

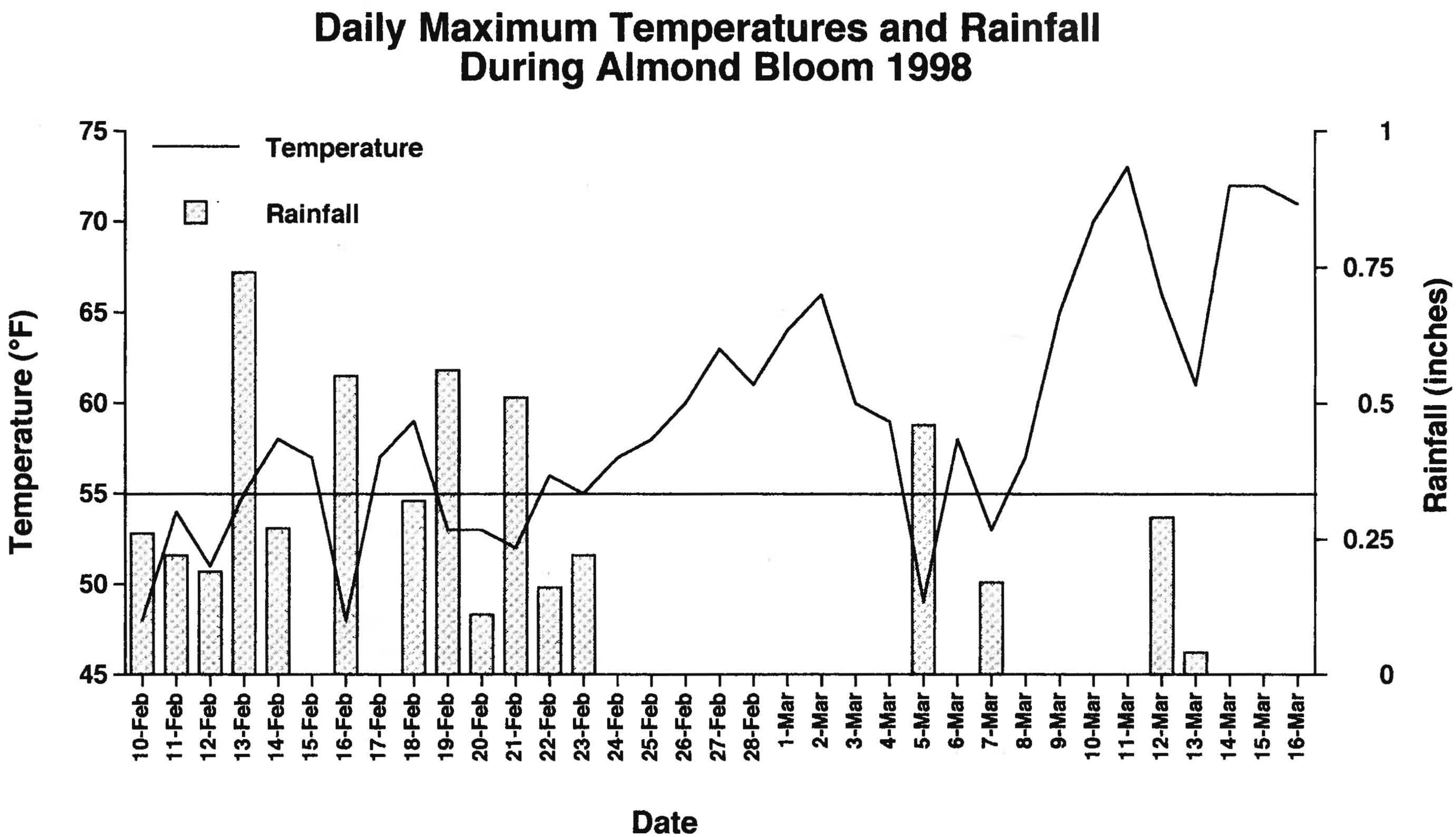


Fig. 2. Daily maximum temperatures and rainfall during almond bloom 1998 based on weather data from Davis, CA.

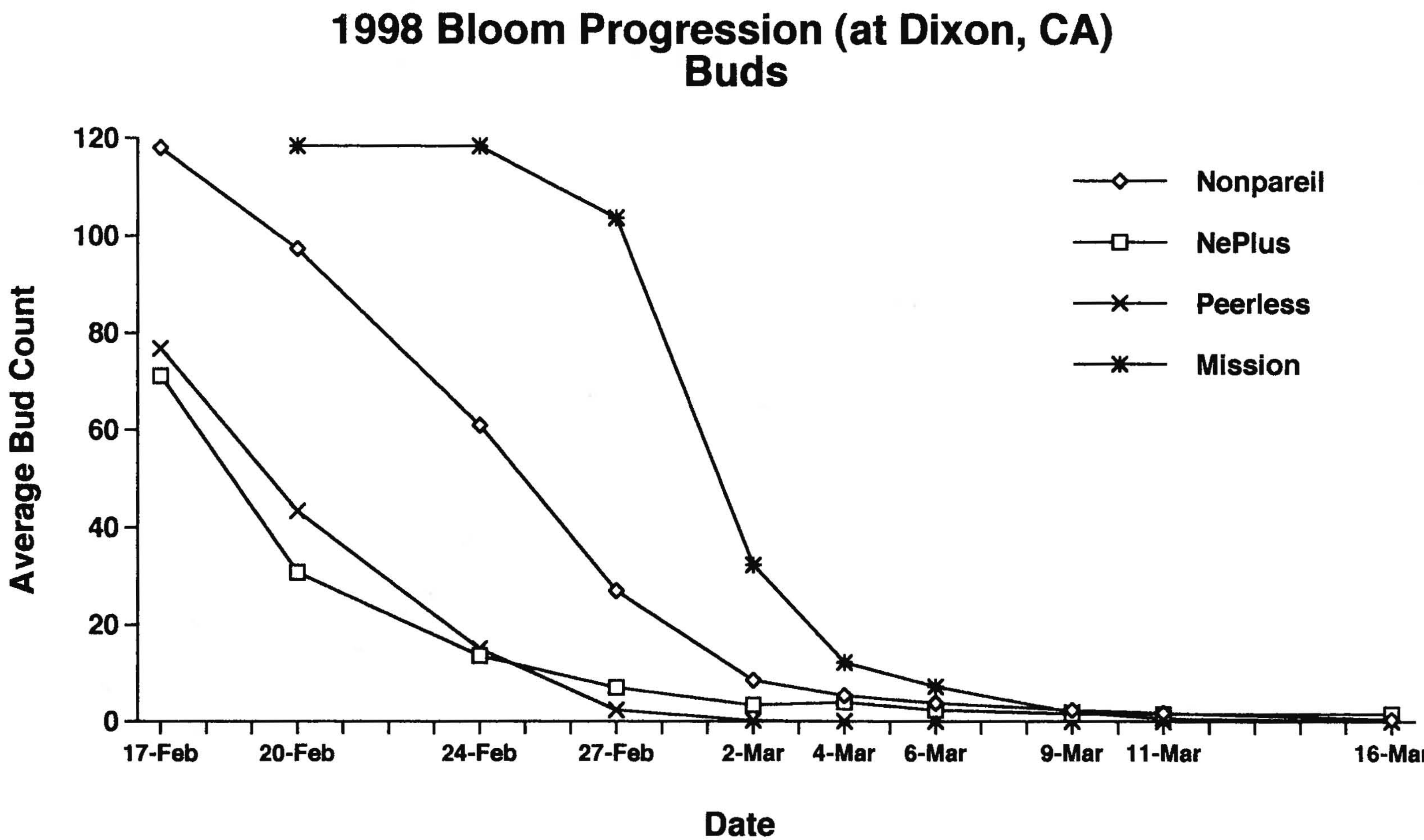


Fig. 3. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Buds.

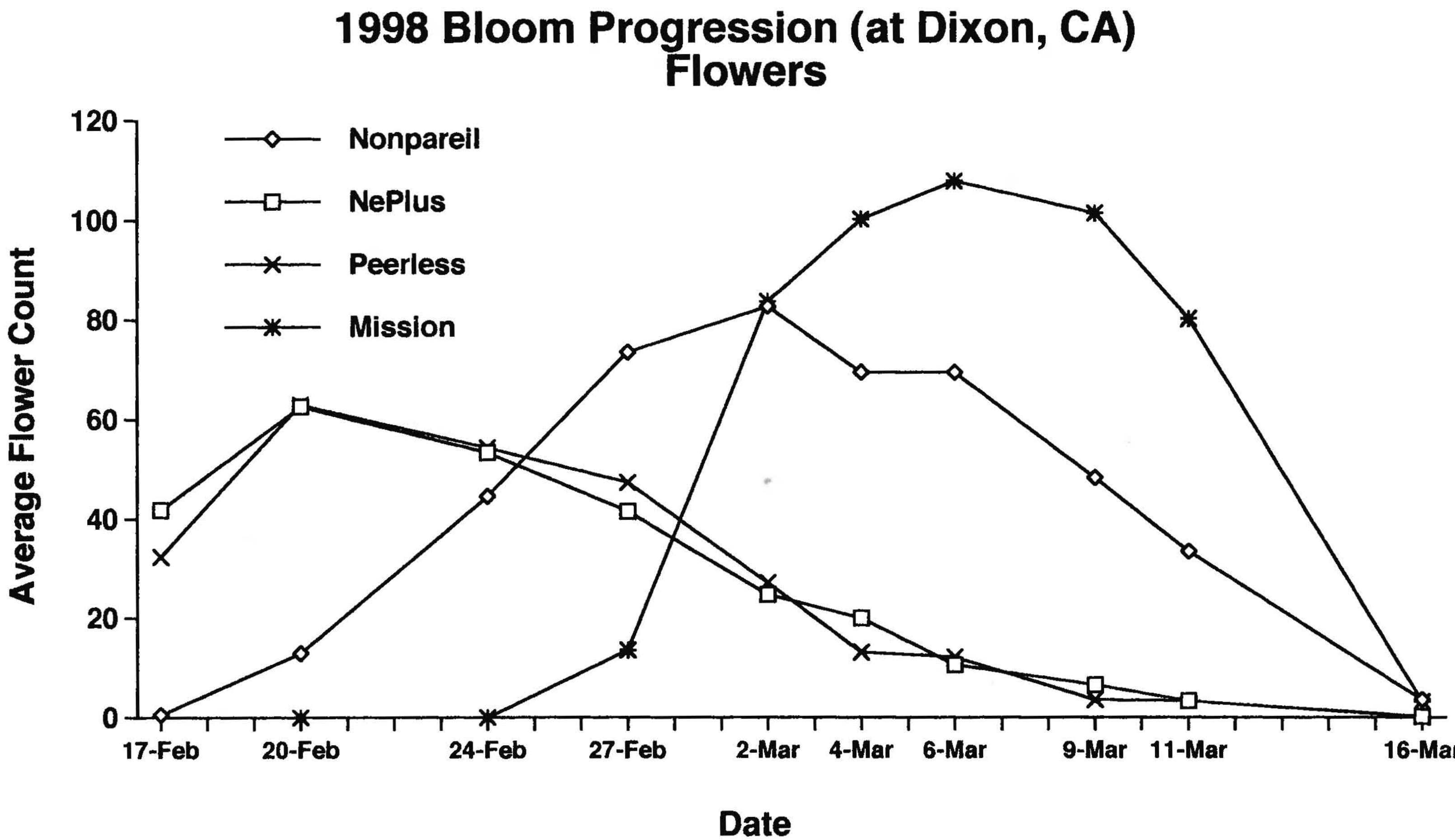


Fig. 4. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Flowers.

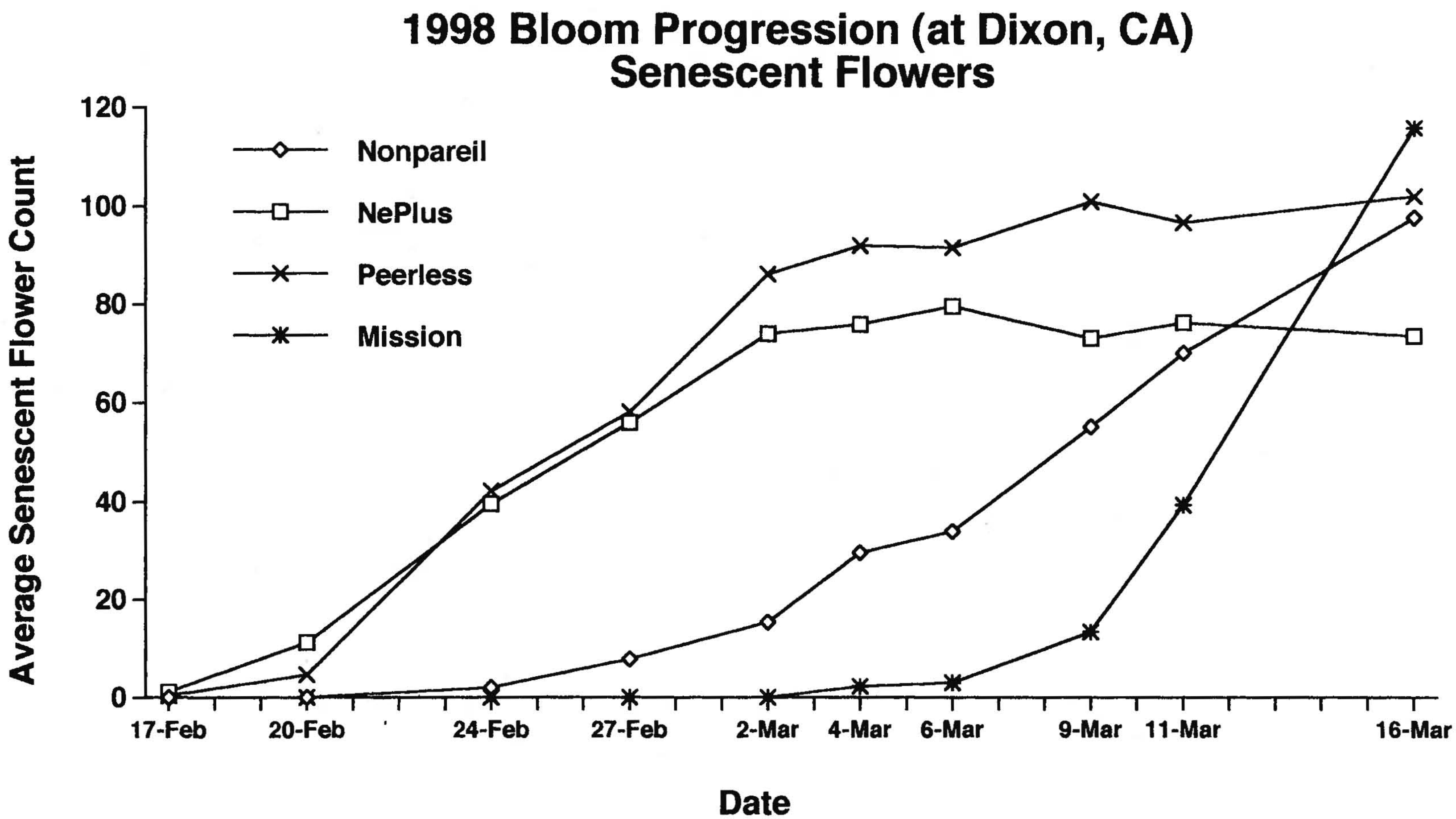


Fig. 5. Bloom progression for four cultivars in an orchard near Dixon, CA for February and March 1998. Senescent Flowers.

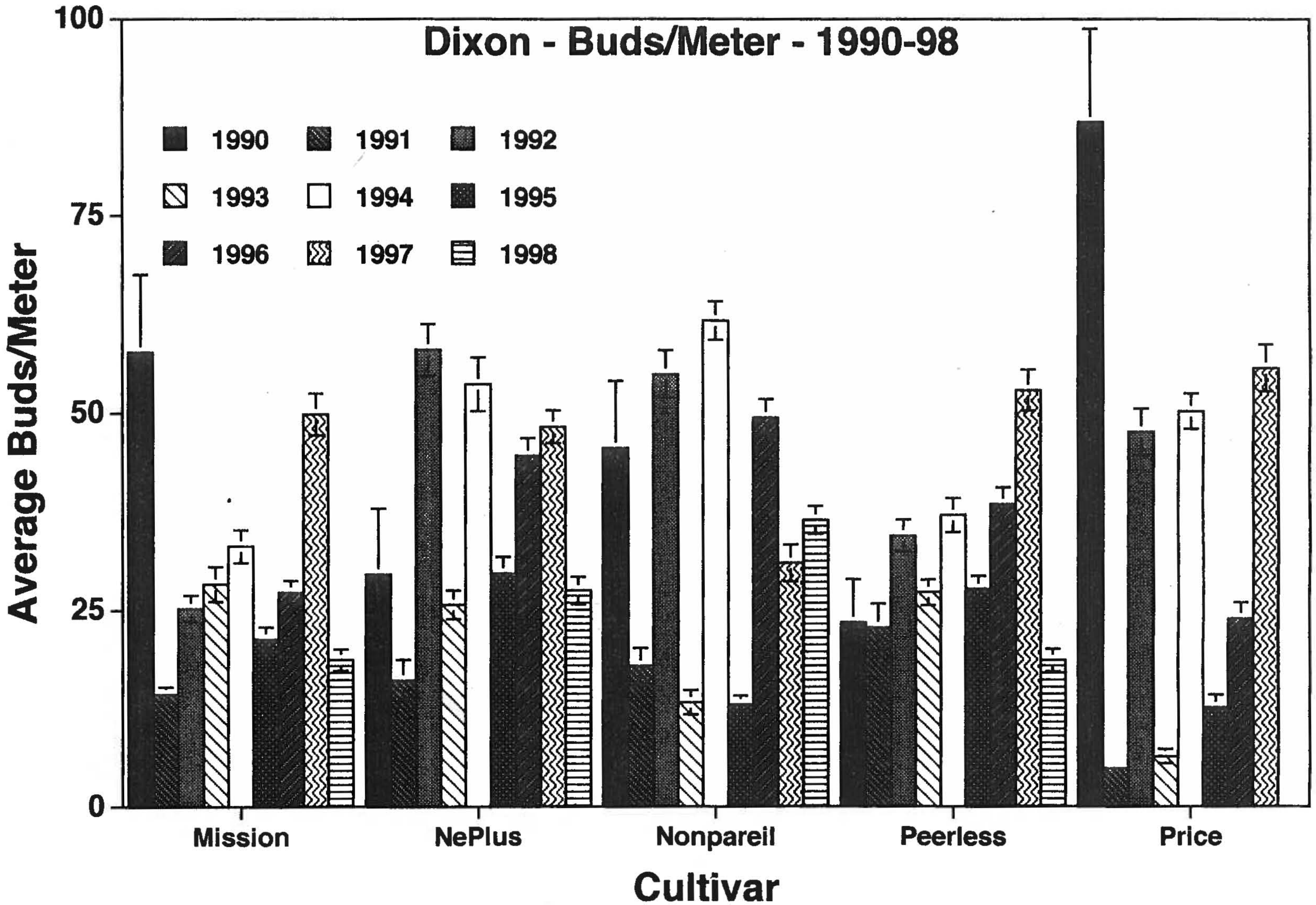


Fig. 6. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

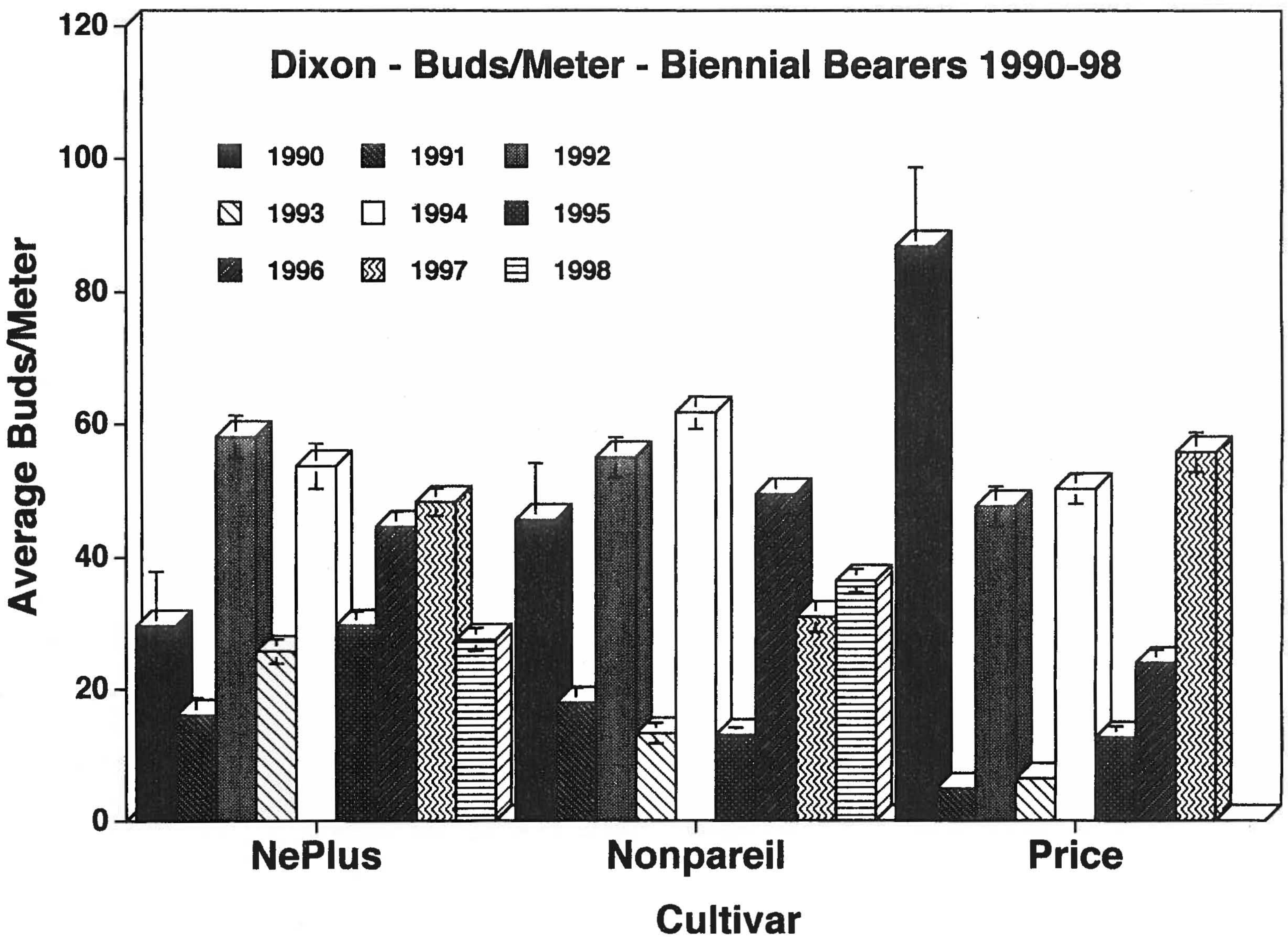


Fig. 7. Buds per meter produced by three of five cultivars showing the strongest biennial patterns in an orchard near Dixon, CA measured over nine years: 1990 through 1998 (a subset of data shown in Fig. 6). (Price not measured in 1998).

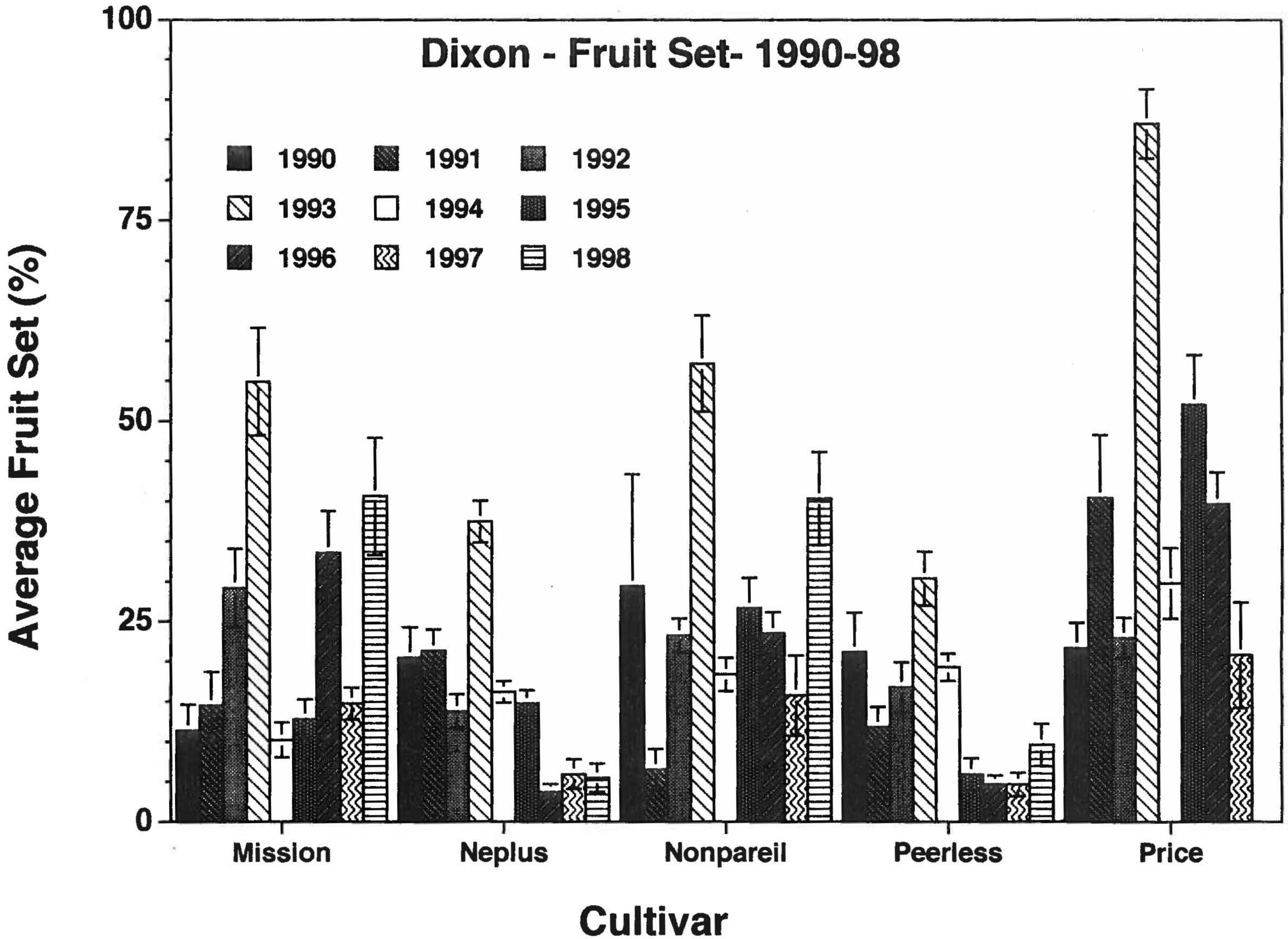


Fig. 8. Fruit set for five cultivars in an orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

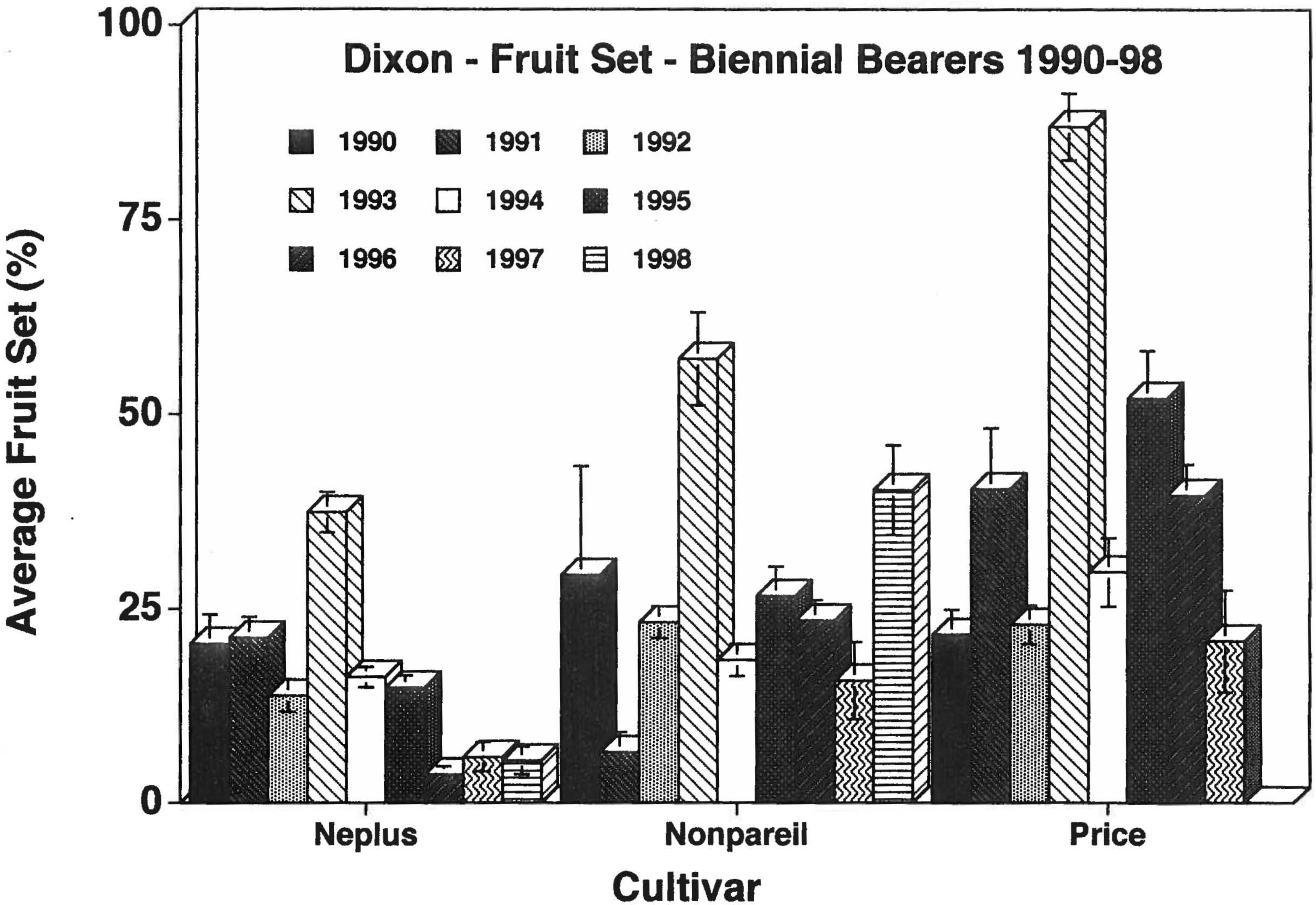
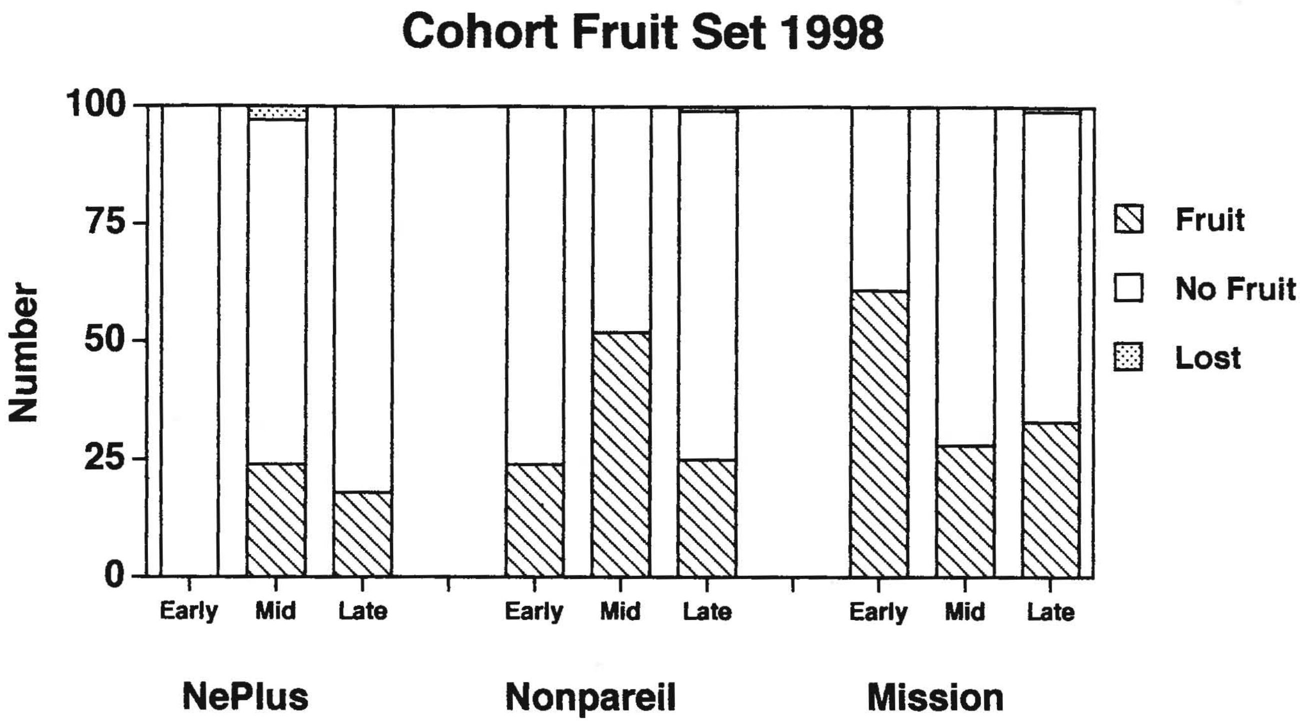


Fig. 9. Fruit set for three of five cultivars showing the strongest biennial patterns of bud production in an orchard near Dixon, CA measured over nine years: 1990 through 1998 (a subset of data shown in Fig. 8). (Price not measured in 1998).



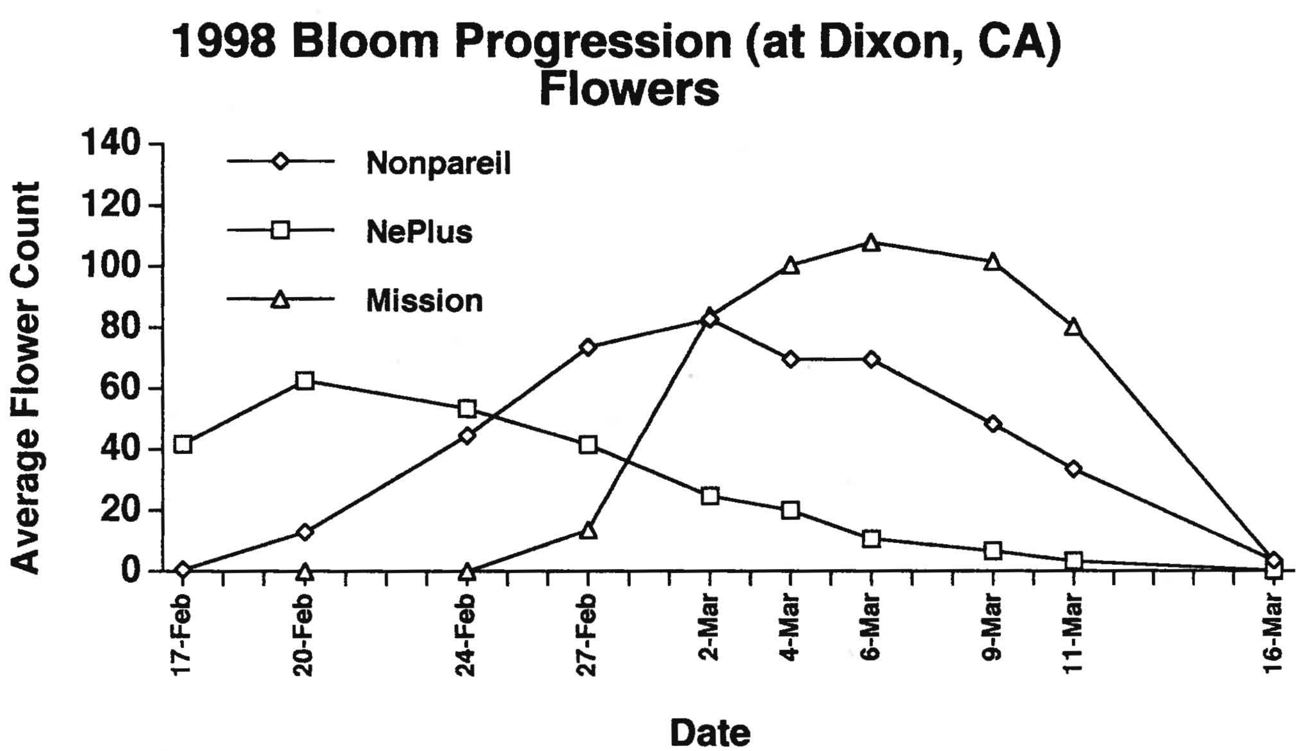


Fig. 10. Top Graph: Fruit set by early, mid, and late blooming cohort flowers for each of three cultivars: NePlus Ultra, Nonpareil, and Mission in an orchard near Dixon, CA in 1998. Based on 100 flowers per cohort per cultivar. Bottom Graph: Flower progression for the three cultivars measured for cohort fruit set in 1998.

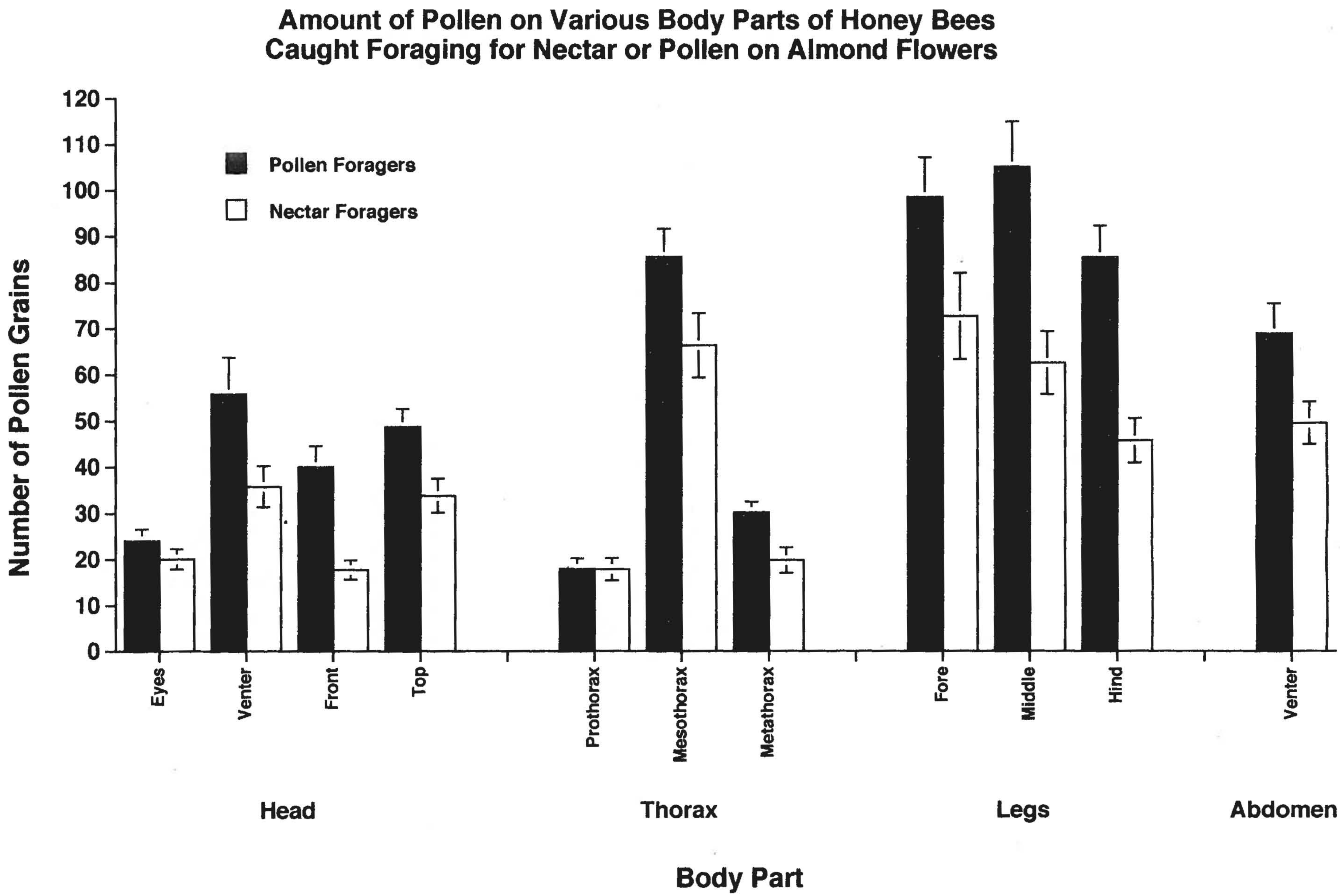


Fig. 11. Amount of pollen on various body parts of honey bees foraging for pollen or nectar from almond flowers.

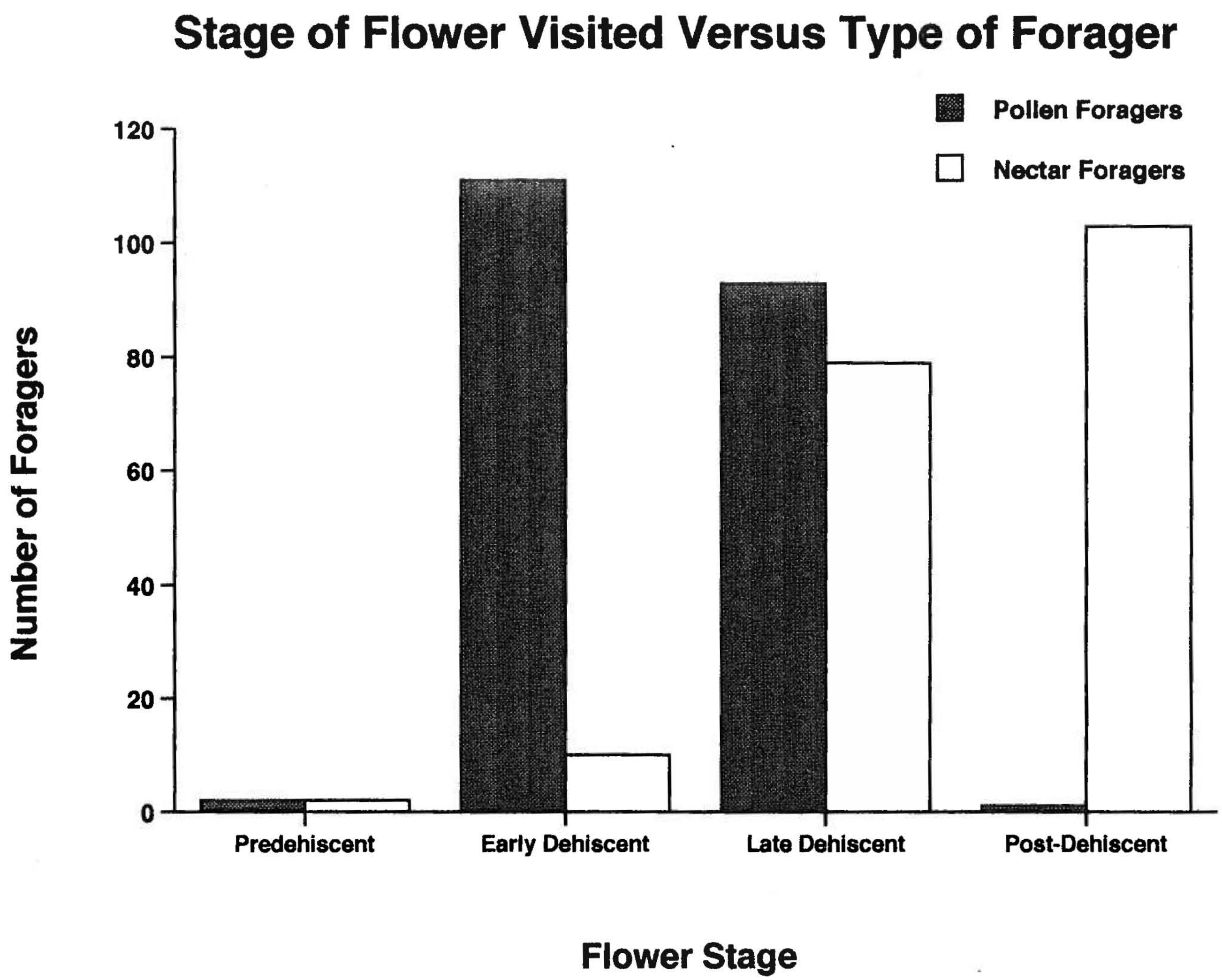
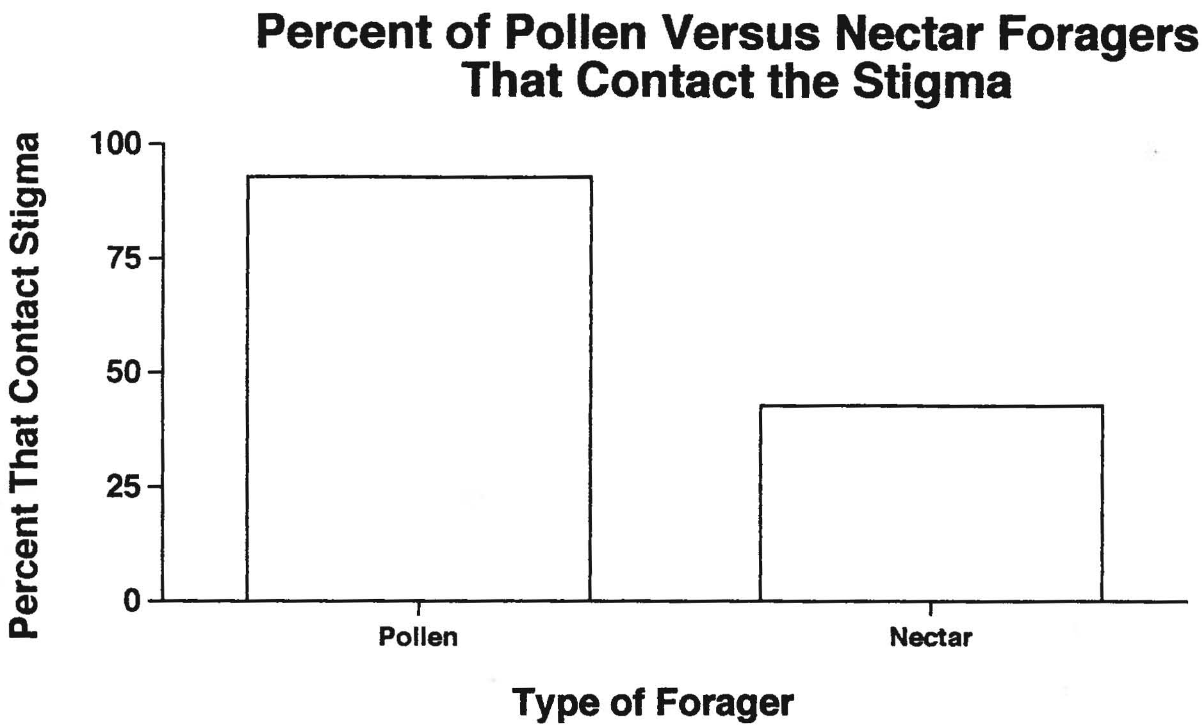


Fig. 12. Pollen vs. nectar foragers relative to age (phenological stage of bloom) of almond flowers.



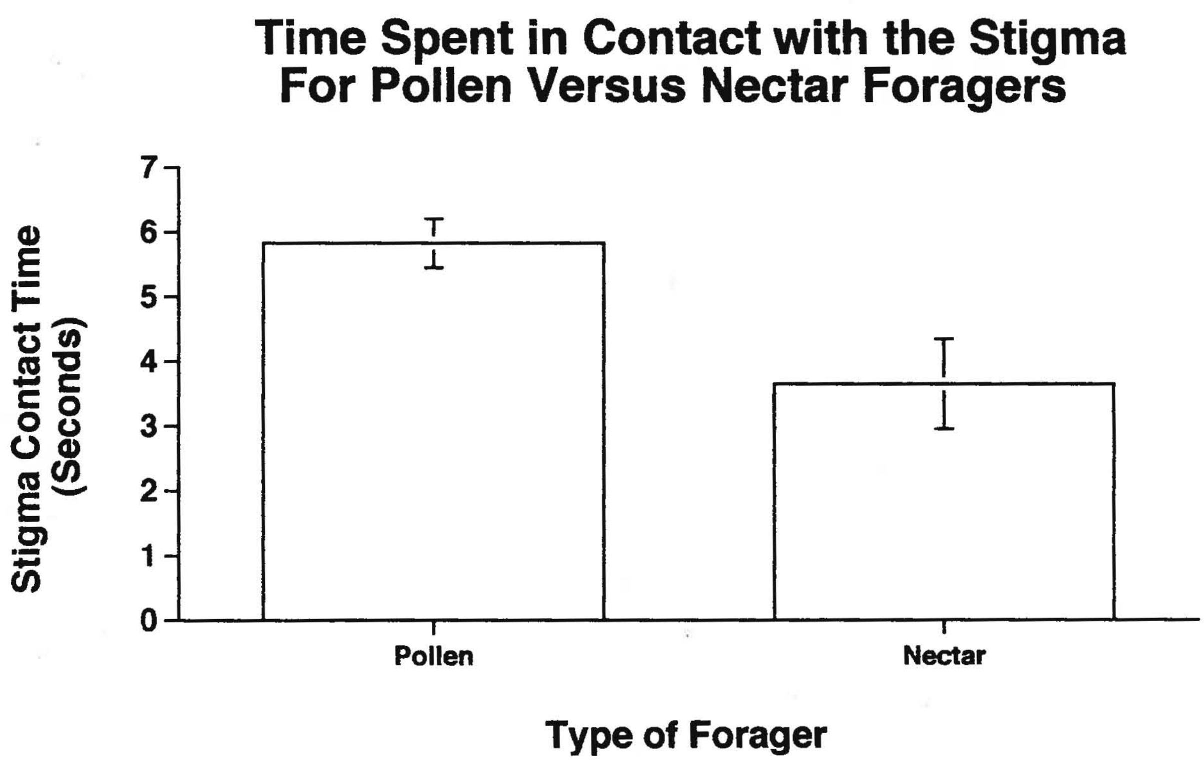


Fig. 13. Stigma contacts in almond flowers by pollen versus nectar foraging honey bees: Top Graph: Percent of pollen vs. nectar foragers that contact stigmas of almond flowers. Bottom Graph: Duration of stigma contact on almond flowers by pollen vs. nectar foragers. (Excludes bees that did not contact the stigma).

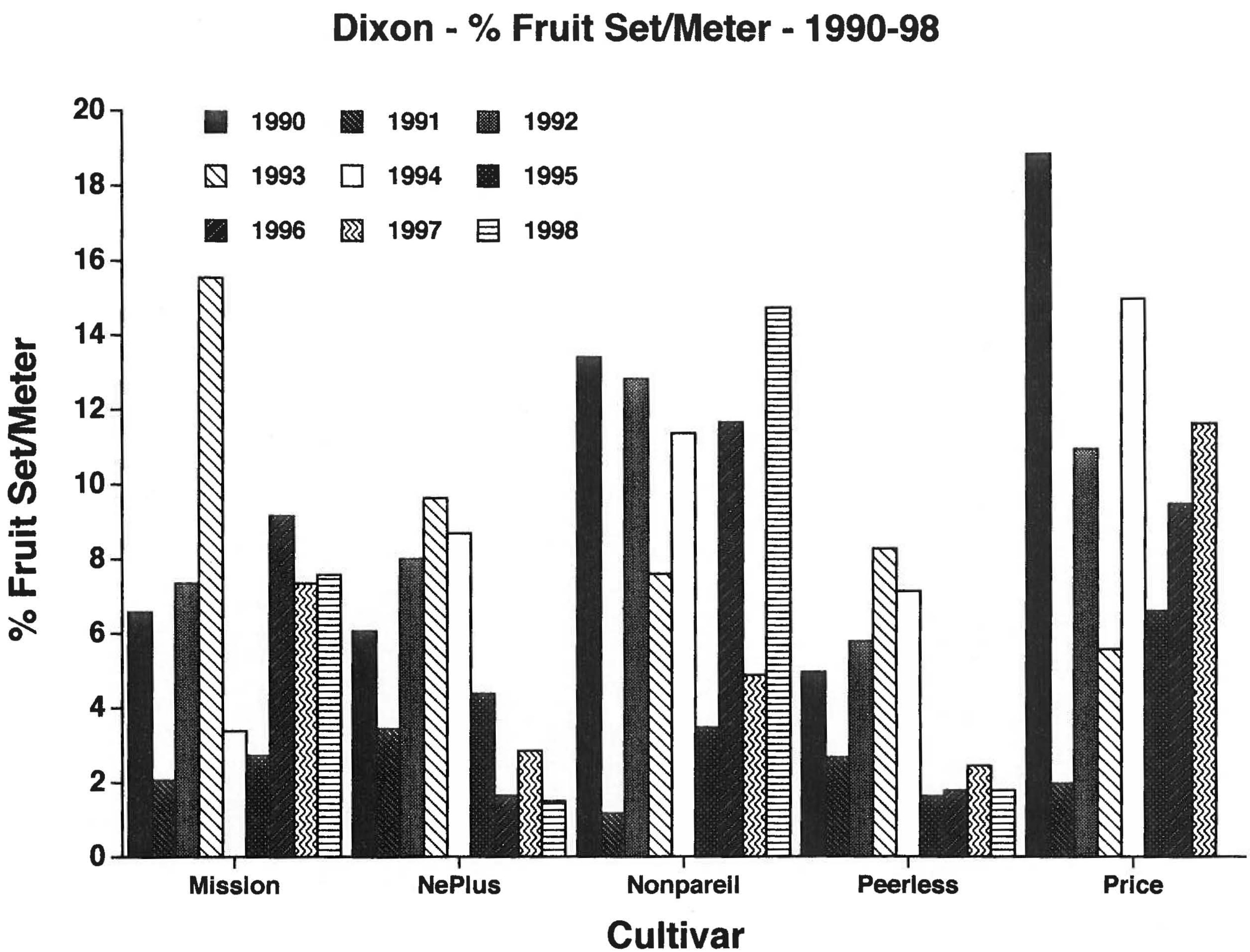


Fig. 14. Percent fruit set per meter in an almond orchard near Dixon, CA measured over nine years: 1990 through 1998. (Price not measured in 1998).

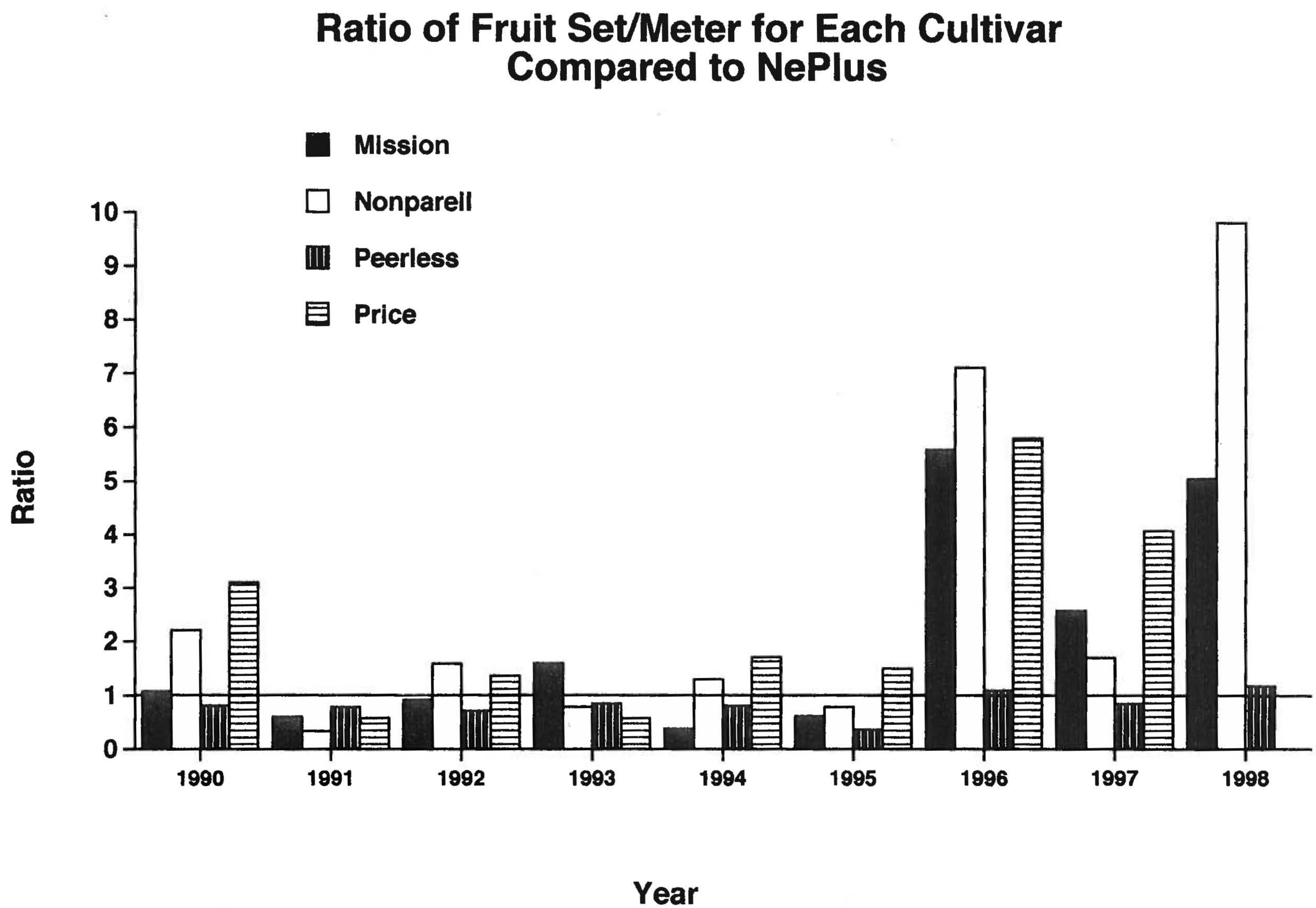


Fig. 15. Ratio of fruit set per meter for each cultivar compared to NePlus for 1990-1998 in an almond orchard near Dixon, CA.

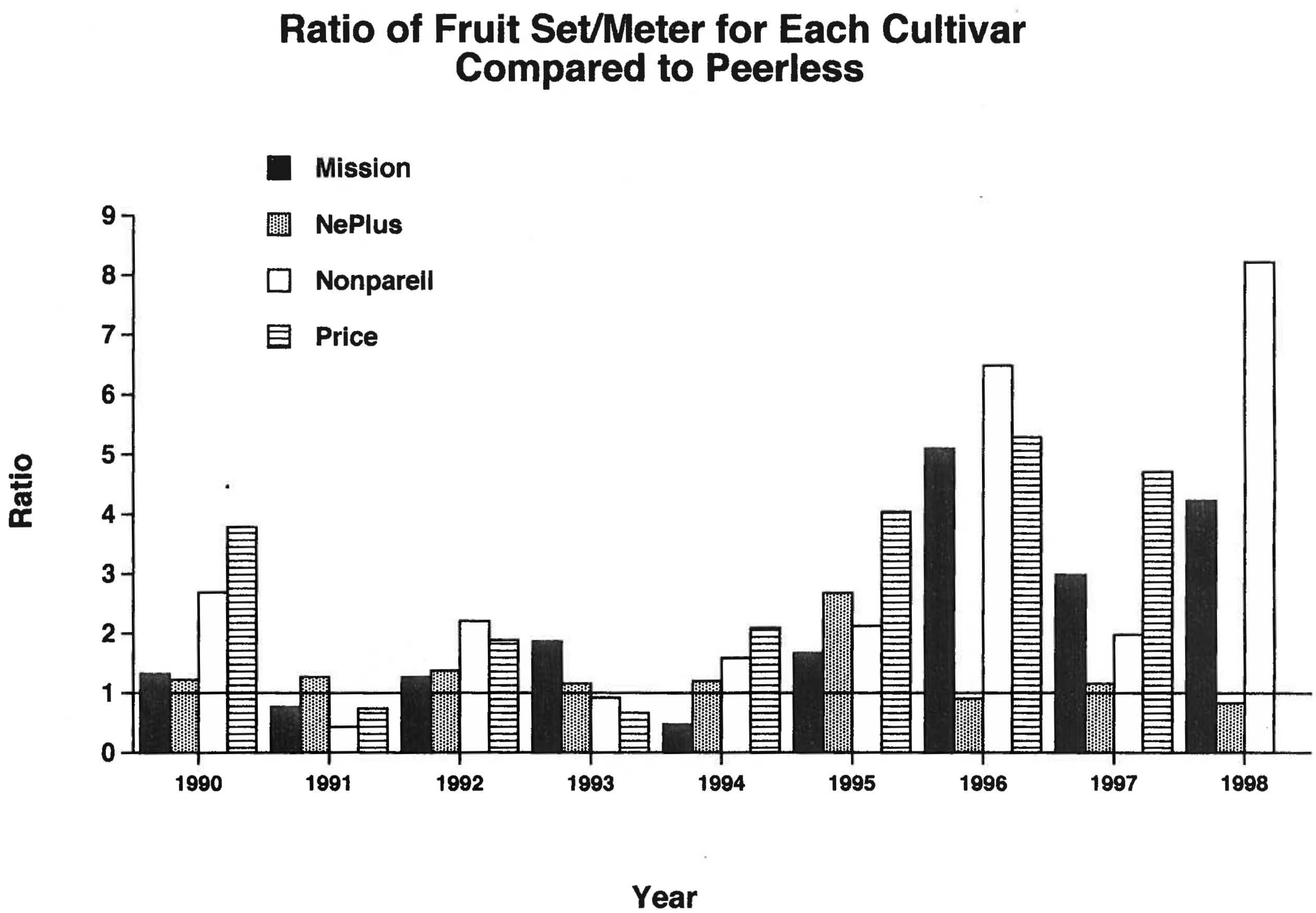


Fig. 16. Ratio of fruit set per meter for each cultivar compared to Peerless for 1990-1998 in an almond orchard near Dixon, CA.

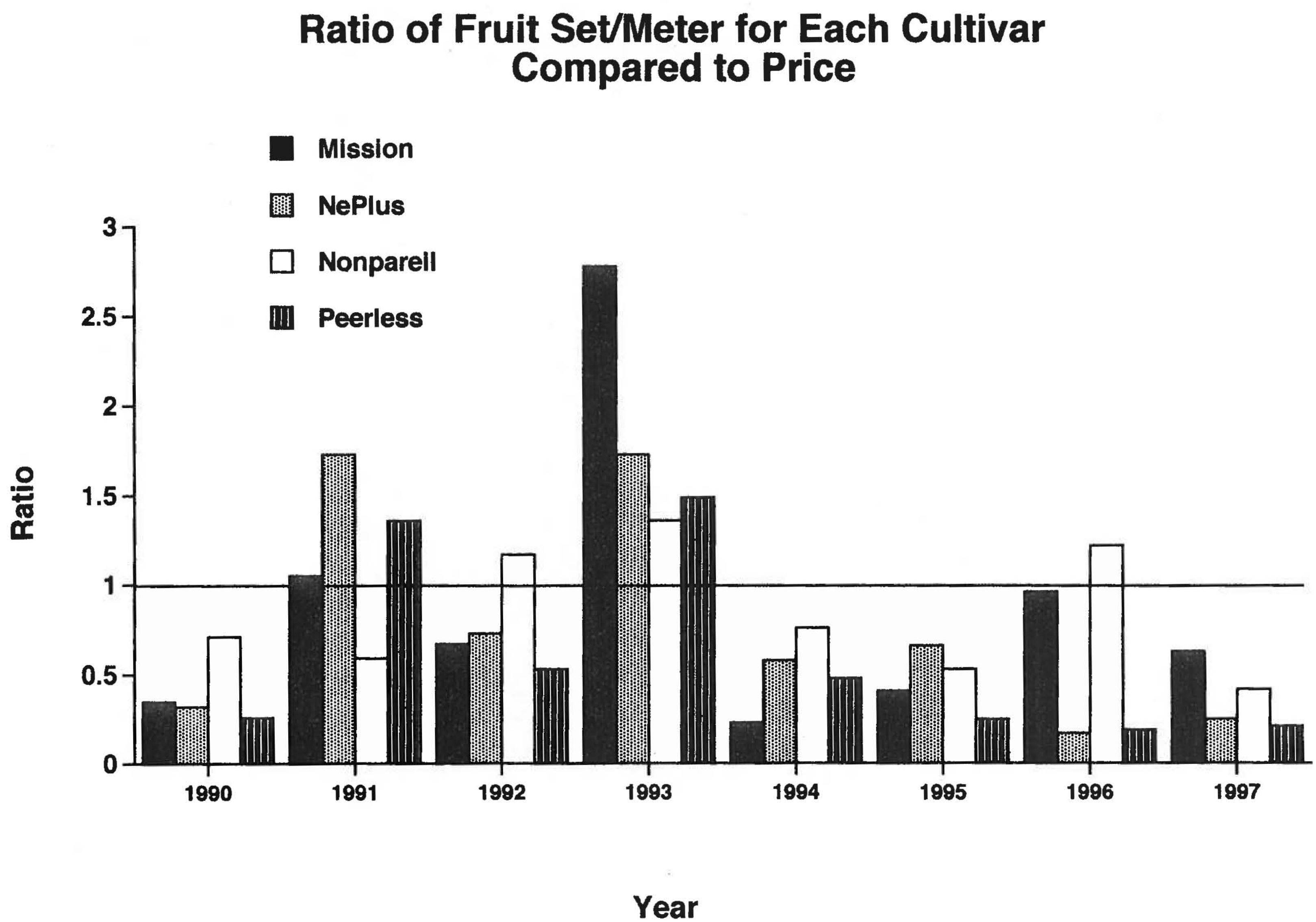


Fig. 17. Ratio of fruit set per meter for each cultivar compared to Price for 1990-1997 in an almond orchard near Dixon, CA.

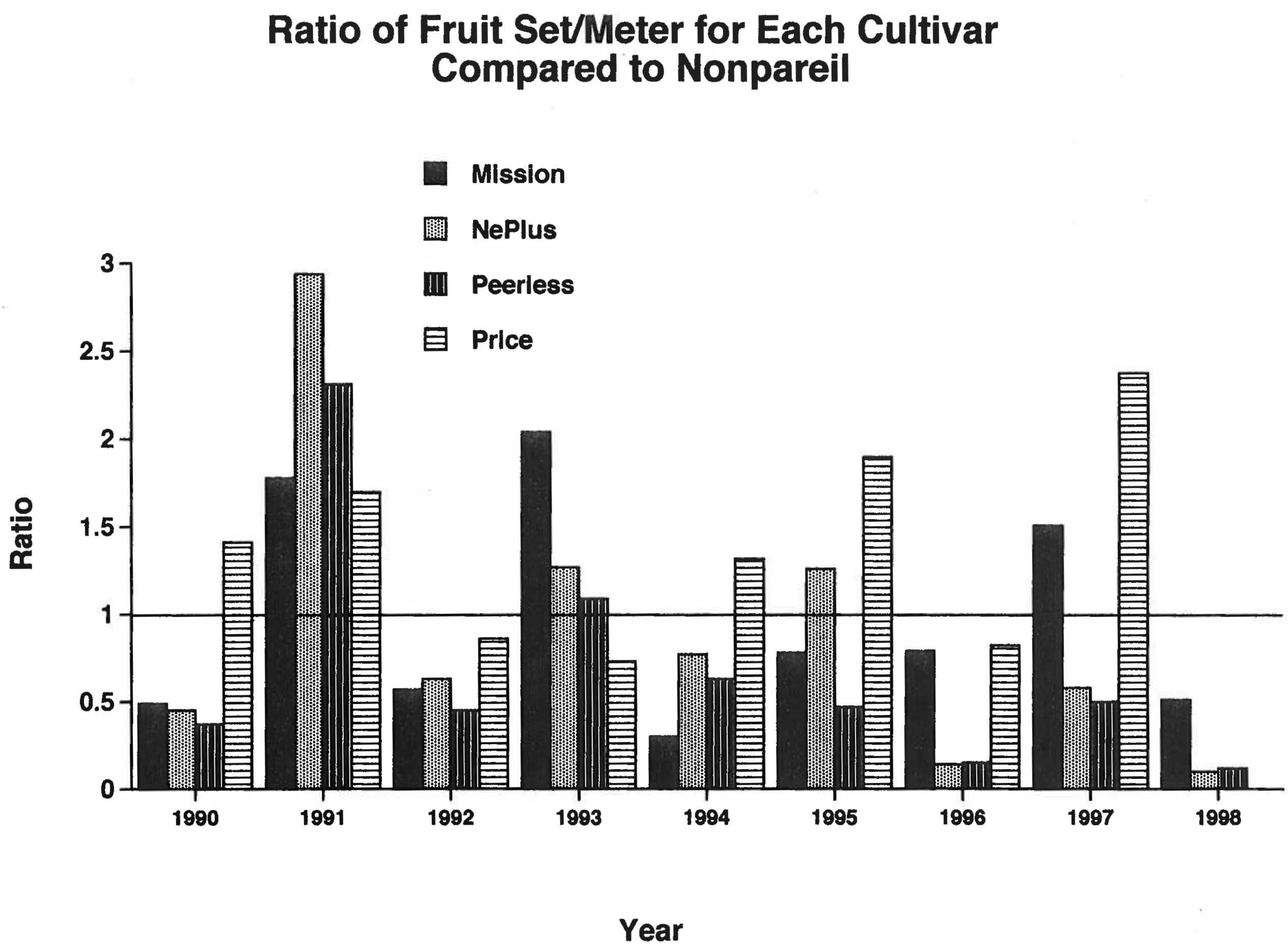


Fig. 18. Ratio of fruit set per meter for each cultivar compared to Nonpareil for 1990-1998 in an almond orchard near Dixon, CA.

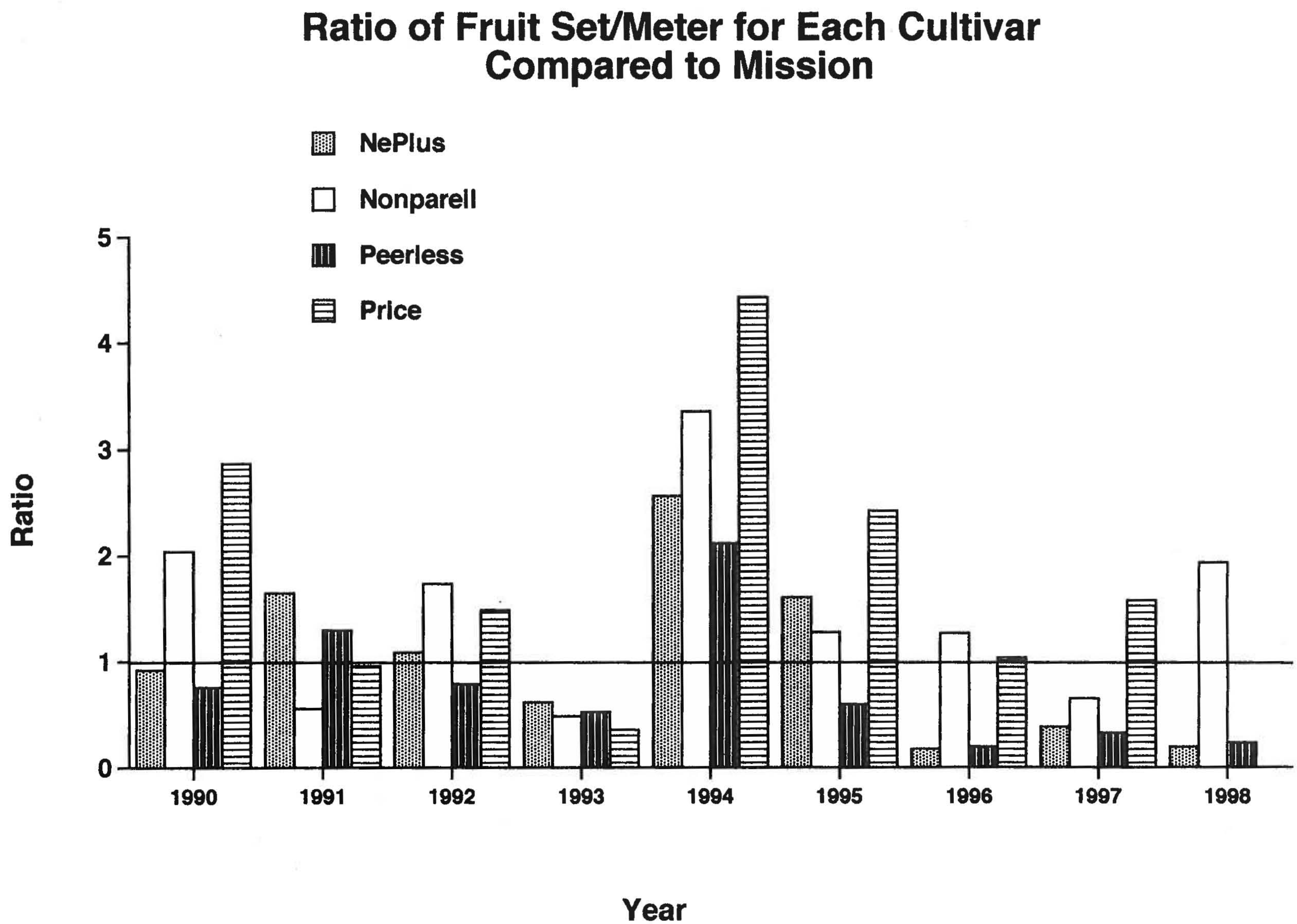


Fig. 19. Ratio of fruit set per meter for each cultivar compared to Mission for 1990-1998 in an almond orchard near Dixon, CA.

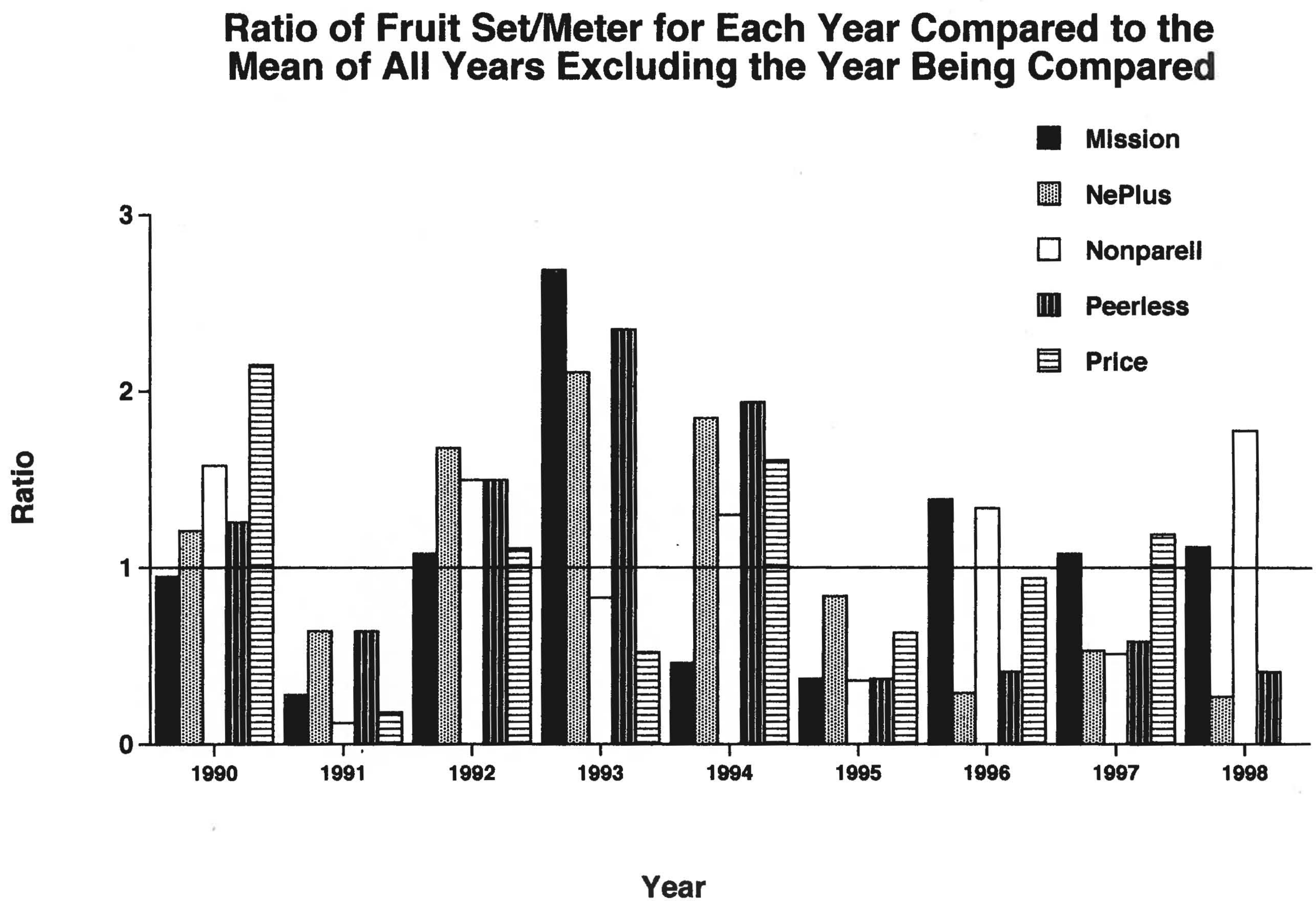


Fig. 20. Ratio of fruit set per meter for each year from 1990 through 1998 in an almond orchard near Dixon, CA compared to the mean of all years excluding the year being compared.

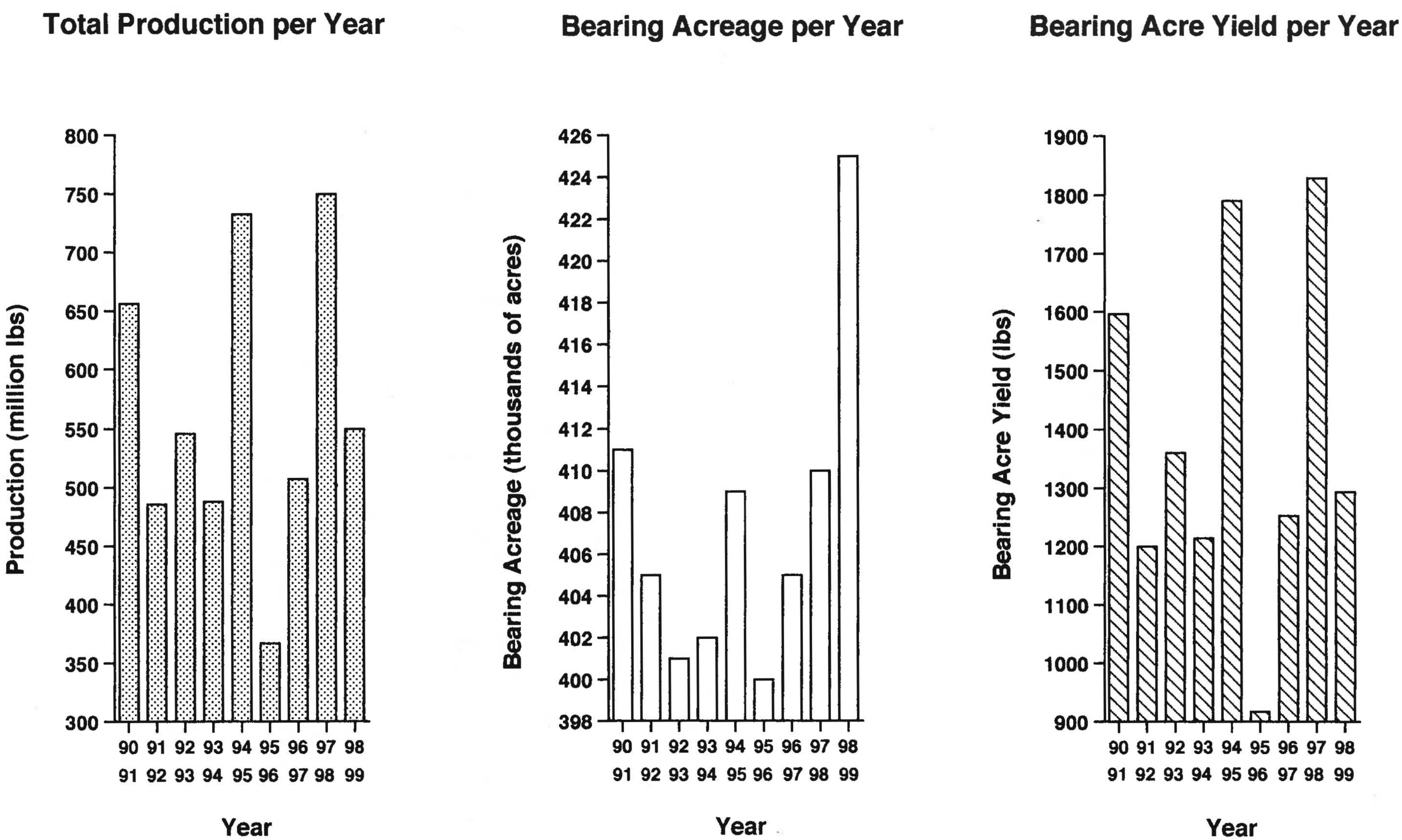


Fig. 21. Statewide figures for almond production, bearing acreage, and per acre yield. For reporting years, the top number is the year of bloom and pollination, the bottom year is the year when the yield is finally determined from processing. Values for 1998-99 are based on the subjective estimate. Left: Total production per year; Middle: Bearing acreage per year; Right: Bearing acre yield per year.

1990 Flower Progression and Maximum Temperatures

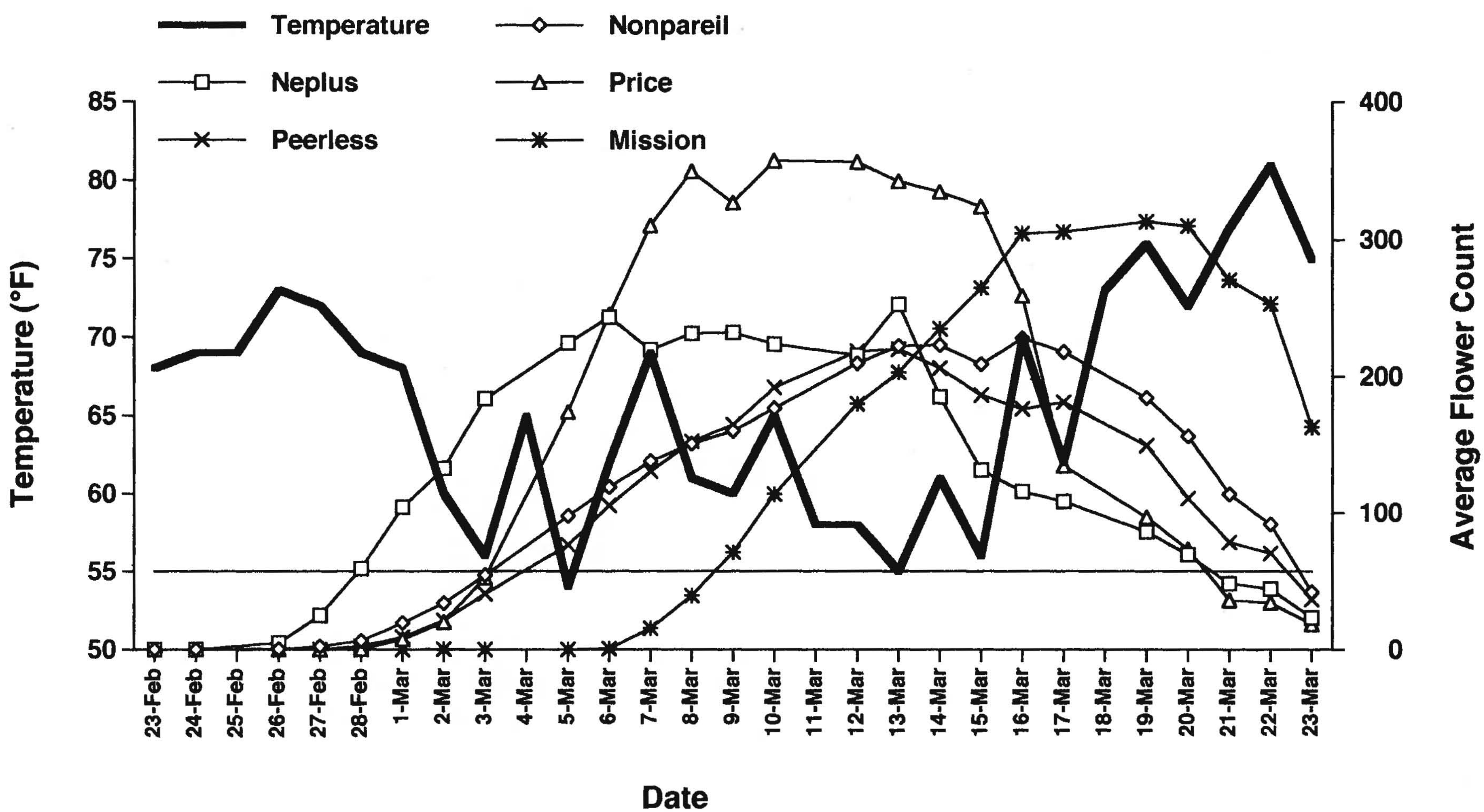


Fig. 22. Flower progression for 1990 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

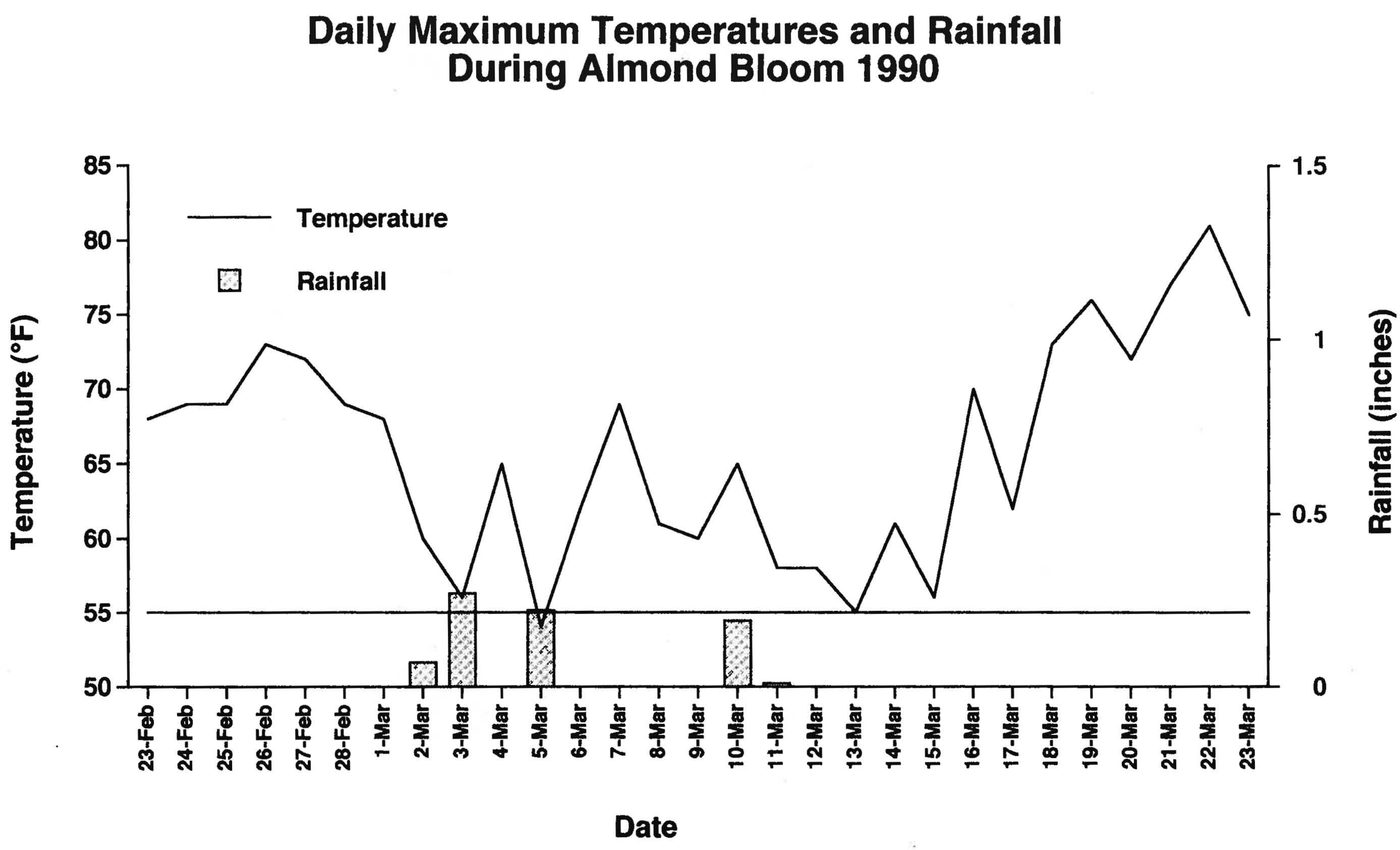


Fig. 23. Daily maximum temperatures and rainfall during almond bloom 1990 for an orchard near Dixon, CA.

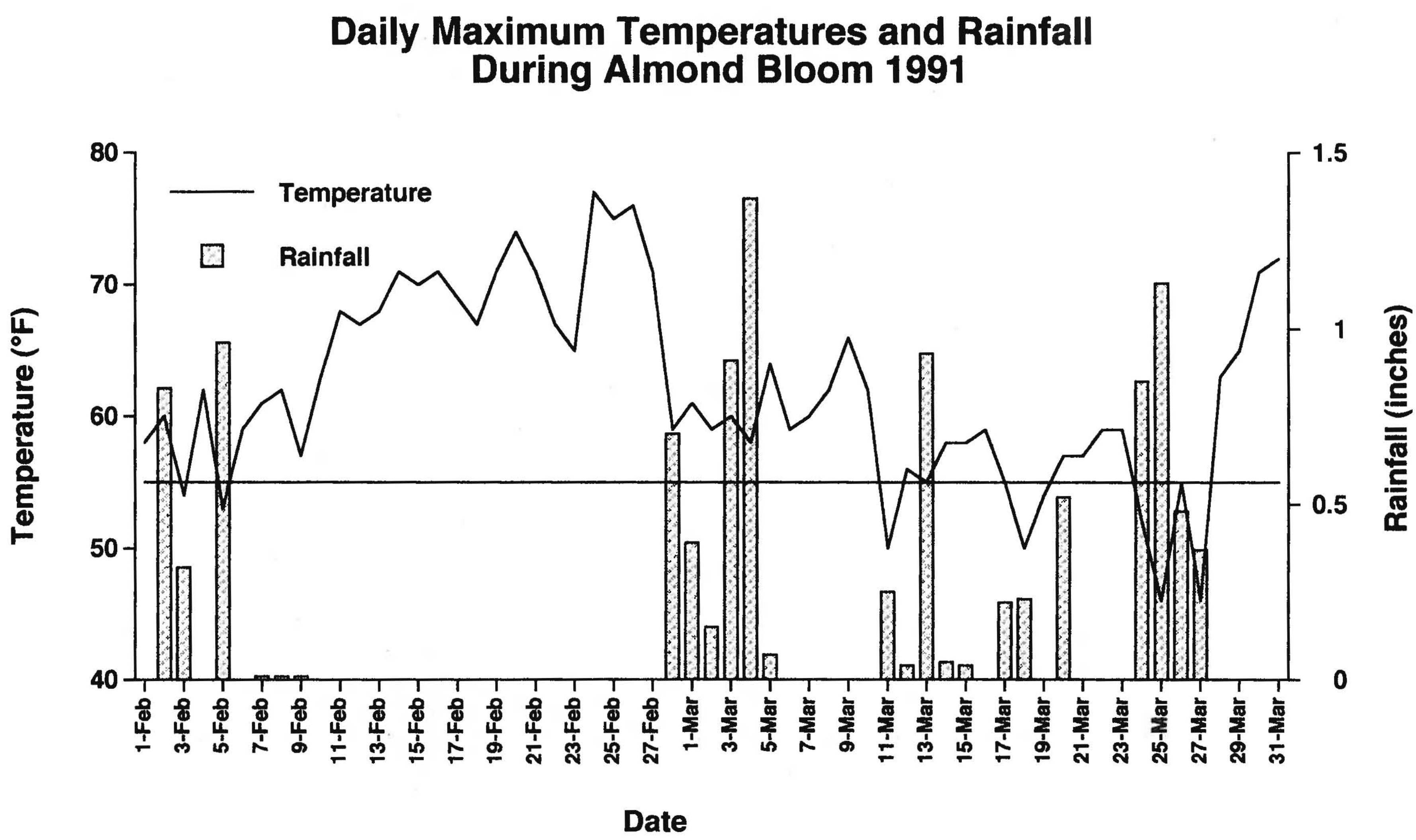


Fig. 24. Daily maximum temperatures and rainfall during almond bloom 1991 for an orchard near Dixon, CA.

1992 Flower Progression and Maximum Temperatures

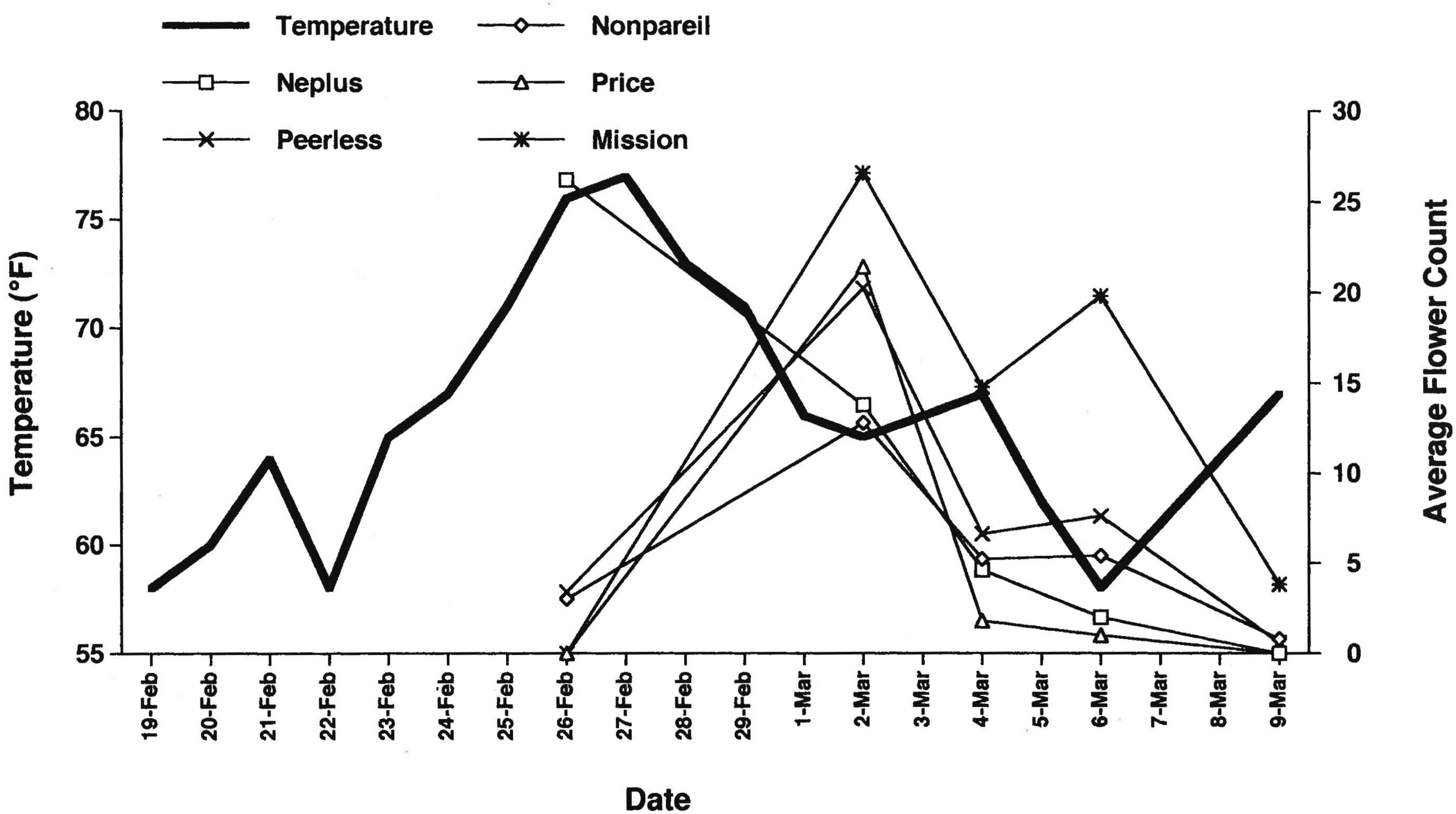


Fig. 25. Flower progression for 1992 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

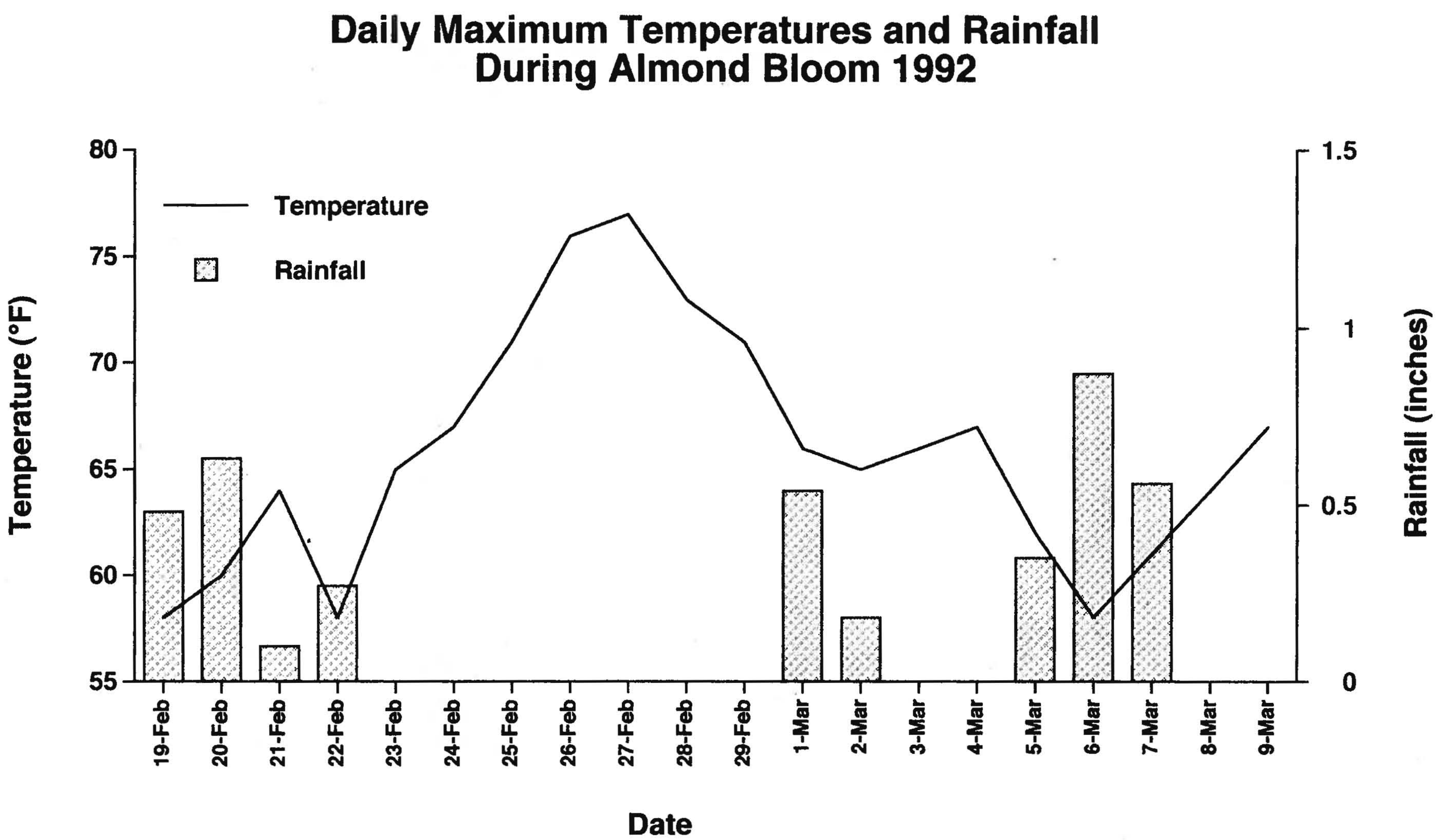


Fig. 26. Daily maximum temperatures and rainfall during almond bloom 1992 for an orchard near Dixon, CA.

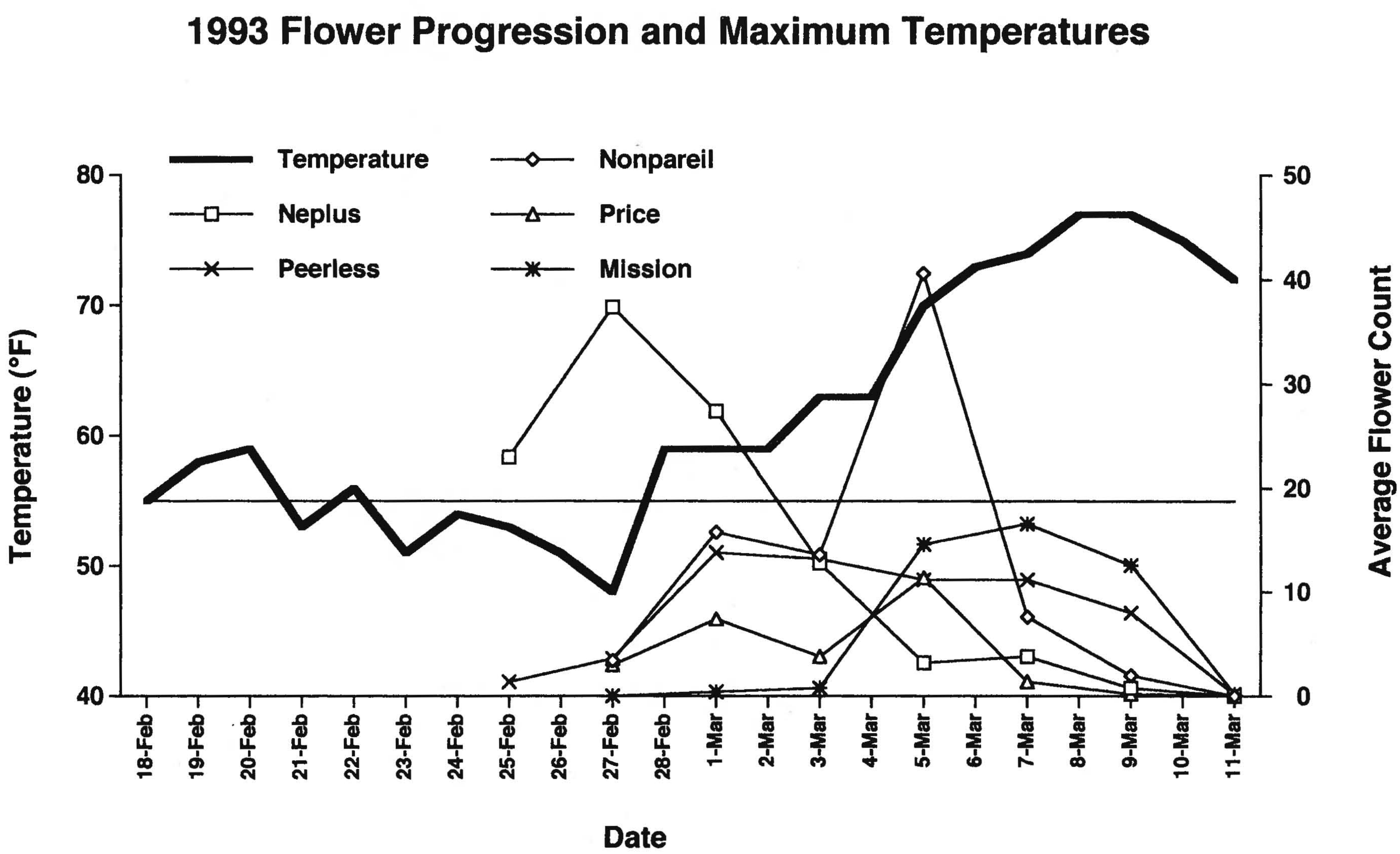


Fig. 27. Flower progression for 1993 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

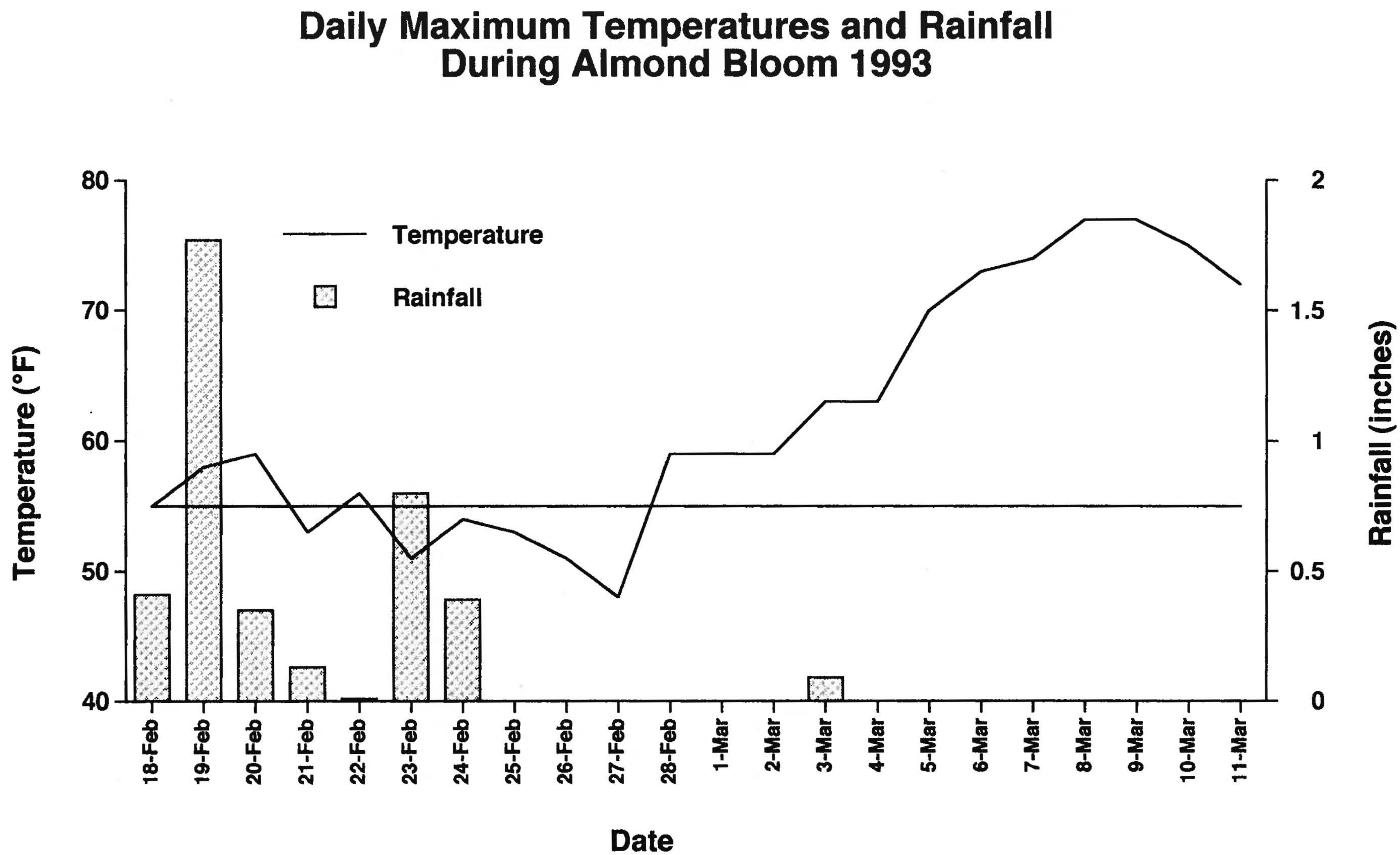


Fig. 28. Daily maximum temperatures and rainfall during almond bloom 1993 for an orchard near Dixon, CA.

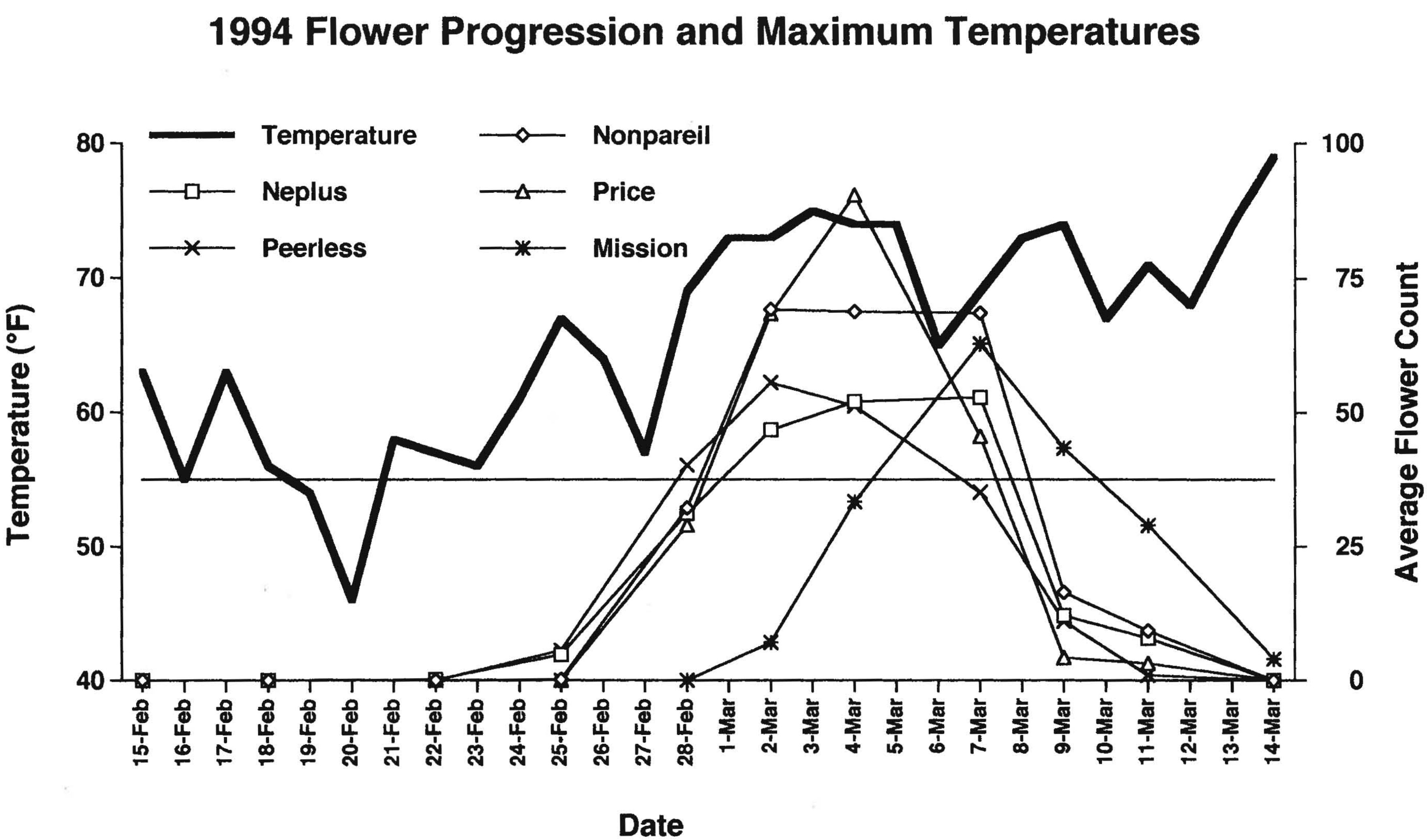


Fig. 29. Flower progression for 1994 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

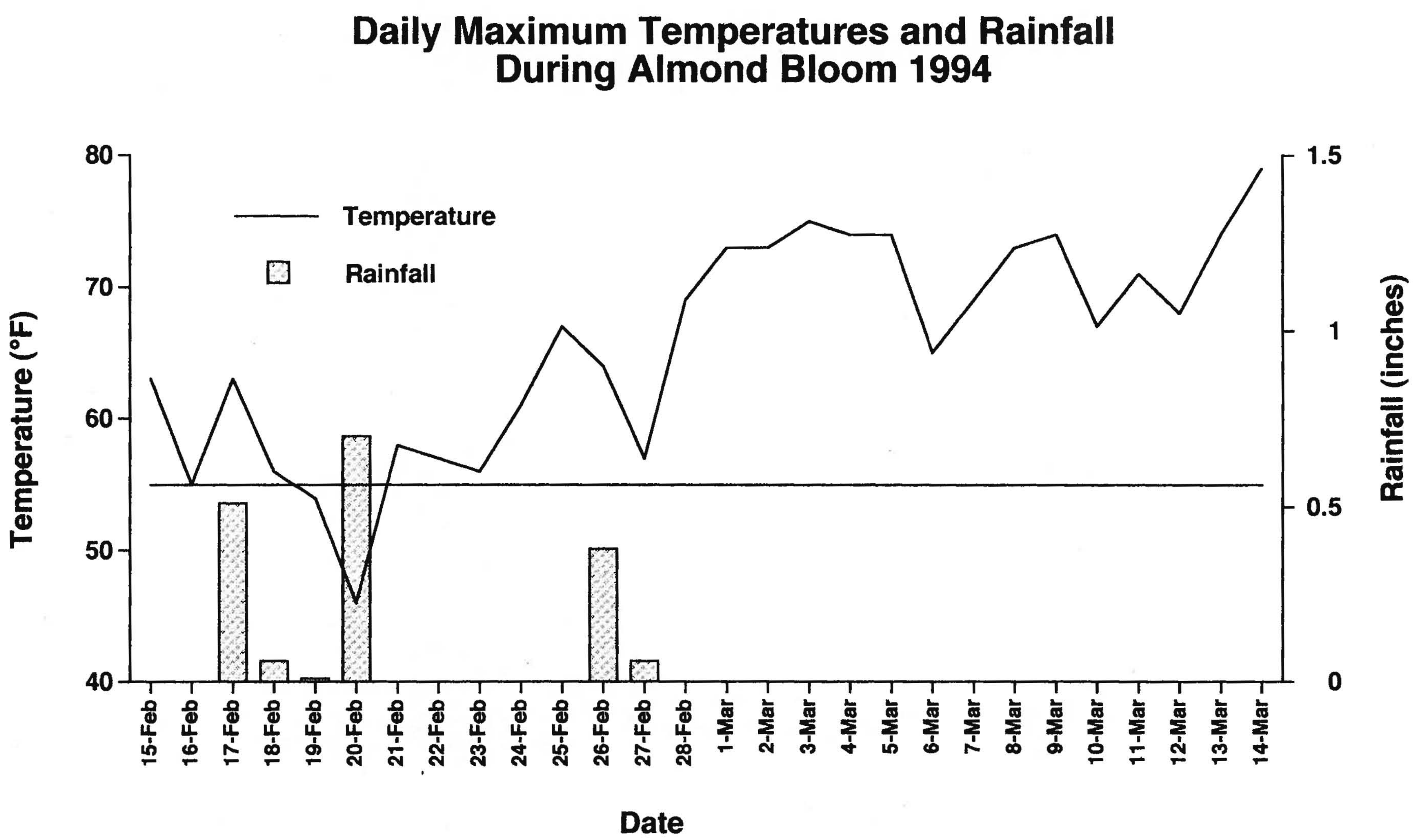


Fig. 30. Daily maximum temperatures and rainfall during almond bloom 1994 for an orchard near Dixon, CA.

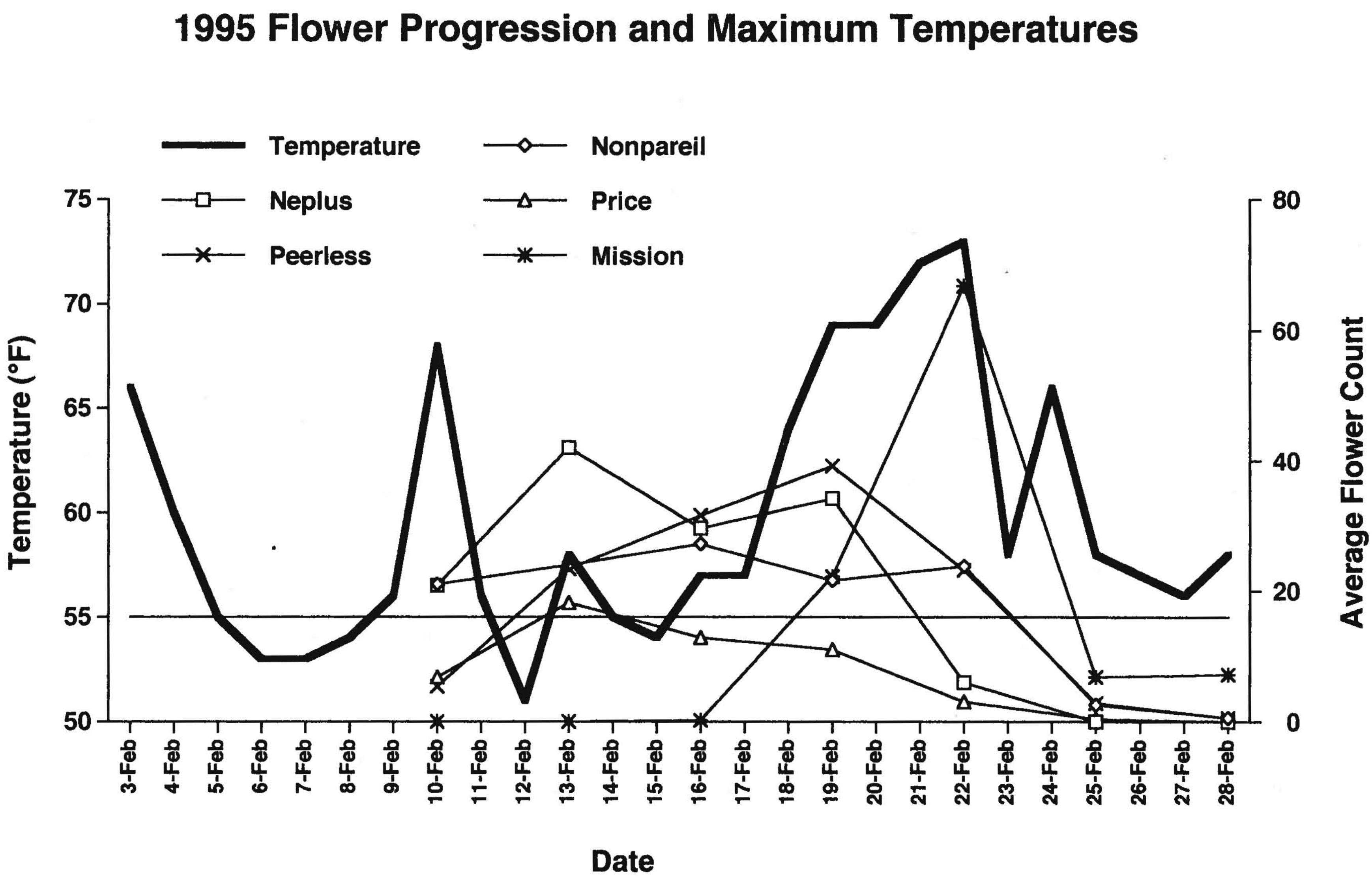


Fig. 31. Flower progression for 1995 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

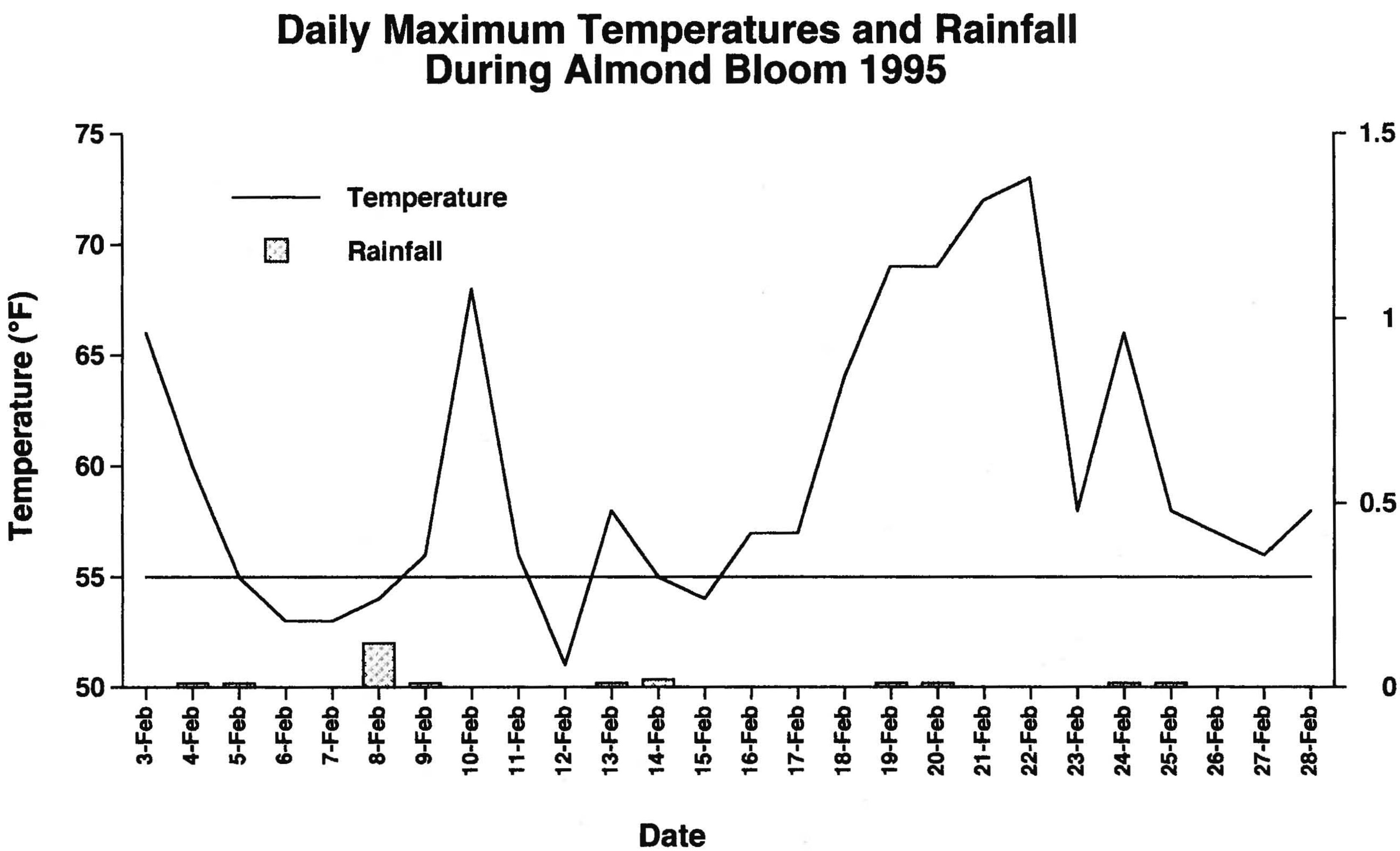


Fig. 32. Daily maximum temperatures and rainfall during almond bloom 1995 for an orchard near Dixon, CA.

1996 Flower Progression and Maximum Temperatures

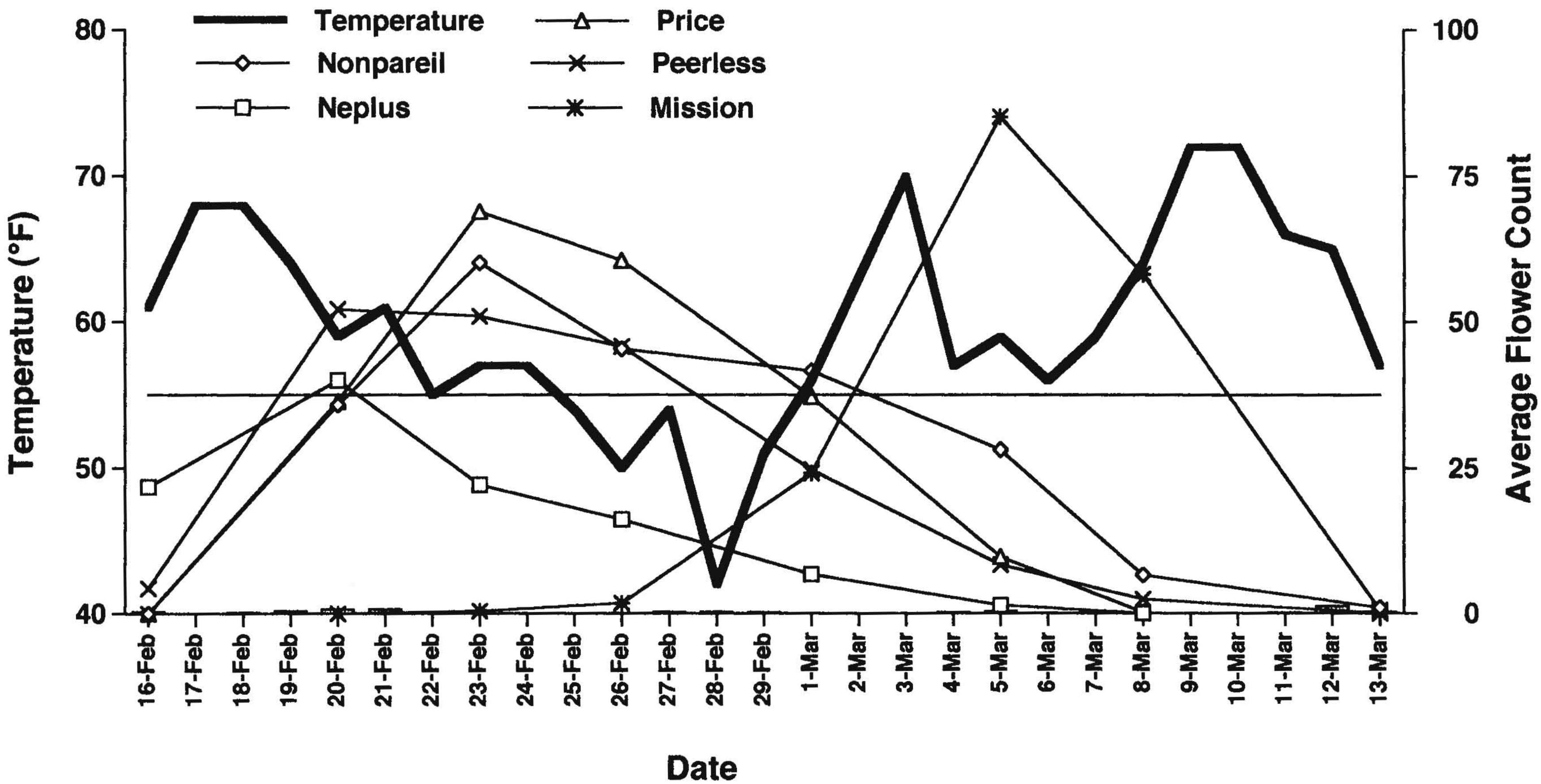


Fig. 33. Flower progression for 1996 in an almond orchard near Dixon, CA and daily maximum temperatures (at UC Davis) with 55°F line indicated since it is considered the threshold for honey bee flight activity.

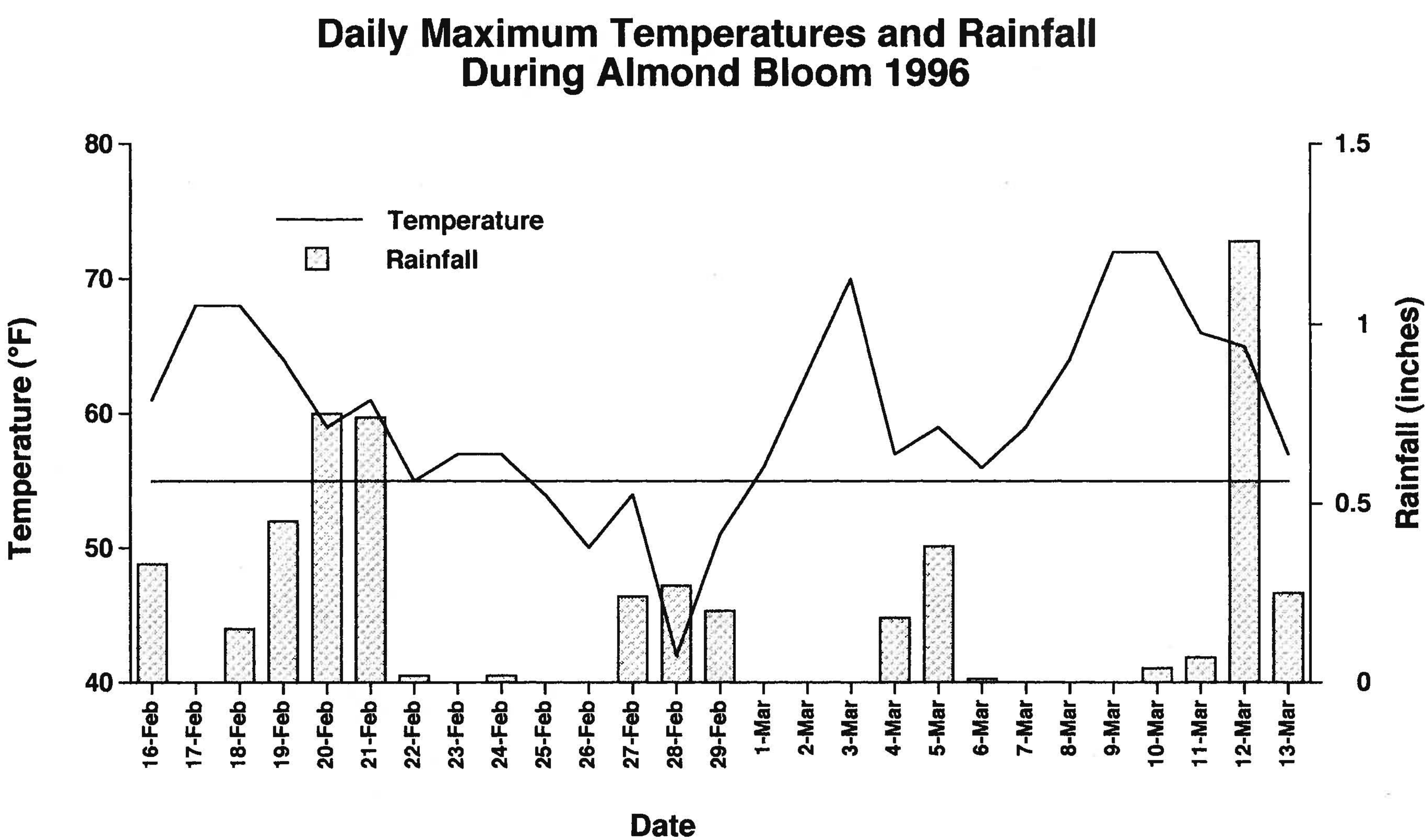


Fig. 34. Daily maximum temperatures and rainfall during almond bloom 1996 for an orchard near Dixon, CA.