# BLOOM PROGRESSION IS THE PREFERRED PREDICTOR OF WHEN TO REMOVE HONEY BEE (APIDAE: APIS MELLIFERA) HIVES FROM ALMOND ORCHARDS

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## Summary

Almond pollination triggers the world's largest mass migration of managed pollinators to a single flowering crop (Somerville, 2007). The University of California, Davis, advises that honey bee hives should be removed from almond pollination when 90% of flowers of the latest blooming variety are at petal fall (Mussen, 2014), but this advice relies entirely on anecdotal evidence and, in Australia, it appears to be unduly conservative.

Almond orchards containing apiaries of commercial hives were used to trap bee-collected pollen (Somerville, 2011) at the hive level and to track bloom progression of three almond varieties (Nonpareil, Carmel and Price) using tagged branches. Bloom progression was correlated with bee-collected almond pollen. Tracking bloom progression is a more practical, and no less accurate, field measurement to ensure hives are removed at an appropriate time, to the mutual benefit of beekeeper and orchardist.

**Keywords:**
Almond, honey bee, pollination, apiculture

## INTRODUCTION

Almonds (*Prunus dulcis*) are highly dependent on insect-vectored cross-pollination (McGregor, 1976, Connell, 2000, Rosenzweig et al., 2012). In the absence of adjacent semi-natural habitat or vegetation strips in the almond orchard native bee pollination services cannot be relied upon (Free, 1975, Klein et al., 2012, Sagili and Burgett, 2015). In Australia, the recommended stocking rate is 5 to 7 honey bee hives per hectare (Somerville, 2007). According to pollination broker T. Monson (personal communication, 4 September, 2017), about 215,000 hives were transported to mature almond plantings in the 2016/17 season in Australia, which constitutes the largest mass migration of bee hives to a single crop in Australia. Almonds made up 62% of Australia's total tree nut crop in the 2017/2018 season with 79,461 tonnes harvested, and yielding $429 million AUD in export earnings (Almond Board of Australia, 2018).

Whereas beekeepers want to transport their hives promptly onto the next mass flowering, almond growers want to maximise yield, so deciding when to remove bee hives from almond orchards is a challenge. The current recommendation is that hives be removed when 90% of flowers on the latest blooming variety are at petal fall (Mussen, 2014), but this recommendation relies entirely on anecdotal evidence. In addition, the unique branching habits and canopy structure of almond trees (Gradziel et. al, 2002) make assessing bloom progression at a canopy level in mature trees difficult to measure objectively (Vassière et. al, 2011) so agronomists and pollination brokers are routinely forced to decide when hives are removed from the orchard by making subjective canopy bloom assessments (Thorp et. al, 1975). In an endeavour to give these operators a more objective basis for making decisions, we show that bloom progression is correlated with bee-collected almond pollen and that tracking tagged variety branches is an objective and practical method to determine when to remove hives from the orchard.

## MATERIALS AND METHODS

Bee-collected almond pollen volumes were measured using pollen traps on forty bee hives containing between 6.5 and 9 frames of bees (Somerville, 2005). Identified hives used to trap pollen were located in two adjacent almond orchards: Study Site 1 (Lake Powell) and Study Site 2 (Narcooyia). A commercial beekeeper owned the hives which were under contract in almond pollination. Bee-collected pollen was collected from pollen traps on alternate days during bloom, between 12 August 2017 and 1 September 2017. Each sample was divided into almond and "other" pollen before weighing. Almond was the dominant pollen present, with "other" pollens present in 70% of Study Site 1 (Lake Powell) samples at quantities of 1 gram or less per sample. At Study Site 2 (Narcooyia), in addition to the dominant almond pollen, 47% of samples contained "other" pollens at quantities of 1.3 grams or less per sample. Representative branches of each almond variety (Nonpareil, Carmel and Price) were tagged at each study site. Buds and flowers were counted every other day during bloom, between 12 August 2017 and 1 September 2017. In this study we ask, what is the correlation between almond bloom progression and bee-collected almond pollen?

**Study site specifics**

The study was conducted in two adjacent almond orchards near Lake Powell, Victoria, in south eastern Australia. Each study site was owned and operated by one of the two largest almond growing businesses in Australia in 2017. Study Site 1 (Lake Powell) consisted of the following hive set down site where pollen, bud and bloom data were collected: LP20 (-34.733747, 142.927534). Distance between study sites as the bee flies was 2.42 kilometres, close enough for foraging range overlap. Study Site 2 (Narcooyia) consisted of two hive set down sites, NC02 (-34.715759, 142.946012) and NC06 (-34.718838, 142.946098), which were 335 metres apart. Pollen data was collected at both NC02 and NC06, while bud and bloom data was collected at NC02 only. Study Site 1 (Lake Powell) almond plantings consisted of two varieties: Nonpareil and Carmel. Study Site 2 (Narcooyia) almond plantings consisted of three varieties: Nonpareil, Carmel and Price.

**Hive assessment methods**

The hives selected to trap pollen were owned and managed by a single commercial beekeeper and placed into almond pollination at the study sites by a pollination broker before anticipated flowering. All hives used in this study were ten-frame single brood boxes and contained movable, full-depth Langstroth frames and between 6.5 to 9 frames of bees.

Frames of bees were assessed on 4 and 5 August 2017 using the simple cluster method (Nasr et al., 1990). Three assessors calibrated hive strength using this accepted standard method. The average temperature across the period of hive assessment on 4 and 5 August 2017 was 11.8°C giving a high level of confidence in accurate assessment of the bee cluster. Assessors graded each hive at the same time to prevent cluster disturbance, chilling of developing bees and stress-related disease incidence. The three assessors gave each hive an independent score for frames of bees. After sixty hives were assessed at each study site, frames of bees scores from each assessor were averaged for each hive to yield final frames of bees scores.

Forty hives made the final selection at each study site and were divided into two groups of twenty hives; Group A and Group B. These hives were chosen based on their frames of bees assessment so that an equal amount of hives containing between 6.5 to 9 frames of bees were present at both sites. The possibility of hive strength skewing the pollen intake between study sites was controlled for in this way.

**Pollen trapping and collection**

A primary goal of this research was to trap bee-collected pollen (corbicular loads) continuously from 12 August 2017 until the end of bloom or when the beekeeper's hives were released from the orchard. The beekeeper's hives were removed before the last petal fell. As a result, pollen was trapped continuously and collected on alternate days starting on 12 August 2017 and finishing on 1 September 2017, for a total of eleven sampling days. Ten-frame hives were required for this study to use compatible pollen traps.

The hives at Study Site 1 (Lake Powell) and Study Site 2 (Narcooyia) were divided into Group A (twenty hives) and Group B (twenty hives). Pollen traps were transferred from Group A hives to Group B hives, after sampling on Day 4 was complete, to prevent a decrease in hive strength affecting the amount of pollen being trapped. Twenty pollen traps were deployed on Group A hives at Study Site 1 (Lake Powell) and twenty traps on Group A hives at Study Site 2 (Narcooyia) on 10 August 2017 with trapped pollen collected from 12 August to 18 August 2017 (Days 1-4). These twenty pollen traps were removed on 18 August 2017 after sampling and placed on Group B hives at Study Site 1 (Lake Powell) and Group B hives at Study Site 2 (Narcooyia) for sampling from 20 August to 1 September 2017 (Days 5-11).

Pollen was collected at the start of each sampling day before temperatures rose above 13°C when foraging began, pending field conditions. On completion of the last sampling day on 1 September 2017, pollen samples were sorted, separating almond pollen and "other" pollen, and weighed to one decimal point.

**Bud and bloom data**

Almond buds and flowers were counted on the same day that pollen sampling occurred. Counts of buds and flowers with 4 or more petals were conducted on tagged branches with a starting number of buds of 100 or just above. 30 branches were selected at Lake Powell (LP20) and 30 branches at Narcooyia (NC02) study sites on 6 August 2017. At Lake Powell (LP20), 15 branches were selected for each of two almond varieties: Carmel and Nonpareil. At Narcooyia (NC02), 10 branches were selected for each of three almond varieties: Carmel, Nonpareil and Price. Bud and bloom counts were taken from tagged branches for a total of 11 sampling days, on alternate days starting 12 August 2017 and finishing 1 September 2017.

**Formal biometric analysis** The smoothing spline framework (Verbyla, 1999) was used to fit trends over time. The ASReml-R package (Butler et al., 2009) was used to fit the models in the R statistical software environment (R Core Team, 2017). For more detail on the biometric methods and analysis, please request supplementary material.

## RESULTS

In Group A (Sampling days 1-4: 12 to 18 August 2017) at both study sites, honey bee-collected almond pollen peaked about 16 August, about halfway through bloom. For Study Site 2 (Narcooyia) in Group A, there were 12 hives located at NC02 (green) and 8 at NC06 (yellow), with no obvious systematic difference between them as shown in Figure 1. In Group B (the second time period), pollen volume peaked around 22 and 24 August. At Narcooyia in Group B, there were 17 hives from NC02 apiary and 3 from NC06 apiary. The three NC06 hives (yellow) in Group B collected consistently low amounts of almond pollen.

Almond pollen (Figure 1) varied systematically between hives at both Study Site 1 (Lake Powell) and Study Site 2 (Narcooyia). That is, some hives collected consistently greater pollen volumes over time and conversely some hives collected consistently lower pollen volumes over time. For instance, a few hives recorded barely any pollen at any time, whereas, at the other end of the spectrum, one hive at Study Site 1 (Lake Powell) yielded 154g on 16 August 2017, the time when trapped almond pollen quantity peaked at all study sites. The same hive also yielded consistently greater quantities of almond pollen than the other hives at other recorded times, as well as the maximum yield, at 1.2g, of “other” pollen at 16 August 2017.

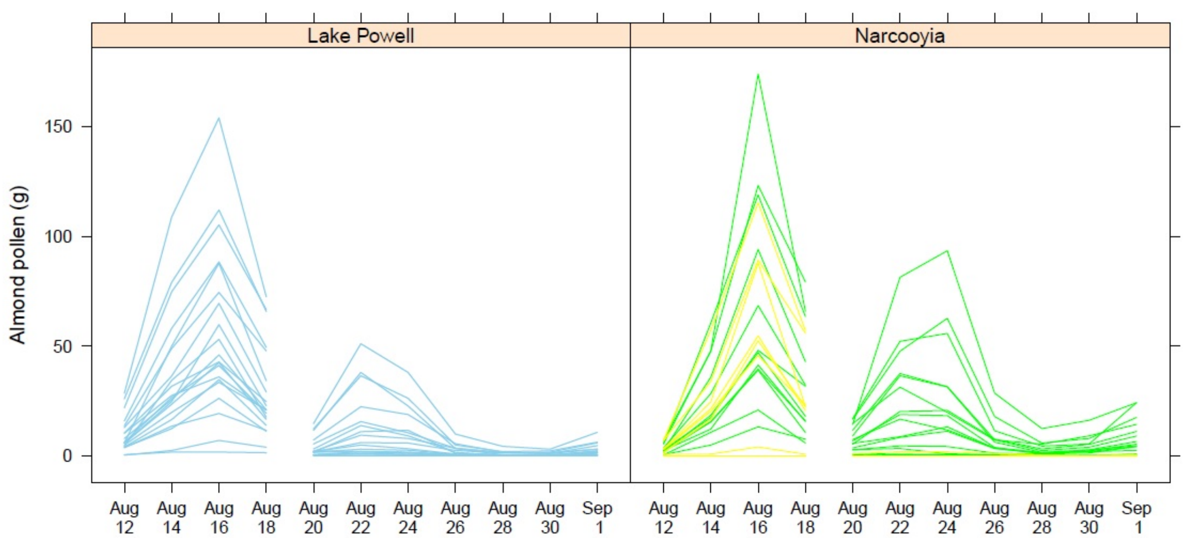


**Figure 1:** Bee-collected almond pollen peaked about 16 August at both study sites. Blue represents hives at LP20. Green represents hives at NC02 and yellow represents hives at NC06.

There may be some relation across all study sites between hive strength and almond pollen in Group A hives during the first sampling period (12 – 18 August 2017), but little if any relation in the second sampling period (20 August – 1 September 2017) with Group B hives (Figure 2). The lack of relation in the second sampling period with Group B hives is likely because of the decrease in overall almond pollen availability as indicated by a rapid decrease in buds from 12 August 2017 (Figure 4) and steady decrease in flowers from 16 August 2017.

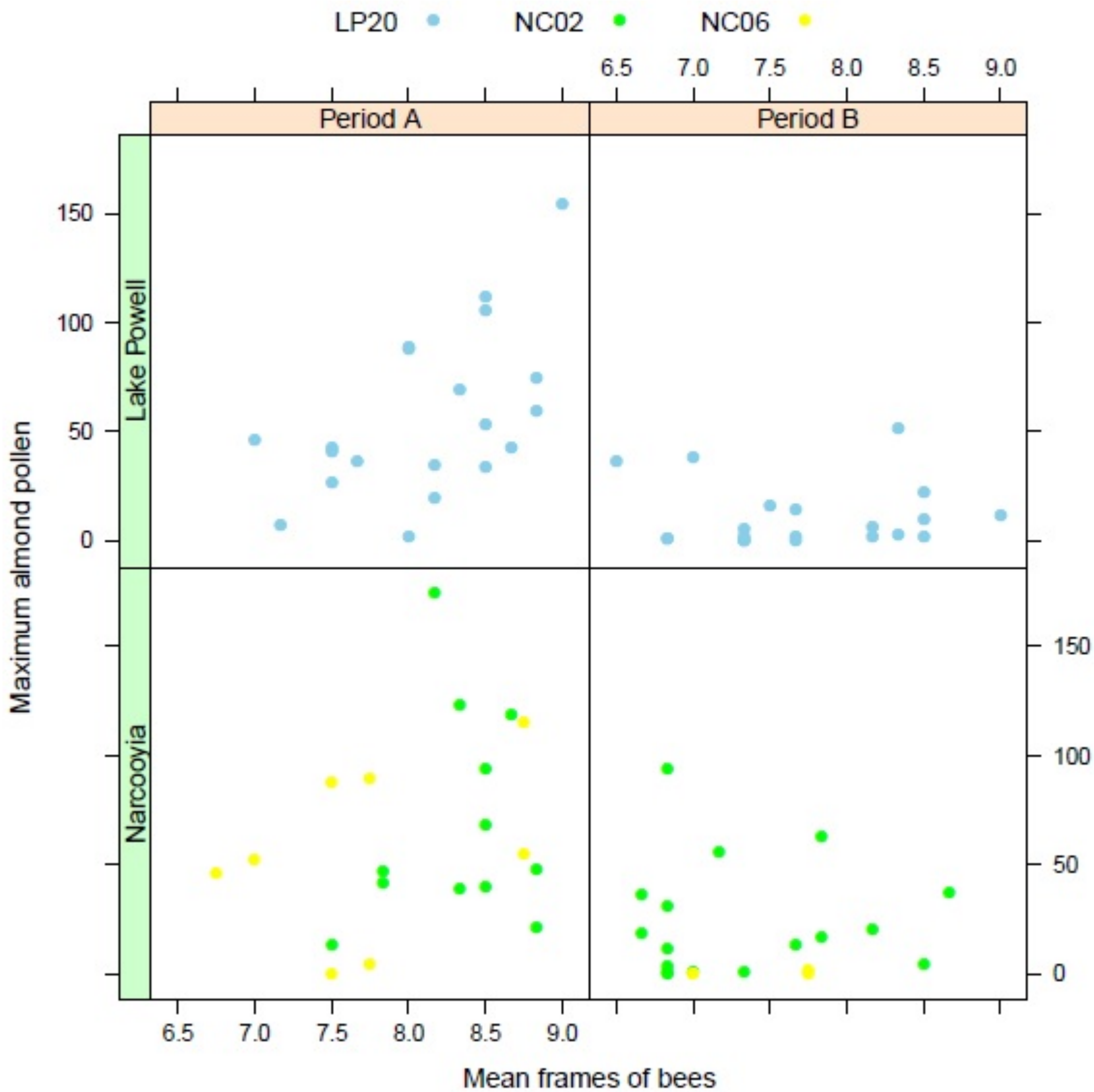


**Figure 2:** There was some relation across all study sites between hive strength and bee-collected almond pollen collected in Period A, as a result of the greater pollen availabity before and after peak bloom, in comparison to Period B.

Flowers peaked around 16 August 2017 at Study Site 1 (Lake Powell), corresponding with the peak for almond pollen, just before halfway through bloom. Flower quantity peaked possibly a little earlier at Study Site 2 (Narcooyia): either 14 or 16 August 2017. At both study sites, flower quantity over time was similar for Carmel and Nonpareil varieties; whereas, at Study Site 2 (Narcooyia), flower production appeared to be different for Price, which was higher at the initial sampling days, but then lower after 18 August 2017. There were significant variety, day and variety-by-day effects for both flower (Sánchez-Pérez, 2014) and bud analysis.

For bud production, there was a general decline over time from the first sampling day onwards. For Study Site 1 (Lake Powell), buds were slightly higher on average for Nonpareil (green) than Carmel (blue) in the earlier sampling days, but then Nonpareil was lower at later times. At Study Site 2 (Narcooyia), bud production was consistently lower for Price (yellow), the earliest flowering variety, than for Nonpareil and Carmel.

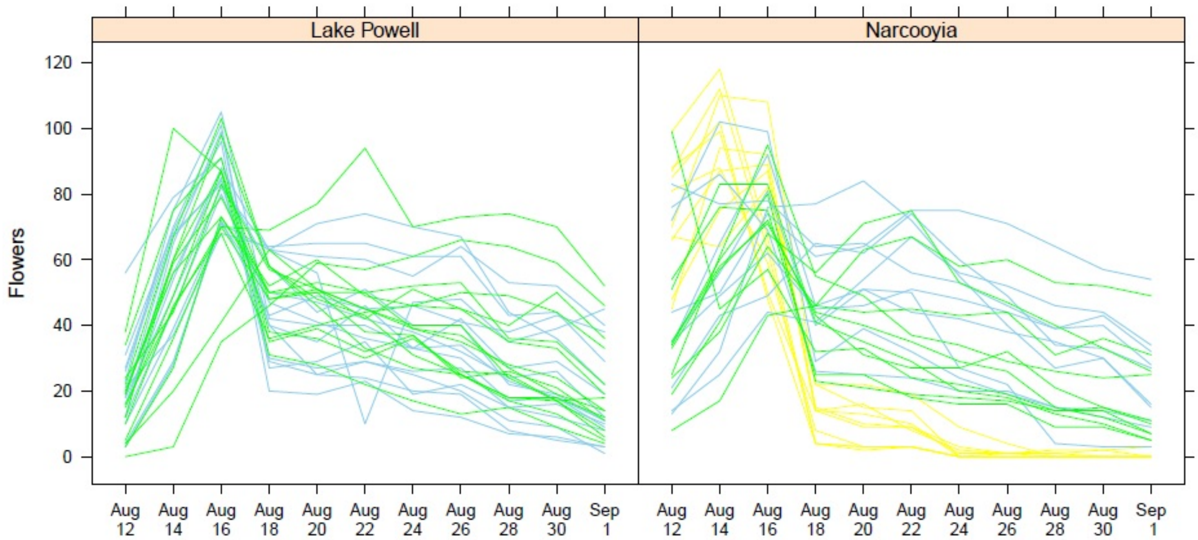


**Figure 3:** Flowers peaked around 16 August 2017 at Study Site 1 (Lake Powell), corresponding with the peak for almond pollen, just before halfway through bloom. Flower quantity peaked possibly a little earlier at Study Site 2 (Narcooyia): either 14 or 16 August 2017. Almond varieties are represented by blue (Carmel), green (Nonpareil), and yellow (Price).

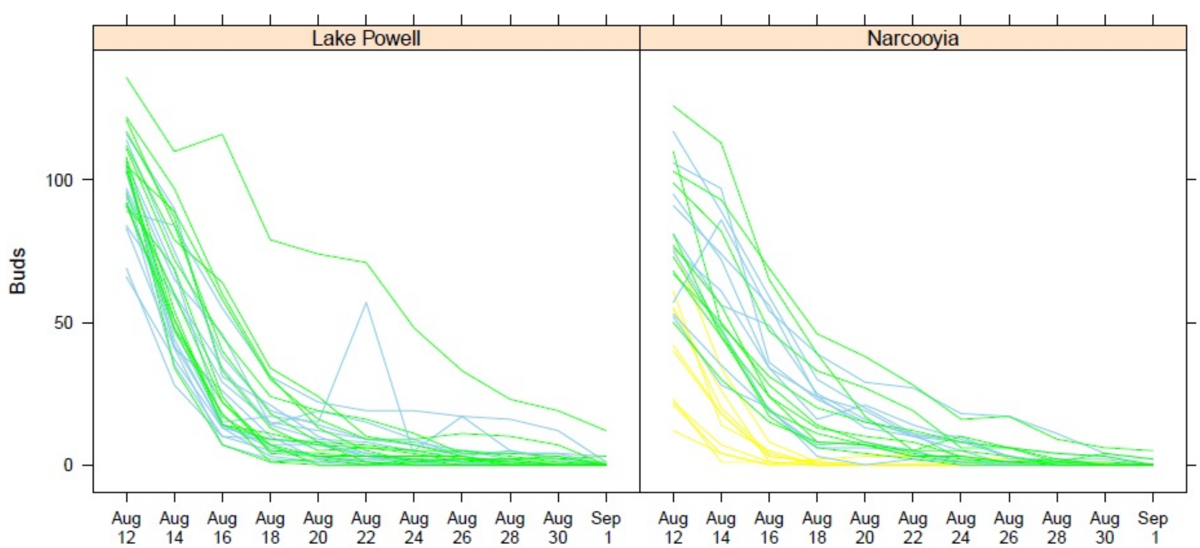


**Figure 4:** There was a general decline in bud production over time from the first sampling day onwards. Almond varieties are represented by blue (Carmel), green (Nonpareil), yellow (Price).

To examine the relationship between almond pollen quantities and flowers, the (back-transformed) predictions of almond pollen were overlaid on those for flowers (Figure 5). In the first period (until 18 Aug 2017), peak almond pollen quantities obviously coincided with peak flower production for Lake Powell, and followed peak flower production by about two days for Narcooyia. In the second period (20 Aug 2017 onward), almond pollen quantity was dramatically reduced. Regarding the second peak in almond pollen quantity, it is possible that decreased amounts on the initial sampling day of Group B on 20 August 2017 (in comparison to quantities collected from Group A hives on 18 August 2017) can, in part, be explained by the transfer of pollen traps from Group A to Group B and a lag time for hives in Group B to get accustomed to the altered hive entrance provided by the pollen traps.

However, the slight increase in pollen around 22-24 August 2017 cannot be attributed to the transfer of pollen traps from Group A to Group B alone, given the increase in flowers around the same time. The minor peak in flowers around 20 August 2017 at both sites mirrors the small increase in pollen quantities collected. Almond phenology shows that, toward the end of the bloom period, flowers may still be present with the remaining majority producing nectar as opposed to pollen (Thorp, 1975). The data supports the notion that flowers were present and gradually declining in the second period of sampling, but that pollen production had bottomed out around 26 August 2017. The slight increase in pollen collected on 1 September 2017 was a result of reduced resource competition, given the test hives were among the last remaining hives in the immediate orchard areas at the end of bloom.

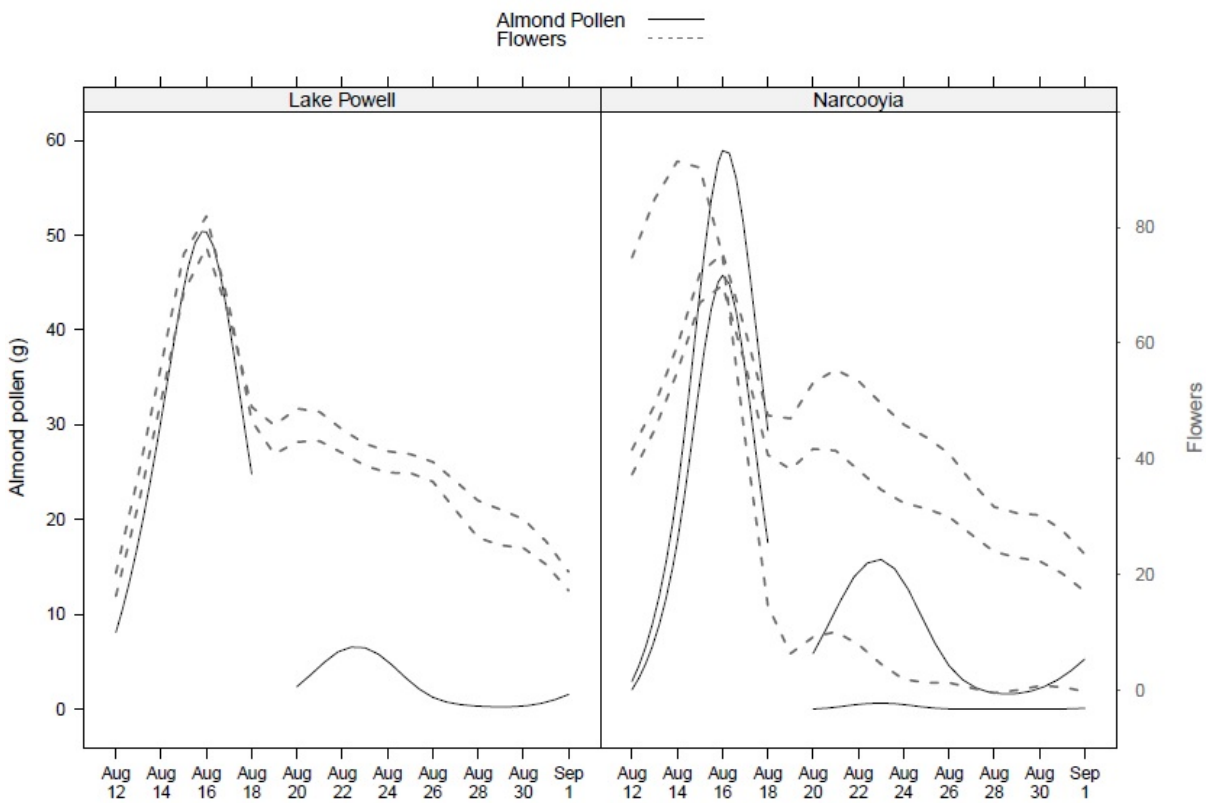


**Figure 5:** Flower quantities and bee-collected almond pollen were strongly correlated before, during and directly after peak bloom. Almond phenology supports the gradual decline of flowers and decreased collection of almond pollen from 20 August onward. For almond pollen, a separate line is shown for the two apiaries in Narcooyia, and for flowers, a separate line is shown for each variety.

## DISCUSSION

Our study shows that tracking individual tagged branches is an objective and practical method to predict when to remove hives from the orchard because bloom progression is strongly correlated with bee-collected almond pollen. Consequently, it is also to be preferred over the current standard of subjective canopy assessment which is open to operator error arising from both misinterpreting the complex branch architecture unique to each tree and also misinterpreting the foraging of bees on remaining flowers when the bees are actually foraging for nectar when pollen production is low.

Looking beyond the second, minor peak in almond pollen quantities, flower quantities in the second sampling period show that, despite the remaining flowers, pollen production was at its lowest point. The low levels of almond pollen collected from 22 August 2017 onward, despite the presence of flowers, highlight that pollen production was depressed which also supports the decision to remove hives from the orchard. As a result of participation in this study, the collaborating beekeeper was one of the last to remove hives from the orchards in the immediate area around the study sites. By the final sampling day, 1 September 2017, partnering growers wanted all hives removed to facilitate their next management tasks, giving remaining hives in this study greater access to available almond pollen as foraging competition decreased. The maximum quantities of almond pollen collected by each hive in this study are consistent with the depressed availability of pollen at study sites during the second sampling period after peak bloom.

In reference solely to the 2017 almond bloom in Australia, the data on bee-collected pollen supports the participating growers' decisions to release contracted hives around 28 August 2017 in the last quarter of the bloom period even though it occurred before 90% petal fall of the last flowering variety.

Overall, this study shows a clear relationship between bloom progression and bee-collected almond pollen decline. The use of tagged branches to track bloom for each variety is both a practical and a superior method that almond growers should choose to increase the accuracy of their decision on when to remove hives from the orchard.

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