The Great Bee Migration: Spatial and Temporal Variation in Honey Bee Colony Shipments into California for Almond Pollination

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Abstract

Over the last two decades, the quantity of honey bee colonies required to perform pollination services for the California almond industry has grown steadily and now equals a substantial share of the U.S. population of honey bee colonies. Most U.S. beekeeping operations have not been willing to expand colony capacity without significant increases in almond pollination fees. Thus, as almond acreage in California has increased, the marginal supplier of colonies for almond pollination has likely moved further away from California, increasing interstate colony shipments. To explore this concept, we analyze temporal and spatial characteristics of the supply of colonies for almond pollination using colony shipment data from 2008 through 2016 provided by the California Department of Food and Agriculture. The largest increases in shipments since 2008 have come from the states of Florida and Texas, where beekeepers have relatively high transportation costs and historically have observed opportunity costs of participating in almond pollination due to the potential for honey production at the time of almond bloom. We estimate that Florida and Texas had the largest number of colonies which did not participate in almond pollination in 2016, so further increases in supply are likely to come from these states.

1 Introduction

California almond production required over 75 percent of honey producing colonies in the United States (U.S.) in 2016 for its pollination needs (NASS, 2016). The magnitude of demand relative to the national supply of managed honey bee colonies has created a complex interaction between honey bee colony health and almond production. The almond pollination market likely has a significant effect on honey bee colony health through a number of avenues. First, colonies are shipped from all over the U.S. to participate in almond pollination, and shipping is potentially stressful for colonies (Simone-Finstrom et al., 2016). Second, colonies from all over the U.S. are located in close proximity in California's Central Valley during almond bloom, facilitating the spread of pests and diseases (Agnew, 2007; Oliver, 2010). Third, colony health can be negatively impacted by exposure to pesticides from placement in an agriculturally intensive area (Krupke et al., 2012). While many colony health stressors are caused or exacerbated by the market for almond pollination, almond production is completely dependent on the health of honey bee colonies. The demand for colonies for almond pollination is relatively inelastic, so fluctuations in the number and health of colonies available for almond pollination can lead to large variations in almond pollination

fees.

The objective of this paper is to explore characteristics of the supply of honey bee colonies for almond pollination in which we answer questions such as: From which states are colonies transported? Where are colonies concentrated upon arrival in California? How has the supply source changed as almond acreage has increased in recent years? Using data provided by the Pest Exclusion Branch of the California Department of Food and Agriculture (CDFA), we analyze shipments of honey bee colonies into California through its Border Protection Stations (BPS) for almond pollination seasons 2008 through 2016. For the 2016 almond pollination season, 1.6 million colonies were shipped into California, with nearly a third of those colonies coming from the top three honey-producing states in 2015: North Dakota, South Dakota and Montana. Honey bee colony shipments were concentrated in major almond-producing counties in California.

Because forage is a limiting factor for honey bee populations (Champetier et al., 2015) and expanding a beekeeping operation's capacity involves large fixed investments (personal communication with Randy Oliver), most beekeeping operations throughout the U.S. would not be willing to expand colony capacity without significant increases in almond pollination fees. Thus, as almond acreage in California has increased, the marginal supplier of colonies for almond pollination has moved further away from California, increasing interstate shipments of honey bee colonies. The largest increases in honey bee colony shipments into California since 2008 have come from the states of Florida and Texas, where beekeepers have relatively high transportation costs. In addition, beekeepers in those states historically have observed opportunity costs of participating in almond pollination due to the potential for honey production at the time of almond bloom (ETBA, 2000; Ellis and Zettel Nalen, 2010). Using 2016 colony shipments into California compared with USDA estimates of honey bee colony populations by state, we estimate that Florida and Texas have the largest number of colonies which did not participate in almond pollination in 2016. Thus, we predict that as almond acreage continues to increase, further increases in colonies shipped will likely occur from

these two states, though per-colony pollination fees may have to increase significantly to cover the opportunity cost of reducing honey production in these areas.

The findings of this paper have implications for beekeepers who participate in the almond pollination market and almond growers who rely on managed honey bee colonies. Shipments of colonies into major almond-producing counties in 2016 resulted in concentrations ranging from 37 to 147 colonies per square mile. Given the flight range of foraging bees, this means significant exposure to other beekeepers' colonies and, potentially, their health issues. This could lead to a rapid spread of colony health issues to colonies supplied by beekeepers from all over the U.S. Most colony shipments into California for almond pollination now come from the Plains, Pacific Northwest and Mountainous beekeeping regions (over 71% of 2016 colony shipments) which means that inclement weather, such as a summer drought or a harsh winter, affecting colonies in any of these regions could lead to substantial decreases in the number of colonies available for almond pollination and corresponding increases in almond pollination fees. Thus, the large demand of colonies for almond pollination relative to the supply of honey bee colonies in the U.S. has created sizable risks for beekeeping and almond operations.

The remainder of this paper is organized as follows. First, we graphically depict and discuss the supply and demand of colonies for the almond pollination market. In Section 3, we describe the data used in this analysis, which is followed by an analysis of colony shipments into the state of California in Section 4. In Section 5, we conclude.

2 Almond Pollination Services Market Equilibrium

Figure 1 shows a conceptual representation of the supply and demand for colonies for almond pollination. The supply of colonies is segmented into beekeeping regions following Nye (1980) as defined in Table 1 and Figure 2. We represent the supply of colonies as a discrete step function in which each region has a unique minimum marginal cost. The regional

differences in marginal costs represent transportation cost and opportunity cost differences across regions.[1] The relative marginal costs depicted here are estimates based on information from industry participants. The dominant fact is that marginal costs increase as the distance travelled to California increases. Table 1 shows estimated per-colony shipment costs from each region using a cost of $3 per-mile for a truck shipment of 393 colonies.[2] These substantial spatial differences in per-colony transportation costs have not been highlighted by previous literature on the economics of pollination services, despite likely being one of the primary factors influencing beekeepers' decisions regarding almond pollination.

The demand for colonies for almond pollination is represented as perfectly inelastic on a per-acre basis using the industry rule of thumb of two colonies per acre of almonds. We depict two demand curves, one which represents recent almond pollination demand in 2016 and one based on the almond pollination demand of 1977. This year was chosen to illustrate a conclusion of Rucker et al. (2012) that the demand for colonies for almond pollination exceeded most of the supply of colonies from Pacific Northwest and California beekeepers after 1977. According to the 1978 USDA Agricultural Census, there were 347,159 acres of almonds (both bearing and non-bearing age), which would have required roughly 600,000 honey bee colonies for pollination. Table 2 shows the USDA Agricultural Census colony populations in each beekeeping region at the end of 1978. California and the Pacific Northwest beekeeping region had just over 600,000 honey bee colonies, consistent with the conclusion of Rucker et al. (2012). Therefore after 1977, the marginal supplier of colonies for almond pollination has been located in other parts of the country with higher transportation costs.

[1] In reality, the regional marginal cost curves may be nonlinear, differ in slope, and likely overlap. For example, a beekeeper in the Southeast region with high transportation costs may choose to transport colonies for almond pollination at a lower price than a beekeeper in the Southwest region if the Southwest beekeeper has relatively high opportunity costs of participating in almond pollination due to honey production. As will be discussed later in Section 4.2, there are beekeepers in regions other than the Southeast and Northeast who are not yet participating in almond pollination. This could be due to other transaction costs of entering the almond pollination market. Additionally, beekeepers may choose not to transport some (or all) of their colonies to California for almond pollination due to the potential risks to colony health.

[2] From conversations with commercial beekeepers, in 2017 per-mile shipment costs ranged from $2.75-3.15 for each semi-load of colonies. The semi-load of 393 colonies was the average number of colonies per truck over all shipments 2008 to 2016 into California from the CDFA dataset.

Figure 1: Conceptual Representation of Supply and Demand of Honey Bee Colonies for Almond Pollination

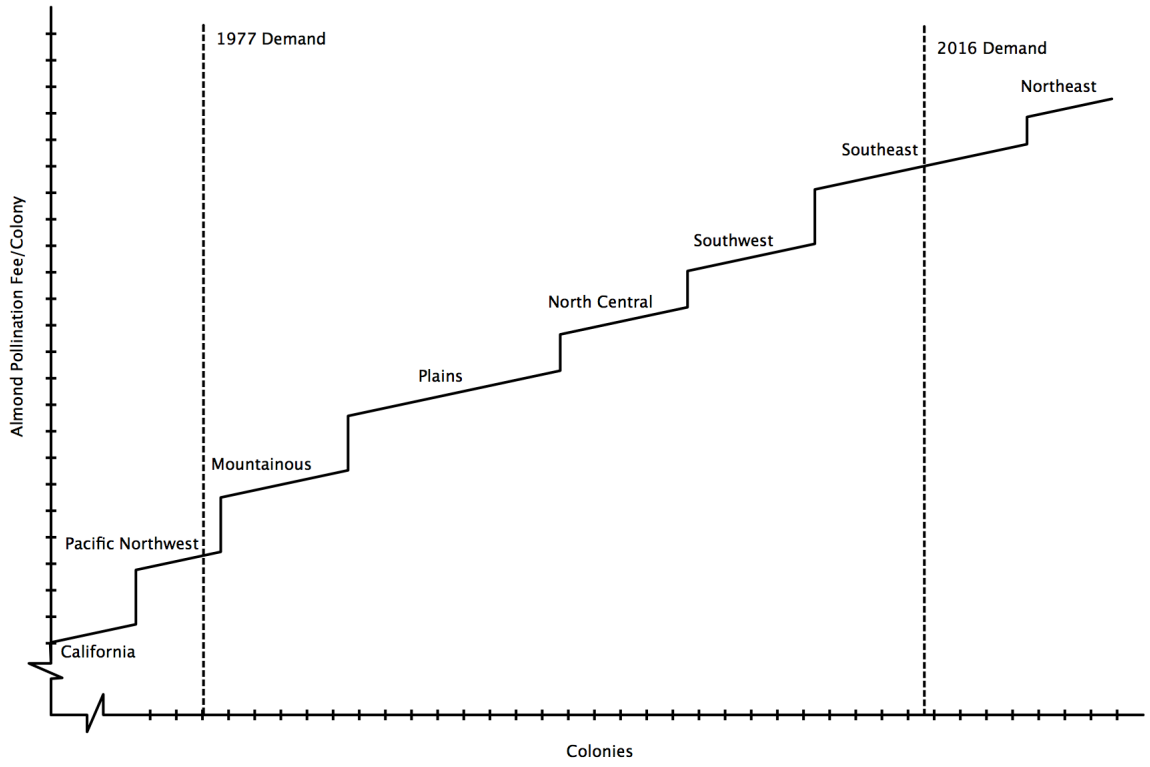


Figure 2: Beekeeping Regions in the United States

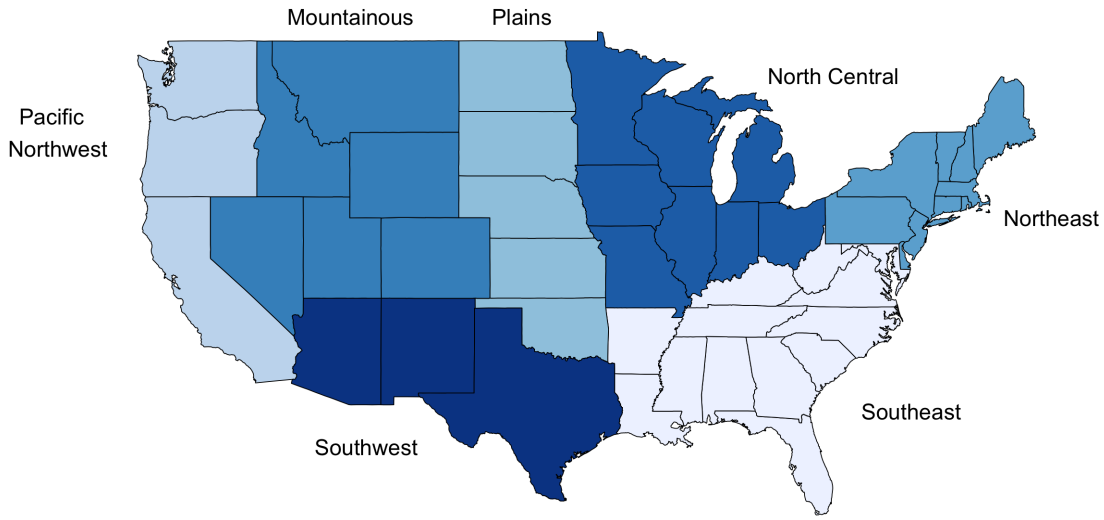


Table 1: United States Beekeeping Regions and Estimated Per-Colony Transportation Costs

Region	States	Estimated Round Trip Shipping Cost Per Colony[†]
Plains	North Dakota, South Dakota, Nebraska, Kansas, Oklahoma	$22-27
Mountainous	Nevada, Utah, Colorado, Idaho, Wyoming, Montana	$7-20
Pacific Northwest	Washington, Oregon	$9-13
Southwest	Arizona, New Mexico, Texas	$11-24
Southeast	Alabama, Arkansas, Florida, Georgia, Louisiana, Kentucky, Maryland, Massachusetts, North Carolina, South Carolina, Tennessee, Virginia, West Virginia	$29-41
North Central	Iowa, Illinois, Indiana, Michigan, Iowa, Minnesota, Missouri, Ohio Wisconsin	$28-36
Northeast	Delaware, District of Columbia, Rhode Island, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Vermont	$42-46

[†]Calculated using a per-mile shipment cost of $3, and 393 colonies per truck shipment at various points in each region. Source of Beekeeping Regions: Nye (1980)

Table 2 provides a comparison of the 1978 colony populations in each region with comparable populations for 2015, i.e., the maximum number of honey bee colonies in each region from October through December 2015.[3] Table 2 illustrates that overall U.S. colony populations have increased slightly since 1978, though this increase could be primarily due to differences in the statistics being compared. The maximum number of colonies from October through December 2015 may not account for any colony mortality taking place during this time, while October through December colony mortality would be accounted for in the December 31, 1978 colony count. Regional colony populations as a percentage of the U.S. total have remained similar across time. The largest fluctuation in the total share of U.S. colonies was in the North Central region, a decrease of less than eight percentage points. California saw a large increase in its share of U.S. colonies from 1978 to 2015, which is likely due to early transport of colonies from other regions for almond pollination. Because the current distribution of colonies throughout the U.S. is fairly similar to the distribution nearly 40 years ago as seen in Table 2, it seems that any supply shocks which have altered beekeeping costs have done so similarly across all regions, leading to vertical shifts in the total supply of colonies. The vertical supply shifts would change the equilibrium almond pollination fee, but would not significantly change the location of the marginal supplier of colonies. Thus, for simplicity, Figure 1 shows one supply curve. The similar distributions in Table 2 also provide evidence that the levels of almond pollination fees thus far have not been high enough to incentivize a large number of beekeeping operations to expand their capacity in any region, even those in close proximity to California.

Figure 1 depicts that as the demand for colonies for almond pollination has increased due to increased acreage, the equilibrium pollination fee has increased to bring colonies from further away regions to meet pollination needs. In 2016, colonies are now being shipped

[3]Because of the migratory nature of commercial beekeeping operations, the maximum number of colonies in each region October-December 2015 is the closest in comparison to the December 31, 1978 population numbers. USDA collects colony populations as of January 1, though these are not useful in comparison to the 1978 population numbers because during the October-December time period many colonies are now transported to California for almond pollination.

Table 2: U.S. Regional Honey Bee Colony Populations, 1978 and 2015

	December 31, 1978		Maximum Oct-Dec 2015†	
Region	Colonies	Percentage of U.S.	Colonies	Percentage of U.S.
Plains	403,838	15.81%	571,500	19.88%
Mountainous	309,174	12.10%	345,000	12.00%
Pacific Northwest	130,589	5.11%	203,000	7.06%
Southwest	166,021	6.50%	295,000	10.26%
Southeast	465,389	18.22%	603,000	20.98%
North Central	483,772	18.94%	319,000	11.10%
Northeast	111,290	4.36%	95,400	3.32%
California	477,013	18.67%	750,000†	26.09%
Total U.S.	2,554,390		2,874,760	

†For California, the colony population as of October 1, 2015 is used because colonies are moved to California from other regions during this time period. Colony movement and mortality during this time period result in discrepancies between the sum of regional colony numbers and the U.S. total (and corresponding regional percentages sum to over 100).
Sources: USDA 1978 Census of Agriculture; USDA May 2016 Honey Bee Colonies Report

into California from as far as the southeastern U.S. Almond pollination fees have risen accordingly to cover transportation and opportunity costs. Additionally, some of this rise in almond pollination fees could be due to vertical supply shifts resulting from colony health issues which have likely increased costs of production for beekeepers.

3 Data

The data used in this analysis contain information collected at every California Border Protection Station (BPS) on individual truck shipments of honey bee colonies entering the state. As seen in Figure 3 there are 16 border stations in California. Most of the apiary shipments go through eight (Blythe, Dorris, Hornbrook, Needles, Vidal, Winterhaven, Yermo and Truckee). The purpose of inspecting apiary shipments is to prevent the spread of invasive species that may be hitchhiking on hives or beekeeping equipment (CDFA, 2015). Information is

gathered on each apiary shipment regarding the origin location, destination in California, and the number of colonies it contains. The origin is important because shipments coming from states with known populations of invasive species are scrutinized more closely.[4] At the border station, the outsides of the apiary shipment are inspected, and then the destination county's Agricultural Commissioner's Office is notified so that a more intensive inspection can be conducted upon arrival at the shipment destination. If an apiary shipment is rejected at the border, it must be cleaned before attempting to re-enter.[5]

The dataset contains records of each apiary shipment into California from January 1, 2007 through December 31, 2016.[6] Because this paper focuses on the almond pollination market which occurs in February each year, we only utilize data on shipments from April 1, 2007 (beginning of shipments for 2008 almond pollination season) through March 31, 2016 (end of 2016 almond pollination season).[7] Table 3 shows the total number of shipments, the total number of colonies shipped and the average number of colonies per shipment for each almond pollination season.

4 Honey Bee Colony Shipments into California, 2008-2016

In this section, we analyze honey bee colony shipments into the state of California from years 2008 through 2016. We begin by highlighting overall trends during this time period, and the patterns of colony shipments throughout the year. We then explore the states and regions from which colony shipments originated, including trends in the number of colonies

[4]For example, apiary shipments from many Southern states, e.g., Texas and Arizona, are searched specifically for the Red Imported Fire Ant.

[5]Nearly all rejected shipments are cleaned and then ultimately enter, so we were not provided any variable regarding acceptance/rejection.

[6]Any records prior to 2007 are not digitized.

[7]For the purposes of this analysis, we define each almond pollination season as April 1 of the previous year through March 31 of the almond pollination season year.

Figure 3: California Department of Food and Agriculture Border Stations

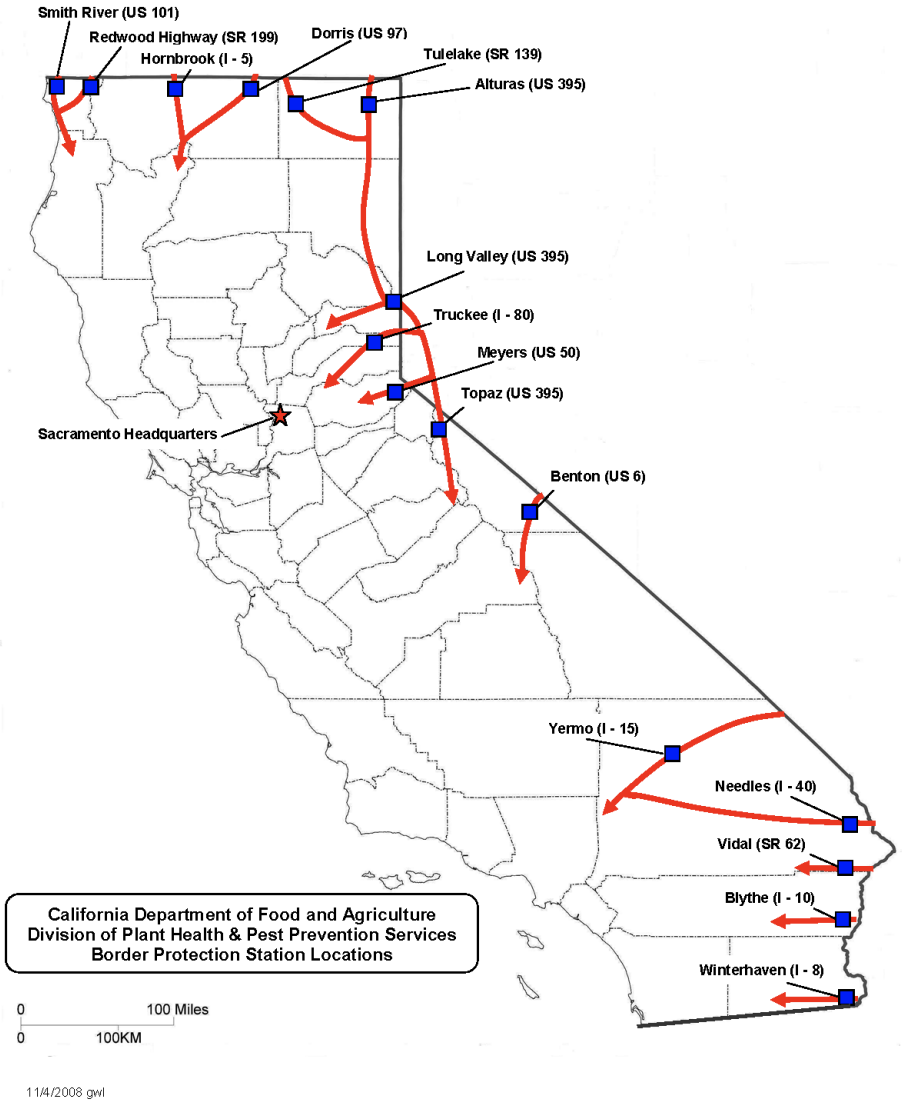


Table 3: Annual Summaries of Apiary Shipments into California, 2008-2016

Almond Pollination Season†	Shipments	Colonies Shipped	Average Colonies per Shipment
2008	2,812	1,095,217	389
2009	2,992	1,164,012	389
2010	2,999	1,171,812	391
2011	3,179	1,247,001	392
2012	3,340	1,324,366	397
2013	3,408	1,332,157	391
2014	3,267	1,291,693	395
2015	3,791	1,506,661	397
2016	3,966	1,567,699	395

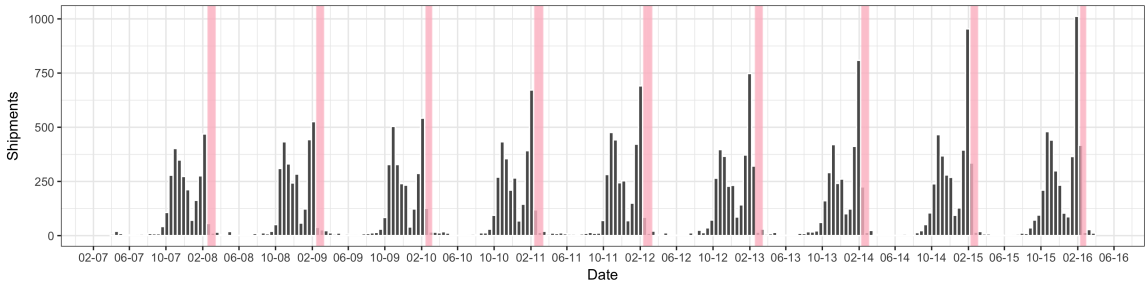
† Almond pollination season defined as April 1 of the previous year through March 31 of the almond pollination season year.
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

shipped by state and region and the timing of shipments from each region. Finally, the section concludes with estimates of the number of colonies throughout the U.S. which did not participate in 2016 almond pollination, to provide an idea of the states which may supply future increases in almond pollination demand.

Honey bee colony shipments into California have increased from roughly 1.1 million colonies in 2008 to 1.6 million colonies in 2016. Figure 4 shows a histogram of truck shipments into California, while Figure 5 displays densities of the colonies shipped into California for each almond pollination season. Because the number of colonies per truck shipment varies, Figures 4 and 5 could, in theory, look very different. However, the two figures are visually similar and show that colonies are primarily transported into California starting in October through the almond bloom period in the following year in February and March. From these seasonal shipment patterns, we conclude that most of the honey bee colony shipments into California are participating in the almond pollination market.[8] Colony shipments during

[8]Historical data are needed to definitively say how many colony shipments into California occur specifically because of almond pollination. Some beekeepers may take part in honey production in the upper Plains states and would transport colonies into California to overwinter in warmer areas regardless of participation in the almond pollination market. Data prior to 1977 (before California almond pollination demand exceeded the in-state supply of colonies) would be necessary to determine a baseline level of shipments into California by California beekeepers.

Figure 4: Histogram of Bi-Weekly Apiary Shipments into California, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



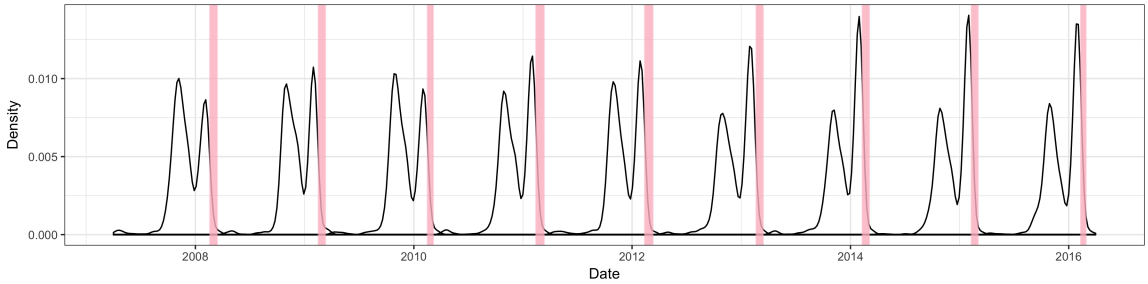
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

January and February have increased from approximately 383,000 colonies in 2008 (35% of total shipments in 2008) to 742,000 in 2016 (47% of total shipments in 2016), implying that most of this increase in colony shipments can be attributed to an increase in demand for colonies for almond pollination. Colony shipments into California begin to pick up in October at a time when honey production is wrapping up in major honey producing states in the Plains region, e.g., North Dakota and South Dakota. Many colonies are transported from these states to California to overwinter in warmer areas before almond bloom. A lull in shipments occurs each year right around the new year likely due to holidays accompanied by limited operating hours and staff at the California BPS (Figures 4 and 5).[9] Annually, only around 3-6 percent of colonies are being transported into California during the months from April to September.

Figure 6 shows the estimated demand for colonies in comparison to the number of colonies shipped into California for each almond pollination season. Each year, there is a gap between the estimated demand and the number of colonies shipped into California of around 300,000-350,000 colonies. The exception to this is the 2014 almond pollination season when significantly fewer colonies were shipped into California widening the gap to roughly 450,000 colonies. The gap between the number of colonies shipped and demand could imply that

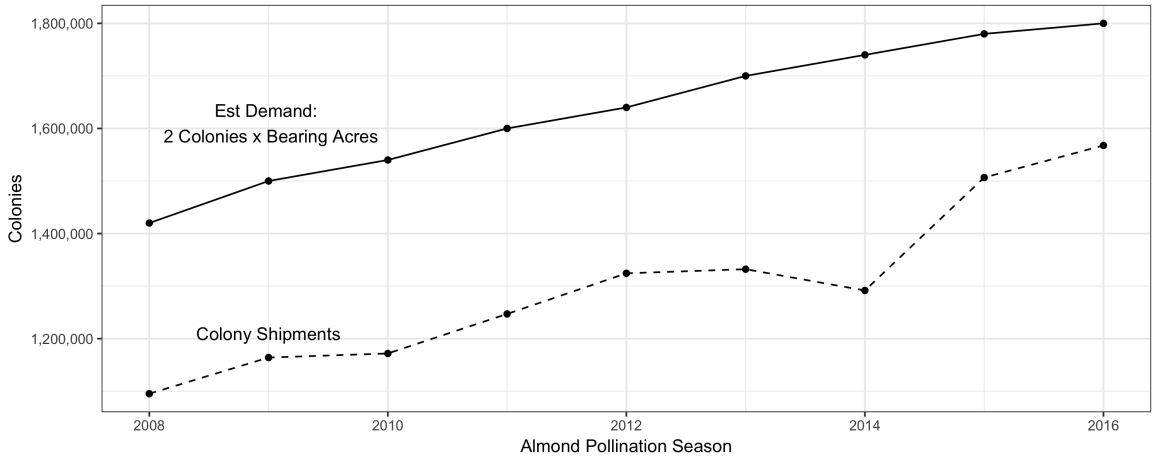
[9]Proper staffing at the Border Stations during peak shipment times is of concern for beekeepers because delays can be detrimental to the colonies being shipped. CDFA discusses how to improve conditions at the Border Inspection Stations with CSBA on an annual basis; see for example the CSBA Board Minutes Summary November 20, 2015 (http://www.californiastatebeekeepers.com/news/Minutes2015/SummaryMinutes-11-20-15.pdf).

Figure 5: Density of Colonies Shipped into California by Almond Pollination Season, Seasons 2008-2016 (Almond Bloom Period for Central California Highlighted)†



†Densities are calculated for each almond pollination season which we define as April 1 of the previous year through March 31 of the almond pollination season year.
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 6: Colonies Shipped into California and the Estimated Demand for Almond Pollination, Seasons 2008-2016†



†Colony shipments are summed for each almond pollination season which we define as April 1 of the previous year through March 31 of the almond pollination season year.
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA NASS 2008-2016 Almond Acreage Reports

using two colonies per acre is a substantial overestimate of the demand for colonies, however due to the wide use of the industry rule of thumb, my assessment is that errors in demand estimates are minor. The migratory nature of beekeeping operations does not lead to accurate estimates of the number of colonies which remain in California year round, therefore we posit most of the remaining demand is met by colonies which do not leave the state of California.

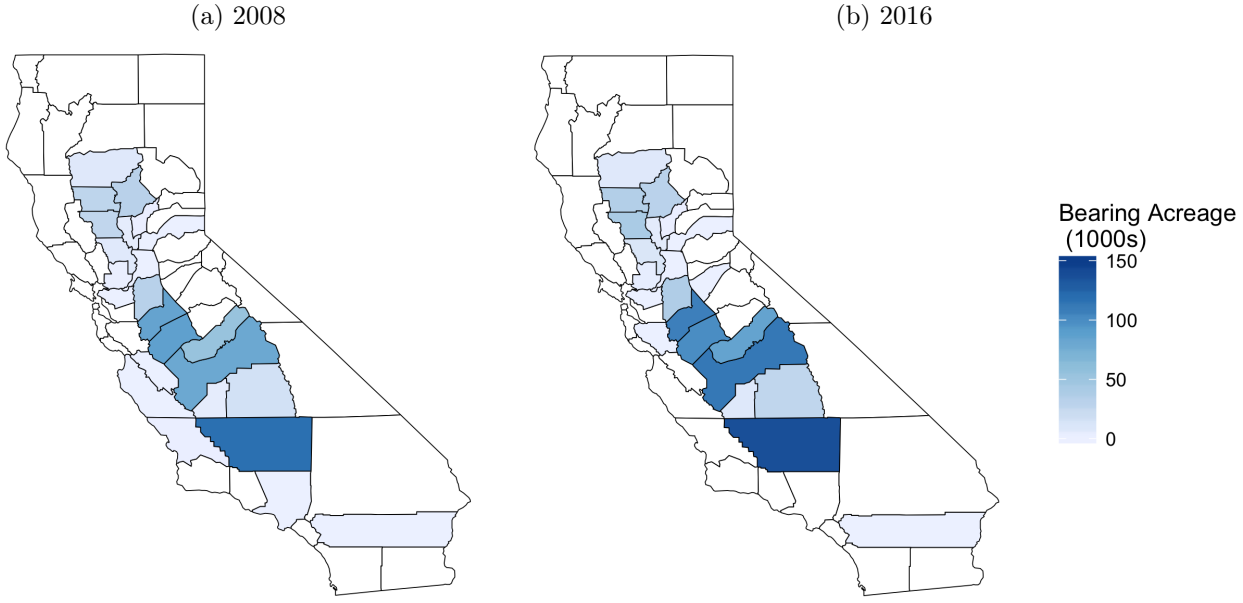
4.1 Colony Shipments and Demand by County

Figures 7 and 8 show county maps of California's bearing almond acreage, the number of colonies shipped into each county. It is clear from Figures 7 and 8 that counties with relatively large almond acreage (Stanislaus, Merced, Madera, Fresno, Kern) tend to receive the largest number of colony shipments. Additionally, as acreage has increased over time in many counties, colony shipments have also increased. Figure 9 shows colony shipments per square mile in each county for the almond pollination seasons 2008 and 2016. The highest concentrations of colonies per square mile are in the major almond-producing counties, and these concentrations increase from 2008 to 2016. The three most-concentrated counties in 2016, Stanislaus, Madera, and Merced, had 147, 89 and 80 colonies per square mile, respectively. These high concentrations likely lead to a large amount of mingling amongst bees from different colonies because foraging bees will fly up to three miles.

Figure 10 shows the number of colonies shipped into the county minus the estimated colonies demanded for almond pollination in 2008 and 2016 and provides some evidence of movement of colonies between counties. Counties which have little or no almond acreage, but share a boundary with a county with a large amount of almond acreage often receive a surplus of colony shipments, e.g., the counties of San Bernardino and Ventura neighboring Kern County. This suggests that some colonies may be moved between counties after their initial inspection by the County Agricultural Commissioner but before almond bloom. As

discussed previously, this could relate to the high demand for relatively safe holding areas for colonies until almond bloom. In every year, Fresno County had a large surplus of colonies, while neighboring Merced County had a deficit. This suggests likely movement between the two counties. Figure 10 shows that many Northern California counties receive fewer colonies than their estimated demand.

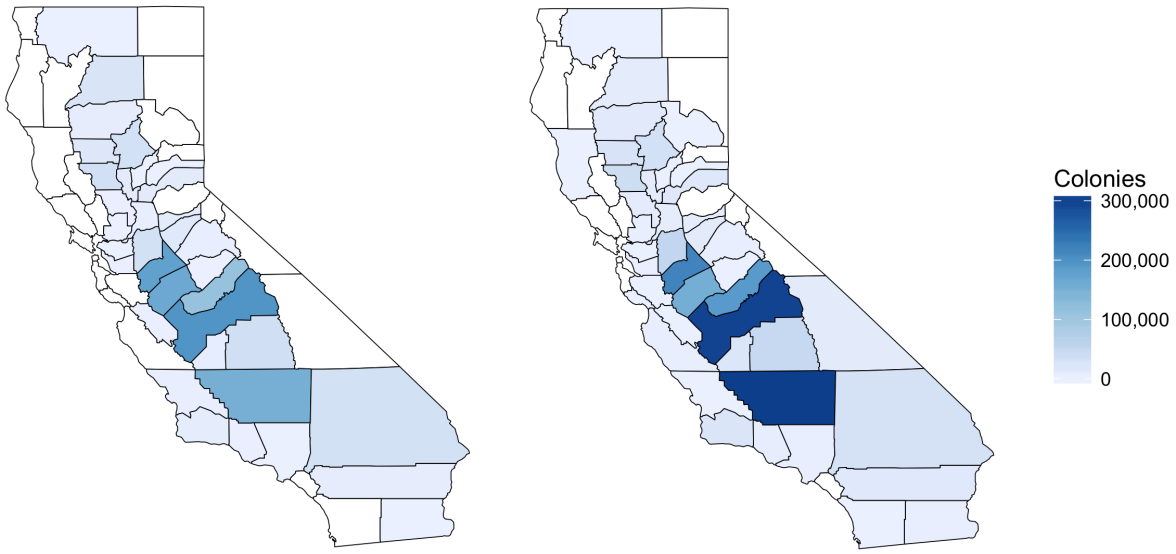
Figure 7: Bearing Almond Acreage by County in California, Seasons 2008 and 2016



Source: USDA NASS 2008-2016 Almond Acreage Reports

Figure 8: Honey Bee Colony Shipments into California Counties for Almond Pollination, Seasons 2008 and 2016

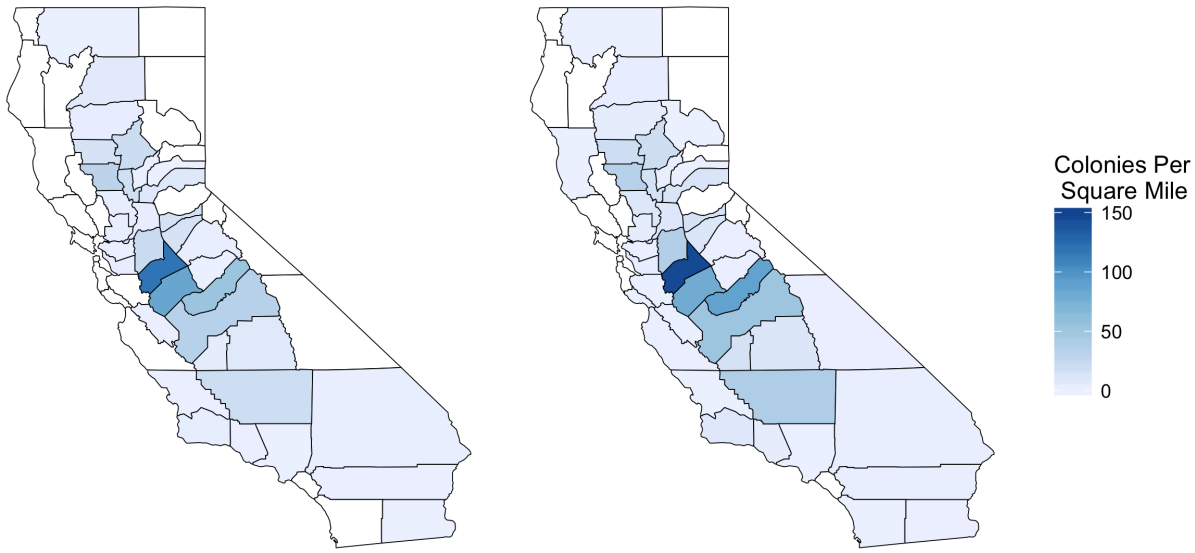
(a) 2008 (b) 2016



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 9: Honey Bee Colonies Shipped into California Counties for Almond Pollination Per Square Mile, Seasons 2008 and 2016

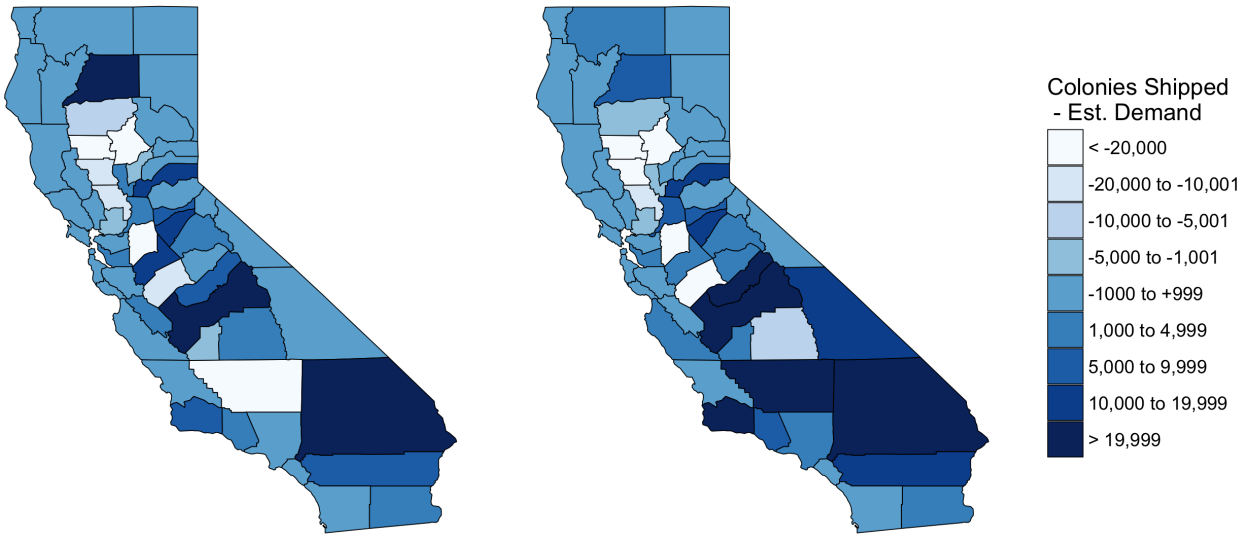
(a) 2008 (b) 2016



Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; U.S. Census Bureau, 2010 Census of Population and Housing

Figure 10: Honey Bee Colony Shipments into California Counties Less County Estimated Demand (2 x Bearing Acreage) for Almond Pollination, Seasons 2008 and 2016

(a) 2008 (b) 2016



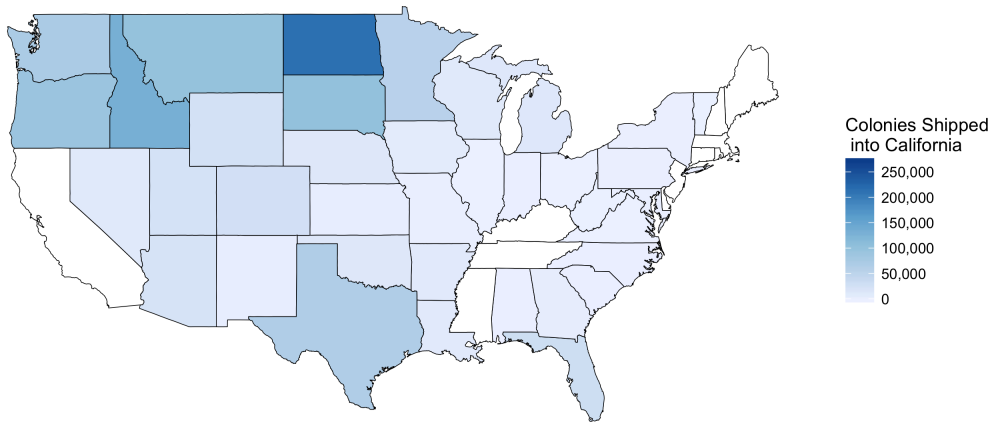
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA NASS 2008-2016 Almond Acreage Reports

4.2 Shipment Origin

Figures 11 and 12 depict the number of colonies shipped from each contiguous U.S. state in the almond pollination seasons 2008 and 2016, respectively. Figures 13 and 14 show the shipments over almond pollination seasons 2008 to 2016 from the eight states which provided the largest number of colonies to California in 2016. Figure 13 illustrates the relative proportions of colony shipments from the top eight states, while Figure 14 illustrates trends in colony shipments from each state over time. North Dakota, South Dakota and Montana are consistently some of the largest providers of colonies for almond pollination and in 2015 were also the top three honey producing states in the U.S (NASS, 2015). By far, the largest number of colonies each almond pollination season are shipped from North Dakota–over 200,000 colonies were shipped from North Dakota to California in every almond pollination

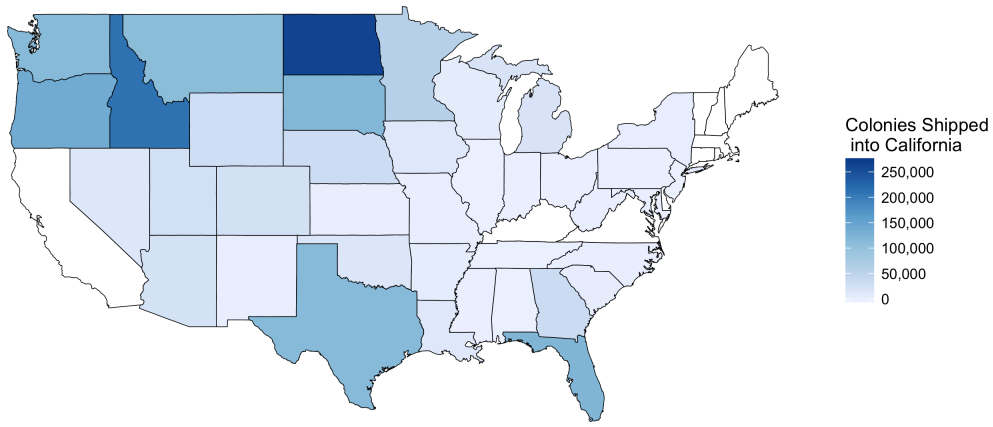
season but 2014. The next largest suppliers, South Dakota and Montana, on average annually ship around 117,000 and 104,000 colonies into California, respectively, 51 and 45 percent of the average number of colonies that North Dakota ships. Comparing Figures 11 and 12, the number of colonies shipped has increased for most states since 2008. The number of colonies shipped from Florida and Texas have increased since 2008 by 278 percent and 75 percent, respectively, which are much larger increases than other states.

Figure 11: Honey Bee Colony Shipments into California for Almond Pollination by State of Origin, Season 2008



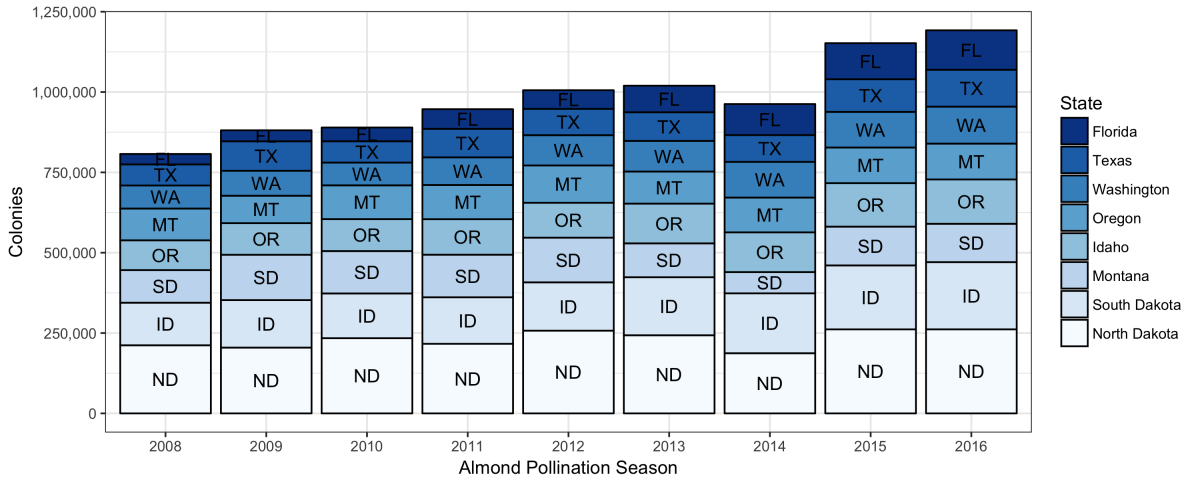
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 12: Honey Bee Colony Shipments into California for Almond Pollination by State of Origin, Season 2016



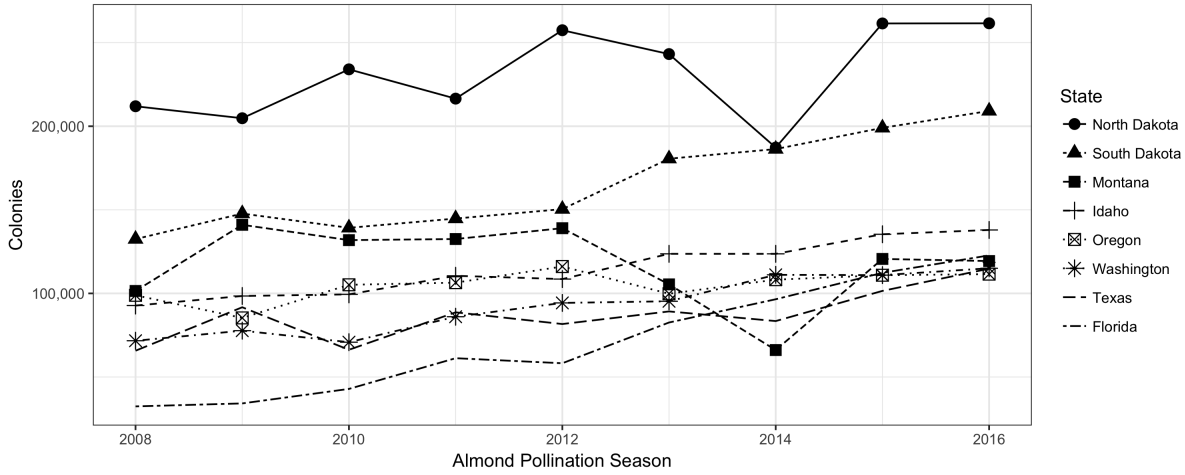
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 13: Total Honey Bee Colony Shipments into California for Almond Pollination from Eight States with Largest Number of Colonies Shipped in 2016, Seasons 2008-2016



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 14: Honey Bee Colony Shipments into California for Almond Pollination from Eight States with Largest Number of Colonies Shipped in 2016, Seasons 2008-2016



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Table 4 reports the percentage of colonies shipped from each beekeeping region (defined in Table 1) to California for almond pollination in 2016. The Plains and Mountainous regions are the largest suppliers of colonies for almond pollination, each supplying nearly 30 percent of the total colonies shipped for almond pollination. Figures 15 and 16 display the shipments for almond pollination from each region over time. Shipments have increased fairly steadily over time for all regions, though the Southeast region has seen some of the largest increases

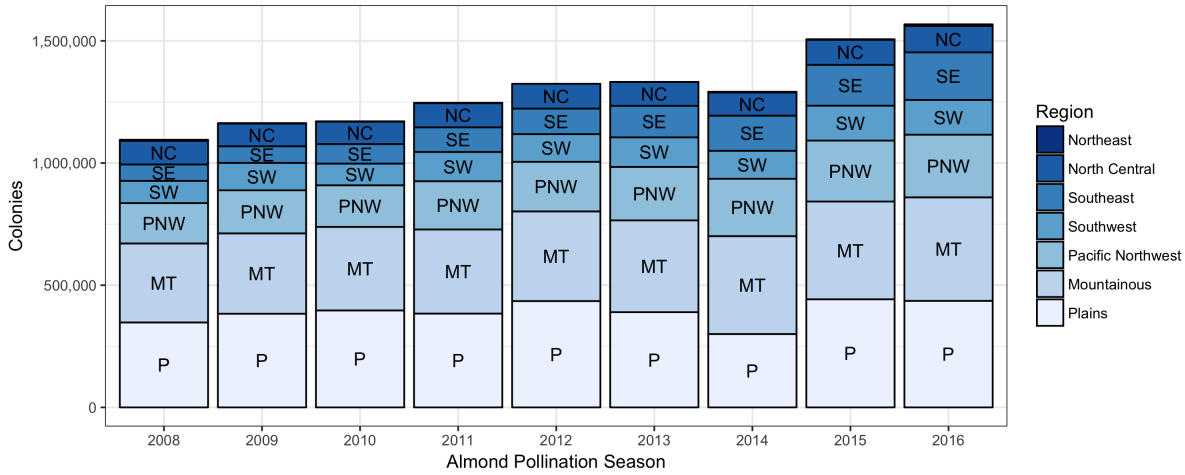
Table 4: Percentage of Total Colony Shipments into California for 2016 Almond Pollination Season from U.S. Beekeeping Regions

Region	Percentage of Total 2016 Shipments
Plains	27.80%
Mountainous	27.03%
Pacific Northwest	16.35%
Southwest	9.08%
Southeast	12.41%
North Central	6.91%
Northeast	0.41%

Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

in colony shipments, consistent with the large increases in shipments from Florida.

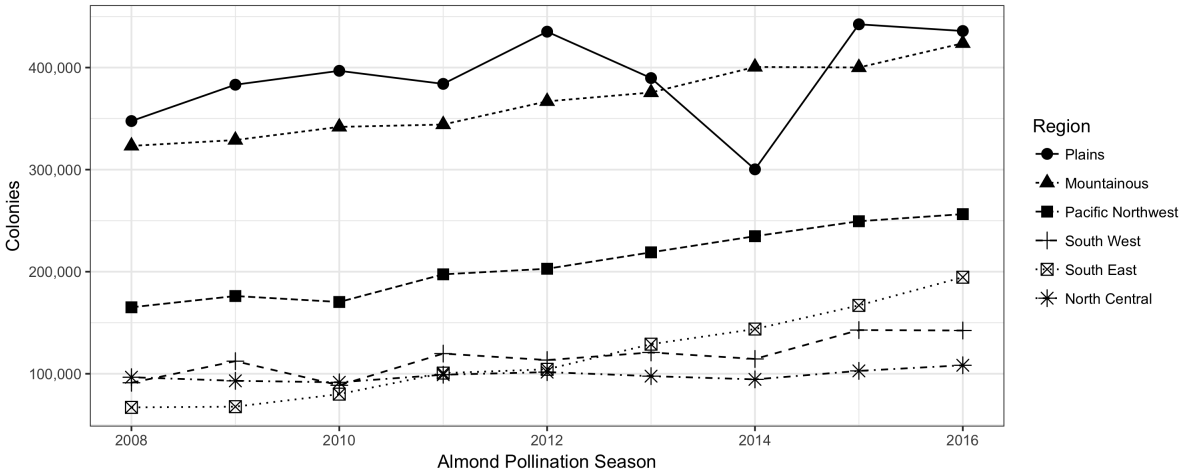
Figure 15: Total Honey Bee Colony Shipments into California for Almond Pollination from U.S. Beekeeping Regions, Seasons 2008-2016



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figures 17-22 are histograms displaying the timing of shipments into California from each beekeeping region. The histogram of timing for the Northeast region is not displayed due to the small number of shipments that occur from this region (often fewer than five per year). The timing of shipments by region appears to depend on proximity to California, as well as regional climate. The Plains and North Central regions tend to have substantial summer honey production, and experience cold winters. Thus, most of the shipments coming into

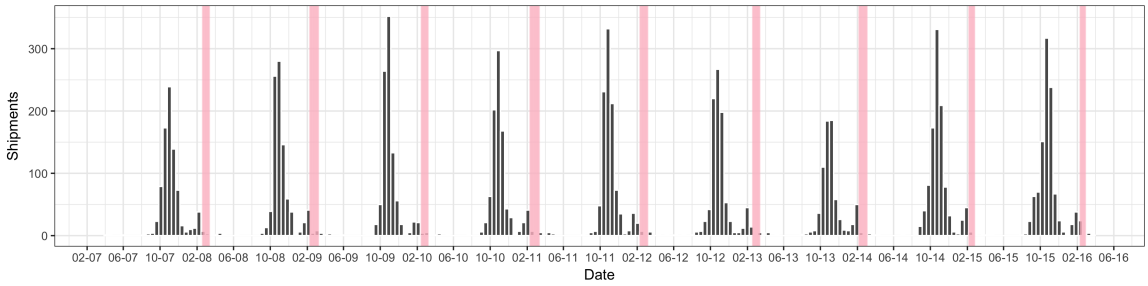
Figure 16: Honey Bee Colony Shipments into California for Almond Pollination from U.S. Beekeeping Regions, Seasons 2008-2016



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

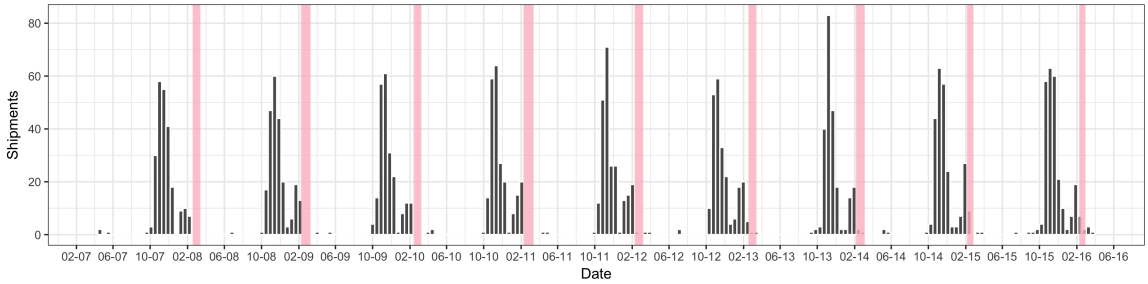
California from these regions arrive after honey flow ends in the fall but before winter begins (Figures 17 and 18). As seen in Figures 19 and 20, the Southeast and Southwest regions ship most colonies to California in late January and early February, immediately before almond bloom occurs. These regions are warm during the months leading up to almond bloom, so beekeepers would not need a warmer place to overwinter colonies. Additionally, in the Southeast and Southwest regions there is potential for honey production leading up to and during almond pollination, creating an opportunity cost of early transport of colonies to California (ETBA, 2000; Ellis and Zettel Nalen, 2010). The Mountainous and Pacific Northwest regions are fairly close to California, and both have a mixture of climates due to their geography. Figure 21 shows that most colonies from the Pacific Northwest arrive close to almond bloom. The Mountainous region has many colonies coming in prior to winter, however in recent years a growing number of shipments have been arriving close to almond bloom (Figure 22).

Figure 17: Histogram of Bi-Weekly Apiary Shipments into California from Plains Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



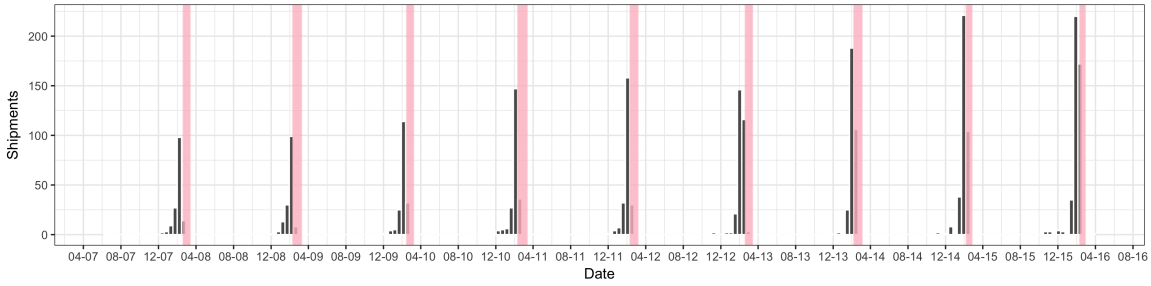
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 18: Histogram of Bi-Weekly Apiary Shipments into California from North Central Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



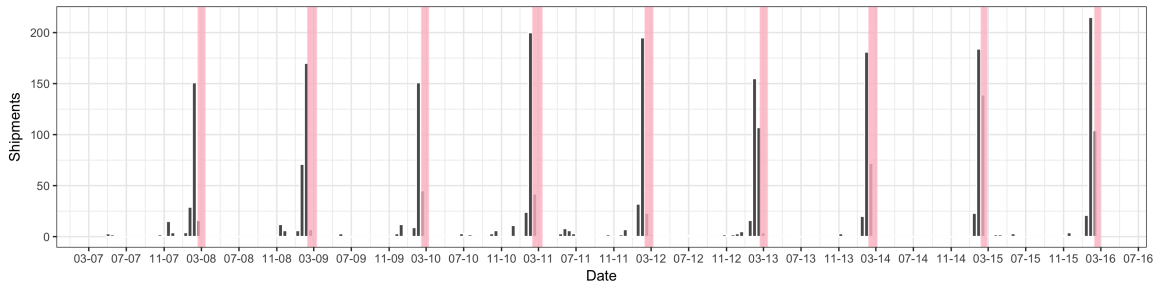
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 19: Histogram of Bi-Weekly Apiary Shipments into California from Southeast Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



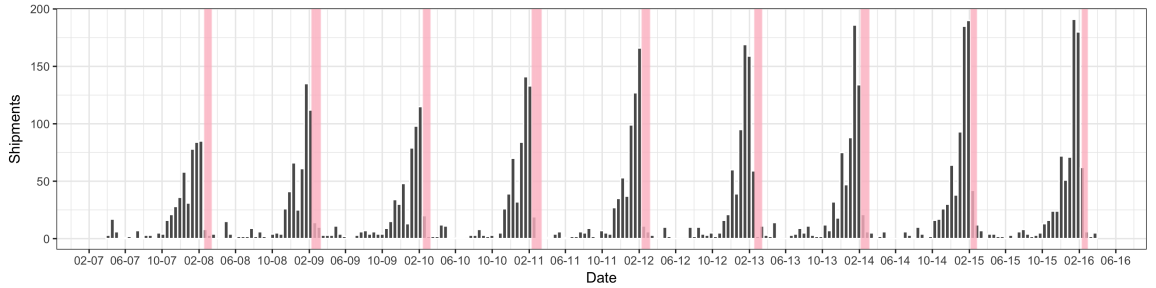
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 20: Histogram of Bi-Weekly Apiary Shipments into California from Southwest Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



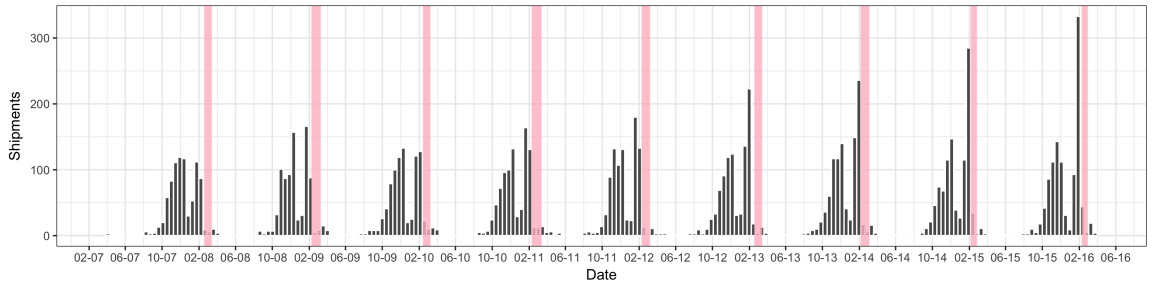
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 21: Histogram of Bi-Weekly Apiary Shipments into California from Pacific Northwest Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 22: Histogram of Bi-Weekly Apiary Shipments into California from Mountainous Beekeeping Region, March 2007- April 2016 (Almond Bloom Period for Central California Highlighted)



Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

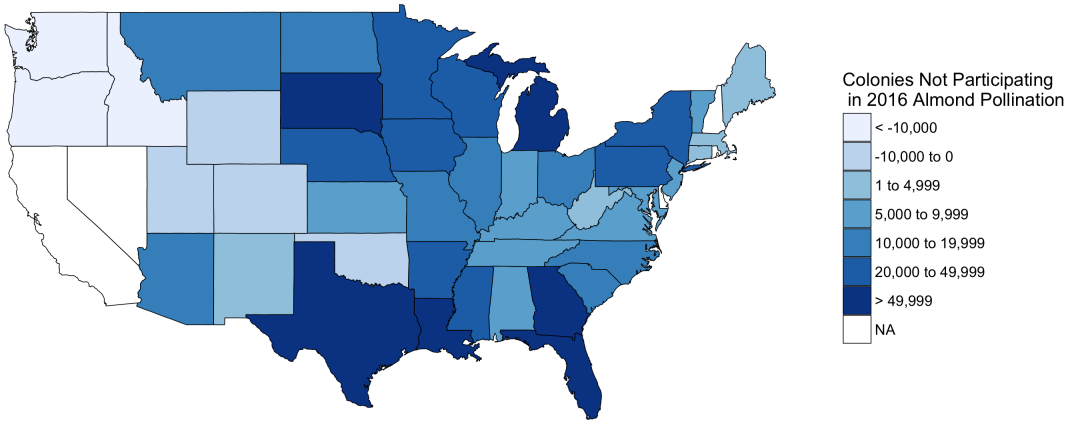
4.3 Future Shipment Origin

Increasing almond acreage has created a particular interest in the number of colonies which would be available for additional increases in demand. Figure 23 displays the estimated number of colonies which did not participate in 2016 almond pollination in each state. To calculate this number, we subtracted the number of colonies that were shipped to California for the 2016 pollination season from the maximum number of honey bee colonies in each state in October-December 2015 reported by the USDA (USDA, 2016). It should be noted that the map does not account for any colony losses over the winter 2015-2016, so the estimated number of colonies which remain in the state not participating in almond pollination are likely overestimated in Figure 23. Despite this potential overestimation, many states in the western U.S. (Colorado, Idaho, Oklahoma, Oregon, Washington and Wyoming) shipped more colonies to California than their colony populations, i.e., the number of colonies not participating in almond pollination was negative. This discrepancy likely arises from two possible issues: 1. It may suggest error in the USDA colony estimates (this seems probable for Utah, Colorado, Wyoming and Oklahoma which each have a shortfall of fewer than 10,000 colonies) 2. Colonies from other, more distant states may be held briefly or over the winter in states which are close to California, i.e., Washington, Idaho, Oregon, before entering the state for almond pollination.[10] Figure 23 shows that most colonies not sent to California are concentrated in southern states of Florida, Texas, Georgia and Louisiana where opportunities for honey production during this time may be more profitable than almond pollination. Figure 23 shows that South Dakota and some of the North Central states (Michigan and Minnesota) may also have some colonies which remain in-state and could potentially be shipped to California to participate in almond pollination.

Summing the colonies which did not participate in almond pollination across all states

[10]Often colonies are not allowed to be placed too early in almond orchards because almond growers must adjust pesticide applications while bees are in the orchard. Thus, in California access to locations where colonies may be placed for an extended period of time (without too much pesticide exposure) is in high demand leading up to almond bloom and therefore is scarce. This may necessitate placement in nearby states.

Figure 23: State Estimates of the Number of Honey Bee Colonies which did not Participate in 2016 Almond Pollination†



†NAs exist for Delaware, Nevada, New Hampshire, and Rhode Island because USDA does not publish honey bee populations for these states.
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA Honey Bee Colonies Report May 2016

(including those with negative numbers) and subtracting an estimated proportion that were lost over the winter using the Bee Informed Partnership (BIP) average U.S. winter mortality rate for 2015-2016, we estimate that in the 2016 almond pollination season around 644,000 colonies throughout the U.S. could have been used for almond pollination but were not transported to California. Using the 2016 USDA almond acreage report, we estimate in the next three years roughly an additional 148,000 colonies will be demanded from almond acreage coming to bearing age, which amounts to 23 percent of those remaining colonies.[11] Unless a significant amount of older almond acreage is removed from production over the next few years, tremendous pressure could be put on pollination fees to to rise to incentivize participation from beekeeping operations with colonies not yet participating in almond pollination.

[11]The estimated increase in colonies from bearing acreage is calculated by: 2 colonies/acre * 67,000 bearing acres of traditional almond varieties +1 colony/acre * 14,000 bearing acres of Independence variety (self-fertile so requires fewer colonies per acre see Doll (2012)).

5 Summary and Implications

Over the years 2008 through 2016, honey bee colony shipments into California have increased fairly steadily due to increased demand from the almond industry. Because of large investment costs of expanding honey bee populations nationwide, much of this increase has been met by additional colonies shipped from Florida and Texas, where beekeepers face relatively high transportation and opportunity costs of participating in almond pollination. We estimate that during the 2016 almond pollination season approximately 644,000 viable colonies throughout the U.S. did not participate in almond pollination, and most of these remaining colonies were located in Florida and Texas. We estimate that in the next three years an additional 23 percent of these remaining colonies will be demanded due to almond acreage coming to bearing age unless a substantial amount of older almond acreage is removed from production. Almond pollination fees may need to increase significantly to cover opportunity costs and incentivize participation by additional beekeepers who are not yet participating in almond pollination.

The relatively large demand for managed honey bee colonies for almond pollination in comparison with the U.S. colony population has led to an interdependent relationship between honey bee colony health and almond production. Leading up to and during almond bloom, honey bee colonies from all over the U.S. are concentrated in major almond-producing counties in California's Central Valley, often at rates above 35 colonies per square mile. This can have substantial impacts on the spread of pests and diseases among honey bee colonies. What would have been a spatially contained pest or disease has the potential to spread rapidly throughout the U.S. by those colonies participating in almond pollination. Additionally, the states which ship the largest number of colonies to California for almond pollination are also some of the largest honey producing states, i.e., North Dakota, South Dakota and Montana. Over three-fourths of honey bee colonies for almond pollination came from eight states, primarily in the Plains, Mountainous and Pacific Northwest regions of the U.S. Thus, a regional colony health shock could cause extreme increases in almond pollination fees given

the inelastic demand for colonies for almond pollination. The geographically concentrated nature of the supply of out-of-state colonies for almond pollination likely increases the risks faced by both beekeepers and almond growers.

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