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Native Pollinators of California Avocado as Affected by Introduced Pollinator Gardens

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Abstract

In three commercial avocado orchards in Southern California, pollinator gardens were established to attract potential avocado pollinator arthropods. Bees species and other insects were monitored on both the gardens, on the avocados and around the gardens. The visitation frequency and species varied at the three sites and over the four years of the trial. The greatest number and diversity of bees occurred during the low rainfall winter of 2015, while the greatest number of all arthropod visitors occurred in the higher rainfall year of 2017.

Keywords: *Persea*, native bees, bee habitat gardens, pollinator management

Introduction

Avocado is a neotropic tree which has been commercialized world-wide, yet it's native pollinators have been little studied. The most frequently studied pollinator has been the old-world insect, *Apis mellifera*. In commercial orchards it is common practice to introduce honey bee colonies, although it is not clear exactly what the extent of their effect is in California orchards in the presence of native bees and other pollinators (Vithanage, 1990; Evans *et al*, 2011). The purpose of this study is to evaluate the range of avocado flower visitors and to assess whether those numbers can be affected by the introduction of gardens that might promote their numbers in the orchards during the avocado bloom period.

Measuring pollinator performance is difficult because of weather impacts, alternate bearing habit and the high level of fruit shedding in avocado. In this study, pollination gardens have been established in three avocado orchards in coastal California near Santa Barbara, just north of Los Angeles. These gardens have been established since 2014 with a variety of perennials that can supply nectar and pollen over the year and especially during the prolonged flower season. The three orchards where the gardens are established each exceed 40 ha. Gardens have been established in just one portion of the orchards, so that flower visitation can be assessed near and far from the gardens. The individual visitation activity of flower visitors was evaluated per unit time and their abundance on avocado flowers near the gardens and away from the gardens. Visitation was also similarly assessed on the pollinator gardens. Pan traps were also used to assess the presence of native bees in the orchards.

Methods

All fieldwork took place on three commercial avocado farms in Ventura and Santa Barbara Counties, Southern California. Avocado orchards in this area are near and against wildland areas that are affected by the Mediterranean rainfall pattern of winter rain/summer drought. The winters of 2014-17 had considerably lower amounts that the average of 457 mm. Each year by late spring the native landscape dries, and often the only green vegetation is the irrigated area.

Each farm site contained two avocado subsites where sampling was focused, including one "treatment" site (on which habitat was expanded) and one "control" site (which was left without added pollination resources).

High quality pollinator habitat was established on all three sites consisting of 24 bee-attractive plant types on approximately 100 m^2 at each site (Table 1). Habitat design was based on 14 years of survey work on ornamental plants and their native bees in 50+ urban gardens in 15 cities across California. Habitat development focused on host plants with flowering times that synchronize with avocado flowering.

Table 1

Pollinator Garden Plant List

1.	*Bulbine frutescens*	13.	*Vitex agnus-castus*
2.	*Lavandula x intermedia* 'Provence'	14.	*Perovskia atricipifolia*
3.	*Grindelia camporum*	15.	*Echium candicans*
4.	*G. stricta*	16.	*Encelia californica*
5.	*Penstemon x gloxinioides* 'Midnight'	17.	*Verbena lasiostachys*
6.	*Salvia brandegei*	18.	*Rhamnus californica*
7.	*S. uliginosa*	19.	*Ceanothus griseus horizontalis* 'Yankee Point'
8.	*S. mellifera x sonomensis*	20.	*Heteromeles arbutifolia*
9.	*Gaillardia aristata*	21.	*Sphaeralcea ambigua*
10.	*Calandrinia grandiflora*	22.	*Scabiosa atropurpurea*
11.	*Leucanthemum* × *superbum*	23.	*Lavandula heterophylla*
12.	Oc*imum kilimandscharicum* × *basilicum*	24.	*Gaillardia aristata* 'Oranges and Lemons'

Orchard monitoring occurred during the 3 main phases of the growing season (late March to early April, mid-May to early June, and mid- to late July) on control and treatment sites. Methods include *pan trapping*, a standard technique that assesses diversity and abundance of bee species in a given area. Fifteen 180 ml plastic pans, alternating between fluorescent blue, fluorescent yellow and plain white, were spread 8m apart in sunny locations along a linear transect. Each pan was filled with a dilute solution of soapy water, which kills bees immediately upon contact, and left out between 10AM and 2PM. Passive collections were complemented by aerial net collections, taking place during the same time period, from surrounding flowering plants. These records are important as many larger bee species, are not attracted to pans, and host flower visits can be recorded. Collected bees were mounted, and identifications made, and then entered into a digital Access database for analysis.

Frequency counts, a standard method of gathering data on the diversity and abundance of bees visiting specific flower types (Frankie et al. 2009, 2013), as well as the resources they collect (pollen and nectar), were employed. This allows us to predict what bees were visiting which flowers at what frequency, and at what times of year. We have used the method extensively in our 15-year California-wide survey of urban areas. Counts were made on flowering patches of $1m^2$ in both treatment and control sites. Patches were observed for 3 minutes and bees making contact with the flower's reproductive parts were recorded. Aerial collections were made to identify visiting bees to species level.

At the same time that bee frequencies were being monitored on the bee plants, other pollinators, such as syrphid flies, flies and wasps were noted, as well as their presence on the avocado panicles. Biocontrol agents, such as syrphid flies and predatory wasps were also noted on pollination garden plants, as well as the avocado flowers.

Results

At this point, data has been compiled only for the bee numbers and species visiting avocado flowers, pan traps and the introduced pollinator gardens. These show the abundance and species number at the three avocado orchards over four spring sampling seasons. The greatest bee diversity and numbers occurred during the relatively low rainfall 2015 winter.

At this point the arthropod visitors on the avocado flowers, in the trap pans and pollinator gardens have not been distinguished by species. The greatest number of all visitors, occurred in the spring 2017 (data not shown). The total number of bee visitors to all of the sites in all years is shown in Table 2. The high variability in visitation by different species in different years is common in avocado pollination research as has been commented by others (Read *et al*, 2017).

Table 2 – Bee Species from Three Orchards with (Control) and without (Garden) Additional Pollinator Habitat. Apidae includes the honeybee, *Apis mellifera*

Bee Species	Site 1 Control	Site 1 Garden	Site 2 Garden	Site 2 Garden	Site 3 Control	Site 3 Garden
ANDRENIDAE = 13						
Totals:	2	9	2	2	2	0
APIDAE = 28						
Totals:	9	13	12	13	11	12
COLLETIDAE = 5						
Totals:	3	3	2	3	3	3
HALICTIDAE =29						
Totals:	15	17	15	14	14	14
MEGACHILIDAE = 7						
Totals:	4	3	1	2	3	1
Total Spp. =	**33 spp.**	**45 spp.**	**32 spp.**	**34 spp.**	**33 spp.**	**30 spp.**

Conclusion

The most abundant visitors in all years have been Syrphid spp. along with a variety of other flies and wasps. The most abundant native bee species have included *Ceratina, Halictus, Agapostemon* and several Andrenid species. The highest diversity and abundance of all arthropod visitors occurred during the higher rainfall year of 2016/17 after previous drought years. This year was still below the average for all bee visitors which might suggest competition with bees for floral resources. The 2017/18 season received more rain and it will be interesting to see what if any impact it has on species diversity and abundance. At one avocado orchard, the pollinator garden is being expanded to 1,000 m^2 (about ¼ acre) to observe the effect.

The results of this work so far, gives an indication of how important is the diversity of bee visitors to avocado, not just the honeybee. And, it's not just bees that are visiting avocado. The work, though, does not show which of the pollinators are the most effective at pollinating avocados, nor which are the most effective at causing fruit set. Those questions are being pursued. A recent article by Pattemore explores some of these questions (Pattemore *et. al.*, 2018).

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Which Way World Avocados?

B. Faber

One avocado tree, wholesale, recently sold for $92 in South Africa with 250 trees in a bunch costing about $23,000. They are 'Maluma', of course, which means it is a new variety that has similar properties to the traditional 'Hass', and might have some unusual properties like higher productivity, upright growth, lending itself to higher planting density and fruit production inside the canopy protecting it from wind and sunburn (Fresh Fruit Portal, 2017).

At a traditional California tree spacing of 273 trees/ha, that would be $25,116/ha. At some of the new high density spacings of 1m x 1m, that is nearly a million dollars per hectare alone in trees, let alone the cost of the land and infrastructure. And that is just one hectare, not the multiples of hectares that growers are planting. There are growers investing in five, ten, twenty and more hectares per planting. Big investment.

One million dollars in trees. Nurseries are happy to hear this. If a grower in California or South Africa or Australia wants to plant a new orchard, they are told to get in line. And then, they need to wait for one or two years until the nursery can ramp up supply. I have gotten calls from China, Philippines, and Italy of all places for trees. Everyone wants to plant trees now, and this has been after a steady increase in world-wide planting that has gone on for the last 20 years. World-wide consumption has seen a steady increase over this time. World-wide, global marketing has assured a steady supply to local markets, regional markets and now all those consumers in far off places like North Dakota in the US, or other countries, such as Beijing and Moscow. French and German consumers have always been reliable importers of the fruit over the years. But now even traditional Italian foodies are eating the fruit.

What is driving this activity? Well, consumers, of course. They have caught the 'avocado toast' bug. And the health benefits bug. It's all online and a lot of the claims are backed up by science (Scott *et al*, 2017). According to IndexBox (2017), a data compiling news service, the avocado market expanded at +5.6% per year from 2007 to 2016. Over the last six years, the market displayed a consistent growth; it accelerated sharply from Price of the fruit showed growth. Wholesale prices in 2016 totaled $13,797M, a growth by 23% over the previous year.

The money drive has thus led to widespread planting in countries such as Mexico that has had potentially significant impacts on native plants, fauna and soil erosion (Bravo-Espinosa, 2012). Avocado plantings in Chile have led to an outcry about their competing water use with villagers (Booth, 2018). Conflict.

Mexico, the U.S. and the Dominican Republic were the major avocado consuming countries in 2017 - 17% in Mexico, 16% in the U.S., and 10% in the Dominican Republic. Consumption in other countries included 5% in Indonesia, 5% in Colombia, 4% in Peru, 3% in Brazil, 3% in China, 3% in Kenya and 3% in Rwanda. The remaining countries together comprised nearly 31% of global consumption.

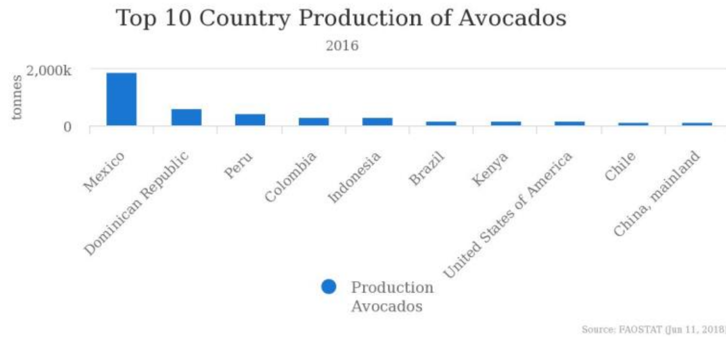
Among the leading consuming countries, high levels of per capita consumption were recorded in the Dominican Republic (54.6 kg/year), which is more than five times the world average of 10 kg/year of the ten largest consuming countries. In this country per capita consumption increased rapidly by +13.6% per year from 2007-2016. US per capita consumption increased from 1.5 kg to 4 kg during this period, which could indicate a long term thriving future for avocados as both a US and world-wide consumer item.

All of these data are based on United Nations Food and Agriculture Organization data (FAO, 2017). This is a huge database and as with all databases that rely on various reporting services are probably at least a year and possibly two years old by the time the information is reported.

An easier database to use is FactFish which compiles FAO data into more easily readable charts. The harvested acreage chart shows the 10 largest producing countries of the fruit: Mexico (180, 536 ha), Peru (37,871), Colombia (37,114), Chile (29,933), Indonesia (23,957), US (23,241), China (20,065), Ethiopia (17,835), Cameroon (16,672) and South Africa (16,584 ha). Again, these are reported 2016 data, so they are not today's data, but they reflect world trends. Lately we are seeing that China is becoming a major producer. This country is now on the verge of becoming the largest importer of Chilean and Mexican avocados and Mission Produce of CA is in the process of installing a second ripening facility (personal communication with Mission).

There is no doubt that Mexico is still the big player in the avocado market place with 1.8 million metric tons produced in 2017/18 according to USDA Foreign Agricultural Service (2017) with other countries producing substantially less (FAOSTAT, Chart 1).

Chart I. Avocado Production (tons) for 10 largest producers, 2016.



In most cases the statistics are based on ‘Hass’ production and fruit movement. Dominican Republic is an interesting case that is exemplified by several other countries in the more tropical avocado growing areas. In this case where per capita consumption is so high, 70% of the fruit produced is of West Indian origin, and ‘Hass’ takes second place. Columbia is similar with nearly 330,000 tons of avocado production, and only 60,000 of which is ‘Hass’.

Much of this non- ‘Hass’ is also exported to other countries, indicating consumer interest in other types of fruit. Which brings up the concern about one variety planted world-wide. There are examples of crops being devastated by disease, witness Citrus Greening or Huanglongbing that is affecting most of the citrus producing areas of the world. To have one single variety in the trade could lead to an Armageddon if something like Laurel Wilt Disease which is currently affecting Florida avocados were to take off (EDIS, 2017).

To that end, there are numerous breeding programs around the world to introduce some genetic variability into the ‘Hass’ stream. This is not only for scions like ‘Hass’, but also for rootstocks that are more tolerant of Avocado Root Rot, White Rot, salinity and other production issues. University of California has several scion varieties that have been released, such as, ‘GEM’, ‘Harvest’, and ‘Sir Prize’. Other varieties have been released from Mexico (‘Carmen’), South Africa (‘Maluma’) and Israel (‘Lavi’). There are many hundreds of named avocado varieties and with the rise of avocado prominence, maybe some of these other varieties will see new light. In most countries consumers have more than one variety of apple or potato available. Why not more than one avocado?

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Evaluating Cost Effectiveness of High Density Planting of Avocados: Experiment on Water and Pruning

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The Coastal Region of California is the main production area for avocados. San Diego County has been the leading County in acreage and production. Beginning the early 1990s, escalating water costs driven by rapid urban development and the competition for land and water resources drove water cost incredibly high in this area, therefore resulting in the industry's decline in the region, particularly in San Diego County. Acreage declined from 33,310 acres in 1990 to 18,400 acres in 2014 in this county. Currently water cost estimate in San Diego is at $1,600/ac. ft. Further increase projection to $2,000/ac. ft. by year 2020 is of major concern.

An experiment to evaluate the potential of high density planting for improving yield and economics was conducted by Dr. Gary Bender (Subtropical Horticulture Farm Advisor Emeritus, San Diego County) principal investigator and team (Sonia I. Rios, Subtropical Horticulture Farm Advisor for Riverside and San Diego Counties and Gary Tanizaki (SRA in San Diego), funded by the Avocado Commission. This analysis is based on a 3 years data obtained from the experiment on yield, water, and pruning requirements (data that were monitored in the trial).

We estimated the costs of water and pruning for the experiment and compared them with the costs of the conventional practices we developed in 2011 (adjusted for inflation). We compared the costs on cost of a unit of production, i.e. cost per lb. of yield (Table 1).

Figure 1. (10' x10' spacing) of 72 trees of Hass and Lamb Hass avocados were planted in Valley Center, CA in August 2012. Also, a pollinizer Zutano tree was planted for every 8 Hass trees.

Table 1. Comparting costs of Water and Pruning for High Density Planting and Conventional Planting of Hass Avocados			
Planting Space	Average Yield (3 years)	$/lb.	
	lbs./Acre	Water	Pruning
High density (10'x10'; 387 Hass trees + 43 Zutano/acre)	19173	0.29	0.07
Conventional (20'x20'; 109 trees best managed grove)	9000	0.62	0.17
Conventional (20'x20'; 109 trees/acre county average)	5925	0.95	0.26

The costs per lb of high-density water and pruning showed to be relatively lower than the conventional method (Table 1), hence high density showing cost effectiveness to those inputs. However, it should be noted that this is just a partial analyses. A complete budget development including costs of establishment and capital investment analyses will be needed to make a sound conclusion.

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Herbicide injury in avocado

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Although the main objective of herbicide use in avocado orchards (and all crops) is to manage weed populations, sometimes unintentional injury of the crop itself can occur when herbicides are incorrectly applied. Herbicide injury in avocado can reduce yield, decrease fruit, reduce plant vigor, increase susceptibility to diseases and pests, and sometimes result in plant death. Common situations resulting in injury include spray drift, tank contamination, application of the wrong herbicide or rates, and herbicide carryover from a previous crop. The extent of herbicide damage on avocado can vary widely according to factors such as herbicide mechanism of action (MOA) and application rate, route of exposure, plant size and growth stage, soil properties, and weather.

Herbicide injury can be difficult to diagnose properly and is often confused with disease, insect damage, nutrient deficiencies, and other environmental stresses. It is recommended that trained researchers or Pest Control Advisers, who may utilize plant tissue, make diagnoses or soil samples along with plant symptoms, injury progression, and other plant species affected, orchard herbicide use history, weather conditions, and other factors to confirm or rule out injury from herbicides or other causes.

Where the injury occurs can also be an indication of herbicide injury. For example, if injury is on just one side of a tree or trees near another field, it may be an indication of spray drift. If it occurs only along the edge of the skirts, it may be a hint that an uneven ground spray was applied.

The majority of herbicides for use in avocado orchards in California fall into eight MOAs as defined by the Weed Science Society of America. MOAs describe the specific biological processes that are disrupted by a group of herbicides. These processes control the growth and development of plants and when interfered with, can result in plant injury or death.

Table 1: Common herbicides used in avocado, their mechanism of action, and possible injury symptoms

WSSA Group	Mechanism of Action	MOA description[1]	Example herbicides	Possible injury symptoms[1]
1	Acetyl CoA Carboxylase (ACCase) Inhibitors	Inhibits lipid creation in grasses, preventing production of plant cell membranes	Fluazifop-P-Butyl (Fusilade DX), Sethoxydim (Poast)	Chlorosis, necrotic spots, leaf crinkling, leaf distortion
3	Mitosis Inhibitors	Inhibits cell division in germinating seedlings and lateral roots	Oryzalin (Surflan)	Thickened, shortened lower stems and small, crinkled leaves
5	Photosystem II Inhibitors	Prevents the transfer of energy generated during photosynthesis, causing a buildup of reactive molecules that damage chlorophyll and cell membranes	Simazine (Princep 4L)	Chlorosis, necrosis progressing from leaf margins toward the center of the leaves, foliar applications will appear as leaf burn
9	Enolpyruvyl Shikimate-3-Phosphate (EPSP) Synthase Inhibitors	Inhibits the production of three aromatic amino acids and the enzymes and proteins built from them	Glyphosate (Roundup)	Leaves of trees and vines become chlorotic 3 to 7 days after exposure, and margins of new leaves become necrotic
12	Carotenoid Biosynthesis Inhibitors	Inhibits production of carotenoid pigments, which harvest light and protect chlorophyll from reactive molecules	Norflurazon (Solicam DF)	Plant foliage turns white and appears bleached
14	Protoporphyrinogen Oxidase (PPO) Inhibitors	Blocks the production of chlorophyll and causes a buildup of reactive molecules that damage existing chlorophyll, carotenoids, and cell membranes	Oxyfluorfen (Goal 2XL), Carfentrazone (Shark EW), Flumioxazin (Chateau)	Drift injury will appear as speckling on leaf tissue. The necrotic spots are sometimes surrounded by a reddish colored ring. Injury from soil applications or residues appears as a mottled chlorosis and necrosis.
21	Cellulose Inhibitors	Inhibit cell wall synthesis and plant growth	Isoxaben (Gallery 75 DF)	Chlorosis, necrosis, leaf crinkling, leaf distortion, purpling of the leaf, and stunting
22	Photosystem I Inhibitors	Disrupts photosynthesis, forming reactive molecules that destroy cell membranes	Paraquat (Gramoxone SL)	Drift injury will appear as speckling or necrotic spots on leaf tissue

[1]Not a complete list. Symptoms listed are likely for established orchards. For detailed descriptions of MOAs and injury symptoms, as well as a searchable database of specific injury images (e.g., "chlorosis, necrosis, stem swelling, etc." visit http://herbicidesymptoms.ipm.ucanr.edu.

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