Bees of the Pine Hill Preserve

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Cover photos: upper left: *Hoplitis albifrons* on *Wyethia angustifolia* (photo: L. Couper); top right: *Halictus farinosus* on *Triteleia laxa* (photo: L. Couper); bottom right: *Bombus melanopygus* on *Salvia sonomensis* (photo: E. Lopez); bottom left: *Diadasia bituberculata* on *Calystegia stebbinsii* (photo: E. Lopez).

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Glossary

Throughout the report, technical terms link to this glossary.

Agroecosystems—The ecosystems represented by human-managed agricultural systems, including soils, cultivated plants, weeds, and associated microorganisms. Although these are often highly modified and manipulated, ecosystem processes continue in such systems.

Asymptote—When the slope of a function begins to decrease.

False positive—In a statistical model, when a result is supported by the model when in fact it is not a correct Result. This contrasts with a *false negative*, in which a model fails to detect patterns that are present in the data. Both types of results can be misleading. False positives are most common in statistical models that test many relationships simultaneously.

Null model—In statistics, a null model is an artificial dataset generated with random samples of a specific statistical distribution. A null model reflects the expectation of what the data would look like if the underlying process were random (for example, if a bee did not show any preference for a particular plant). By comparing the null model to the real data, it is possible to determine whether the observed data is significantly different from what would be expected under random conditions (e.g., do bee species show a preference for particular plant species).

P—The threshold of statistical significance. In most statistical tests, a results is evaluated based on a pre-defined threshold. The most common threshold is $P < 0.05$, which means that the result shown by the test is expected less than 5% of the time due to random chance. Thresholds help to reveal whether a given result is meaningful, or just a random occurrence.

Standard error—A measure of the statistical accuracy of an estimate based on modeled data. This is equal to the standard deviation (amount of dispersion) across a large number of such models. The standard error thus gives a measure of the how much variation there was in a model. For example, if in 100 iterations of a null model, the mean result is 100, and the standard error is 10, then most of the iterations gave a result between 90 and 110.

Systematics—The study of relationships amongst organisms, including taxonomy, phylogenetics (trees), and nomenclature.

Executive Summary

Gabbro-derived soils of northern California's Pine Hill formation are a hotspot of vascular plant diversity and endemism. More than 10% of California's native vascular plant species are known to occur within the 50 km^2 area of the Pine Hill formation, including eight rare species, five of which are endemic to the formation. As in most terrestrial ecosystems, nearly all of the flowering plant species of the Pine Hill formation depend on insects, especially bees, to facilitate sexual reproduction. However, little is known about pollinator diversity and plant-pollinator interactions in this area. Information on pollinators of the Pine Hill formation will help to facilitate management practices that incorporate plants and pollinators.

Dylan Burge was contracted by the Motherlode Field Office of the United States Bureau of Land Management to conduct a study on the relationships between plants and native bees on the Pine Hill formation. The goal was to determine how the diverse and highly endemic flora of the Pine Hill area effects the diversity of native bees. Over the course of five years, surveys at 16 sites were used to determine which bees are associated with plants of the Pine Hill formation. The study identified 145 native bee species visiting 65 native plants. Several native plants hosted a disproportionate amount of bee diversity (up to 40 species). The eight rare plants of the Pine Hill formation hosted 68 bee species (47% of the fauna), with at least one near-specialist bee species in the context of this study, Diadasia bituberculata, which mainly visited *Calystegia stebbinsii*. The results have implications for habitat and rare plant management on the Pine Hill formation.

Introduction

An extensive body of research supports the idea that native bees are among the most important pollinators of wild flowering plants (Brown and Paxton, 2009; Ollerton et al., 2011; Kremen, 2018) and crops (Kremen et al., 2002; Kremen, 2005; Losey and Vaughan, 2006; Winfree et al., 2007; Lautenbach et al., 2012; Garibaldi et al., 2013). Recent research suggests that native bee populations are in dramatic decline the world over, likely as a result of climate change, pesticide use, habitat loss, and pathogens (Cane et al., 2006; Winfree et al., 2007; Grixti et al., 2009; Murray et al., 2009; Potts et al., 2010; Cameron et al., 2011; Goulson et al., 2015). Declines in native bees, if not reversed, may lead to declines in native plant species that depend on them for pollen dispersal (Kearns and Inouye, 1997). Such declines are likely to be dramatic for rare plants, in which populations are often small (Spira, 2001; Wilcock and Neiland, 2002).

The dire state of wild bee populations and the potential for risks to both native flora and agroecosystems is motivating increased research scrutiny, including studies on bee systematics and taxonomy (Gonzalez et al., 2012), patterns of bee diversity across the landscape (Forrest et al., 2015; Senapathi et al., 2017), factors that promote bee diversity and abundance (Carvell et al., 2011; Williams et al., 2012; Pardee and Philpott, 2014), and the response of bees to specific human-induced pressures, including pesticides (Lundin et al., 2015), honey bees (Mallinger et al., 2017), invasive plants (Stout and Tiedeken, 2017), pathogens (Collison et al., 2016), and climate change (Brittain et al., 2013; Renner and Zohner, 2018). Such work is likely to yield insights that will help preserve native bees and the plants that depend upon them.

The present research focuses on the Pine Hill formation, a hotspot of botanical diversity and endemism in the foothills of the central Sierra Nevada of California (Figure 1; Wilson, 1986; Hunter and Horenstein, 1991; Wilson et al., 2009); the formation hosts around 10% of the native vascular plant species known to occur in California, including seven rare and endangered plant species (Table 1), three of which are endemic (CNPS Rare Plant Program, 2019; Wilson et al., 2009; USFWS, 1996). As in most of the world's terrestrial ecosystems, nearly all of the vascular plant species of the Pine Hill formation depend on insects, especially native bees, to facilitate pollen dispersal and sexual reproduction. However, very little is known about plant-pollinator interactions in this region, especially on rare plants.

In order to prescribe objective, defensible conservation and management measures that will preserve both plant and bee diversity in the Pine Hill region, there is a need for information on the bee species that are associated with each of the plants, and the conditions that predict their occurrence. Using a set of 16 sites selected to represent the diversity of habitats on the Pine Hill formation, a multi-year (2014-2019) hand net survey was carried out. This data was then used to determine 1) how many native bee species are likely present on the Pine Hill formation, 2) which bee species pollinate the rare plants, and 3) which bees are specialists in the context of the study. Based on the results, recommendations are made as to management and conservation measures that might help to preserve the plant-bee mutualism on the Pine Hill formation.

Taxon	CNPS	Endangered Status	Endemic
Calystegia stebbinsii Brummitt	1B.1	Federal/State Endangered	Yes
Ceanothus roderickii W. Knight	1B.1	Federal Endangered	Yes
Chlorogalum grandiflorum Hoover	1B.2	--	No
Crocanthemum suffrutescens (B. Schreib.) Sorrie	3.2	--	No
Fremontodendron decumbens R.M. Lloyd	1B.2	Federal Endangered	Yes[1]
Galium californicum subsp. *sierrae* Dempster & Stebbins	1B.2	Federal Endangered	Yes
Packera layneae (Greene) W.A. Weber & Á. Löve	1B.2	Federal Threatened	No
Wyethia reticulata Greene	1B.2	--	Yes

Table 1. Rare plants of the Pine Hill formation.

CNPS: rare plant status according to the California Native Plant Society (CNPS Rare Plant Program 2019). *Endangered Status:* listing in California state or federal endangered species program (USFWS, 1996). *Endemic:* found only on the Pine Hill formation.

[1]Some plants potentially assignable to this taxon are found off of the Pine Hill formation.

Methods

Bee-plant interaction survey

Preliminary collections of bees were obtained by L. Eldredge and D. Burge between 16 April 2014 and 25 November 2017, during a pilot investigation of bee diversity on plants of the Pine Hill formation. These were obtained from six sites (Table 2, *Preliminary*). The sites were selected to maximize the number of rare plant species co-occurring, and were only visited when rare plants were known to flower. At each site, bees were collected within a 500 m radius of the coordinates given in Table 2. Bees were collected using a hand net, secured in plastic vials, and labeled with the associated plant. Bees were killed by freezing. Plants from which bees were collected were identified according to the Jepson Manual (Baldwin et al., 2012).

Following the preliminary collection efforts, an expanded, systematic hand-net survey was carried out, targeting a larger number of sites. Sixteen sites were selected for this work (Figs. 1, 2; Table 2). These were selected to maximize representation of rare and endangered plant species known to occur (Table 1), but also to represent habitat types (chaparral, forest, and savanna) on the ~ 100 square mile area of the Pine Hill formation, which helped to ensure a broad cross-section of native plant diversity was represented at the sites. From 4 February 2018 to 17 August 2018, the sites were visited at least once per month, and at least one hour spent at each site searching for bees visiting plants. Such bees were collected as described above.

Following the 2018 systematic survey, some additional collections were obtained from several plant species at the same subset of sites used for preliminary collecting. These collections targeted sites supporting two rare plants that were not well represented in the 2015-2018 sample, *Packera layneae* (Greene) W.A. Weber & Á. Löve and *Calystegia stebbinsii* Brummitt. However, all other bees observed visiting flowering plants were also collected. The bee collections were obtained on 20 April 2019 and 12 May 2019. Methods were as above.

All bee samples were stored frozen until they could be processed. Upon processing, bees were thawed, pinned, labeled, and sorted according to family and genus. Identification of bees to

the species level was carried out mainly by D. Burge and L. Eldredge; bees from *Lasioglossum* subgenus *Dialictus* were identified by J. Gardner (University of Manitoba). Some identifications were carried out or confirmed by R. Thorp and T. Zavortink (Bohart Museum of Entomology, U. C. Davis). Only female bees were identified and included in the analysis, as, in general, female bees play a more significant role in pollination than male bees (Ne'eman et al., 2006).

Site Name	Code	Preliminary	Habitat	Latitude	Longitude
Airborne Lane	AL	--	Savanna	38.7504	-121.0200
American River	AR	--	Chaparral	38.7642	-121.0227
Cameron Park 1	CP1	Yes	Chaparral	38.6758	-120.9729
Cameron Park 2	CP2	--	Forest	38.6779	-120.9715
Crocker Creek	CC	--	Savanna	38.7406	-121.0231
Dorado Ridge	DR	--	Savanna	38.7644	-121.0328
Farview	FV	--	Chaparral	38.7312	-120.9948
Kanaka Valley	KV	Yes	Savanna	38.7540	-121.0260
Meder Road	MR	Yes	Chaparral	38.6800	-120.9767
Mira Loma	ML	--	Savanna	38.6885	-120.9775
Pine Hill	PH	Yes	Chaparral	38.7199	-120.9891
Ponderosa 50	P50	Yes	Chaparral	38.6639	-120.9552
Salmon Falls	SF	Yes	Chaparral	38.7601	-121.0320
Square Nail	SN	--	Savanna	38.7786	-121.0063
Tiffany Hill	TH	--	Chaparral	38.7202	-120.9598
Wildcat Canyon	WC	--	Chaparral	38.7696	-121.0076

Table 2. Sites targeted for bee and plant surveys.

Code: code used to refer to the site in figures and datasets. *Preliminary:* included in early collections, between April, 2014 and November, 2017. *Habitat:* habitat type at the site. Latitude and Longitude are in the WGS84 datum. See Figure 1 for locations of these sites on the Pine Hill formation, and Figure 2 for photos.

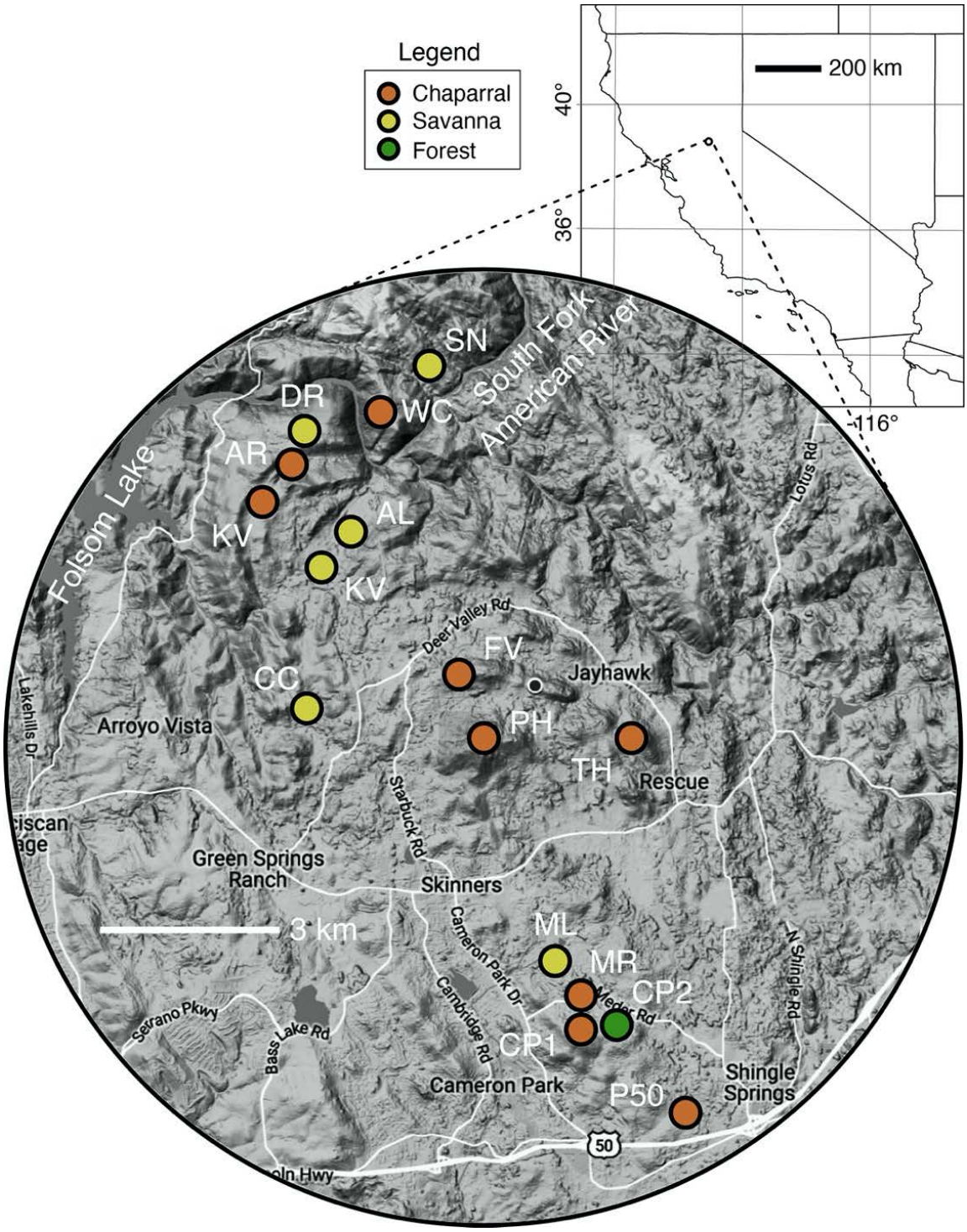

Figure 1. Overview map of sites targeted for bee and plant surveys.

Grid dimensions are in degrees of latitude and longitude (WGS84 datum). See Table 1 for more information on the sites, and Figure 2 for photos of the sites.

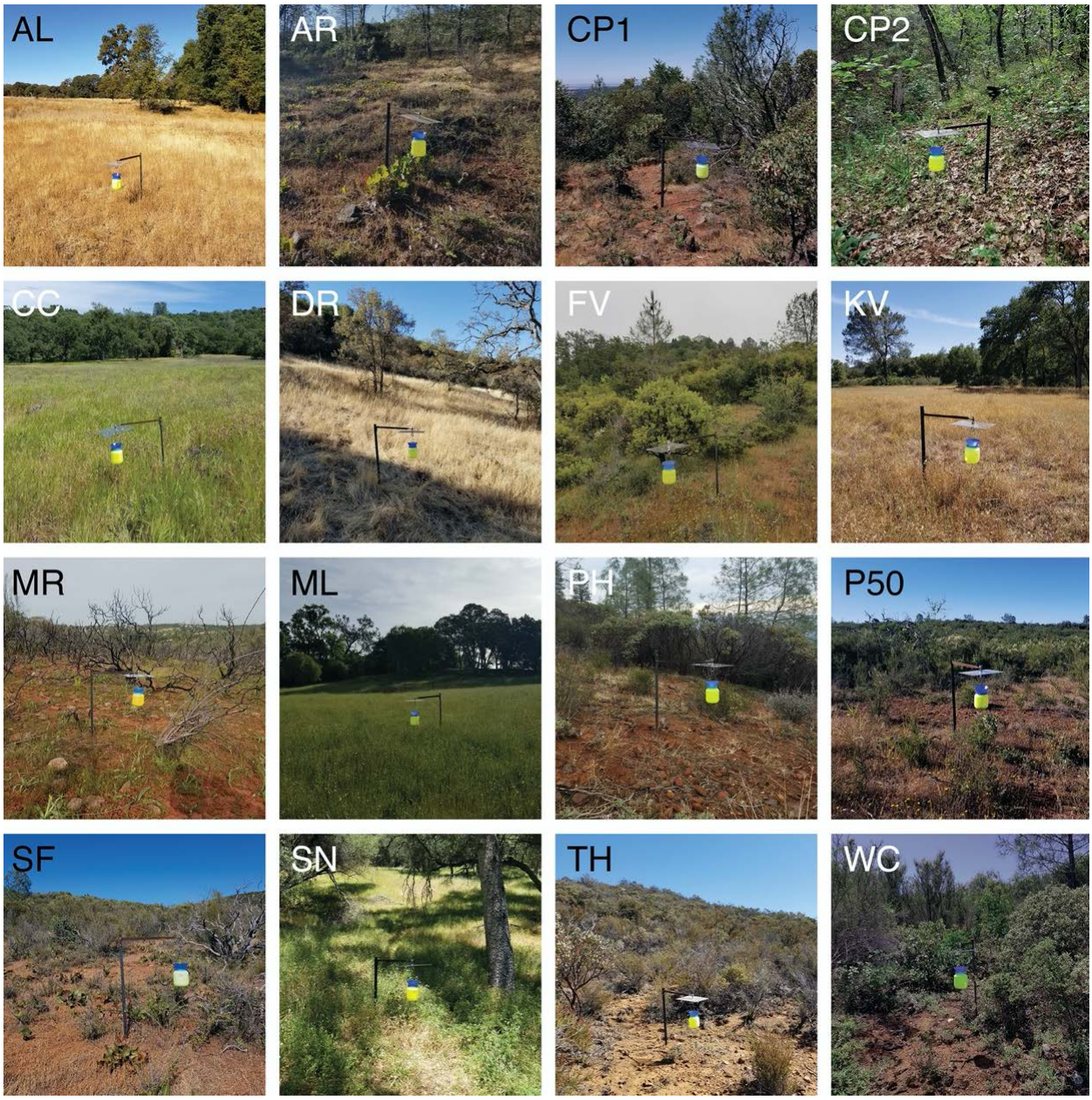

Figure 2. Photos of sites targeted for bee and plant surveys.
See Table 2 for more information on sites. Blue vane traps (~ 1.0 m tall) are shown for scale. All photographs taken by D. Burge in 2018.

Ecological network analysis

Relationships between bee and plant species were tested and visualized using the R package *econullnetr* v 0.2.0 (Vaughan et al., 2018). The package *econullnetr* was developed to aid in discerning the strength of interactions in predator-prey and plant-pollinator interactions (Vaughan et al., 2018). It tests the strength of interactions between plant-pollinator pairs by