

Bees of The Presidio of San Francisco

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September 2019**

In areas like California, a ‘priority ecoregion,’ where high biological diversity and growing human land-use collide (Ricketts and Imhoff, 2003), there is a need to know how to manage natural habitats to support native species. The remaining fragments of these natural habitats within the urban envelope (i.e. parks) provide a unique opportunity for conservation. Urban parks can be reservoirs of biodiversity (Frankie and Ehler, 1978, Bolger et al., 1997*a, b*, McFrederick and LeBuhn, 2006, Clarke et al 2008), corridors for migration or dispersal (Bowne et al., 1999, Fried, 2005) and temporary refuges (Marzluff and Ewing, 2001, Martell et al., 2002, Palomino and Carrascal, 2005). Parks, especially wild-lands within parks, when managed and designed appropriately, are the basis for maintaining biodiversity within cities. Not only do they support wildlife, these urban natural areas provide a connection with nature to urban dwellers, and can serve as a testing ground for natural area management for the future (Marzluff and Ewing, 2001, Connor et al., 2002, Watts and Lariviere, 2005).

The Presidio of San Francisco, a 6.08 km² national park at the northern end of the San Francisco Peninsula contains some of the largest wild areas left in the urban envelope. While surrounded by saltwater on two sides and dense urbanization on the other two, it is an important reservoir of biodiversity and a unique area for nature conservation. Because of its long history of monitoring, the Presidio can be viewed as a sentinel site for our California coastal habitats in a changing climate.

In 2004 and 2008, surveys of the native bee populations were undertaken by Dr. John Hafernik and his students (Wood et al 2005, Van Den Berg et al 2009). In 2004, they sampled nine sites once per month from March to October. Five sites were restored habitats of varying age at the time of sampling: Crissy Field, Inspiration Point, Lincoln and Pershing, Lobos Creek Valley, and World War II Memorial. Two additional sites, Battery Marcus Miller and Presidio Hills comprised small areas of relatively intact native habitat. Thompson Creek and Lobos Creek Valley Historic Forest were severely degraded. 2,418 bees were collected representing 23 genera and 60 morphospecies (Van Den Berg et al 2009). The most diverse sites were Presidio Hills, Thompson Creek, and Lobos Creek Valley with 37, 29, and 28 species respectively. These sites also had the highest abundance with 490, 535, and 526. (Van Den Berg et al 2009). In 2008-2009, four sites were sampled six times in 2008 (April, May, June, July August, October) and three times in 2009 (February and twice in April). 975 bees were collected in the pan traps from six families, 18 genera, and 26 species. Six of these species were new (Van Den Berg et al 2009). A new species (*Stelis* nr *franciscana*) was netted at Lobos Dunes. (Van Den Berg et al 2009). These collections provide a baseline data set to track overall pollinator health in the Presidio. In addition, there are a set of coastal specialist bees that are of particular interest including *Anthidium palliventre*, *Andrena barbilabris*, and *Lasioglossum pavonotum*. These bees are found only in coastal regions and their persistence in the Presidio is a testament to the ecological history of the site. It is also surprising that *Anthophora bomboides*, another coastal specialist was not detected in any year.

Key points:

- Overall in the Presidio, the 2018 species richness detected represents a decline in species richness relative to what was detected in 2004 which had slightly less intensive sampling.
- Baker Beach, Lobos Creek Valley Historic Forest, Inspiration Point, and WWII Memorial had increases in their species richness and abundance. Each of these sites has a high diversity of flowering plants, although plant diversity was not formally quantified at these sites.

- WWII Memorial and Inspiration Point had the most unique species.
- Presidio Hills and Lobos Creek Valley /Lobos Dune had large declines in species detected.
- Twenty-one species were newly detected in 2018.
- For the 44 species that were detected in different years, three species showed significant decreases in population size and three species showed significant increases.
 - *Bombus vosnesenskii* and *Agapostemon texanus*, two common species, appear to be declining.
- Three species that were previously in reasonably high abundance in 2004 (*Lasioglossum* (*Erylaeus*) *sp. 1*, *Anthophora urbana* and *Halicus ligatus*) were not detected again in either 2008 or 2018.

Methods.

Field Sampling. We sampled bees at 11 locations (Figure 1, Appendix A) within the Presidio National Park, San Francisco, CA, USA. To exactly match previous sampling, we visited each site with Dr. John Hafernik, the previous principal investigator and we geo-located each of his previous transects. The previous research used non-standardized methods for sampling so, we implemented a slightly modified sampling regime that more precisely matches current standards in the field (LeBuhn *et al.* 2013). At each site, we set a transect of thirty pan traps monthly from March to October 2018 (Appendix B). We painted the traps fluorescent blue, fluorescent yellow or did not paint them so they remained white. We deployed ten traps of each color per transect and we alternated the order of colors across the transect. Traps were placed out prior to 9:00 AM and picked up after 16:00 PM. Due to cool summers with rare heat waves, we chose to only sample on days where temperatures reached at least 15.5°C with little to no cloud cover and minimal wind. When we placed a pan trap, we filled it with soapy water. The water consisted a squirt of Dawn dishwashing liquid (approx. 15 mL) in one gallon (3.8 L) of water. Insects were collected by pouring the water through a small strainer and placing them in a whirl pack bag with enough 95% ETOH to cover the sampled bees. Bees were stored in the freezer until they could be washed, pinned and labelled. Once labelled, bees were identified by Jaime Pawelek using the previous collections as a guide. This allowed Ms. Pawelek to match morphospecies from the previous samples to the current samples. All specimens are labelled with species names and stored in the LeBuhn lab at San Francisco State University.

To compare data to regional records, we generated species lists from the online database of the insect collection at the California Academy of Sciences (<https://monarch.calacademy.org/collections/misc/collprofiles.php?collid=17>).

Analysis.

To look for trends in species richness and abundance between 2004 and 2018, we created a generalized linear model to estimate the slope of the curve between the two years. We considered

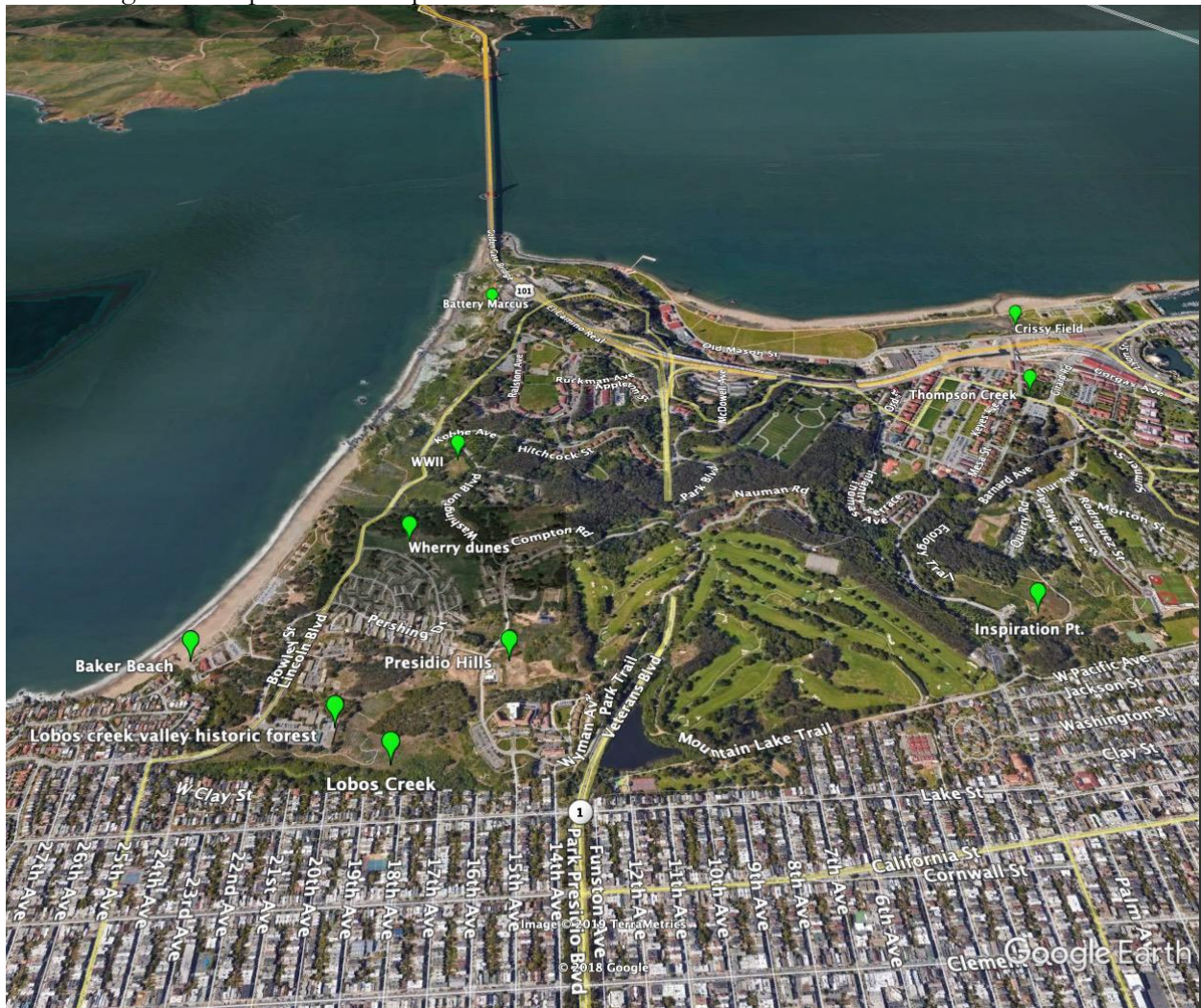
the number of traps deployed each year to be a covariate to correct for interannual variation in sampling effort. Species richness was normally distributed; therefore, we used a linear model. Abundance was better fit by a negative binomial distribution; therefore, we used a generalized linear model and assumed a negative binomial distribution. When the exact number of traps was previously reported as a range, we did the analysis using the high estimate, the low estimate and the mean estimate. There were no large differences in the slopes or the probabilities across the three analyses, therefore, we report the slope from the analysis using the mean estimate of sampling effort.

To look for trends in individual species population sizes between 2004, 2008 and 2018, we created a generalized linear model to estimate the slope of the curve between the earliest and latest year that a species was detected. For example, if a species was only detected in 2008 and 2018, the slope was estimated for the difference in abundance between those years. We did not do an analysis of species that were only detected in one year. We considered number of traps placed in a year to be a covariate. When the exact number of traps was previously reported as a range, we did the analysis using the high estimate, the low estimate and the mean estimate. There were no large differences in the slopes or the probabilities across the three analyses, therefore, we report the slope from the analysis using the mean estimate of sampling effort. As the data were overdispersed, we assumed a quasipoisson distribution.

To evaluate the impact of restoration on species richness and abundance, we created two generalized linear models. We used the earliest year that restoration was known to have been initiated as our metric for restoration. One model included the variable years since restoration. The other did not include it. Years since restoration, Year sampled, and Effort were all considered to be fixed effects. Site was considered to be a random effect. While the data are overdispersed, we could not use a quasipoisson distribution with a mixed effects model so, these are modelled as a Poisson distribution. The effect of Years since restoration was evaluated by comparing the difference in the AIC between the two models using a Log-likelihood test.

All analyses were done using R version 3.4.4. Code can be found in Appendix.

Figure 1. Map of sites sampled in the Presidio in 2018.



Results.

In 2018, we collected a total of 2,349 bee specimens representing approximately 58 species (Appendix C) from the eleven sites (Appendix E). Because the ten undetermined species represented by male specimens cannot be matched to females, the true species estimate is probably slightly less than 58. Though it is an overestimate, for the rest of the report, when we refer to number of species, we will include both male and females as if they were separate species. 97 species (84 species if we exclude undetermined males) detected in the three surveys. Note that this is equivalent to the number of species found in the count of San Francisco in the CAS collections though the species do not overlap completely.

We detected a negative trend over time for species richness (slope = -0.44, $p=0.26$) and no real trend for abundance (slope = -0.03, $p=0.43$). In neither case, was the decline statistically significant. Even though the decline in species richness from detected between 2004 and 2018 was not significant at $p<0.20$, we believe it is concerning.

The sampling in 2008 was so very different that a comparison between 2008 and 2018 is not valid.

Effect of restoration.

We detected a significant negative effect of year since restoration on bee species abundance (Log likelihood ratio = -7.52, $p < 0.05$) trend but no significant effect of year since restoration (Log likelihood ratio = 2.36, $p < 0.20$) on species richness. As the time since restoration increased, abundance decreased.

Because, the sample size is small ($N=11$) and both the method of restoration and length of time that the sites were actively being restored varied across sites, these results should be interpreted with caution. A larger sample size would increase the power of this test. The best designs for asking questions about the impact of management are before after control impact designs.

Individual species.

There is substantial year to year variation in the bee fauna. This variation probably reflects true interannual variation in species as well as variation due to sampling. Twenty-three of the 60 species detected in 2004 have not been found again. At the four sites sampled in 2008, five species detected in 2008 have not been detected again (Van Den Berg et al 2009). Twenty-one species were newly detected in 2018. Three of these species were in reasonably high abundance in 2004 (*Lasioglossum (Eurylaeus) sp. 1*, *Anthophora urbana* and *Halictus ligatus*) and their continued lack of detection should be of concern. None of the other species that have disappeared were detected in high abundance which makes it difficult to draw conclusions about their presence or absence. When species are in low abundance in surveys, the possibility that they are missed by sampling is greater.

The collections at the California Academy of Sciences (CAS) from San Francisco County are a reasonable species list for comparison. Their collection has 88 species recorded from San Francisco County. This list does not include the many unidentified or un-named specimens in the collection. If we compare the 2018 sample from the Presidio to the CAS collection, we find that there are eleven species not yet in the CAS collection (Table 1).

Table 1. Species detected in 2018 from the Presidio that are not in CAS collection from San Francisco County. This does not include morphospecies except for the genus *Dufourea* which is a new genus for their records.

<i>Andrena</i> (<i>Diandrena</i>) <i>submoesta</i>
<i>Andrena</i> (<i>Melandrena</i>) <i>cerasifolii</i>
<i>Andrena</i> (<i>Micrandrena</i>) <i>microchlora</i>
<i>Anthidium</i> (<i>Anthidium</i>) <i>manicatum</i>
<i>Diadasia</i> <i>bituberculata</i>
<i>Dufourea</i> sp. 1
<i>Halictus</i> (<i>Halictus</i>) <i>rubicundus</i>
<i>Hesperapis</i> (<i>Panurgomia</i>) <i>pellucida</i>
<i>Hylaeus</i> (<i>Paraprosopis</i>) <i>polifolii</i>
<i>Hylaeus</i> (<i>Prosopis</i>) <i>episcopalis coquilletti</i>
<i>Lasioglossum</i> (<i>Dialictus</i>) <i>incompletus</i>
<i>Lasioglossum</i> (<i>Dialictus</i>) <i>tegulariformis</i>

The number of bees collected varied from high diversity and abundances of 29 species (409 specimens) at Inspiration Point and 27 species (884 specimens) at the WWII Memorial to lower diversity and abundances at 7 species (66 specimens) at Lobos Creek Valley Historic Forest and 9 species (44 specimens) at Lobos Creek Valley (Table 2).

Table 2. Number of species detected by site in each year and the change in the number of species detected since 2004. Note that this does not correct for the significant variation in the sample effort from year to year at each site. The sampling was more intensive in 2018 than in either previous year which should increase the number of species detected if everything is equal.

	Species	Number of species detected	Change in number of species detected
BAKER BEACH	2008	6	
*NOTE THIS IS FROM 2008	2018	14	8
BATTERY MARCUS	2004	27	
	2018	20	-7
CRISSY FIELD	2004	21	
	2018	20	-1
THOMPSON REACH	2004	31	
	2008	21	-10
	2018	15	-16
LOBOS CREEK VALLEY HISTORIC FOREST	2004	17	
	2018	7	8
INSPIRATION POINT	2004	22	
	2018	29	7
WHERRY DUNES	2004	12	
	2018	11	-1
LOBOS CREEK VALLEY /LOBOS DUNE	2004	28	
	2008	23	-5
	2018	9	-19
PRESIDIO HILLS	2004	42	
	2018	17	-25
WWII MEMORIAL	2004	19	
	2008	28	9
	2018	27	8

Almost half of the species (31 species) were singletons meaning that they were collected at only of the sites. Which site species were detected varied across species. Many studies of bee

communities record large numbers of singletons, however, this is a higher proportion than is usually detected. WWII Memorial and Inspiration Point had the most unique species. This suggests that maintaining the quality of these sites will be key to management of the biodiversity of pollinator species.

We detected two species at all ten sites, *Lasioglossum (Dialictus) sp. 1*, and *Bombus (Pyrobombus) vosnesenskii*, and, two species at nine sites, *Lasioglossum (Lasioglossum pavonotum)*, and the Western Honey bee, *Apis mellifera*.

Species of Concern:

For the 44 species that were detected in different years, three species showed significant decreases in population size and three species showed significant increases (Appendix C). We evaluated significance at $p < 0.20$ as it is considered better to detect a false decline than to miss a true decline when managing species. We did not detect significant changes in population sizes in the remaining species. We caution that when species are in low abundance, it is very difficult to detect shifts in population sizes with any accuracy. In addition, there was variation in the amount of collecting effort between 2004, 2008 and 2018. The effort in 2018 was higher than in any of the previous years suggesting that detections should have been more likely. Thus, we interpret these species levels declines in abundant species to be notable.

***Bombus vosnesenskii*.** We were surprised and dismayed to detect a significant decline in population size of *Bombus vosnesenskii*, the “Western bumble bee”. *B. vosnesenskii* is currently the most common bumble bee in San Francisco and is considered abundant regionally. *B. vosnesenskii* has not been considered to be a bumble bee experiencing a population decline in the Western United States. It ranges from Mexico to Canada. It is a generalist that nests below ground with large colony sizes (~100-300 workers). In a previous study of bumble bees in San Francisco, the frequency of *B. vosnesenskii* was inversely correlated with the bee species richness suggesting that *B. vosnesenskii* outcompetes other bee species for space and resources (McFrederick and LeBuhn 2006). Studies have demonstrated that paved environments in human urban settings have reduced *B. vosnesenskii* nesting densities (Saifuddin and Jha 2014).

***Agapostemon texanus*.** We also detected a decline in different regionally abundant species, *A. texanus*. *A. texanus*, is a common sweat bee and one of the more charismatic native bee species because of its iridescent green coloring. *A. texanus* is generalist forager with a wide distribution. These bees are also ground nesting.

***Lasioglossum (Lasioglossum) pavonotum* (Cockerell).** We detected a decline in *L. pavonotum*, a small generalist bee known to visit *Eschscholzia californica* among other species.

Species that have increased their population size.

***Andrena chalybaea*.** *A. chalybaea* increased significantly during the period between 2004 and 2018. This species is a pollen specialist on *Taraxia ovata*. It constructs nests in heavy clay-loam soils where its plant host grows (Thorpe 1969).

***Megachile (Xanth.) perihirta* Cockerell.** *M. perihirta*, commonly known as the Western leafcutting bee, is found from Mexico to Canada. This is a generalist forager known to visit plants

from a broad range of families. Unlike many other members of the genus *Megachile*, this species nests in underground tunnels.

Lasioglossum (Dialictus) sp. MA. These males are only identified to morphospecies so, we cannot speak to its biology.

Other bees of note. We did not detect *Stelis* nr. *franciscana*, or the coastal bees, *Anthidium palliventris* and *Andrena barbilabris* in 2018. However, we did detect relatively large numbers of *Lasioglossum pavonotum*, another coastal specialist.

Functional traits of bees.

We did not see shifts in the frequency of foraging or nesting habits represented in the bee species found in 2004 and 2018 (Table 3).

Table 3. The foraging and nesting behaviors of female bee species found in 2004 and 2018.

	Foraging							
	Generalist		Parasite		Specialist		Unknown	
NESTING	2004	2018	2004	2018	2004	2018	2004	2018
CAVITY	8	7			1	1	4	3
GROUND	29	28			6	5	5	3
PARASITE			4	2				
UNKNOWN	1							

Summary and recommendations.

We detected a decline in the species richness and significant declines in two of the most common species at the Presidio. At this point, we cannot say whether these declines are specific to the Presidio, the city of San Francisco or part of a larger trend in California. We would suggest that the Presidio continue to implement formal sampling on a five-year interval to ensure there are not greater declines. Increasing the number of sites sampled would enhance our ability to detect trends and creating a structure specifically designed to test management options (restored versus un-restored) would help provide more management directions.

An analysis of the bee species that are declining did not suggest a specific causal agent as both *Agapostemon texanus* and *Bombus vosnesenskii* are ground nesting generalist bees like many of the other species that are not of concern. Given the restoration that has happened at the Presidio, these results are surprising. Putting these data into a city-wide or regional context would help to understand how best to manage for pollinators. Both of these species of concern are fairly easy to identify. It may be possible to set up a volunteer monitoring program to establish a baseline and detect trends in the future. We would envision a sampling regime that had a variety of sites across the Presidio, preferably in areas with high floral abundance and richness where volunteers did standardized counts of these species. The *A. texanus* is distinctive enough that it is unlikely to be confused with any other species when observed on a flower. The bumble bee, *B. vosnesenskii*, is easily confused with two other bee species found in the Presidio. For the bumble bee, we would recommend catching and photographing individuals to ensure that the bee is truly *B. vosnesenskii*.

There was the suggestion in the data that the as sites get further from the date they were restored, there may be a decline in bee species richness. Since bees do not prefer to forage in shady areas, this is not unexpected when part of restoration may lead to canopy increase or canopy closure. In some habitats, regular disturbance can maintain diversity (Winfree *et al* 2009)

While we did not survey plant species richness formally in this study, we were aware that the sites where we were detecting more bees had more flowers and more species of flowering plants. Numerous studies have shown that at a local scale (e.g. Hülsmann *et al.* 2015, Sutter *et al.* 2017), having a diversity of flowering plants across the flight season contributes to the maintenance of healthy pollinator communities. Continuing to enhance the plant species richness in the Presidio and including native plant species that are more likely to support specialist native pollinators as well as generalists like the *Bombus vosnesenskii* and *Agapostemon texanus*, should benefit these communities.

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List of Appendices.

Appendix A. Site and sampling descriptions from 2004-2018. Parts of this table are from 2005 report.

Appendix B. Total number of pan traps recovered by date by site in 2018. Each site and date started with 30 traps.

Appendix C. Bee species abundances at each site during 2018 field season. Males of unidentified species use letters for the specific epithet. Females use numbers.

Appendix D. Slopes of differences in abundance by species between earliest and latest sampling period a species was detected. Those species in bold have a significant change in abundance across the Presidio as a whole at $p < 0.20$. The value of “slope” indicates whether the species are increasing or decreasing between the two years. If the bee was only caught in 2004 and 2008, the slope reflects the difference between those dates. These slopes are corrected for the differences in effort between sample periods by using the effort in each sampling season as a covariate.

Appendix E. Reconciliation of Historic and Contemporary Site Names.

Appendix F. R Code used for analysis.

Appendix A. Site and sampling descriptions from 2004-2018. Parts of this table are from 2005 report.

Site	Dimensions (m ²)	# of pan traps 2004	# pan traps 2010	# pan traps 2018	Site descriptor from 2005	Restoration data from 2005 report	Restoration data from J. Young 2019
Battery Marcus Miller		10 - 16	21	30	Coastal bluff -- mostly native, fairly pristine		2007
Crissy Field	65 X 50	10	21	30	Sand dunes - - mostly native	Fall 1998	1999
Thompson Reach	100 X 75	20 - 22	21	30	Army landfill -- mostly invasive s, degrade d land	to be restored	Tennessee Hollow, Thompson Reach subsite. From database records planting started in 2005/2006
Lobos Creek Valley Historic Forest	100 X 100	20 - 30	21	30	Non- native planted trees -- only a few invasive s as underst ory		Still cypress forest.

Inspiration Point	70 X 60	13 - 15	21	30	Serpentine grassland -- both native and non-native grasses	Winter 2000-01	Inspiration Pt., East Grassland. From database records planting started in 1996 but picked up in 1998/1999.
Wherry Dunes	40 X 85	10	21	30	Coastal shrub -- mostly native	Fall 1997	Southwest Dunes, North Pershing Dunes. From database records planting started in 1996.
Lobos Creek Valley	167 X 60	20 - 30	21	30	Sand dunes - mostly native	Fall 1995	1996
Presidio Hills	65 X 65	13 - 20	21	30	Shrub - mostly native, some invasives		Presidio Hills, Landfill 8. From database records planting started in 2010
WWII Memorial	60 X 90		21	30	Sand dunes - mostly native	Fall/Winter 2003-04	World War II, Sunset Scrub subsite. From database records planting started in 2003/2004

Baker Beach (added 2008)			21	30			Baker Beach, Foredunes subsite. From database records planting started in 1994 but really picked up in 1999.
Presidio Hills (added 2008)			21	30			Pre sidio Hills, Landfill 8. From database records planting started in 2010

Appendix B. Total number of pan traps recovered by date by site in 2018. Each site and date started with 30 traps.

2018 sampling data	Baker Beach	Inspiration Pt.	Crissy Field	WWII	Marcus Miller	Lobos Creek Valley	Thompson Reach	Wherry dunes	Presidio Hills	Lobos Creek
April	15	29	29	30	30	30	30	30	30	30
May	30	29	29	30	29	30	30	30	30	30
June	29	30	24	30	29	30	30	30	30	30
July	30	30	30	30	30	30	30	30	30	30
August	26	30	29	29	30	30	30	30	30	30
September	26	30	30	28	30	30	30	29	30	30
Total	156	178	171	177	178	180	180	179	180	180

Appendix C. Bee species abundances at each site during 2018 field season. Males of unidentified species use letters for the specific epithet. Females use numbers.

Baker Beach	91
<i>Apis mellifera</i>	4
<i>Bombus</i> (<i>Pyrobombus</i>) <i>vosnesenskii</i>	3
<i>Ceratina</i> (<i>Zadontomerus</i>) <i>acantha</i>	24
<i>Ceratina</i> (<i>Zadontomerus</i>) <i>nanula</i>	2
<i>Colletes hyalinus gaudialis</i>	1
<i>Halictus</i> (<i>Seladonia</i>) <i>tripartitus</i>	1
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. 1	14
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. 5	8
<i>Lasioglossum</i> (<i>Dialictus</i>) <i>tegulariformis</i>	6
<i>Lasioglossum</i> (<i>Evyllaesus</i>) <i>kincaidii</i>	2
<i>Lasioglossum</i> (<i>Lasioglossum</i>) <i>pavonotum</i>	23
<i>Lasioglossum incompletum</i>	1
<i>Sphecodes</i> sp. 1	1
<i>Sphecodes</i> sp. 3	1
Battery Marcus	229
<i>Andrena</i> (<i>Euandrena</i>) <i>nigrocaerulea</i>	31
<i>Apis mellifera</i>	3
<i>Bombus</i> (<i>Pyrobombus</i>) <i>melanopygus edwardsii</i>	1
<i>Bombus</i> (<i>Pyrobombus</i>) <i>vosnesenskii</i>	3
<i>Ceratina</i> (<i>Zadontomerus</i>) <i>acantha</i>	19
<i>Ceratina</i> (<i>Zadontomerus</i>) <i>nanula</i>	29
<i>Colletes hyalinus hyalinus gaudialis</i>	9
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. 1	52
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. 4	2
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. 8	7
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. MC	1
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. MF	3
<i>Lasioglossum</i> (<i>Dialictus</i>) <i>tegulariformis</i>	3
<i>Lasioglossum</i> (<i>Evyllaesus</i>) <i>kincaidii</i>	1
<i>Lasioglossum</i> (<i>Lasioglossum</i>) <i>pavonotum</i>	2
<i>Lasioglossum incompletum</i>	52
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. MD	1
<i>Lasioglossum</i> (<i>Dialictus</i>) sp. ME	7
<i>Nomada</i> sp. 2	1
<i>Panurginus melanocephalus</i>	2
Crissy Field	258
<i>Apis mellifera</i>	1
<i>Bombus</i> (<i>Pyrobombus</i>) <i>vosnesenskii</i>	3
<i>Ceratina</i> (<i>Zadontomerus</i>) <i>acantha</i>	1

Ceratina (Zadontomerus) nanula	1
Colletes hyalinus hyalinus gaudialis	96
Epeolus minimus	4
Halictus (Seladonia) tripartitus	1
Hoplitis (Alcidamea) producta gracilis	1
Hylaeus (Paraprosopis) polifolii	2
Lasioglossum (Dialictus) sp. 1	23
Lasioglossum (Dialictus) sp. 5	12
Lasioglossum (Dialictus) sp. 8	3
Lasioglossum (Dialictus) tegulariformis	32
Lasioglossum (Evylaeus) kincaidii	59
Lasioglossum (Lasioglossum) pavonotum	5
Lasioglossum incompletum	3
Megachile (Sayapis) fidelis	1
Megachile (Xanthosarus) perihirta	2
Melissodes sp. 1	7
Sphecodes sp. A	1
Thompson Creek	89
Anthidium (Anthidium) manicatum	1
Apis mellifera	6
Bombus (Pyrobombus) vosnesenskii	4
Ceratina (Zadontomerus) acantha	25
Halictus (Seladonia) tripartitus	12
Hoplitis (Alcidamea) producta gracilis	16
Hylaeus (Prosopis) episcopalis coquilletti	1
Lasioglossum (Dialictus) sp. 1	3
Lasioglossum (Dialictus) sp. 4	3
Lasioglossum (Dialictus) sp. 8	2
Lasioglossum (Dialictus) sp. MH	1
Lasioglossum (Evylaeus) kincaidii	8
Lasioglossum incompletum	4
Megachile (Xanthosarus) perihirta	2
Osmia sp. MA	1
Lobos Creek Valley Historic Forest	66
Andrena (Euandrena) nigrocaerulea	1
Bombus (Pyrobombus) vosnesenskii	2
Halictus (Seladonia) tripartitus	3
Hoplitis (Alcidamea) producta gracilis	1
Lasioglossum (Dialictus) sp. 1	1
Lasioglossum (Dialictus) sp. 8	4
Lasioglossum (Lasioglossum) pavonotum	54
Presidio Hills	233
Apis mellifera	9

Bombus (Pyrobombus) vosnesenskii	1
Ceratina (Zadontomerus) nanula	4
Colletes hyalinus hyalinus gaudialis	5
Halictus (Halictus) rubicundus	2
Halictus (Seladonia) tripartitus	22
Lasioglossum (Dialictus) sp. 1	4
Lasioglossum (Dialictus) sp. 4	5
Lasioglossum (Dialictus) sp. 5	8
Lasioglossum (Dialictus) sp. 8	1
Lasioglossum (Dialictus) sp. MH	1
Lasioglossum (Dialictus) tegulariformis	41
Lasioglossum (Evylaeus) kincaidii	90
Lasioglossum (Evylaeus) sp. 2	1
Lasioglossum (Lasioglossum) pavonotum	19
Lasioglossum incompletum	17
Megachile (Xanthosarus) perihirta	3
Inspiration Pt.	409
Andrena (Diandrena) chlorosoma	9
Andrena (Diandrena) subchalybea	1
Andrena (Diandrena) submoesta	1
Andrena (Euandrena) auricoma	5
Andrena (Euandrena) nigrocaerulea	1
Andrena (Melandrena) cerasifolii	1
Andrena (Micrandrena) microchlora	1
Apis mellifera	2
Bombus (Pyrobombus) vosnesenskii	5
Ceratina (Zadontomerus) acantha	11
Ceratina (Zadontomerus) nanula	36
Colletes hyalinus hyalinus gaudialis	4
Dufourea sp. 1	2
Halictus (Seladonia) tripartitus	153
Lasioglossum (Dialictus) incompletus	4
Lasioglossum (Dialictus) sp. 1	1
Lasioglossum (Dialictus) sp. 4	14
Lasioglossum (Dialictus) sp. 8	55
Lasioglossum (Dialictus) sp. MH	1
Lasioglossum (Evylaeus) sp. 2	1
Lasioglossum (Evylaeus) sp. 3	1
Lasioglossum (Evylaeus) sp. 4	1
Lasioglossum (Lasioglossum) pavonotum	3
Lasioglossum (Lasioglossum) titusi	1
Lasioglossum incompletum	91
Lasioglossum (Dialictus) sp. MD	1

Osmia (Mystacoscma) nemoris	1
Osmia sp. MA	1
Sphecodes sp. 4	1
Wherry Dunes	46
Apis mellifera	2
Bombus (Pyrobombus) vosnesenskii	3
Ceratina (Zadontomerus) acantha	5
Ceratina (Zadontomerus) nanula	3
Colletes hyalinus hyalinus gaudialis	1
Hylaeus (Paraprosopis) polifolii	2
Hylaeus (Prosopis) episcopalis	5
Hylaeus (Prosopis) episcopalis coquilletti	4
Lasioglossum (Dialictus) sp. 1	4
Lasioglossum (Dialictus) tegulariformis	2
Lasioglossum (Lasioglossum) pavonotum	14
Lasioglossum incompletum	1
Lobos Creek Valley	44
Apis mellifera	4
Bombus (Pyrobombus) vosnesenskii	7
Colletes hyalinus hyalinus gaudialis	2
Halictus (Seladonia) tripartitus	1
Hesperapis (Panurgomia) pellucida	1
Hylaeus (Prosopis) episcopalis coquilletti	1
Lasioglossum (Dialictus) sp. 1	2
Lasioglossum (Dialictus) sp. 5	4
Lasioglossum (Lasioglossum) pavonotum	22
WWII	884
Agapostemon (Agapostemon) texanus	2
Andrena (Euandrena) nigrocaerulea	1
Apis mellifera	8
Bombus (Pyrobombus) vosnesenskii	4
Ceratina (Zadontomerus) acantha	2
Ceratina (Zadontomerus) nanula	1
Colletes simulans fulgidus longiplumosus	2
Diadasia bituberculata	1
Halictus (Seladonia) tripartitus	317
Hylaeus (Prosopis) episcopalis	1
Lasioglossum (Dialictus) incompletus	5
Lasioglossum (Dialictus) sp. 1	41
Lasioglossum (Dialictus) sp. 4	2
Lasioglossum (Dialictus) sp. 8	41
Lasioglossum (Dialictus) sp. MF	1
Lasioglossum (Dialictus) sp. MG	3

Lasioglossum (Dialictus) tegulariformis	1
Lasioglossum (Evyllaenus) kincaidii	1
Lasioglossum (Evyllaenus) sp. 18	1
Lasioglossum (Evyllaenus) sp. 2	185
Lasioglossum (Evyllaenus) sp. 4	1
Lasioglossum (Evyllaenus) sp. MA	14
Lasioglossum (Evyllaenus) sp. MB	4
Lasioglossum (Lasioglossum) pavonotum	3
Lasioglossum incompletum	238
Lasioglossum (Dialictus) sp. MD	1
Lasioglossum (Dialictus) sp. ME	3

Appendix D. Slopes of differences in abundance by species between earliest and latest sampling period a species was detected. Those species in bold have a significant change in abundance across the Presidio as a whole at $p < 0.20$. The value of “slope” indicates whether the species are increasing or decreasing between the two years. If the bee was only caught in 2004 and 2008, the slope reflects the difference between those dates. These slopes are corrected for the differences in effort between sample periods by using the effort in each sampling season as a covariate.

Species	N	Slope	Probability	Interval between sample years
<i>Agapostemon texana</i> Cresson	10	-3.14	0.12	14
<i>Andrena (Diandrena) chalybaea</i> (Cresson)	1	0.48	0.07	14
<i>Andrena (Euandrena) nigroaerulea</i> Cockerell	5	0.44	0.79	14
<i>Anthidium palliventris</i> Cresson	4	-7.36	0.45	4
<i>Apis mellifera</i> Linnaeus	15	0.09	0.59	14
<i>Bombus caliginosus</i> (Frison)	6	0.38	0.28	4
<i>Bombus melanopygus</i> Nylander	8	-0.07	0.76	14
<i>Bombus vosnesenskii</i> Radoszkowski	20	-0.84	0.02	14
<i>Ceratina acantha</i> Provancher	15	-0.50	0.69	14
<i>Ceratina nanula</i> Cockerell	11	-0.65	0.47	14
<i>Colletes hyalinus gaudalis</i> Cockerell	15	1.14	0.30	14
<i>Diadasia bituberculata</i> (Cresson)	3	-0.03	0.59	14
<i>Epeolus minimus</i> (Robertson)	1	-0.65	0.72	14
<i>Halictus tripartitus</i> Cockerell	16	-0.38	0.93	14
<i>Hesperapis pellucida</i> Cockerell	3	-1.81	0.48	14
<i>Hoplitis productus gracilis</i> (Michener)	3	-0.43	0.74	14
<i>Hylaeus (Prosopis) episcopalis coquilletti</i>	4	0.23	0.65	14
<i>Lasioglossum (Dialictus) incompletum</i> (Crawford)	12	-3.89	0.35	14
<i>Lasioglossum (Dialictus) sp. 1</i>	16	0.35	0.77	14
<i>Lasioglossum (Dialictus) sp. 4</i>	6	-2.30	0.64	14
<i>Lasioglossum (Dialictus) sp. 5</i>	9	-1.92	0.41	14
<i>Lasioglossum (Dialictus) sp. 8</i>	10	0.98	0.49	14
<i>Lasioglossum (Dialictus) sp. MA</i>	2	5.98	0.16	4
<i>Lasioglossum (Dialictus) sp. MB</i>	1	1.19	0.39	4
<i>Lasioglossum (Dialictus) tegulariformis</i> (Crawford)	12	0.71	0.49	14
<i>Lasioglossum (Erylaeus) kincaidii</i> (Cockerell)	5	-1.61	0.76	10
<i>Lasioglossum (Erylaeus) sp. 2</i>	5	4.99	0.43	14
<i>Lasioglossum (Erylaeus) sp. 3</i>	3	-0.94	0.62	14
<i>Lasioglossum (Erylaeus) sp. 4</i>	2	0.19	0.41	14
<i>Lasioglossum (Lasioglossum) pavonotum</i> (Cockerell)	15	-1.65	0.19	14
<i>Megachile (Xanth.) perihirta</i> Cockerell	4	0.14	0.02	14
<i>Melissodes lupina</i> Cresson	5	-0.32	0.73	4

<i>Osmia nemoris</i> Sandhouse	1	-0.49	0.89	14
<i>Sphecodes</i> sp. 1	2	0.00	0.67	14
<i>Sphecodes</i> sp. MA	4	-0.81	0.26	4

Appendix E. Reconciliation of Historic and Contemporary Site Names.	
Old Site Names (2004/2008)	Contemporary Site Name (2019)
Baker Beach	Baker Beach
Forested Site/Historic Forest	Lobos Creek Valley Historic Forest
Lobos Creek	Lobos Creek Valley
Southern Site/Hospital Hill	Presidio Hills
Lincoln & Pershing	Wherry Dunes
WWII Memorial	WWII Memorial/Sunset scrub
Battery Marcus	Battery Marcus
Fill Site 6/Thompson Reach	Thompson Creek
Crissy Field	Crissy Field
Inspiration Point	Inspiration Point

Appendix F. R code used for analysis.

```
#Program to generate data for analysis of population trends in bees

update.packages()
library(MASS)
library(broom)
library(lme4)
library(readr)
library(tidyr)
library(dplyr)
library(broom)
library(ggplot2)
library(ggmap)
library(maps)
library(RColorBrewer)
library(car)

setwd("~/Dropbox/Presidio_bees/Deliverables/2019 analysis/")

#Read in data
bee.sum<-read.csv( "data_04_08_18.csv")

#create data for each site in each year
site_yr <- group_by(bee.sum, site, year_sampled)
LPI_site<-summarise(site_yr, abund=sum(count),richness=n_distinct(species),
years_since_rest= max(years_since_rest), effort=mean(pans_min*sample_events)) ##change pans
variable to adjust for effort in 2004
#write.csv(LPI_site, "site.data.csv")

# data visualization of different distributions to determine what model to use.

qqp(LPI_site$richness, "norm")
#richness appears to be normally distributed
qqp(LPI_site$abund, "norm")

qqp(LPI_site$richness, "lnorm")
qqp(LPI_site$abund, "lnorm")

nbinom <- fitdistr(LPI_site$richness, "Negative Binomial")
qqp(LPI_site$richness, "nbinom", size = nbinom$estimate[[1]], mu = nbinom$estimate[[2]])

nbinom <- fitdistr(LPI_site$abund, "Negative Binomial")
qqp(LPI_site$abund, "nbinom", size = nbinom$estimate[[1]], mu = nbinom$estimate[[2]])
# Abundance is best fit by the negative binomial distribution

#plot data
p<-ggplot(LPI_site, aes(x=years_since_rest, y=pred.rich, label=site)) + geom_point()
```

```

p + geom_text(check_overlap = TRUE)

#plot data
p<-ggplot(LPI_site, aes(x=richness, y=pred.rich, label=site)) + geom_point()
p + geom_text(check_overlap = TRUE)

#RICHNESS

model.rich<-lm(richness ~ year_sampled + effort, data = LPI_site)
summary(model.rich)
coefficients(model.rich)

LPI_site$pred.rich = predict(model.rich) #adds predicted to data set

# #plot data
# p<-ggplot(LPI_site, aes(x=year_sampled, y=pred.rich, label=site)) + geom_point()
# p + geom_text(check_overlap = TRUE)
#
# #plot data
# p<-ggplot(LPI_site, aes(x=richness, y=pred.rich, label=site)) + geom_point()
# p + geom_text(check_overlap = TRUE)

#ABUNDANCE

model.abund<-glm.nb(abund ~ year_sampled + effort, data = LPI_site)
summary(model.abund)
LPI_site$year_sampled = predict(model.abund) #adds predicted to data set
coefficients(model.abund)

#####
# Evaluate effect of restoration on species richness and abundance, use lmer because of
small sample sizes
#####

#RICHNESS
#model with restoration
model.rich.rest<-lmer(richness ~ year_sampled + years_since_rest+ effort + (1 | site), data =
LPI_site)
summary(model.rich.rest)
LPI_site$pred.rich.rest = predict(model.rich.rest) #adds predicted to data set

#LPI_site$pred.rich = predict(model.rich) #adds predicted to data set

#model without restoration
model.rich.norest<-lmer(richness ~ year_sampled + effort + (1 | site), data = LPI_site)

```

```

summary(model.rich.norest)

#plot data

p<-ggplot(LPI_site, aes(x=years_since_rest, y=pred.rich.rest, label=site)) + geom_point()
p + geom_text(check_overlap = TRUE)

#test for significant effect of restoration
(AIC(model.rich.rest)-AIC(model.rich.norest))*log2(exp(1))

#ABUNDANCE
model.abund.rest<-lmer(abund ~ year_sampled + years_since_rest+ effort + (1 | site), data =
LPI_site)
summary(model.abund)

LPI_site$pred.abund.rest = predict(model.abund.rest) #adds predicted to data set

model.abund.norest<-lmer(abund ~ year_sampled + effort + (1 | site), data = LPI_site)
summary(model.abund.norest)

#plot data

p<-ggplot(LPI_site, aes(x=years_since_rest, y=pred.abund.rest, label=site)) + geom_point()
p + geom_text(check_overlap = TRUE)

#test for significant effect of restoration
(AIC(model.abund.rest)-AIC(model.abund.norest))*log2(exp(1))

#create data for each species based on the earliest and latest year detected

LPI_long <-bee.sum %>%
group_by(., species) %>% # group rows so that each group is one population

# Create columns for the first and most recent years that data was collected

mutate(., maxyear = max(year_sampled), minyear = min(year_sampled)) %>%
mutate(., lengthyear = maxyear-minyear) %>% # Create a column for the length of time
data available
ungroup(.) # Remove any groupings you've created in the pipe, not entirely necessary but
it's better to be safe

```

```

# Create a list of data frames by splitting `LPI_long` by species
LPI_long_list <- split(LPI_long, f = LPI_long$species)

#Add effort as a covariate

# `lapply()` a linear model (`lm`) to each data frame in the list and store as a list of linear
models
LPI_list_lm_effort <- lapply(LPI_long_list, function(x) glm(count ~ year_sampled +
pans_events, family="quasipoisson", data = x))

# See data structure
coef(summary(LPI_list_lm_effort$`Agapostemon texana Cresson`))

#Extract model coefficients and store them in a data frame
LPI_models_effort <- filter(data.frame(
  "species" = names(LPI_list_lm_effort),
  "n" = unlist(lapply(LPI_list_lm_effort, function(x) df.residual(x))),
  "intercept" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[1])),
  "slope" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[2])),
  "slope_effort" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[3])),
  "intercept_se" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[4])),
  "slope_se" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[5])),
  "slope_effort_se" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[6])),
  "intercept_p" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[10])),
  "slope_p" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[11])),
  "slope_effort_p" = unlist(lapply(LPI_list_lm_effort, function(x) summary(x)$coeff[12])),
  "lengthyear" = unlist(lapply(LPI_long_list, function(x) max((x)$lengthyear)))
), n > 0)

save(LPI_models_effort, file = "LPI_models_effort.min.RData")
View(LPI_models_effort)
write.csv (LPI_models_effort, "LPI_models_effort.min.csv")

```

Community analysis

```

# evaluate effect of restoration on species richness and abundance
model.rich<-glm(richness ~ site + year_sampled +years_since_rest+ effort,
family="poisson", data = LPI_site)
summary(model.rich)

LPI_site$pred.rich = predict(model.rich) #adds predicted to data set

```