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Research Article

Examining the Impact of Human Presence on Insect Pollinators in Coastal Sage Scrub Habitat in North San Diego County

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Abstract: Pollinator conservation is an important field of research due to the essential role of pollinators in plant reproduction in all ecosystems. Pollinator diversity is a key indicator of the overall health of an ecosystem. We conducted a long-term focal survey of the insect pollinators of a southern California native Coastal Sage Scrub (CSS) habitat, while examining the effect of human presence on the diversity of those insect pollinators. We additionally evaluated the frequency of plant-pollinator interactions, comparing sites of high and low human activity at the San Diego Safari Park. Our results showed that while invasive European Honey bees (A. mellifera) dominated pollinator networks in both sites, there was significant difference in evenness between the sites (Shannon's Diversity Index 0.47 vs 0.84).

Loss of biodiversity is increasingly observed in many ecologically important communities, including pollinators (Hallmann et al., 2017; Ollerton et al., 2011). Pollinators hold special importance within our ecosystems as well as our economy (Gibson, 2012). Biotic pollinators are vital in the reproduction of almost 90% of flowering plants by transferring pollen from the male reproductive organ of the flower to the female organ, producing seed and fruit, and providing food for humans and other animals. Economically, this service is an important aspect of agricultural practices, contributing to 75% of crop yield globally (Lawrence, 2022). This critical role in the phenology of plants has been challenged largely by anthropogenic activities.

Human disturbances such as habitat loss and fragmentation due to agriculture, grazing and logging, and light pollution are known contributors to the decline in pollinator populations (Rhodes, 2018; Kevan, 1999; Altermatt & Ebert, 2016). Some insects have been shown to be more sensitive to human presence and activities than others (LeBrun et al., 2012; Simons et al., 2018; Sladonja et al., 2023) and specialist pollinators, like many native bees of southern California, have a greater chance of negative impact due to disturbance (Hung, et al., 2015). One response to these concerns has been a substantial increase in pollinator gardens worldwide, however best practices for supporting pollinators in this manner have not yet been developed (Johnson et al., 2017).

If the goal of a pollinator garden is to support native pollinators, then it is necessary to describe the plant-pollinator networks of the local habitat, to provide baseline data to measure success. Coastal Sage Scrub habitat was the dominant plant community of San Diego County but there is limited research into its associated pollinators (Hung et al., 2015; *County of San Diego*, n.d.). In this study, we investigate the flower-visiting insect assemblage in CSS habitat in San Diego County. Through the assessment of two adjacent regions that vary with respect to human interference, we will evaluate the biodiversity and pollination frequency at each site.

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Research Problem

We conducted a long-term survey of the insect pollinators of CSS habitat, while examining the effect of human presence on the diversity of those insect pollinators and the frequency of their plant interactions. Human activity is expected to influence the occurrence of pollination activity by insects by disrupting insect activity such as foraging, resting and mating (Hung et al., 2015; LeBrun et al., 2012; Simons et al., 2018; Sladonja et al., 2023). If there is an influence, we expect to observe lower numbers of insects and decreased pollination activity in the Garden site with increased human visitation as compared to isolated regions.

This study is Project 2 of the San Diego Pollinator Monitoring Program (SDPMP), which involves longitudinal surveys of plant-pollinator networks in coastal and inland sage scrub communities in northern San Diego County (Simokat, 2019). Within each of the three SDPMP projects, there is a "Natural" site, located in a low-to-no human access preserve, and a "Garden" site which is an intentionally planted and managed horticultural area.

The Project 2 sites are within the San Diego Safari Park (SDSP), an 1,800-acre zoo in Escondido, California. The SDSP has significant numbers of visitors; in 2018 alone, over 1.5 million people visited the zoo (Newsroom, 2019). SDSP is located within the San Pasqual Valley which contains CSS and other native plant communities (*County of San Diego*, n.d.). This survey initiated in January 2022 and focused on two different locations at the SDSP with varying levels of human impact: the Nativescapes Garden, and the Biodiversity Reserve.

Garden Site: Nativescapes Garden

The SDSP exhibit called the Nativescapes Garden features over 1,500 individual plants from 500 species that are native to California (Nativescapes Garden, n.d.). Plant communities such as chaparral and CSS are represented within the exhibit and help provide structure for local pollinators. This area is managed by the SDSP horticultural department and includes trails for public and staff access, mostly on foot but also by maintenance vehicles. The garden receives regular weekly care from volunteers, as well as daily visitors to the SDSP.

Natural Site: Biodiversity Reserve

Adjacent to the SDSP is the Safari Park Biodiversity Reserve (SPBR) with 900 acres of chaparral and CSS habitat. The SPBR was established in 1997 as part of the San Diego Multi Species Conservation Plan (MSCP). The land set aside for conservation efforts is an integral component of the larger network of habitat and open space efforts done throughout San Diego to protect and enhance biodiversity. The SPBR is managed by the SDSP Conservation Department. The habitat is mature and established, and the only active management currently performed in the SPBR is as-needed invasive plant removal by a small team (*Safari Park Biodiversity Reserve,* 2021).

Methods

Focal Monitoring Protocol

Weekly monitoring took place at two locations within the SDSP: the Nativescapes Garden site and the Biodiversity Reserve site. We established two transects at both the Garden and Natural site. Each linear transect is approximately 25 meters in length, and one transect is a plot 50 meters square on either side of the access trail used as a baseline. The transects are comprised of 20-25 plants from the SDPMP master list of CSS plants (Tables S1 and S2).

In the Natural site transect one is a 50 square meter plot transect in a mature, dense coastal sage scrub habitat (Figure 1). Transect two is a 25-meter linear transect along a south facing slope mountain approximately 20 meters away from transect one, on the other side of the access path. In the Garden site, transect one is a 25-meter linear transect located along the pathway of the CSS plant community exhibit (Figure 2). Transect two is a 25-meter linear transect located along the pathway of the chaparral plant community exhibit. These transects remained consistent throughout the monitoring period.

Figure 1: Garden site showing transects 1 and 2 in SDSP Nativescapes Garden.

Focal monitoring consists of five-minute observations of each plant in the transect containing blooms, recording each pollinator interaction, which we define as an individual insect touching a flower in any way that it could gather pollen or deliver pollen. We used ArcGIS Survey123 to collect data with cell phones or tablets and took photographs of the insects when possible.

Figure 2: Natural site showing transect 1 and 2 in SDSP Biodiversity Reserve

Timed focal observation in transects and the use of pan traps to trap and kill the insects for specific identification later are the two most widely used methods of sampling flower-visiting insects (O'Connor et al., 2019). While each method has its advantages and limitations, we chose focal observations to ensure that the insect recorded was involved in a pollination interaction, and the SDPMP research group focuses on optimizing non-kill methods of insect data collection.

We performed weekly data collection at each site from January to October, monitoring each plot between the hours of 8:00 a.m. and 3:00 p.m. Pacific Standard Time while it was warm enough for the pollinators to move around and forage on plants (Nabors, 2019). Data was not collected when plants were not flowering, or during inclement weather conditions such as rain or high winds when conditions would impede pollinators from collecting nectar (Nabors, 2019). Monitoring was planned for 12 months in this study, to allow for a complete picture of seasonal activity.

Coastal Sage Scrub Plant Community

Coastal Sage Scrub (CSS) is a plant community found along the coast of California from San Francisco into Baja Mexico. Sometimes called "soft chaparral", this community is found at lower elevations than chaparral, generally from sea level to 1000 meters. Plants in this community include low, woody, soft-leaved, drought-deciduous subshrubs, with grasses and forbs found in open areas. The community is named after its dominant species, California sagebrush (*Artemisia californica*). Southern sage scrub has three main subtypes primarily influenced by availability of moisture at different latitudes, with variations in plant species accordingly (*County of San Diego*, n.d.).

Insect Groupings

Of the approximately 30 orders of insects, the San Diego Pollinator Monitoring Program (SDPMP) focuses on 18 orders that include flower-visiting insects and the order Araneae, spiders, with the goal of producing a broad insect assemblage of pollinators of our target plant community, CSS (Table S3). Two large orders were further separated into families: *Apidae*, *Bombidae*, *Vespidae* and *Sphecidae* from order *Hymenoptera*, and *Syrphidae, Bombyliidae* and *Asilidae* from order *Diptera*. Non-native European honeybees (*Apis mellifera*) were coded separately from all other bees. *A. mellifera* is native to Africa or Asia and is now found on every continent except Antarctica. Brought to the United States for agriculture, it is known to produce negative effects on native bee populations and on native plants (Iwasaki & Hogendoorn, 2022; Nabors et al., 2018).

The ant family *Formicidae* was separated from *Hymenoptera* and noted as native or non-native ant species, so that we could discuss the presence and activity of native ants within the context of the California super colony of Argentine ants (*Linepithema humile*). This distinction is important because the vast majority of ant species encountered are invasive Argentine ants, and they are more prevalent in areas with greater human activity (Van Wilgenburg, et al. 2010).

Finally, we noted spiders (order *Araneae*) which are not insects and have varied interactions and impacts on plant-pollinator networks, being incidental pollinators, but also predators of pollinating insects, and of plant-eating insects (Knauer, et al. 2018).

Discriminating between species can be challenging during field operations, so we obtained photographs of observed insects whenever possible to confirm identifications through use of our SDPMP photo database, iNaturalist and BugGuide.net.

Results

Monitoring took place from January 28, 2022, through October 7, 2022, for a total of 16 site visits, approximately 55-60 hours. Site visits could not be performed in some cases due to weather (fog, wind, rain, or extreme heat) which reduces insect activity or was dangerous for the researchers.

Insect assemblage

Researchers documented a total of 857 plant-pollinator interactions throughout all sites during the duration of the study (Table S4; Figure 3). The Natural site had a total of 351 plant-pollinator interactions, while the Garden site had 506 interactions. Honey bees (*A. mellifera)* were the most commonly observed insect pollinator, comprising 68% of observations overall. Argentine ants (*Linepithema humile*) were the only other non-native insects detected, and there were very few at only 1% of each site's observations.

The second most common insect grouping, and the most common native insects observed, was native bees (Clade *Anthophila*, inclusive of *Andrenidae, Megachilidae, Colletidae, Andrenidae, Halictidae, Melittidae*) at both sites. Native bees emerged later than honey bees at both sites, in March at the Garden and May at the Natural site, and the last sighting was July at the Natural site and October at the Garden (Table S4).

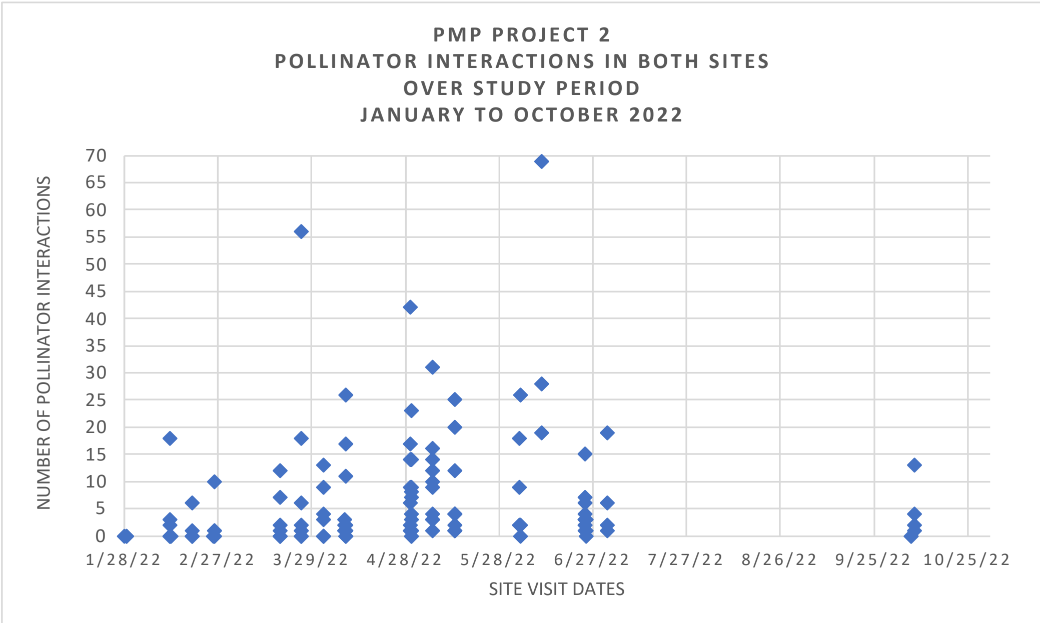

Figure 3. Time series of pollinator interactions at all sites over the monitoring period. Blue dots indicate a total number of pollinator interactions across all site visits.

Data analysis

Interactions by honeybees (*A. mellifera*) and non-native ants *(Linepithema humile*) were removed from our data sets prior to analysis as our goal is to identify native insect activity. Shannon and Simpson diversity indices showed both sites to have similar guild diversity which was supported by chi-square test of independence showing the relation was not significant, X^2 (12, N=55) = 9.98, p = 0.618 (Table S4).

However, the diversity of insect interactions was significantly greater at the Natural site, demonstrated in both Shannon and Simpson diversity indices, and again supported by chi-square test of independence, X^2 (12, N=264) = 105, p = 0.001 (Table S4). The Shannon index indicated that the Natural site had greater evenness in native insect interactions (Table S4). The Garden site was dominated by native bee species, whereas the top three groupings of native insects at the Natural site were evenly distributed between native bees, flies, and beetles (Figure 4).

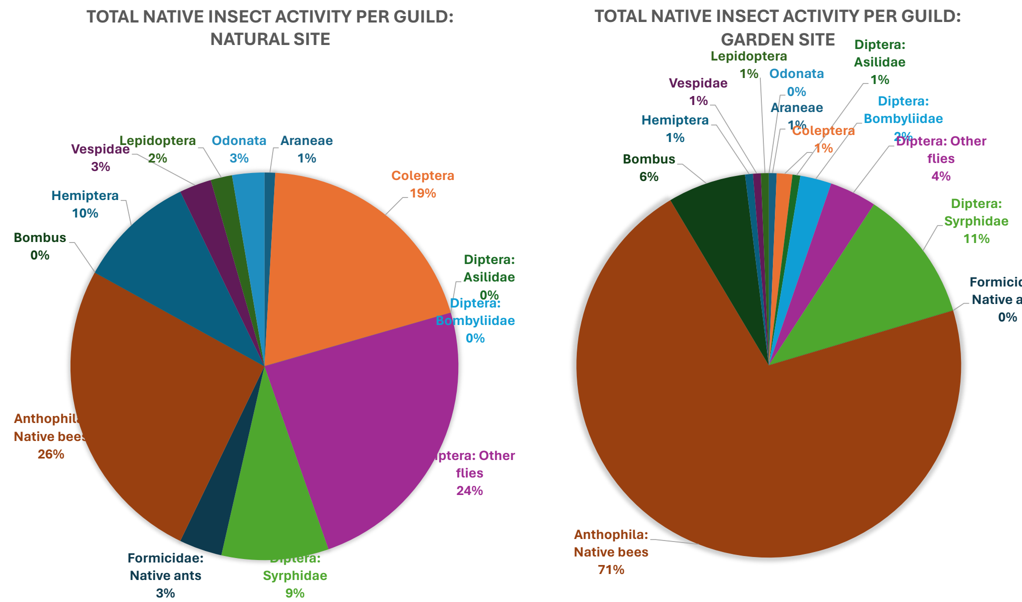

Figure 4. Rank abundance of native insect interactions at each site.

Discussion

Insect Assemblage

As expected, the invasive western or European honey bees *(A. mellifera)* were by far the most common insect pollinator observed in both gardens. This species is native to Africa or Asia and is now found on every continent except Antarctica. Brought to the United States for agriculture, it is known to produce negative effects on native bee populations and on native plants, making this finding a concern for native pollinator conservation (Thomson, 2004).

It is noable that beetles (Coleoptera) and true bugs (Hemiptera) were the fourth and fifth most common groups at the Natural site, while very few were involved in interactions at the Garden site. Almost all the insects involved in pollinator interactions at the Garden site were bees, bumblebees, and flies. The lack of beetles and bugs in the Garden site could be due to landscaping and cleaning activities, such as the use of leaf blowers. Methods of supporting these insects should be further investigated.

Phenology

Our data shows an expected high in plant blooms and pollinator interactions between March and July (Figure 3). We were unable to collect data in August and September primarily due to extreme heat, but we would expect to find successively fewer blooms over those months as temperatures are at their highest and many CSS plants are drought deciduous. Blooming ends and seed set occurs for the majority of CSS species by late autumn (Gray, 1982).

A finding of interest is the difference in phenology between native bees and honey bees. Honey bees were seen with the first day of blooms, and native bees were not present for another month at the Garden site, and for three months at the Natural site (Table S5). Peak activity for native bees at the Garden site was almost immediate, but the peak was later, and similar to honey bees at the Natural site. Finally, all bees were seen longer at the Garden than the Natural site. Many native bees emerge around March in San Diego County, which would explain the later appearance, and the greater availability of water in later summer at the Garden site may have better supported bee activity. Further data collection would help determine if these trends are consistent.

Human Impact on Insect Pollinator Diversity

Contrary to our prediction, the Garden had higher pollination interactions (Table S4), which may indicate that human activity consisting of walking, running, and talking does not have a negative impact on insect pollinator activity. In terms of diversity, the Natural and Garden sites exhibited similar richness of insect groups present though the Natural site has more evenness (Table S4). If we interpret the observations at the Natural site to be comparable to the natural insect pollinator assemblage associated with the CSS community, then these findings imply the Nativescapes Garden is being managed successfully in its role as a pollinator garden, as it is supporting similar groupings of insect pollinators to the mature and far less disturbed Natural stand of CSS in the Biodiversity Reserve.

While human impact could be causing differences in insect pollinator evenness between the sites, other studies have found that higher temperature, water availability, and other environmental factors may cause differences in pollinator distribution. (Neil, 2014).

Notably, the Natural site at the Biodiversity Reserve has less water available than the Garden site inside the SDSP. The Garden site, the Nativescapes exhibit, is surrounded by non-native plants which results in blooms being present almost constantly, which supports the super-generalist *A. mellifera*, but also supports some native bees. While native bees are more specialized, they may expand their foraging when drought reduces normal plant host availability (Hung, et al, 2021 & Martinez, 2020).

Future Recommendations

Having determined that native bees are the most common native insect grouping allows us to recommend a focus of support for conservation and future research. As beetles and bugs were found at the Natural site but not the Garden, it would be of interest to investigate what factors would help support the presence and activity of beetles and true bugs at the Nativescapes Garden, to increase the diversity of pollinators at that site.

Further data collection with enhanced techniques would help us better understand pollinator activity of managed gardens compared to natural landscapes in CSS. We are currently developing camera traps that can collect data during times when human researchers are not able be present, such as heat waves and at night to observe nocturnal insects.

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Appendix

Table S1: Plant and transect list for Garden site.

Plant List: The Nativescapes Garden			
Transect 1 *Coastal Sage Scrub habitat within the Nativescapes Garden*			
# of Plants	**Common Name**	**Scientific Name**	**Plant Code**
Up to 5	Sages (choose from any that are blooming)	*Salvia spp.*	
	White Sage	*Salvia apiana*	SAAP
	Cleveland Sage	*Salvia clevelandii*	SACL
	Black Sage	*Salvia mellifera*	SAME
5	California Buckwheat	*Eriogonum fasciculatum*	ERFA
5	Bush Sunflower	*Encelia californica*	ENCA
2	Bush Monkeyflower	*Mimulus aurantiacus*	MIAU
2	Coyote Bush	*Baccharis pilularis*	BAPI
2	California Sagebrush	*Artemisia californica*	ARCA

2	Chamise	*Adenostoma fasciculatum*	ADFA
2	Bush Rue	*Cneoridium dumosum*	CNDU
Total plants: 25			

Transect 2 *Chaparral habitat within the Nativescapes Garden*			
# of Plants	**Common Name**	**Scientific Name**	**Plant Code**
5	California Buckwheat	*Eriogonum fasciculatum*	ERFA
5	Bush Sunflower	*Encelia californica*	ENCA
2	Bush Monkeyflower	*Mimulus aurantiacus*	MIAU
1	Coyote Bush	*Baccharis pilularis*	BAPI
2	Black Sage	*Salvia mellifera*	SAME
3	Menzies' Goldenbush	*Isocoma menziesii*	ISME
3	Laurel Sumac	*Malosma laurina*	MALA
2	Chamise	*Adenostoma fasciculatum*	ADFA
1	California Sagebrush	*Artemisia californica*	ARCA
1	Bush Rue	*Cneoridium dumosum*	CNDU
2 Anywhere on site	Narrow Leaf Milkweed	*Asclepias fascicularis*	ASFA
2 Anywhere on site	California Poppy	*Eschscholzia californica*	ESCA
Total plants: 28			

Table S2: Plant and transect list for Natural site.

Plant List: Biodiversity Reserve			
Transect 1 *West facing slope on the left side of the vehicle trail*			
# of Plants	**Common Name**	**Scientific Name**	**Plant Code**
5	Chamise	*Adenostoma fasciculatum*	ADFA
5	White Sage	*Salvia apiana*	SAAP
5	California Sagebrush	*Artemisia californica*	ARCA
2	Menzies' Golden Bush	*Isocoma menziesii*	ISME
3	Bush Rue	*Cneoridium dumosum*	CNDU
5	California Buckwheat	*Eriogonum fasciculatum*	ERFA
Total plants: 25			
Transect 2 *South facing slope on the right side of the vehicle trail*			
# of Plants	**Common Name**	**Scientific Name**	**Plant Code**
1	Brickle Bush	*Brickellia californica*	BRCA
14	California Buckwheat	*Eriogonum fasciculatum*	ERFA
3	Laurel Sumac	*Malosma laurina*	MALA

Plant List: Biodiversity Reserve			
Transect 1 *West facing slope on the left side of the vehicle trail*			
# of Plants	**Common Name**	**Scientific Name**	**Plant Code**
5	Chamise	*Adenostoma fasciculatum*	ADFA
5	White Sage	*Salvia apiana*	SAAP
5	California Sagebrush	*Artemisia californica*	ARCA
2	Menzies' Golden Bush	*Isocoma menziesii*	ISME
3	Bush Rue	*Cneoridium dumosum*	CNDU
5	California Buckwheat	*Eriogonum fasciculatum*	ERFA
Total plants: 25			
Transect 2 *South facing slope on the right side of the vehicle trail*			
7	Prickly Pear	*Opuntia chlorotica*	OPCH
Total plants: 25			

Table S3: PMP Insect list with common and scientific names and monitoring codes.

INSECT GROUPING	INSECT CODE		EXAMPLES
Coleoptera	COLE	**Beetles**	Flower longhorn beetle (S. emarginata), Tumbling Flower Beetle (Mordellistena spp.), Stink Beetle (Eleodes spp.), Darkling Beetle (A. pubescens), Black Rain Beetle (P. puncticollis), Asian lady beetle (Harmonia axyridis), Convergent Lady Beetle (Hippodamia convergens)
Dermaptera	DERM	**Earwigs**	
Diptera	DIPT	**Flies**	Flies not otherwise categorized
Diptera: Asilidae	DASI		Robber flies
Diptera: Bombyliidae	DBBY		Bee flies
Diptera: Syrphidae	DSYR		Hover flies, flower flies
Ephemeroptera	EPHE	**Mayflies**	
Formicidae: native	FONA	**Ants**	**Native ants** -- California Harvester Ant (Pogonomyrmex californicus), Small Honey Ant/ winter ant (P. imparis), Field Ant (F. moki), Odorous House Ant (T. sessile),
Formicidae: non-native	FONO		**Non-native ants** - Argentine ant (Linepithema humile), Red Fire Ant / RIFA (S. invicta)
Hemiptera	HEMI	**Bugs**	**True bugs** -- aphids, leafhoppers, cicadas, Small Milkweed Bug (Lygaeus kalmii), Say's Stink Bug (C. sayi), Leafhopper (G. angulata)
Homoptera			Cicadas, aphids, scale, whitefly

Hymenoptera	HYME	**Wasps**	Wasps not otherwise categorized: family Chrysididae (Chrysalidae), family Tiphiidae, family Scoliidae, and velvet ants (family Mutillidae)
Hymenoptera: Sphecidae, Crabronidae	HSYH		Thread-waisted wasps, mud dauber wasps
Hymenoptera: Vespidae	HVES		Yellow jackets (Vespula pensylvanica, V. vulgaris), paper wasps (Polistinae spp.), hornets, paper, mason (all social wasps found in this family)
Hymenoptera: Clade Anthophila	HANT	**Bees**	**Bees not otherwise categorized**: Carpenter, Digger, mining bees (family Andrenidae), leafcutter bees (family Megachilidae), families Colletidae, Andrenidae, Halictidae, Melittidae
Hymenoptera: Apis mellifera	HAPI		Honey bees
Hymenoptera: Bombus spp	HBOM		Bumble bees
Isopoda: Armadillidiidae	ARMA	**Pillbugs**	
Isoptera	ISOP	**Termites**	
Lepidoptera	LEPI	**Moths**	Moths, butterflies
Mantodea	MANT	**Mantids**	
Neuroptera	NEUR	**Lacewings**	
Odonata	ODON	**Dragonflies, damselflies**	
Orthoptera	ORTH	**Grasshoppers**	Grasshoppers, katydids, crickets
Phasmatodea	PHAS	**Stick-insects**	Stick-insects, walking sticks
Plecoptera	PLEC	**Stoneflies**	
Psocoptera	PSOC	**Woodlice**	
Thysanoptera	THYS	**Thrips**	
Araneae	ARAN	**Spiders**	

Table S4. Project 2 Diversity index.

Period: January to October 2022	**Garden site (Nativescapes)**	**Natural site (Biodiversity Reserve)**	**Total (both sites)**
# of days monitored	16	16	16
Total pollination interactions	506	351	857
Native insect pollination interactions observed	152 (30%)	112 (32%)	264 (31%)
% of interactions by Honeybees (*A. mellifera*)	69%	67%	68%
Most common native insect group observed	Native bees 8%	Native bees 21%	
Shannon's Diversity of Native Insect activity at each site (interactions)	*Garden*	*Natural*	
Shannon Diversity Index (H)	1.08	1.85	

Evenness	0.469	0.841	
Richness (as number of groups)	10	9	
Total interactions	151	111	
Average	15.1	12.3	
Shannon's Diversity of Native insects observed at each site (groupings)	*Garden*	*Natural*	
Shannon Diversity Index (H)	2.14	2.06	
Evenness	0.894	0.893	
Richness (as number of groups)	11	10	
Total groups	26	29	
Average	2.36	2.9	
Simpson's Diversity of Native Insect activity at each site (interactions)	*Garden*	*Natural*	
Simpson's Index (D)	0.53	0.18	
Simpson's Diversity Index (1-D)	0.47	0.82	
Simpson's Reciprocal Index (1/D)	1.89	5.54	
Simpson's Diversity of Native insects observed at each site (groupings)	*Garden*	*Natural*	
Simpson's Index (D)	0.11	0.12	
Simpson's Diversity Index (1-D)	0.89	0.88	
Simpson's Reciprocal Index (1/D)	9.03	8.29	

Table S5. Comparison of first appearance of honey bees and native bees at start of spring bloom of CSS plants.

Natural site (Biodiversity Reserve) - First bloom observed 2/11/22			
	First observation	Peak observations	Last observation
Honey bees (HAPI)	2/11/22	6/10/22	6/24/22
Native bees (HANT)	5/6/2022	6/24/2022	7/1/22
Garden site (Nativescapes Garden) - First bloom observed 2/11/22			
	First observation	Peak observations	Last observation
Honey bees (HAPI)	2/18/2022	6/10/2022	10/7/2022
Native bees (HANT)	3/18/2022	3/25/2022	10/7/2022