Arthropod Ecosystem Services as Indicators of Ecosystem Health and Resiliency for Conservation Management and Climate Change Planning

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Executive Summary

Protection and/or restoration of biodiversity and ecosystem functioning is a central tenet of conservation biology. This focus is often paired with the idea that creating large preserve systems proactively will protect the ecosystem and decrease the risk that species will be extirpated. Conservation plans like the San Diego Multiple Species Conservation Plan (MSCP) have complementary goals of protecting individual species and the broader community and ecosystem. In most conservation plans the focus is on a limited number of high-profile species on a list (e.g. IUCN Red List or Endangered Species Acts at the state and federal level) and function is given less attention. Conserving diversity and function will be increasingly difficult due to population growth, habitat fragmentation, and climate change. It is important to improve our understanding of the impact that diverse communities have on ecosystem-level properties. Insects are a very species-rich group performing different roles in the ecosystem. Conservation management will benefit from an improved understanding of the interaction between insects and the many other elements of the ecosystem.

Invertebrates represent around 70% of the described species on Earth and insects make up a majority of those invertebrate species. It is estimated that the actual number of insects is between 5-30 million species worldwide. Currently, there are almost 100,000 insect species that have been described in the US. In contrast, there are fewer than 25,000 species for plants and animals (vertebrates) combined. Despite their diversity, insects go unnoticed (or at least under-appreciated) due to their small size and ephemeral nature. Without knowing even basic information on species identity, distribution, and life history traits, it is difficult to assess their status and include them in conservation planning and management. For these reasons, insects represent a disproportionately low number of species on federal, state, and local conservation lists relative to their species richness and biomass on Earth.

Insects have a vast array of different roles in the ecosystem. These roles often provide direct benefits to humans (e.g. pollination of crops, recreation, and even religious significance) as well as to the native communities (e.g. pollination of most plants, expediting nutrient cycling, and acting as prey, predator, and parasite). While species richness is often assumed to be a proxy for the health of an ecosystem, this assumption has not been adequately tested. Moreover, richness may be an inconsistent or unreliable proxy unless all species are of equal importance. Although correlations between richness and ecosystem health are often observed, strictly using the number of species present can be misleading as it may mask important changes in species composition. Resilience in the face of change or disturbance has been proposed as an alternative measure of ecosystem health. Redundancy in terms of multiple species performing the same ecological function is taken as a measure of resilience. It has been hypothesized that redundancy in species' traits or functions will be important in times of rapid and significant change (e.g. climate change).

Our overall goal was to assess the resilience of the insect communities associated with pollination and decomposition. In order to quantify resilience, we studied the composition of the insect community and used this information to explore redundancy (multiple species performing similar functions). This ecosystem-level approach answers the call for more direct measurements of ecosystem functions and natural processes written in the MSCP and other conservation plans.

Specifically, we addressed the following questions:

1. Which arthropod species pollinate *Acanthomintha ilicifolia* (San Diego thornmint) and *Deinandra conjugens* (Otay tarplant)?
2. Which arthropod species are responsible for decomposition of small-mammal carcasses?
3. How does habitat and landscape composition affect the structure and function (e.g. rate) of pollinator and decomposer communities?
4. What is the relative importance of each species related to pollination and decomposition? Is there evidence of redundancy/resiliency?
5. What role do non-native arthropod species (e.g. honey bees or European earwigs) have in pollination and decomposition?

This project focused on coastal sage scrub and grassland vegetation communities at 20 preserves in western San Diego County, on conserved lands with differing landscape characteristics. To quantify the local landscape, we calculated the proportion of different community types using a vegetation map of western San Diego. Since the scale at which insects interact with their environment is unknown and likely quite variable, we calculated the proportion of each habitat type within a 100-, 1000-, and 5000-meter radius from the trap locations. Pollinator communities were quantified by capturing specimens with cup traps and recording insect visits to flowers. Decomposer communities were quantified by capturing specimens with a baited bucket trap and conducting field trials to measure carcass decomposition rates.

A total of 18,867 specimens were processed from the cup traps. As expected, the pollinator communities varied across sites. At the order level, Coleoptera (beetles) represented the most specimens, followed by Hymenoptera (bees/wasps), and Diptera (flies). Few Lepidoptera (butterflies/moths) were captured. At the family level, insects in the family Melyridae (Coleoptera) comprised 58% of all specimens. The second and third most abundant families, Synneuridae (Diptera) and Halictidae (Hymenoptera) accounted for ~ 24% of all specimens. Thus members of these three dominate families accounted for 82% of all insects in the cup traps. This trend observed at the family level was, itself, driven by a few species. A soft-winged flower beetle (Melyridae morphospecies) was the most common species, representing 30 percent of all specimens. *Exiliscelis californiensis* was the most common fly while *Lasioglossum microlepoides* (Halictidae), *Apis mellifera* (European honey bee, Apidae) and *Halictus tripartitus* (Halictidae) were the more common bees.

The habitat analysis yielded some consistent patterns including the positive association of Coleoptera with grasslands but a negative correlation with riparian forest habitats. Diptera correlated positively with riparian woodlands and negatively correlated with chaparral, Hymenoptera negatively correlated with riparian forest, and Lepidoptera correlated negatively with the amount of urban area. The lack of strong habitat relationships is not surprising considering the diversity of the cup trap samples, resulting in each order being composed of many species with potentially differing natural life histories. Due to the magnitude and distribution of individuals, the family-level analysis was conducted with three families Melyridae, Apidae, and Halictidae. Likewise, only four species were analyzed at the finest taxonomic level. These were Melyridae morphospecies 1, European honey bee, *Halictus tripartitus*, and *Lasioglossum microlepoides*. In general, there were several positive correlations with non-native habitats and grasslands, as well as urban areas. Interestingly, the European honey bee had a negative correlation with coastal sage scrub at the 1000- and 5000-meter scale.

Flower observations were conducted to evaluate whether there were common insects that had low capture rates in traps and to quantify the contribution of each insect species to pollination Approximately 3,400 visits were observed in 37 distinct 20-minute observation trial. We recorded fewer insect visitors to the San Diego thornmint than to Otay tarplant. Thornmint visitors were primarily flies or bees, depending on the site. In contrast, beetles were the most common visitor to Otay tarplant, about five times more common than either flies or bees. In addition to 20-minute fixed observations, we followed an insect for one minute and recorded their movements among flowers and plants. In our 1-minute evaluation of insect movement we found that bees tended to move between flowers more frequently than the other common insects. The abundant beetles (Melyridae) and flies (*Exiliscelis californiensis*) rarely moved between flowers. This suggests there are two general pollinator strategies, fewer individuals quickly move between flowers or a large number of individuals visit a smaller number of flowers.

A total of 11,171 specimens were processed from the bucket traps that were designed to describe the decomposer communities. The diversity of decomposers was less than what was observed in the cup traps. Again, the community varied across sites and the order-level analyses offered little information regarding potentially important species and their biological requirements. At the family level, three groups exhibited similar distributional patterns: (1) ants and earwigs – nearly all non-native; (2) flies and Chalcididae, a wasp that parasitizes flies; and (3) beetles and Playgastridae, a wasp that parasitizes beetles. At the species level, the 14 most abundant species represented 90 percent of the total specimens. The Argentine ant (*Linepithema humile*), a parasitoid wasp (Platygastridae), and the European earwig (*Forficula auricularia*) together represent 70 percent of all specimens. The ant and earwig are non-native species and are likely to have substantial impacts to the ecosystems due to their large numbers.

Only the most abundant families or species were included in the assessment of insect-habitat relationships. The Histeridae and Silphidae (both beetle families) had a negative correlation with urban and non-native habitat. Based on museum specimens, it appears that the Silphidae specimens have been lost from the insect communities in the urban preserves. The Sarcophagidae flies were negatively correlated with urban and non-native habitat and positively correlated with coastal sage scrub and chaparral. Argentine ants exhibited a positive correlation with urban, non-native habitat, riparian forest and riparian woodlands while negatively correlated with coastal sage scrub. Field trials were conducted to assess decomposition rate at a rural and urban location. The decomposition rate was lower at the urban site suggesting that the differences in the insect communities are affecting this process.

Sampling for this project resulted in a large and complex data set involving quantifying the insects and relating the community to different elements in the surrounding habitats. Analysis of this data demonstrated large differences in the insect communities. Because of the complexity of this data, further statistical analyses are warranted.

We also sampled insects from patches of flowering California buckwheat to include a more widespread assessment of the pollinator communities. This is a common species that was present at all sampling sites. The specimens from the buckwheat patches are currently being processed. Identification and analysis of these specimens is ongoing.

Given the observed differences among sites, conducting more focused pollinator and decomposer studies should continue. Options include flower observations, developing insect-flower networks, and carcass processing trials. More focused data collection will allow us to describe how ecosystem functioning is related to changes in the communities. Many of the common species involved with pollination and decomposition have been identified, allowing us to quantify the relative importance of selected species.

Continued sampling is imperative so that inter-annual variation can be gauged. This is a necessary first step in assessing the potential impacts of climate change. Additional sampling to include more sites would also allow us to further refine habitat relationships. Finally, having this well-established understanding of the baseline community will facilitate further efforts to obtain funding from local, state, and federal agencies.

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Introduction

San Diego's Multiple Species Conservation Program (MSCP) intends to conserve the diversity and function of the southwestern San Diego County ecosystems through preservation and adaptive management of habitat. The MSCP covers an ambitious list of 85 species. A prioritization scheme implemented by Regan et al. (2006) identified 26 species at highest risk of loss or extinction. Like many conservation efforts, most of the focus is on a limited number of species on a list (i.e. species identified by state and federal Endangered Species Acts). Ecosystem functioning is often a stated objective, but is generally given less attention. Conserving diversity and function will be increasingly difficult due to climate change and thus ecosystem management should include invertebrates because of their high level of diversity and their critical role in ecosystem function.

Invertebrates, specifically insects, compose the majority of species present on Earth. Including plants, invertebrates represent around 70% of the described species and insects around 50% (Wilson 1992, Adams 2009). The number of insect species is likely to increase as scientists are continually discovering and describing new species, with the actual number estimated to be between 5-30 million worldwide (May 1988, Gaston 1991). Virtually nothing is known about the species that have already been identified. We lack basic information on these insects including their basic natural history, distribution, and function(s) in the ecosystem.

Most insects are likely to go undetected, in part due to their small size and ephemeral activity patterns (Cardoso et al. 2011). Without knowing even basic life history traits and distribution, it is difficult to assess their status and include them in conservation planning and management. This is reflected by the disproportionately low number of insect species protected by Endangered Species Acts (United States and the State of California) and covered species lists for California's Natural Community Conservation Planning (NCCPs) compared to their component of Earth's total biodiversity (Table 1). This pattern is observed at a global scale as well (Thomas et al. 2004).

Table 1. Proportion of species in each taxon group for different federal, state, and local conservation efforts compared to Earth's biodiversity. The Endangered Species Acts (ESAs) include species listed as threatened and endangered. The Natural Community Conservation Plans (NCCPs), and Management Strategic Plan include all species listed under those plans.

	Earth's Biodiversity		ESAs		California NCCPs				
	Wilson (1992)	Adams (2009)	Federal (USFWS)	State (CDFW)	MHCP	MSCP	North County	East County	Management Strategic Plan
Plant	17.6%	14.3%	58%	66%	41%	54%	44%	54%	52%
Fish	1.3%	1.4%	10%	8%	0%	0%	1%	0%	1%
Amphibian	0.3%	0.3%	2%	5%	3%	2%	6%	5%	3%
Reptile	0.4%	0.5%	2%	3%	5%	4%	4%	9%	5%
Bird	0.6%	0.6%	6%	9%	33%	32%	30%	18%	27%
Mammal	0.3%	0.3%	6%	7%	10%	4%	7%	9%	7%
Invertebrate			16%	1%	8%	5%	7%	5%	5%
Insect	53.1%	54.3%	5%	0%	5%	2%	4%	3%	4%

Assessing the status of each insect species independently would require an incredible effort and is impossible with the information and resources that are currently available. While efforts to better describe the basic biology and status of poorly understood insect species is warranted, we should be allocating efforts to assess their role or roles in the natural communities. Conserving these ecosystem processes is also a goal of Natural Community Conservation Plans (e.g. MSCP, MHCP) and should accompany the protection and conservation of listed species. Insects are an integral part of the environment because of their great number of individuals (biomass) and variety of natural histories, surely related to their high level of species diversity. Ecosystem processes provided by insects are critical to the natural community as a whole, often linking multiple trophic levels.

Ecosystem Functioning

Investigating the role of insects in ecosystem processes provides important information for conservation, not only related to the insects themselves, but of natural communities. Insects are a very species-rich group and have a vast array of different roles in the ecosystem. These roles often provide direct benefits to humans (ecosystem services) as they may provide a resource (e.g. honey), pollination of crops (e.g. almonds), be of religious significance (e.g. dung rolling scarab beetles represented the sun moving across the sky in Egyptian culture), or a form of recreation (e.g. field guides and binoculars are being developed for insect viewing). Similar roles are important to the natural components of the ecosystem and do not directly benefit humans (although a strong argument can be made that humans indirectly benefit). These include being a food source (e.g. San Diego horned lizard feeds almost exclusively on native ants), expediting nutrient cycling (decomposition of animal and plant material), and pollinating most plant species (78% to 94% of plants are insect pollinated in temperate and tropical ecosystems, respectively (Ollerton et al. 2011)).

While species richness (the number of species in an area) is often assumed to be a proxy for the health of an ecosystem, it is not always reliable and assumes equal importance of all species. Earlier studies simply looked at the correlation of species richness between two species groups such as plants and butterfly species (Öckinger et al. 2006, Panigaj and Panigaj 2008). Although correlations are often observed, strictly using the number of species present can be misleading as it may mask important changes in species composition. For instance, native habitat specialists may be replaced by “weedy” or common, wide-ranging species (Tylianakis et al. 2005). In addition, the number of species will reveal little about changes in species abundance or specific mechanisms of species interactions.

An alternative measure of ecosystem health is the level of resiliency in the face of disturbance and change. A number of researchers have identified redundancy in terms of ecological functions within insect communities. For example, there are multiple species that pollinate apple trees (Sheffield et al. 2013), watermelon (Cariveau et al. 2013), and a native crucifer shrub (Gomez and Zamora 1999). This redundancy provides resilience within the pollinator community as other species can perform the same service if any one species is lost. Redundancy in species’ traits or functions will be important in times of rapid change.

With redundancy built into most systems, it may be that function is not compromised until several species are missing. For conservation planning and management, it is important to know when this occurs. Some theoretical (but realistic) examples are shown below. Curve B represents proportional reduction of function as species richness declines. This is mathematically simple, but biologically unrealistic. Curve A shows a function that is drastically impacted with the loss of just a few species (low resiliency), while curves C and D show resilient communities where the remaining species are able to compensate for the loss of other species. The function is minimally impacted until a certain number (threshold) of species is lost. Curve C is more resilient that Curve D since the threshold for loss of function does not occur until severe species loss. The order in which species are lost is also influential.

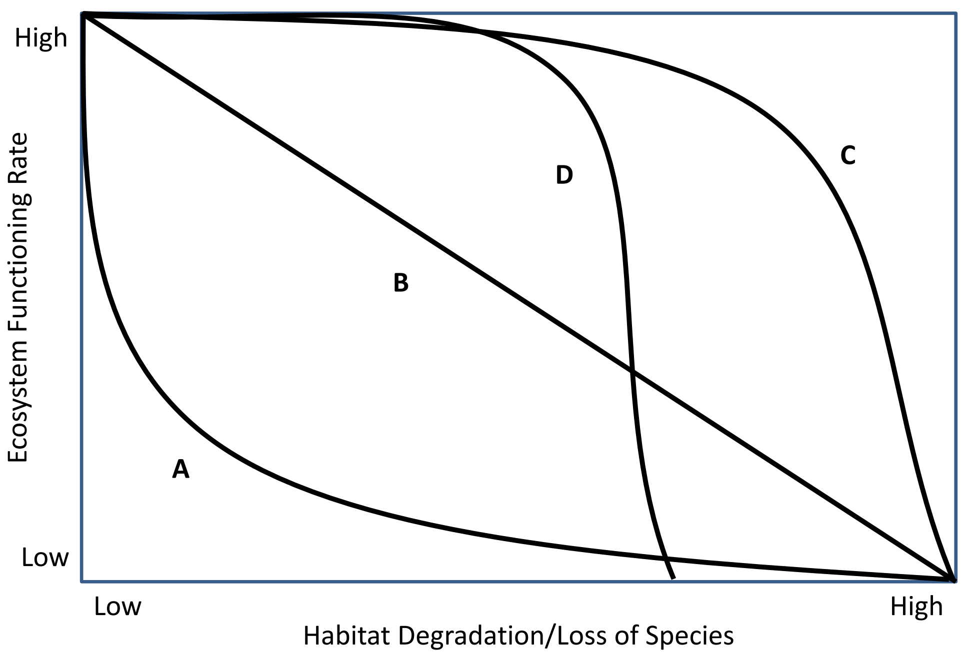

Figure 1. Hypothetical examples of how ecosystem functioning could be influenced by habitat degradation or loss of species. Loss of function may be linear or there may be a threshold, and may vary depending on the specific function measured.

Pollination, decomposition (nutrient cycling), and prey availability (food source; energy flow) are three ecosystem processes that are heavily reliant on insects. Many papers have been published on insect-mediated pollination and decomposition, with well-established sampling methods and analyses. However, most of the previous ecosystem function studies involving insects have been conducted in highly controlled environments at very small-scales, which may have little relevance to natural areas (Cariveau et al. 2013). They also tend to focus on a single, well-defined function. While this is a necessary starting point, future work should investigate multiple functions performed by a community of insects in the same area (Geijzendorffer and Roche 2013, Mitchell et al. 2013, Nagendra et al. 2013).

Allan et al. (2013) recommend shifting conservation's focus to preserving these functions, and states that an understanding of the mechanisms underlying these ecological functions can improve our predictive ability and therefore ecosystem management. In addition, we can look at which functions are more sensitive to changes to the habitat (Allan et al. 2013). Our understanding must go beyond just the number of species present to their relative importance to ecosystem processes (functional diversity). A solid understanding of functional diversity should be incorporated into conservation and management decision-making in order to preserve and/or restore healthy, functioning ecosystems (Cadotte et al. 2011). Ecosystems are being challenged with a changing climate in combination with other anthropogenic stressors. The preservation of resilience in functional diversity that supports ecosystem processes should be a conservation priority.

Objectives

Our overall goal was to assess the resilience and functionality of habitats by quantifying the insect communities associated with pollination and decomposition. This will lead to identifying trigger points in habitat and landscape conditions where resiliency begins to decrease and restoration actions should be considered or initiated. This is important for management since resilient ecosystems will be more likely to maintain key ecosystem functions in the face of increasingly detrimental impacts from climate change. This is a novel framework to assess the health of the existing reserve system in southern California. More direct assessments of ecosystem functions and natural processes have been called for by the MSCP and similar plans.

Specifically, we addressed the following questions:

1. Which arthropod species pollinate *Acanthomintha ilicifolia* (San Diego thornmint) and *Deinandra conjugens* (Otay tarplant)?
2. Which arthropod species are responsible for decomposition of small-mammal carcasses?
3. How does habitat and landscape composition affect the structure and function (rate) of pollinator and decomposer communities?
4. What is the relative importance of each species related to pollination and decomposition? Is there evidence of redundancy/resiliency?
5. What role do non-native arthropod species (e.g. honey bees or European earwigs) have in pollination and decomposition?

Methods

We have adapted a suite of methods that have been used in other research on the role insects play in ecosystems. The proposed application (and combination) of these methods is a relatively novel approach to address the conservation of natural habitats. Understanding ecosystem resiliency, ecosystem functioning, and functional diversity offers a predictive and explanatory ability that species richness cannot. Our approach uses two scales of sampling to link habitat characteristic with the arthropod community and ecosystem resiliency and functioning. A coarse or general sampling scheme was used to assess the overall arthropod communities which are responsible for important ecosystem functions. A fine-scale or site-specific sampling scheme was used to quantify local pollination and decomposition rates.

Site Selection and Characteristics

Sampling occurred at 20 different sites in San Diego County (Figure 2). All sampling was conducted on conserved lands in coastal sage scrub and grassland vegetation communities. Sites included a range of conditions including degraded, restored, and more intact ecosystems. An initial list of sites was selected based on the presence of San Diego thornmint or Otay tarplant. Other sites were added to broaden the sample to include a range of preserve sizes, cover of exotic vegetation, and differing surrounding landscapes. Our sampling of the insects associated with rare plants was limited to the few sites where they can be found. We were not as constrained in assessing the decomposer community or the general pollinator community.

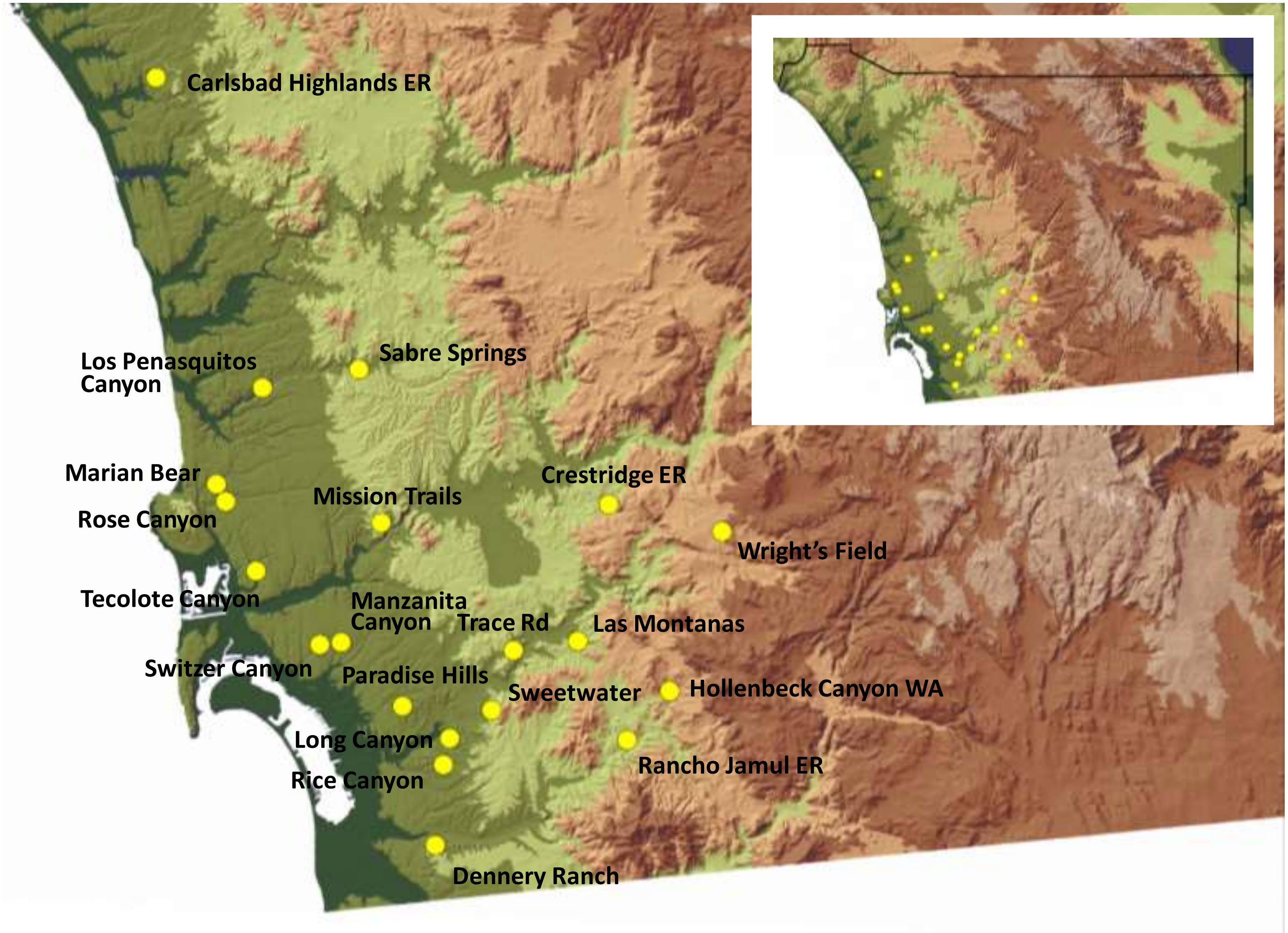

Figure 2. Twenty sampling sites, all in western San Diego County. Insert shows San Diego County.

The two rare plant species were selected based on the Management Strategic Plan and information provided by P. Gordon-Reedy (Conservation Biology Institute), J. Vinje (Conservation Biology Institute), and B Miller (City of San Diego). Studying San Diego thornmint pollination is a research priority based on a recently developed Adaptive Management Framework for the species. In addition, there are nearly 70 known populations on conserved lands within the Management Strategic Plan Area which should provide a variety of habitat quality conditions. Some plants generally flower even in dry years. This species only reproduces sexually so pollinators are critical for this species. Otay tarplant is an outcrossing species so it is also dependent on pollinators, but flowering is more sensitive to dry conditions compared to San Diego thornmint. Populations are present on conserved lands but they are restricted to southern San Diego County. Morning glory (*Calystegia macrostegia*), clustered tarweed (*Deinandra fasciculata*), and California buckwheat (*Eriogonum fasciculatum*) are relatively common and occur at many sites, providing greater flexibility in the sampling design for the general description of pollination.

At flower patches, the number of flowering plants (including San Diego thornmint or Otay tarplant) vary and may represent different habitat qualities for pollinators. The numbers of flowers for each of the two rare plant species were estimated. Other habitat patch characteristics were determined using a 1995 Holland code vegetation map (SANGIS 2014) in ArcGIS 10.3.1. This involved calculated the area of each habitat type within a radius of 100, 1000, and 5000 meters around each location (Figure 3). A forward stepwise General Linear Model (GLM) was used to assess the relationship between insect and habitat data. Models were run with and without site name so that we could assess if a pattern may be driven by site-specific phenomena that may be unrelated to the variables we measured. Insect data were log transformed ($\ln\{X+1\}$) due to pronounced right-skew in the distributions. For many of the less common taxa, we used a presence/absence data transformation because of the preponderance of zeros. Finally, we used Nonmetric Multidimensional Scaling (NMDS) to describe the complex relationships among the many taxa.

Pollinator Community

The pollinator community was assessed with two methods for each of four plant species. Utilizing multiple techniques allows the ability to describe different aspects of the system. In addition, this a valuable approach when working with a poorly understood system, increasing the chances that meaningful trends will be detected.

We used two general approaches: direct observations of insects on flowers and the deployment of cup traps. Two types of flower observations were also implemented. Detailed 20-minute observations involved a biologist sitting near a patch of flowers and recorded each flower visitor (species and frequency). Taking a sitting position was to minimize altering the behavior of the insects. At the end of the time period, the biologist would walk around the flowers to look for small, sessile individuals which are more easily missed. We also conducted 1-minute observations, flowing a single individual and recording the plant species and number of flowers it visited. Initially, we found almost no flower visitors before 9:00 or after 14:00 so we restricted observation to 9:00 to 14:00. We used binoculars, a camera with a telephoto lens, and the collection of voucher specimens to assist with counting and identifying flower visitors. Observations were conducted at patches of San Diego thornmint and Otay tarplant, with the largest and best quality flowers selected. The individuals selected for the 1-minute observations were opportunistic, but priority was given to rarely encountered species if a choice was possible.

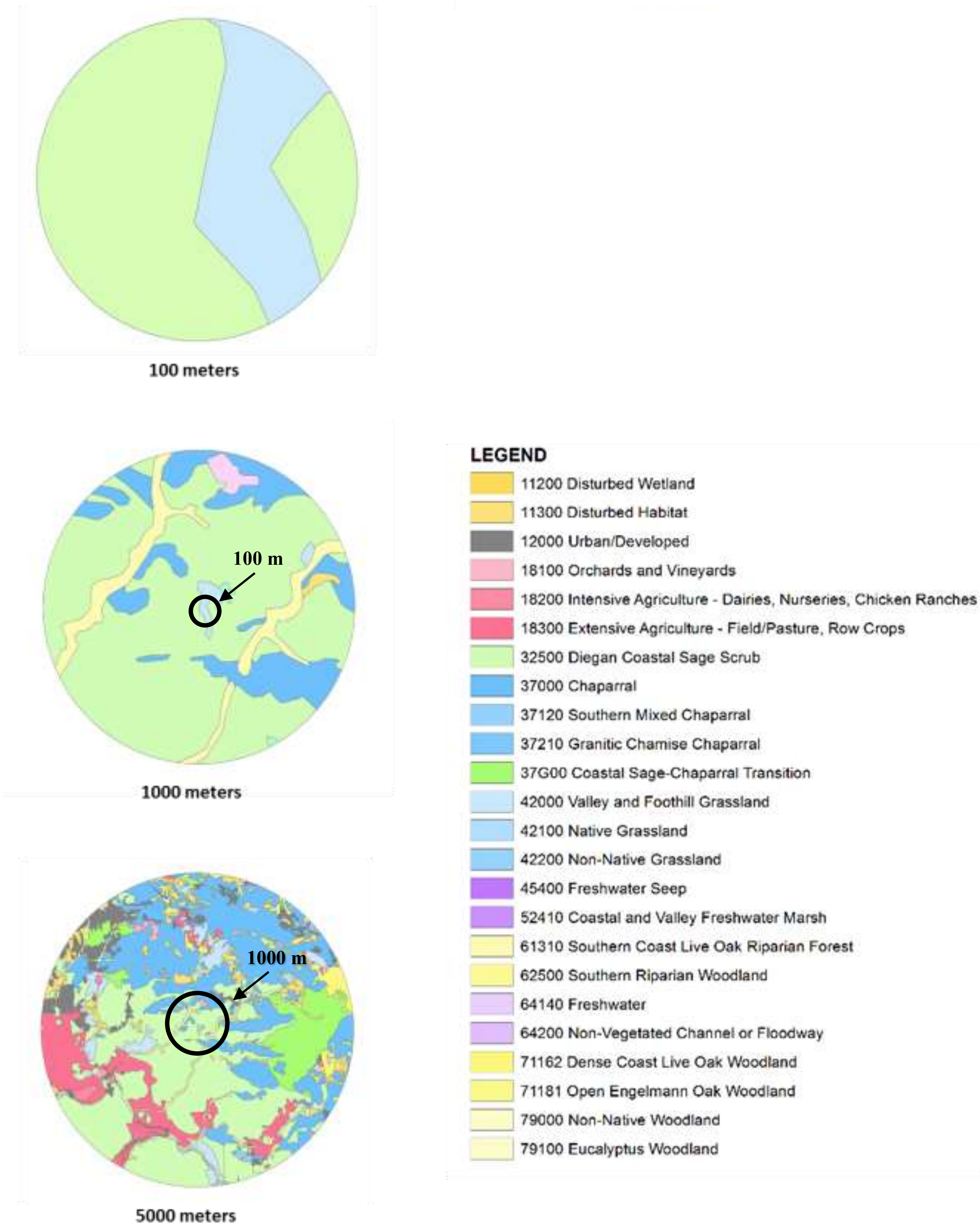

Figure 3. An example of a habitat analysis, calculating the area of each habitat type within three different distances from the trap location. The figures show the 1995 Holland code vegetation classifications within a 100, 1000, and 5000-meter radius of the trap location.

Cup traps (Figure 4) were used to sample the pollinator communities in association with San Diego thornmint and Otay tarplant, as well as other vegetation patches. The traps always included a yellow, blue, and white cups which are standard for bee sampling but collect many other insect groups. Purple and red cups were also used at certain times as there were several plant species with purple flowers earlier in the season and red can be an effective color for sampling cactus bees, especially *Macrotera* (Droege 2002). A wood frame elevated the cups 18 inches above the ground in an attempt to standardize protocol across sites and to have the cups at roughly the same height as the flowers. The height of 18 inches was selected because it represented a compromise of San Diego thornmint which can reach 12 inches in height and Otay tarplant 24 inches in height. The drought conditions resulted in most individuals of both endangered species being much shorter. In fact, some flowering individuals were 10cm tall or less. To adjust for these low-stature plants, a cup was placed on the ground and attached to the wooden frame.

Twelve-ounce plastic white cups were used and a subset were painted with the following spray paints: Ace Glo Spray Fluorescent Solar Yellow 17052/17052A; Ace Glo Spray Fluorescent Blue 19716/19716A; Rust-oleum Painter's Touch 2X Ultra Cover Paint+Primer Gloss Grape 249113, Rust-oleum Painter's Touch 2X Ultra Cover Paint+Primer Satin French Lilac 249079; and Rust-oleum Gloss Protective Enamel Sunrise Red 7762. During trapping, each cup was filled within one inch of the top with soapy water. Specimens from the traps were collected every six days (Table 2). Leaving the traps out for a longer time period reduces the cost associated with sampling (fewer trips to the field required). However, specimen condition would start to deteriorate if traps were left out longer.

Table 2. Total cup trap sampling effort at each site. A sampling bout was generally a six-day period, with the number of traps and length of trapping time varying among sites due to the number and type of plant populations present.

Site	Number of Sampling Bouts
Carlsbad Highlands Ecological Reserve	2
Dennery Ranch Park	13
Hollenbeck Canyon Wildlife Area	12
Long Canyon	7
Los Penasquitos Canyon Park	5
Mission Trails Regional Park	8
Paradise Hills Community Park	10
Rancho Jamul Ecological Reserve	42
Rice Canyon	22
Rose Canyon	3
Sabre Springs Park	4
Tecolote Canyon	2
USFWS - McGinty Mountain	6
USFWS - Sweetwater	20
Wright's Field	4

Flower observations and trapping occurred during the flowering season for both the San Diego thornmint and Otay tarplant. In 2015, this was earlier and shorter than normal due to the hot and dry winter. Trapping started on 5 March 2015 for flowering thornmint, continued with Otay tarplant flowering in April-May, and extended into June to sample around flowers of California buckwheat.

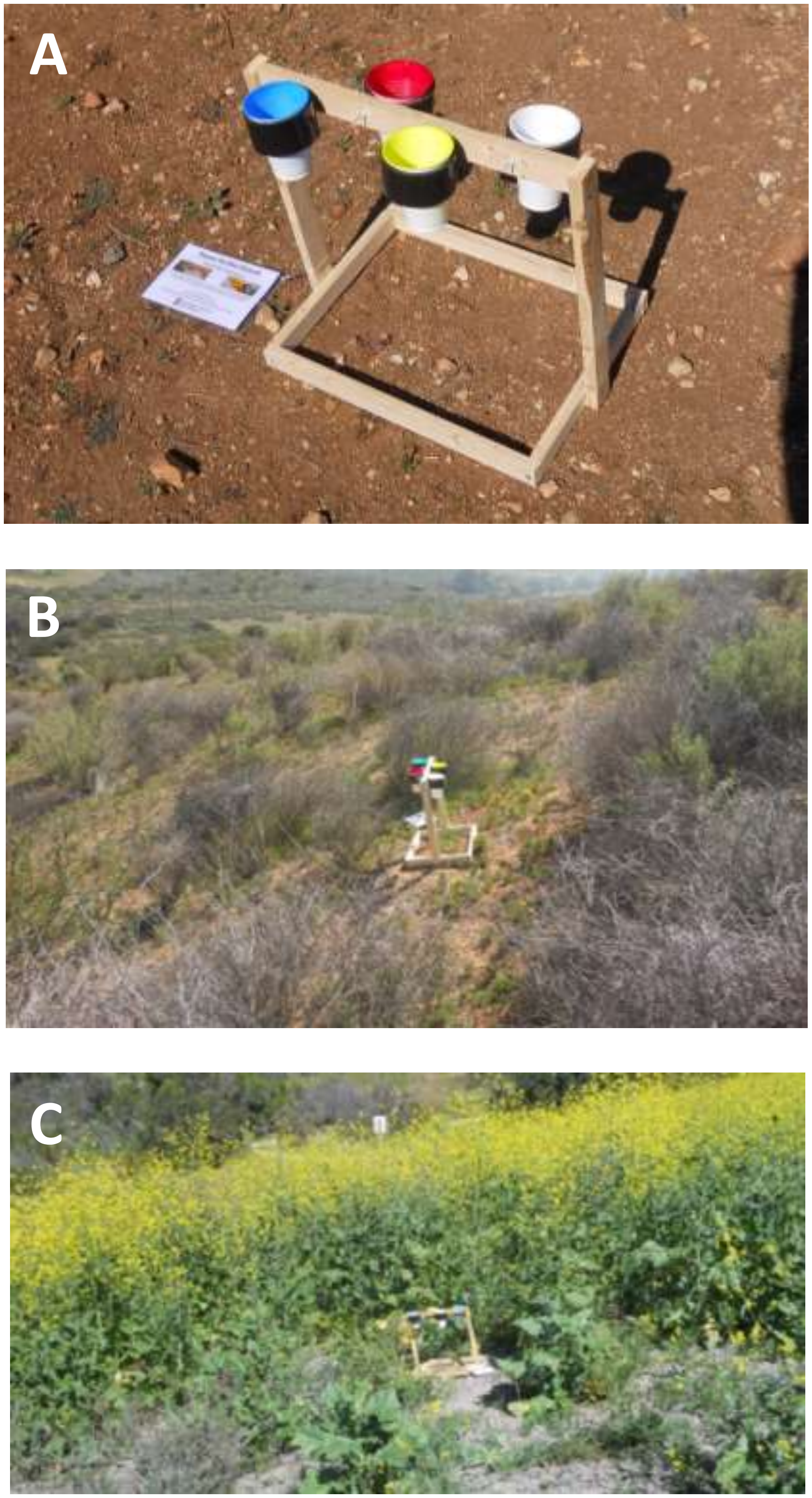

Figure 4. Elevated cup trap setup. A) A wood structure elevated colored cups with soapy water about 18 inches above the ground and included an informational sign. B) Trap placed in coastal sage scrub. C) Trap placed in a degraded area with flowering mustard.

Decomposer Community

The decomposer community was assessed with two methods: baited traps and controlled field trials. Baited traps were used to determine the identity and relative abundance of decomposers at each site. Controlled trials were used to measure decomposition rates and quantify the contribution of insects. In both cases, we used rat carcasses as a standard bait in the field.

Modified bucket pitfall traps were used to sample the arthropods associated with the animal carcass decomposition process (Figure 5). A five-gallon bucket was fitted with a 4' x 4' piece of plywood that had a hole just smaller than the opening of the bucket. A small piece of wood was placed across the opening as it provided a way to attach the lid as well as provided about a one-inch gap under the lid so arthropods could access the bucket. The bait was also hung from this piece of wood, suspended above the water which was added to trap and preserve the specimens. The trap was placed on the ground and secured with strings from each corner of the plywood. The plywood offered a landing platform for flying insects since the trap was not placed in the ground. Placing the trap in the ground is a more traditional protocol (pitfall trap) but digging in soils with rock and hard clay is time consuming. Also, a pitfall trap that is level with the ground surface increases inadvertent bycatch. We wanted to catch those species that were specifically attracted to the bait.

The traps were baited with a rotting rat carcass that was placed in a plastic bin and exposed to the sun for four days prior to trapping. All rats were previously frozen and of similar size (175-250 g) as was used by Whipple and Hoback (2012). It has been shown the carcass taxonomic group, size, and time since death all influence the attractiveness of the bait to different arthropods. These variables were held consistent in all of our traps, and the rats represent a realistic carcass type for San Diego County. Traps were deployed at each site for two different six or seven-day periods with the first period either 21-28 May, 29 May-4 June, or 5-11 June and the second either 12-18 June, 19-25 June, or 26 June-2 July (Table 3). Initial pilot tests were conducted at a small number of sites as a trial from 25-26 February and 20-22 April to assess insect activity. As with the cup traps, bucket trap specimens were collected every six days to provide enough time to capture a large number of specimens but avoid deterioration (decomposition) of the arthropod specimens. Bucket trap placements were well separated as the scent of the carcasses were likely to attract insects from at least 100 meters away. Although we had planned on conducting trials with dung as well, we were unable to obtain appropriate dung from the San Diego Zoo or other wildlife care facilities. As a result, we were only able to conduct a small trial with dung-baited traps.

Carcasses were also placed in the field to measure the rate of decomposition attributable to arthropods. In a paired design, one carcass was placed under a wire cage that allowed access by arthropods but restricted vertebrates (mainly mammals). The second carcass was wrapped with fine netting and also placed under a wire cage. The netting restricted arthropod but allowed for any water loss/gain, acting as a control. Due to time limitations, this trial was only conducted at Hollenbeck Canyon Wildlife Area and Tecolote Canyon.

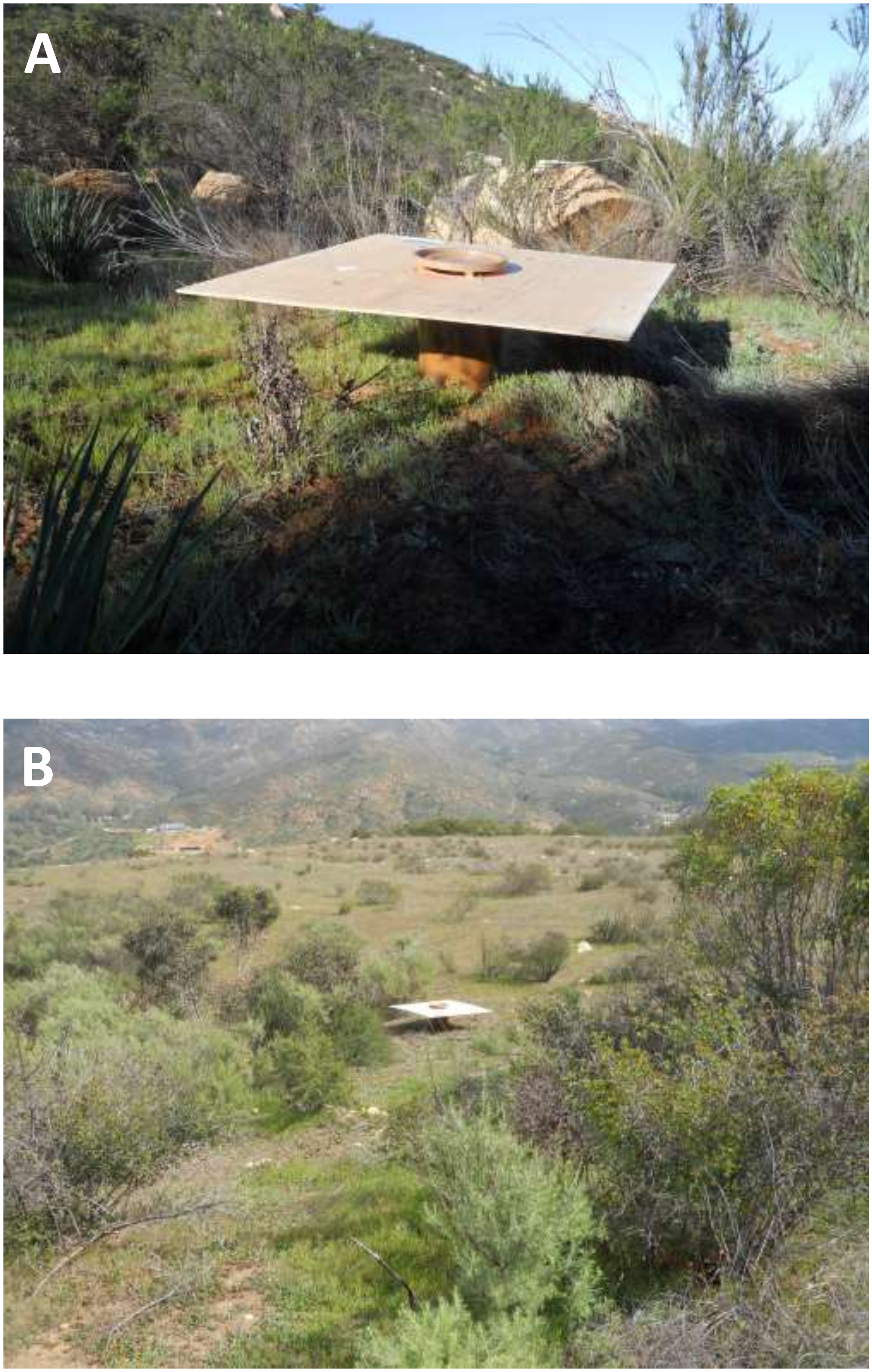

Figure 5. Bucket trap setup. A) Close-up of a bucket trap. B) A bucket trap in a grassland-sage scrub habitat.

Table 3. Total bucket trap sampling effort at each site. Each trap was deployed for two different six-day periods. The number of traps at each site varied due to the size of the reserve and the different habitat types present.

Site	Number of Traps Deployed
Carlsbad Highlands Ecological Reserve	2
Crestridge Ecological Reserve	3
Dennery Ranch Park	2
Hollenbeck Canyon Wildlife Area	2
Long Canyon	1
Los Penasquitos Canyon Park	1
Manzanita Canyon	1
Marian Bear Park	1
Mission Trails Regional Park	1
Paradise Hills Community Park	1
Rancho Jamul Ecological Reserve	2
Rice Canyon	1
Rose Canyon	1
Sabre Springs Park	1
Switzer Canyon	1
Tecolote Canyon	2
USFWS - Las Montanas	1
USFWS - Sweetwater	1
USFWS - Trace Road	1
Wright's Field	2

Specimens

All collected specimens were pinned or placed in 75% ethanol, depending on the standard preferred long-term preservation for the specific arthropod group. Each specimen was labeled with the collection information, assigned a unique number on a separate label, and databased. When there were many specimens of the same morphospecies, they were sorted, counted (estimated if more than 15) and preserved in ethanol. Most of the specimens will be deposited in the entomology collection at the San Diego Natural History Museum.

Results

Participants

Involvement of students was an important aspect of this project. We recruited graduate and undergraduate students to assist with field data collection and processing of samples. This provides valuable hands-on experience to complement their coursework and aid career development.

Two Master's students worked alongside with one of the Authors (Marschalek). These three conducted flower observations and served as crew leaders for the insect sampling. A field technician from the San Diego Natural History Museum also assisted with the flower observations. Setting traps out for insects represents a relatively small amount of time compared to processing and identifying specimens. Undergraduate student interns and volunteers assisted with collecting specimens from the traps. More importantly they were essential to this project as they pinned, labeled, and databased most of the 30,000+ specimens. The final dataset represents the cumulative effort of 20 volunteers and 5 interns contributing ~1100 hours to this project.

Pollinator Community

Cup Traps

A total of 18,867 specimens were processed from the cup traps. Analysis was restricted to specimens in the orders Coleoptera, Diptera, Hymenoptera, and Lepidoptera as these groups are the primary pollinators. Thysanoptera (thrips) can also be important pollinators (Moog et al. 2002) but their small size made collecting difficult. Many specimens belonging to Hemiptera were captured but their capture is likely accidental or they were attracted to the water. Summary tables reporting community composition include all specimens from all cup traps; however, the habitat analyses were restricted to only the specimens captured in the yellow, blue, and white elevated cups. The summary tables often contain many taxonomic groups to illustrate the differences of the insect communities across sites. Shading, from red to blue representing high to low abundances, is included to assist with visualizing these differences.

The average total number of specimens varied across sites, ranging from an average of 34.6 at Paradise Hills Community Park to 441.6 at Long Canyon (Table 4). The composition of the potential pollinator community also varied within each site. Few Lepidoptera (butterflies/moths) were captured regardless of site. Generally, Coleoptera (beetles) were the most abundant group followed by Hymenoptera (bees/wasps), and Diptera (flies). However, there were exceptions such as a large number of flies captured at Los Penasquito Canyon or the paucity of beetles captured at Rice Canyon. These patterns may be related to the time of trapping, adjacent flowering plant numbers and species, habitat type and/or quality, or a combination of these and other environmental variables.

A Principal Component Analysis (PCA) was conducted to initially investigate the relationship among the insect groups (Figure 6). The patterns of abundance were similar for the orders Coleoptera and Hymenoptera. The abundance of Diptera was independent of the Coleoptera and Hymenoptera. The Lepidoptera were not well characterized with the PCA likely due to their low abundances.

Classification to order is very coarse and offers little information regarding potentially important species, and therefore their ecological requirements and behaviors. Table 5 lists the insect specimens based on the family-level identification. Within each order there tended to be one or two families that were much more abundant than the others. This was especially true for the Coleoptera, where Melyridae which represented 58 percent of all Coleoptera specimens collected with bucket traps. Synneuridaa represented about two-thirds of the Diptera and Halictidae represented about half of the Hymenoptera.

Table 4. The average number of specimens of four insect order captured in cup traps for a 6-day sampling period at each site. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts.

Site	Coleoptera	Hymenoptera	Diptera	Lepidoptera	Total
Carlsbad Highlands Ecological Reserve	84.0	8.0	2.5	0.0	94.5
Dennery Ranch Park	100.5	43.6	4.2	0.3	148.7
Hollenbeck Canyon Wildlife Area	18.2	6.6	19.0	0.5	44.3
Long Canyon	375.9	56.3	9.0	0.4	441.6
Los Penasquitos Canyon Park	37.2	16.4	154.2	0.4	208.2
Mission Trails Regional Park	36.8	26.4	15.1	0.5	78.8
Paradise Hills Community Park	15.2	9.8	8.9	0.7	34.6
Rancho Jamul Ecological Reserve	67.4	27.0	7.8	0.8	103.0
Rice Canyon	15.6	19.3	22.2	0.5	57.6
Rose Canyon	66.3	36.7	23.0	0.0	126.0
Sabre Springs Park	6.0	9.3	20.8	0.0	36.0
Tecolote Canyon	36.5	25.0	6.5	0.0	68.0
USFWS - McGinty Mountain	30.0	18.8	19.7	3.7	72.2
USFWS - Sweetwater	119.3	25.1	5.1	0.4	149.8
Wright's Field	22.0	14.0	24.3	0.8	61.0
Average:	68.7	22.8	22.8	0.6	114.9

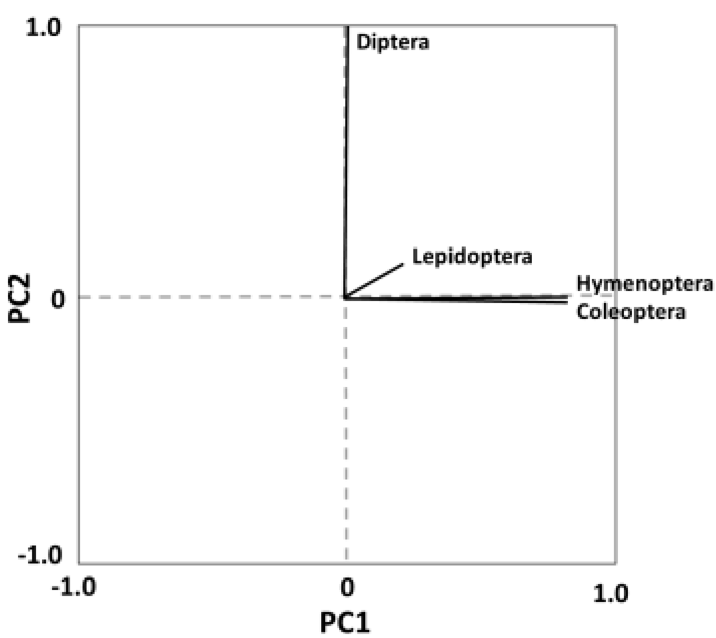

Figure 6. A visualization of the relationship among four insect orders captured in cup traps using Principal Component Analysis.

Table 5. The average number of specimens for each family within four insect order captured in cup traps for a 6-day sampling period at each site. The families are listed alphabetically within each order. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts. Prevalence describes the frequency of occurrence at the site level, while proportion describes the relative contribution of the particular family to the entire sample.

Site	Coleoptera												
	Buprestidae	Cerambycidae	Chrysomelidae	Coccinellidae	Curculionidae	Dermestidae	Meloidae	Melyridae	Mordellidae	Ripiphoridae	Scarabaeidae	Staphylinidae	Other
Carlsbad Highlands Ecological Reserve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.5	0.0	0.0	0.0	0.0	0.5
Dennery Ranch Park	0.5	0.1	0.0	0.3	0.0	0.0	0.2	99.2	0.2	0.0	0.0	0.0	0.1
Hollenbeck Canyon Wildlife Area	0.1	0.0	0.0	0.1	0.1	0.0	2.6	15.3	0.1	0.0	0.0	0.0	0.0
Long Canyon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	375.6	0.3	0.0	0.0	0.0	0.0
Los Penasquitos Canyon Park	0.2	0.0	0.0	0.2	0.0	0.0	0.0	35.4	0.0	0.2	0.6	0.4	0.2
Mission Trails Regional Park	0.0	0.0	0.0	0.0	0.0	0.0	1.3	34.8	0.0	0.0	0.6	0.0	0.1
Paradise Hills Community Park	0.1	0.0	0.0	0.0	0.0	1.7	0.0	13.1	0.1	0.0	0.0	0.0	0.2
Rancho Jamul Ecological Reserve	0.1	0.0	0.0	0.1	0.0	0.0	0.2	66.3	0.4	0.0	0.0	0.0	0.1
Rice Canyon	0.4	0.0	0.0	0.2	0.0	0.2	0.0	13.9	0.4	0.0	0.3	0.0	0.1
Rose Canyon	0.0	0.0	0.0	0.0	3.7	1.0	0.0	56.7	1.0	0.0	0.0	0.7	3.3
Sabre Springs Park	1.8	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.0	0.0	0.3	0.0	0.5
Tecolote Canyon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.0	1.0	0.0	0.5	0.0	0.0
USFWS - McGinty Mountain	0.5	0.5	0.0	0.0	0.7	0.0	0.7	26.7	0.3	0.0	0.0	0.2	0.5
USFWS - Sweetwater	0.0	0.0	0.0	0.1	0.0	0.0	0.0	118.7	0.4	0.0	0.0	0.1	0.1
Wright's Field	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0	0.0	0.0	0.0	0.0	1.0
Average:	0.2	0.0	0.0	0.1	0.3	0.2	0.3	66.5	0.3	0.0	0.1	0.1	0.4
Prevalence:	0.53	0.20	0.07	0.40	0.33	0.27	0.33	1.00	0.73	0.07	0.33	0.40	0.80
Proportion:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00

Site	Diptera														
	Anthomyiidae	Asilidae	Bombyliidae	Calliphoridae	Chironomidae	Dolichopodidae	Hippoboscidae	Muscidae	Phoridae	Sarcophagidae	Synneuridae	Syrphidae	Tachinidae	Tipulidae	Other
Carlsbad Highlands Ecological Reserve	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.5
Dennery Ranch Park	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.4	0.0	0.5	0.5	0.0	2.0
Hollenbeck Canyon Wildlife Area	2.2	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	11.8	0.2	0.5	0.0	3.4
Long Canyon	0.4	0.0	0.1	0.0	0.0	0.4	0.0	0.3	0.7	1.9	0.3	0.3	0.3	0.0	4.3
Los Penasquitos Canyon Park	0.8	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.2	149.8	0.0	0.6	0.0	2.4
Mission Trails Regional Park	0.4	0.0	0.4	0.0	0.0	0.3	0.0	0.3	0.0	0.4	11.3	0.0	1.5	0.0	0.8
Paradise Hills Community Park	1.0	0.0	0.0	0.1	0.0	0.3	0.0	0.4	0.1	0.6	0.9	2.9	0.9	0.0	1.7
Rancho Jamul Ecological Reserve	1.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.6	1.2	0.3	0.4	0.0	3.5
Rice Canyon	0.6	0.0	0.0	0.0	0.0	1.4	0.0	0.4	0.6	0.0	15.0	0.4	0.2	0.0	3.6
Rose Canyon	0.7	0.0	0.0	0.3	0.0	5.7	0.0	0.0	0.7	1.3	0.3	4.0	2.7	0.0	7.3
Sabre Springs Park	1.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	17.0	0.3	0.0	0.0	1.3
Tecolote Canyon	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.5	0.0	0.5	0.0	0.0	2.0	0.0	1.5
USFWS - McGinty Mountain	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	10.7	0.2	1.5	0.0	6.0
USFWS - Sweetwater	1.3	0.0	0.1	0.0	0.1	0.1	0.0	0.3	0.3	0.6	0.2	0.2	0.6	0.1	1.4
Wright's Field	2.3	0.3	0.0	0.0	0.0	0.0	0.0	0.3	2.8	0.0	13.5	0.0	0.0	0.0	5.3
Average:	1.0	0.1	0.1	0.0	0.0	0.7	0.0	0.2	0.4	0.6	15.5	0.6	0.8	0.0	3.0
Prevalence:	0.93	0.27	0.40	0.20	0.07	0.60	0.07	0.60	0.60	0.93	0.80	0.67	0.80	0.07	1.00
Proportion:	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.14	0.01	0.01	0.00	0.03

Site	Hymenoptera														Lepidoptera		
	Andrenidae	Apidae	Chalcididae	Colletidae	Formicidae	Halictidae	Megachilidae	Melittidae	Mutillidae	Pompilidae	Scoliidae	Tenthredinidae	Vespidae	Other	Hesperiidae	Sphingidae	Other
Carlsbad Highlands Ecological Reserve	0.0	4.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Dennery Ranch Park	0.1	4.5	0.0	0.0	0.1	36.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	2.1	0.0	0.0	0.3
Hollenbeck Canyon Wildlife Area	0.4	1.2	0.0	0.0	0.3	2.4	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.9	0.0	0.0	0.5
Long Canyon	0.0	9.9	0.0	0.0	0.0	44.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.4
Los Penasquitos Canyon Park	2.4	6.0	0.0	0.0	0.4	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.8	0.0	0.0	0.4
Mission Trails Regional Park	2.3	9.4	0.0	0.0	0.6	12.6	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.5
Paradise Hills Community Park	0.0	4.2	0.1	0.0	1.4	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.1	0.0	0.6
Rancho Jamul Ecological Reserve	1.5	9.4	0.0	0.0	0.1	9.6	2.6	0.0	0.0	0.2	0.0	0.0	0.3	1.5	0.0	0.0	0.8
Rice Canyon	0.0	6.0	0.0	0.0	3.5	7.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.9	0.0	0.0	0.5
Rose Canyon	0.0	15.3	0.0	0.0	6.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	0.0	0.0	0.0
Sabre Springs Park	0.0	2.8	0.0	0.0	0.3	4.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0	0.0	0.0	0.0
Tecolote Canyon	0.0	9.5	0.0	0.0	0.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
USFWS - McGinty Mountain	1.3	6.7	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.3	0.0	0.0	3.7
USFWS - Sweetwater	0.2	9.1	0.0	0.0	0.2	13.3	0.1	0.0	0.0	0.1	0.0	0.0	0.6	1.0	0.1	0.0	0.4
Wright's Field	0.0	1.5	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.8	0.0	0.0	0.8
Average:	0.5	6.6	0.0	0.0	0.9	11.5	0.2	0.0	0.0	0.0	0.0	0.1	0.1	1.9	0.0	0.0	0.6
Prevalence:	0.53	1.00	0.07	0.13	0.73	1.00	0.20	0.13	0.13	0.20	0.07	0.20	0.33	1.00	0.20	0.07	0.73
Proportion:	0.00	0.06	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01

Table 6. The average number of specimens for each species captured in cup traps for a 6-day sampling period at each site. The species are listed from most abundant (left) to least abundant (right). For simplification, the 118 least abundant species representing less than 3% of all specimens are consolidated. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts. Prevalence describes the frequency of occurrence at the site level, while proportion describes the relative contribution of the particular family to the entire sample. Codes for the order are listed above each species (C = Coleoptera, D = Diptera, H = Hymenoptera).

Sites	Melyridae sp1	Melyridae sp2-5	Exiliscelis californiensis	Lasioglossum microlepoides	Apis mellifera	Halictus tripartitus	Diptera Other	Anthomyiidae	Tachinidae	Linepithema humile	Tetraloniella davidsoni	Dolichopodidae	Hymenoptera Other	Melissodes tessellata	Syrphidae sp1	Wasp	Sarcophagidae
Order:	C	C	D	H	H	H	D	D	D	H	H	D	D	H	D	H	D
Carlsbad Highlands Ecological Reserve	15.0	68.5	0.0	3.0	3.5	0.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0
Dennery Ranch Park	56.2	41.7	0.0	22.5	2.6	13.0	1.1	0.6	0.5	0.1	1.1	0.1	0.6	0.0	0.5	0.5	0.4
Hollenbeck Canyon Wildlife Area	6.3	8.8	11.8	1.5	0.3	0.3	3.1	2.2	0.5	0.1	0.1	0.0	0.0	0.3	0.2	0.8	0.7
Long Canyon	182.0	193.6	0.3	40.1	6.9	3.7	2.4	0.4	0.3	0.0	2.3	0.4	0.4	0.3	0.3	0.1	1.9
Los Penasquitos Canyon Park	17.4	15.0	149.8	4.2	3.4	0.0	2.4	0.8	0.6	0.0	1.2	0.0	0.6	0.0	0.0	1.0	0.2
Mission Trails Regional Park	24.9	9.9	11.3	12.0	3.8	0.5	0.8	0.4	1.5	0.0	1.4	0.3	0.0	1.1	0.0	0.3	0.4
Paradise Hills Community Park	7.9	5.2	0.9	2.4	3.7	0.3	0.5	1.0	0.9	1.1	0.0	0.3	0.2	0.0	2.9	0.0	0.6
Rancho Jamul Ecological Reserve	15.1	50.7	1.2	6.3	1.6	2.5	2.4	1.2	0.4	0.0	0.0	0.0	0.6	4.8	0.3	0.5	0.6
Rice Canyon	2.1	11.2	15.0	5.0	4.8	0.3	2.6	0.6	0.2	3.4	0.7	1.4	0.1	0.1	0.4	0.3	0.0
Rose Canyon	35.0	20.3	0.3	1.0	15.0	3.0	3.0	0.7	2.7	6.0	0.0	5.7	6.3	0.0	4.0	1.7	1.3
Sabre Springs Park	0.8	1.0	17.0	2.5	2.8	1.3	1.0	1.5	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.5	0.5
Tecolote Canyon	18.0	17.0	0.0	10.0	7.5	2.0	0.0	0.0	2.0	0.0	2.0	2.0	0.0	0.0	0.0	1.0	0.5
USFWS - McGinty Mountain	6.7	17.7	10.7	5.7	2.7	0.0	5.5	0.8	1.5	0.0	2.0	0.0	0.8	0.5	0.2	1.3	0.3
USFWS - Sweetwater	98.7	19.6	0.2	9.3	3.7	3.8	0.8	1.3	0.6	0.1	0.1	0.1	0.1	2.1	0.2	0.4	0.6
Wright's Field	21.0	0.0	13.5	4.8	1.3	3.5	5.3	2.3	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.0
Average:	33.8	32.0	15.5	8.7	4.2	2.3	2.1	1.0	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
Proportion:	0.30	0.28	0.14	0.08	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cummulative Proportion:	0.30	0.58	0.71	0.79	0.83	0.85	0.86	0.87	0.88	0.89	0.89	0.90	0.90	0.91	0.92	0.92	0.93
Prevalence:	1.00	0.93	0.80	1.00	1.00	0.80	0.93	0.93	0.80	0.47	0.60	0.60	0.67	0.53	0.67	0.93	0.93

Sites	Diptera sp12	Hymenoptera Other	Phoridae	Wasp 2	Melyridae sp9	Eucera tricinctella	Macrotera tristella	Wasp 1	Coleoptera Other	Mordellidae sp1	Curculionidae Other	Anthrenus	Osmia sp1	Muscidae	Melyridae sp6	Melyridae sp6B	Scarabaeidae	Augochlorella texanus	Lytta stygica	Anthophorula nitens	Less than 3% (118 taxa)	Total
Order:	D	H	D	H	C	H	H	H	C	C	C	C	H	D	C	C	C	H	C	H		
Carlsbad Highlands Ecological Reserve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	94.5
Dennery Ranch Park	0.4	0.3	0.1	0.4	1.0	0.0	0.0	0.6	0.1	0.2	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.2	3.5	148.3
Hollenbeck Canyon Wildlife Area	0.1	0.3	0.0	0.1	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	3.3	43.0
Long Canyon	1.3	0.4	0.7	0.1	0.0	0.0	0.0	0.6	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.1	1.3	440.7
Los Penasquitos Canyon Park	0.0	0.4	0.2	0.2	2.8	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.6	0.0	0.0	0.2	2.8	207.0
Mission Trails Regional Park	0.0	0.5	0.0	0.1	0.0	1.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	0.1	0.0	0.5	5.5	78.3
Paradise Hills Community Park	0.4	0.6	0.1	0.2	0.0	0.0	0.0	0.4	0.1	0.1	0.0	1.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	2.3	34.2
Rancho Jamul Ecological Reserve	0.3	0.6	0.1	0.2	0.4	1.2	1.4	0.3	0.1	0.1	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.1	0.0	0.1	5.5	101.3
Rice Canyon	0.5	0.4	0.6	0.2	0.4	0.0	0.0	0.2	0.0	0.1	0.0	0.2	0.0	0.4	0.1	0.0	0.3	1.0	0.0	0.0	3.1	56.1
Rose Canyon	2.7	0.0	0.7	2.0	0.0	0.0	0.0	0.7	3.0	0.7	3.0	0.7	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	5.3	126.0
Sabre Springs Park	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.3	1.0	0.0	0.0	0.0	0.0	0.5	0.3	0.3	0.0	0.0	0.0	3.0	35.3
Tecolote Canyon	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.5	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.5	0.0	0.0	1.0	68.0
USFWS - McGinty Mountain	0.3	2.3	0.0	0.2	0.2	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.3	0.7	0.0	0.0	0.0	0.2	8.8	70.7
USFWS - Sweetwater	0.1	0.4	0.3	0.2	0.4	1.0	0.2	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.7	4.0	149.2
Wright's Field	0.0	0.8	2.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.5	57.8
Average:	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	3.5	114.0
Proportion:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	< 3%	
Cummulative Proportion:	0.93	0.93	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	1.00	
Prevalence:	0.73	0.73	0.60	0.87	0.40	0.40	0.40	0.73	0.47	0.60	0.20	0.27	0.13	0.60	0.33	0.20	0.33	0.47	0.13	0.47	1.00	

We also conducted a PCA of the most common insect families to assess patterns of covariation among these groups. Two of the three families represented by the most species (Coleoptera: Melyridae and Hymenoptera: Halictidae) exhibited similar patterns of variation along with Apidae (Figure 7). The second most commonly collected family was Synneuridae which exhibited a pattern of variation most different from all other groups. Formicidae was also had a relatively distinct pattern. The Diptera and Hymenoptera did not overlap in PCA space.

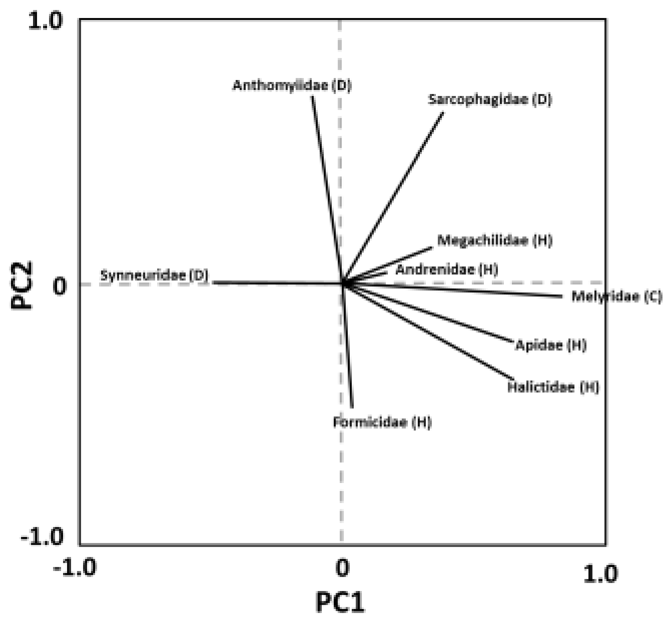

Figure 7. A visualization of the relationship among the common insect families captured in cup traps using Principal Component Analysis. Codes for the order of each family are listed in parentheses (C = Coleoptera, D = Diptera, H = Hymenoptera).

A fine-scale species-level assessment shows that there is an uneven species composition of the potential pollinator community. Only 14 species and some unidentified Diptera species represented 89 percent of the total specimens.

An unexpected finding was two specimens belonging to the bee species *Diadasia angusticeps*. This species was not known from San Diego County. The previously reported southernmost record for this species came from Orange County (Discover Life 2016).

Habitat Analysis

The proportion of each habitat type within 100 meters, 1000 meters, and 5000 meters of the sampling locations were assessed for each insect order. In addition to the habitats, a variable including site name was included in all GLMs so that we could assess any patterns driven by a site-specific phenomenon. Assessing the pollinator-habitat relationship was problematic at the 100-meter scale due to observations with high leverage. This was likely influenced by our site selection of coastal sage scrub and grassland habitats, and the placement of the trap close to the center of these habitat patches. For this reason, other habitat types within the 100-meter radius were rare. However, when they occurred, they often had undue influence on the model.

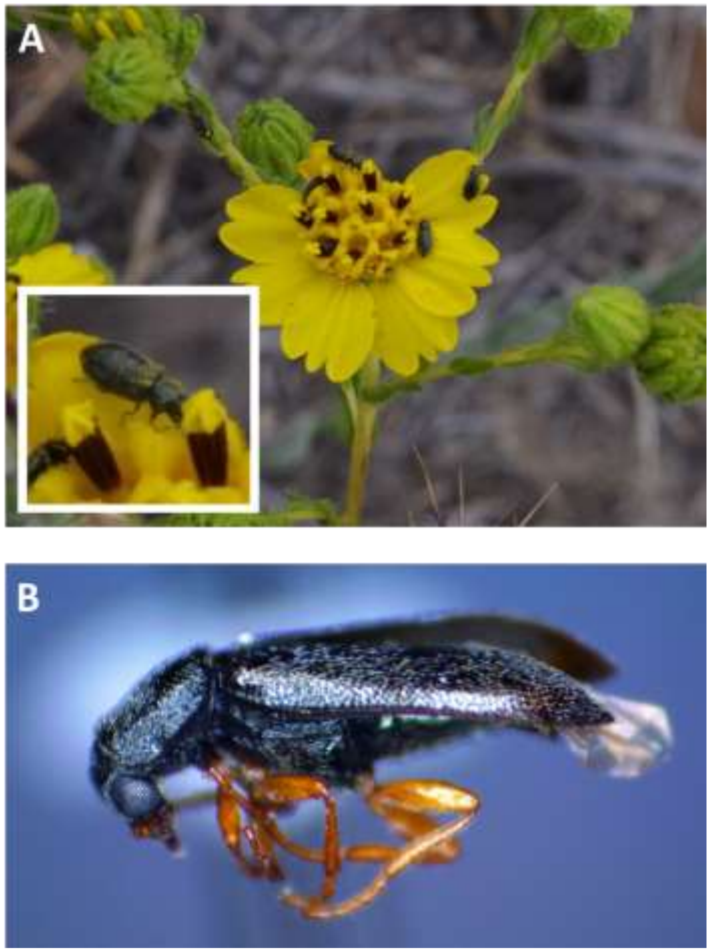

Figure 8. Melyridae morphospecies 1. A) several individuals on Otay tarplant flowers, with pollen on the dorsal side, B) A pinned specimen.

At the order level, the GLMs using habitat variable within 100 meters of the sampling location were unreliable as indicated by the red text (Table 7). Some consistent patterns emerged including the positive association of Coleoptera with grasslands but a negative correlation with riparian forest habitats. Diptera correlated positively with riparian woodlands and negatively correlated with chaparral, Hymenoptera negatively correlated with riparian forest, and Lepidoptera correlated negatively with the amount of urban area. The lack of strong habitat relationships is not surprising considering the diversity of the cup trap samples, resulting in each order being composed of many species with potentially differing natural life histories.

A family-level and species-level analysis provides further refinement. Due to the magnitude and distribution of individuals, the family-level analysis was conducted with three families Melyridae, Apidae, and Halictidae. Likewise, only four species were analyzed at the finest taxonomic level. These were Melyridae sp1, European honey bee, *Halictus tripartitus*, and *Lasioglossum microlepoides*. In general, there were several positive correlations with non-native habitats and grasslands, as well as urban areas (Table 8, 9). The European honey bee had a negative correlation with coastal sage scrub at the 1000- and 5000-meter scale.

Table 7. Pollinator insect order-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

	Holland	Coleoptera			Diptera			Hymenoptera			Lepidoptera		
Habitat	**Code**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**
Non-native	11xxx				+				+		-		
Urban	12xxx		-							-		-	-
Agriculture	18xxx			-				-					
Coastal Sage Scrub	32xxx	-		+				-					
Chaparral	37xxx				-	-	+	-				+	-
Grassland	42xxx		+	+			-	-	+				
Riparian Forest	61xxx	-	-			+		-	-	-		-	+
Riparian Woodlands	62xxx				+	+							
Oak Woodlands	71xxx				-		-						
	R^2 =	0.126	0.146	0.222	0.146	0.103	0.117	0.226	0.215	0.171	0.021	0.156	0.182

Table 8. Pollinator insect family-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

	Holland	Melyridae (C)			Apidae (H)			Halictidae (H)		
Habitat	**Code**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**
Non-native	11xxx		+		+		-		+	
Urban	12xxx		-		+			+		
Agriculture	18xxx			-			-	-		
Coastal Sage Scrub	32xxx	-		+		+	+	-		+
Chaparral	37xxx									
Grassland	42xxx			+	+	+			+	+
Riparian Forest	61xxx		-			-	-	-		
Riparian Woodlands	62xxx				+			-		
Oak Woodlands	71xxx					-				
	R^2 =	0.111	0.169	0.228	0.272	0.222	0.196	0.304	0.248	0.217

Table 9. Pollinator insect species-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

Habitat	Holland Code	Melyridae Sp1 (C) 100m	Melyridae Sp1 (C) 1000m	Melyridae Sp1 (C) 5000m	European Honey Bee (H) 100m	European Honey Bee (H) 1000m	European Honey Bee (H) 5000m	*Halictus tripartitis* (H) 100m	*Halictus tripartitis* (H) 1000m	*Halictus tripartitis* (H) 5000m	*Lasioglossum microlepoides* (H) 100m	*Lasioglossum microlepoides* (H) 1000m	*Lasioglossum microlepoides* (H) 5000m
Non-native	11xxx		+		+				+	+	+	+	
Urban	12xxx			-	+						+	+	
Agriculture	18xxx	-	+	-				-			-		-
Coastal Sage Scrub	32xxx	-				-	-	-		+	-		+
Chaparral	37xxx						-						
Grassland	42xxx		+	+		+			+	+		+	
Riparian Forest	61xxx					-					-		
Riparian Woodlands	62xxx				+		+				-		-
Oak Woodlands	71xxx						+				+		
	R^2 =	0.156	0.146	0.316	0.227	0.194	0.216	0.139	0.148	0.151	0.337	0.28	0.289

Flower Observations

Flower observations were conducted to detect insects that may have low capture rates in traps and to quantify the contribution of each insect to pollination. The relative contribution of an insect species to the pollination of a particular plant species involves the number of individuals and the frequency of flower visits. We conducted 20-minute observations to quantify the number of individuals of each insect present in a flower patch, and 1-minute observations to quantify the number of flowers a particular species will visit. These observations were conducted within either San Diego thornmint or Otay tarplant populations/patches.

San Diego Thornmint

During the 20-minute observations, we recorded few insect visitors to San Diego thornmint flowers (Table 10). Most of the Diptera visitors were *Exiliscelis californiensis* (Figure 9) (86%) followed by Syrphidae (10%). Hymenopteran visitors were more evenly distributed across Apidae, Halictidae, and Megachilidae (*Osmia*) (Figure 10).

Two bee groups (Apidae and *Osmia*) move among flowers more frequently than the fiery skipper (*Hylephila phyleus*) (Table 11). Only two formal observations were made of *Exiliscelis californiensis* moving among flowers. Given their abundance, it was clear they exhibited a relatively sessile behavior resulting in slowly/rarely moving among flowers. Syrphidae also visited the flowers but spent most of their time basking in the sun rather than feeding.

Table 10. The average daily total of insect individuals visiting a patch of flowering San Diego thornmint and Otay tarplant. The number of observations in parenthesis, red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts.

Species	Site	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Total
San Diego Thorn-mint	Dennery Ranch (1)	0.0	1.0	0.0	0.0	1.0
	Hollenbeck Canyon (1)	0.0	1.0	3.0	0.0	4.0
	Los Penasquitos (1)	1.0	5.5	0.0	0.0	6.5
	McGinty Mountain (2)	0.0	0.0	0.5	0.0	0.5
	Rice Canyon (4)	0.0	23.9	4.6	0.3	28.7
	Average:	0.2	6.3	1.6	0.1	8.1
Otay Tarplant	Dennery Ranch (3)	8.3	2.8	3.9	1.0	15.9
	Long Canyon (2)	18.6	3.5	7.3	2.0	31.4
	Rancho Jamul (2)	62.6	1.9	3.2	3.1	70.8
	Rice Canyon (3)	5.0	13.8	7.4	2.1	28.4
	Sweetwater (1)	2.8	2.0	2.3	0.0	7.0
	Average:	19.4	4.8	4.8	1.6	30.7

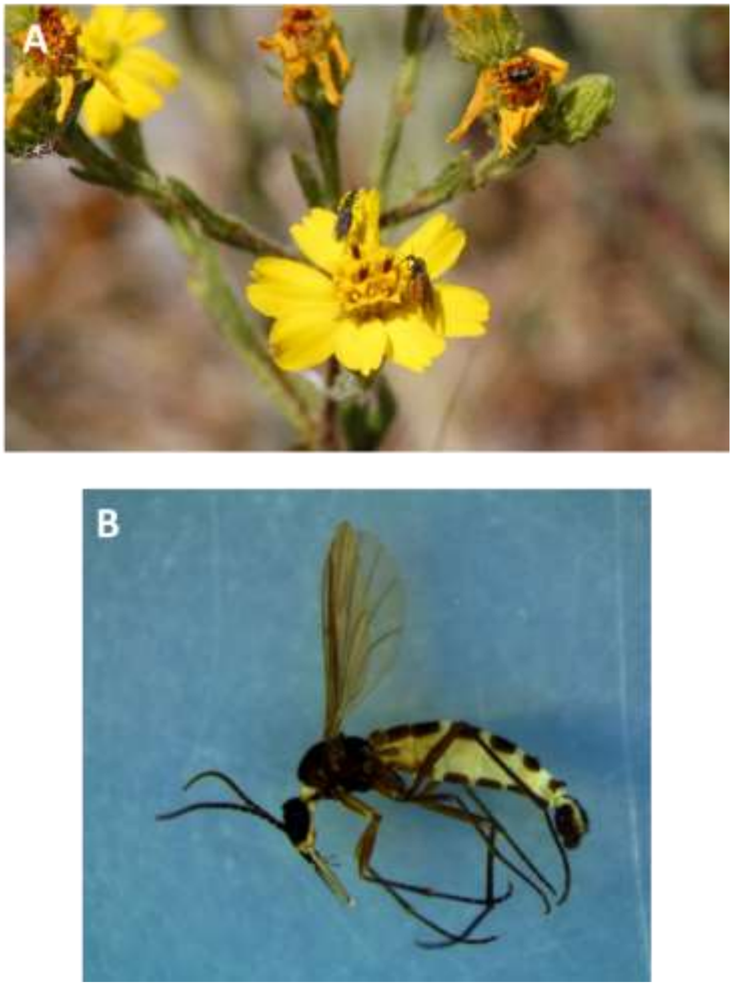

Figure 9. The fly Exiliscelis californiensis in the family Synneuridae A) on an Otay tarplant flower, B) under magnification.

Figure 10. A bee (Megachilidae: Osmia) feeding on San Diego thornmint flowers. The front of the head is covered with white pollen grains from the flowers.

Table 11. The average number of flowers visited by each insect during a 1-minute observation and the number of observations (n). Only the groups with at least three observations are reported. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts.

Plant Species	Insect Name	Avg Flowers	n
San Diego Thorn-mint	Apidae	18.8	4
	Osmia	11.8	4
	Hylephila phyleus	7.4	8
Otay Tarplant	Melyridae	1	11
	Bombyliidae	4.9	7
	Exiliscelis californiensis	1.5	5
	Syrphidae	4.8	18
	Unknown Hymenoptera	9.3	18
	Apis mellifera	12.9	49
	Speyeria callippe	10.8	5
	Pontia protodice	7.1	10

Otay Tarplant

There were more insect visitors to Otay tarplant flowers than to the flowers of San Diego thornmint during the 20-minute observations (Table 10). Coleoptera were the most common flower visitor, almost exclusively Melyridae (96%). At most sites, there were more Hymenopteran visitors than Dipterans (Figure 11) but Rice Canyon was an exception where there were many *Exiliscelis californiensis* (Figure 9) individuals. Again, Lepidoptera (mainly butterflies) were rarely encountered but Rancho Jamul Ecological Reserve had a moderate number. Across sites, the composition varied at the order level (Figure 12) as well as within orders at the family level (Figure 13).

Figure 11. A fly (Syrphidae) visiting a Otay tarplant flower, with yellow pollen grains on its legs and the ventral side of the body. Syrphid flies commonly resemble bees.

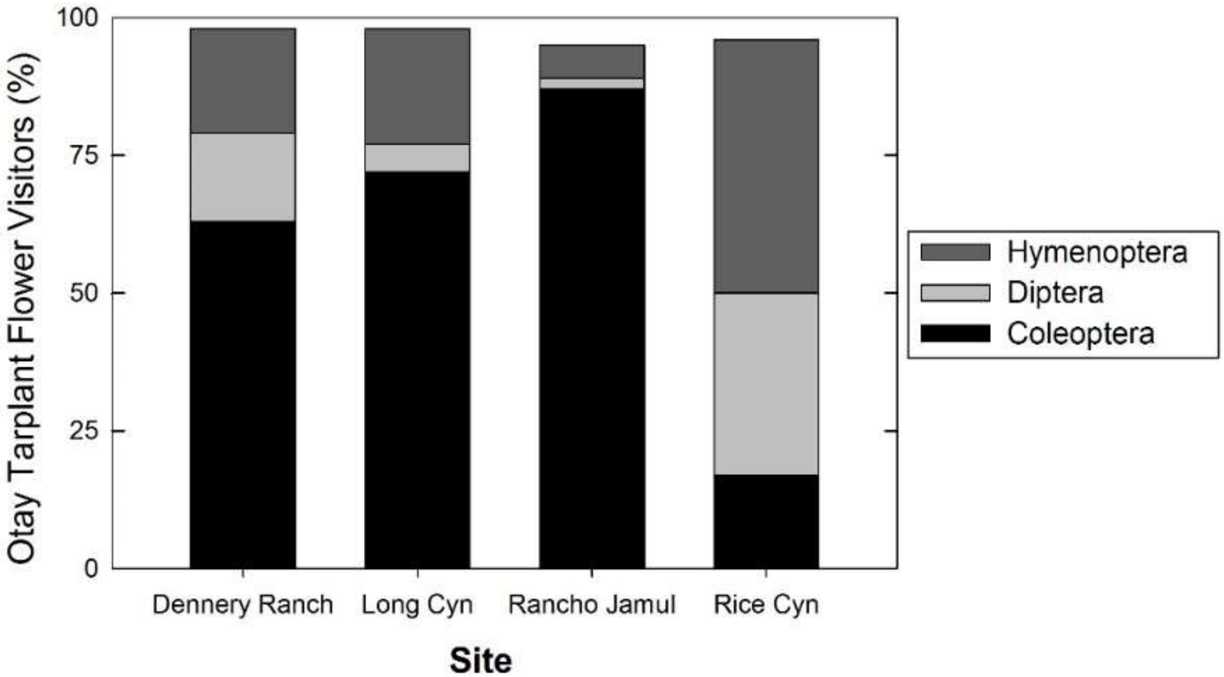

Figure 12. Proportion of Otay tarplant flower visitors at four sites within the three primary orders.

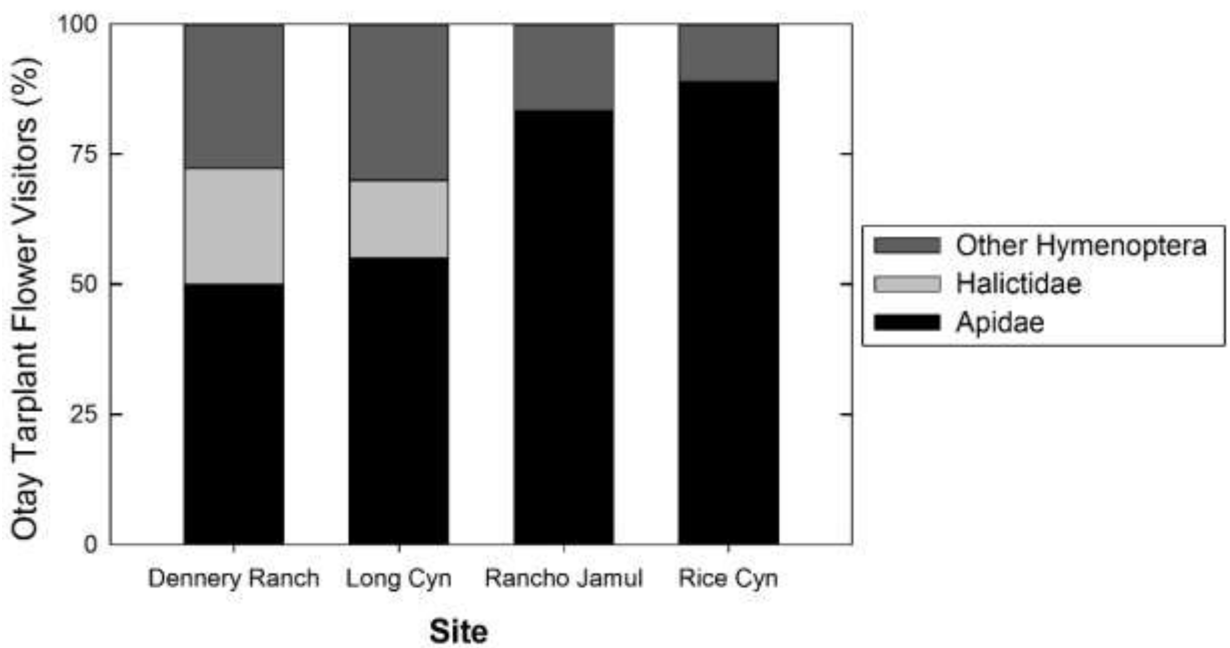

Figure 13. Proportion of Otay tarplant flower visitors at four sites within Hymenoptera.

Decomposer Community

Composition

A total of 11,171 specimens were processed from the bucket traps. Summary tables (Tables 12-14) reporting community composition include all specimens from all bucket traps including two initial trial trapping period; however, the habitat analysis was restricted to only the specimens captured during the two six-day trapping periods. The initial trapping trials of 25-26 February and 20-22 April resulted in a relatively low number and diversity of insect specimens, including few Coleoptera. These preliminary data were valuable in determining when full trapping should start.

The average number of specimens found in each trap varied across sites, ranging from 28 at Manzanita Canyon to 1329 at Carlsbad Highlands Ecological Reserve (Table 12). The composition of the decomposer community also varied within each site. Few cockroaches (Blattodea) were captured across all sites, Hollenbeck Canyon Wildlife Area and Rancho Jamul Ecological Reserve had high numbers of beetles (Coleoptera), and only Carlsbad Highlands Ecological Reserve had high numbers of earwigs (Dermaptera). The numbers of flies (Diptera) and ants/wasps (Hymenoptera) were more variable.

Table 12. The average number of specimens within each insect order captured in bucket traps during a 6-day sampling period at each site. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts.

Site	Blattodea	Coleoptera	Dermaptera	Diptera	Hymenoptera	Total
Carlsbad Highlands Ecological Reserve	0.5	9.0	495.0	46.0	778.5	1329.0
Crestridge Ecological Reserve	0.0	11.7	0.0	112.7	79.3	203.7
Dennery Ranch Park	0.0	7.0	0.0	8.5	159.5	175.0
Hollenbeck Canyon Wildlife Area	0.0	216.0	2.0	113.0	438.0	769.0
Long Canyon	0.0	4.0	0.0	27.0	372.0	403.0
Los Penasquitos Canyon Park	0.0	6.0	0.0	110.0	186.0	302.0
Manzanita Canyon	0.0	18.0	0.0	8.0	2.0	28.0
Marian Bear Park	0.0	12.0	0.0	15.0	127.0	154.0
Mission Trails Regional Park	0.0	16.0	0.0	70.0	233.0	319.0
Paradise Hills Community Park	0.0	25.0	1.0	6.0	137.0	169.0
Rancho Jamul Ecological Reserve	0.0	159.5	45.5	35.0	84.0	324.0
Rice Canyon	1.0	6.0	0.0	19.0	12.0	38.0
Rose Canyon	0.0	10.0	0.0	18.0	1085.0	1113.0
Sabre Springs Park	3.0	11.0	0.0	50.0	739.0	803.0
Switzer Canyon	0.0	15.0	0.0	0.0	88.0	103.0
Tecolote Canyon	0.0	23.0	0.5	56.5	171.0	251.0
USFWS - Las Montanas	0.0	39.0	0.0	35.0	130.0	204.0
USFWS - Sweetwater	0.0	56.0	7.0	20.0	194.0	277.0
USFWS - Trace Road	0.0	35.0	0.0	19.0	46.0	100.0
Wright's Field	0.0	88.5	0.0	201.5	85.0	375.0
Average:	0.2	38.4	27.6	48.5	257.3	372.0

A PCA was conducted to describe the relationship among the insect groups. The distribution of the orders Blattodea and Dermaptera was more similar to each other than to the orders. Similarly, Diptera, Coleoptera, and Hymenoptera covaried (Figure 14).

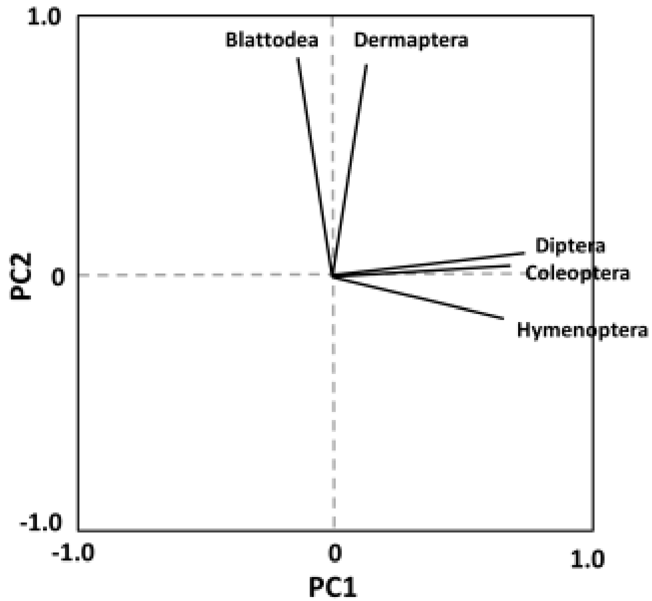

Figure 14. A visualization of the relationship among five insect orders captured in bucket traps using Principal Component Analysis.

The order level identifications are very coarse and offer little information regarding potentially important species, and therefore their ecological requirements and behaviors. Table 13 lists the insect specimens based on their identification to the family level. Within each order there tended to be one or two families that were much more abundant than the others. This was especially true for the Hymenoptera, where Formicidae and Platygastridae represented 45 and 23 percent of all specimens, respectively, regardless of order. Sarcophagidae represented about half of the Diptera, Forficulidae represented nearly all of the Dermaptera, while the four main families of Coleoptera were more evenly distributed.

We also conducted a PCA of the most common insect families to assess the variation among these groups. Two earwig families (Forficulidae and Carcinophoridae) and ants (Formicidae) exhibited similar patterns of variation and were most distinct from the other groups (Figure 15). All beetle families (Dermestidae, Histeridae, Silphidae, and Staphylinidae) were similar to one another, while the flies (Sarcophagidae, Muscidae, and Calliphoridae) formed another group. The one fly exception is the Phoridae that most closely resembled the beetles. Of the two wasp parasitoid families, Platygastridae was similar to the beetles and Chalcididae was more similar to the flies. The distribution of these two families is likely driven by their biology. Although not decomposers themselves, they are part of the decomposer community. Platygastridae are often parasitoids of beetles (Buhl and Notton 2009) while Chalcididae are often parasitoids of flies (Grissell and Schauff 1990). The position of species that were grouped into the “Other Hymenoptera” category was intermediate to the beetles and flies, likely representing a more generalist foraging strategy or a combination of foraging preferences.

Table 13. The average number of specimens for each family within the insect orders captured in bucket traps during a 6-day sampling period at each site. The families are listed alphabetically within each order. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts. Prevalence describes the frequency of occurrence at the site level, while proportion describes the relative contribution of the particular family to the entire sample.

	Blattodea		Coleoptera						Dermaptera			Diptera								Hymenoptera				
Site	**Blattellidae**	**Blattidae**	**Dermestidae**	**Histeridae**	**Melyridae**	**Silphidae**	**Staphylinidae**	**Other**	**Carcinophoridae**	**Forficulidae**	**Labiidae**	**Anthomyiidae**	**Calliphoridae**	**Fanniidae**	**Muscidae**	**Phoridae**	**Sarcophagidae**	**Tachinidae**	**Other**	**Chalcididae**	**Encyrtidae**	**Formicidae**	**Platygastridae**	**Other**
Carlsbad Highlands Ecological Reserve	0.0	0.5	2.5	5.5	0.0	0.0	0.5	0.5	10.0	484.5	0.5	0.0	13.0	0.0	0.5	1.0	27.5	0.0	4.0	6.0	0.0	750.0	22.5	0.0
Crestridge Ecological Reserve	0.0	0.0	0.3	4.0	0.0	6.7	0.7	0.0	0.0	0.0	0.0	0.0	13.3	0.7	13.7	4.3	55.3	0.0	25.3	2.3	0.0	70.7	3.7	2.7
Dennery Ranch Park	0.0	0.0	2.5	4.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	1.0	4.5	0.0	0.0	8.0	0.0	27.0	124.5	0.0
Hollenbeck Canyon Wildlife Area	0.0	0.0	36.5	129.0	0.5	44.0	6.0	0.0	0.0	2.0	0.0	0.5	13.5	0.0	2.5	17.5	58.0	0.5	20.5	2.0	0.5	56.5	377.5	1.5
Long Canyon	0.0	0.0	2.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	14.0	0.0	1.0	2.0	6.0	0.0	2.0	1.0	0.0	0.0	371.0	0.0
Los Penasquitos Canyon Park	0.0	0.0	2.0	3.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.0	1.0	1.0	95.0	0.0	4.0	22.0	0.0	84.0	80.0	0.0
Manzanita Canyon	0.0	0.0	3.0	14.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
Marian Bear Park	0.0	0.0	10.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	1.0	0.0	3.0	0.0	3.0	0.0	0.0	126.0	1.0	0.0
Mission Trails Regional Park	0.0	0.0	7.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	1.0	2.0	1.0	55.0	0.0	2.0	24.0	0.0	20.0	189.0	0.0
Paradise Hills Community Park	0.0	0.0	7.0	18.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	129.0	0.0
Rancho Jamul Ecological Reserve	0.0	0.0	15.5	59.0	0.0	77.5	7.5	0.0	0.0	45.5	0.0	0.0	7.0	0.0	0.0	15.5	5.0	0.0	7.5	0.5	0.0	33.0	50.0	0.5
Rice Canyon	0.0	1.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	1.0	0.0	8.0	0.0	1.0	0.0	0.0	3.0	9.0	0.0
Rose Canyon	0.0	0.0	5.0	4.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	3.0	11.0	0.0	1.0	4.0	0.0	1074.0	7.0	0.0
Sabre Springs Park	3.0	0.0	3.0	6.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	10.0	3.0	29.0	0.0	4.0	14.0	0.0	720.0	5.0	0.0
Switzer Canyon	0.0	0.0	6.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87.0	1.0	0.0
Tecolote Canyon	0.0	0.0	12.5	9.0	0.0	1.5	0.0	0.0	0.5	0.0	0.0	0.0	11.0	0.0	6.0	1.5	25.0	0.0	13.0	5.5	0.0	155.0	10.5	0.0
USFWS - Las Montanas	0.0	0.0	6.0	13.0	0.0	19.0	1.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	4.0	16.0	0.0	3.0	2.0	0.0	94.0	34.0	0.0
USFWS - Sweetwater	0.0	0.0	6.0	47.0	0.0	3.0	0.0	0.0	0.0	7.0	0.0	0.0	3.0	1.0	0.0	5.0	10.0	0.0	1.0	1.0	3.0	6.0	181.0	3.0
USFWS - Trace Road	0.0	0.0	8.0	24.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	13.0	0.0	2.0	2.0	0.0	2.0	41.0	1.0
Wright's Field	0.0	0.0	9.0	24.0	0.0	20.5	35.0	0.0	0.0	0.0	0.0	0.0	38.0	1.0	32.5	17.5	23.0	0.0	89.5	17.0	0.5	0.5	64.5	2.5
Average:	0.2	0.1	7.2	19.5	0.0	9.0	2.6	0.0	0.5	27.0	0.0	0.1	9.2	0.2	3.6	4.0	22.3	0.0	9.1	5.6	0.2	165.8	85.2	0.6
Prevalence:	0.05	0.10	0.95	1.00	0.05	0.60	0.40	0.05	0.10	0.25	0.05	0.10	0.95	0.25	0.55	0.75	0.90	0.05	0.80	0.75	0.15	0.90	1.00	0.30
Proportion:	0.00	0.00	0.02	0.05	0.00	0.02	0.01	0.00	0.00	0.07	0.00	0.00	0.02	0.00	0.01	0.01	0.06	0.00	0.02	0.01	0.00	0.45	0.23	0.00

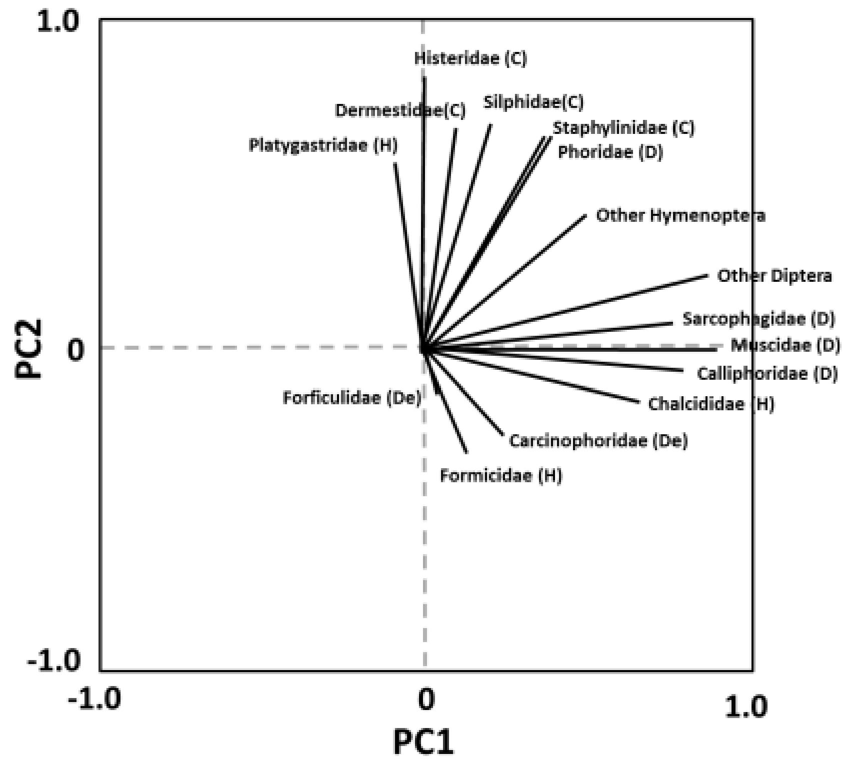

Figure 15. A visualization of the relationship among the common insect families captured in bucket traps using Principal Component Analysis. Codes for the order of each family are listed in parentheses (C = Coleoptera, De = Dermaptera, D = Diptera, H = Hymenoptera).

A species-level assessment shows that the decomposer community is uneven. Individuals from the 14 most abundant species represented 90 percent of the total specimens. The Argentine ant (*Linepithema humile*), a parasitoid wasp (Platygastridae), and the European earwig (*Forficula auricularia*) together represent 70 percent of all specimens. The ant and earwig are non-native species and are likely to have substantial impacts to the ecosystems due to their large numbers. Although some families are listed, there were no obvious differences in the specimens and represent morphospecies, and may actually represent a single (yet to be identified) species. These higher taxonomic groups are included so that the results are not biased towards the more easily identified species.

Table 14. The average number of specimens for each species captured in bucket traps during a 6-day sampling period at each site. The species are listed from most abundant (left) to least abundant (right). For simplification, the 54 least abundant species representing less than 2% of all specimens are consolidated. Red highlight represents the highest counts, white represents intermediate counts, and blue the lowest counts. Prevalence describes the frequency of occurrence at the site level, while proportion describes the relative contribution of the particular family to the entire sample. Codes for the order are listed above each species (C = Coleoptera, De = Dermaptera, D = Diptera, H = Hymenoptera).

Site	Linepithema humile	Platygastridae	Forficula auricularia	Sarcophagidae	Histeridae sp1	Dermestes sp1	Calliphoridae sp1	Nicrophorus guttula	Nicrophorus marginatus	Muscidae	Tetramorium sp2	Phoridae sp9	Solenopsis sp	Chalcididae sp2	Histeridae sp3	Camponatus sp1	Histeridae Large sp1	Chalcididae sp1	Callifora sp3	Diptera sp28	Nicrophorus nigrita	Histeridae sp4	Borophaga sp	Diptera	Dermestes sp2	Diptera sp7	Formicidae sp1	Diptera sp3	Staphylinidae sp8	Formicidae sp2	Diptera sp29	Creophilus maxillosus	Histeridae sp5	Euborellia annulipes	Staphylinidae sp1	Less than 2 % (54 taxa)	Total
Order:	H	H	De	D	C	C	D	C	C	D	H	D	H	H	C	H	C	H	D	D	C	C	D	D	C	D	H	D	C	H	D	C	C	De	C		
Carlsbad Highlands Ecological Reserve	748.5	22.5	484.5	27.5	3.0	2.5	13.0	0.0	0.0	0.5	0.0	1.0	0.0	4.5	0.0	0.0	2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.5	0.0	10.0	0.0	6.5	1329.0
Crestridge Ecological Reserve	10.3	3.7	0.0	55.3	2.3	0.3	7.0	1.7	0.0	13.7	0.0	3.7	0.0	0.0	0.0	58.3	1.3	2.3	4.0	1.7	5.0	0.3	0.7	2.7	0.0	1.3	0.0	11.3	0.0	0.7	0.7	0.3	0.0	0.0	0.0	15.0	203.7
Dennery Ranch Park	26.5	124.5	0.0	4.5	1.5	2.5	3.0	0.5	0.0	0.0	0.0	1.0	0.0	6.5	1.0	0.0	0.0	1.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1.0	0.0	0.0	0.0	175.0
Hollenbeck Canyon Wildlife Area	0.0	755.0	4.0	116.0	183.0	46.0	8.0	50.0	29.0	5.0	64.0	19.0	45.0	0.0	31.0	0.0	19.0	4.0	18.0	2.0	9.0	21.0	15.0	5.0	23.0	21.0	3.0	0.0	0.0	0.0	2.0	3.0	3.0	0.0	6.0	29.0	1538.0
Long Canyon	0.0	371.0	0.0	6.0	1.0	2.0	6.0	0.0	0.0	1.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	5.0	403.0
Los Penasquitos Canyon Park	83.0	80.0	0.0	95.0	0.0	2.0	8.0	1.0	0.0	1.0	0.0	1.0	0.0	13.0	1.0	0.0	1.0	9.0	0.0	0.0	0.0	1.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	302.0
Manzanita Canyon	0.0	2.0	0.0	1.0	14.0	3.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	28.0
Marian Bear Park	120.0	1.0	0.0	3.0	0.0	10.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	5.0	154.0
Mission Trails Regional Park	1.0	189.0	0.0	55.0	4.0	7.0	8.0	0.0	0.0	2.0	0.0	1.0	0.0	19.0	1.0	0.0	2.0	5.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	15.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	6.0	319.0
Paradise Hills Community Park	4.0	129.0	1.0	0.0	13.0	6.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	1.0	0.0	0.0	1.0	169.0
Rancho Jamul Ecological Reserve	16.0	50.0	45.5	5.0	52.0	10.0	1.5	30.0	45.0	0.0	0.0	10.5	13.5	0.5	2.5	0.0	2.0	0.0	5.5	0.0	2.5	0.5	4.5	2.5	5.0	1.0	0.0	0.0	0.0	1.0	0.0	6.0	0.0	0.0	1.0	10.5	324.0
Rice Canyon	0.0	9.0	0.0	8.0	3.0	0.0	4.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	4.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	38.0
Rose Canyon	1074.0	7.0	0.0	11.0	1.0	5.0	1.0	1.0	0.0	0.0	0.0	2.0	0.0	3.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1113.0
Sabre Springs Park	718.0	5.0	0.0	29.0	1.0	3.0	4.0	2.0	0.0	10.0	0.0	1.0	0.0	10.0	0.0	0.0	5.0	4.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	803.0
Switzer Canyon	87.0	1.0	0.0	0.0	5.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	103.0
Tecolote Canyon	153.0	10.5	0.0	25.0	3.5	12.5	9.5	0.0	0.0	6.0	0.0	0.0	0.0	1.0	0.0	0.0	5.0	4.5	0.0	0.0	1.5	0.0	1.0	1.0	0.0	0.0	0.0	5.5	0.0	0.5	0.0	0.0	0.5	0.5	0.0	10.0	251.0
USFWS - Las Montanas	92.0	34.0	0.0	16.0	5.0	6.0	8.0	7.0	1.0	0.0	0.0	3.0	0.0	0.0	5.0	0.0	1.0	2.0	4.0	0.0	11.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0	4.0	204.0
USFWS - Sweetwater	0.0	181.0	7.0	10.0	16.0	4.0	3.0	2.0	0.0	0.0	0.0	5.0	0.0	0.0	11.0	0.0	0.0	1.0	0.0	0.0	1.0	14.0	0.0	0.0	1.0	0.0	6.0	1.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	8.0	277.0
USFWS - Trace Road	2.0	41.0	0.0	13.0	20.0	8.0	2.0	2.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	2.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	100.0
Wright's Field	0.0	64.5	0.0	23.0	14.5	8.0	33.0	6.0	0.0	32.5	0.0	9.5	0.0	0.0	4.0	0.0	4.0	17.0	3.5	44.5	14.5	1.0	7.5	13.0	0.5	0.0	0.0	0.0	19.0	0.0	15.0	1.0	0.0	0.0	3.5	36.0	375.0
Average:	156.8	104.0	27.1	25.2	17.1	7.2	6.7	5.2	3.8	3.7	3.2	3.1	2.9	2.9	2.9	2.9	2.9	2.7	2.5	2.4	2.3	2.1	1.6	1.5	1.5	1.2	1.2	1.0	1.0	0.9	0.9	0.6	0.6	0.5	0.5	7.8	410.4
Proportion:	0.38	0.25	0.07	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	< 2%	
Cummulative Proportion:	0.38	0.64	0.70	0.76	0.80	0.82	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.91	0.91	0.92	0.93	0.93	0.94	0.94	0.95	0.95	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	1.00	
Prevalence:	0.70	1.00	0.25	0.90	0.90	0.95	0.95	0.55	0.15	0.55	0.05	0.70	0.10	0.45	0.45	0.05	0.80	0.65	0.40	0.15	0.40	0.50	0.35	0.45	0.20	0.20	0.15	0.25	0.05	0.50	0.15	0.35	0.25	0.10	0.15	1.00	

Habitat Analysis

As with the cup trap specimens, the proportions of each habitat type within 100 meters, 1000 meters, and 5000 meters of the sampling locations were calculated. Site was included as a predictor variable in all GLMs as well. Due to the rarity of Blattodea specimens, this order was not included in the habitat analysis.

Similar to the pollinator communities, outliers and influential data points created problems for the models at the 100-meter radius level. Again, this was likely influenced by our site selection. At the order level, a negative relationship between Coleoptera and the amount urban area was the only consistent relationship. The orders yielded no other consistent habitat relationship patterns.

Only the most abundant families or species were included in the habitat assessment. Some families were exclusively or nearly completely composed of a single species so it made sense to conduct the analysis at the species level. Other families had a large number of specimens but species-level identification was difficult, meaning family-level assessments were appropriate. The Histeridae and Silphidae (both beetle families) had a negative correlation with urban and non-native habitat. The Sarcophagidae flies were negatively correlated with urban and non-native habitat and positively correlated with coastal sage scrub and chaparral. Argentine ants exhibited a positive correlation with urban, non-native habitat, riparian forest and riparian woodlands while negatively correlated with coastal sage scrub.

Decomposer Field Trials

We were able to conduct pilot field trials to evaluate the use of dung-baited traps as well as for quantifying decomposition rates with carcasses.

Unfortunately, we were unable to obtain animal dung from any local zoo or wildlife facility. A relatively large amount would have been required to match the number of rat-baited traps. Initial trials with a limited supply of dung yielded few specimens at both Hollenbeck Canyon Wildlife Area and Tecolote Canyon. For this reason, we did not continue to pursue the use of dung-baited traps. This approach could be reconsidered if a stable source of wildlife dung supply is found.

Decomposition rates were estimated from paired carcasses with and without netting. The netting was not successful in excluding all arthropods as fly maggots were present on all carcasses; however, it appears to have restricted some access based on the lower decomposition rates (Figure X). Several important trends emerged. The decomposition rate of all netted rats were lower than the exposed rats. This may be due to the exclusion of beetles. Hollenbeck Canyon Wildlife Area had a higher decomposition rate compared to Tecolote Canyon. A closer comparison of the decomposer communities from these two sites is necessary to fully understand this pattern. The two Hollenbeck Canyon trials were about 600 meters apart but in different habitat types (although close to the edge) and had very similar results to one another. This supports the thought that insects associated with carcass decomposition will be attracted by the scent from the surrounding area (100s meters), not just the immediate area (less than 100 meters).

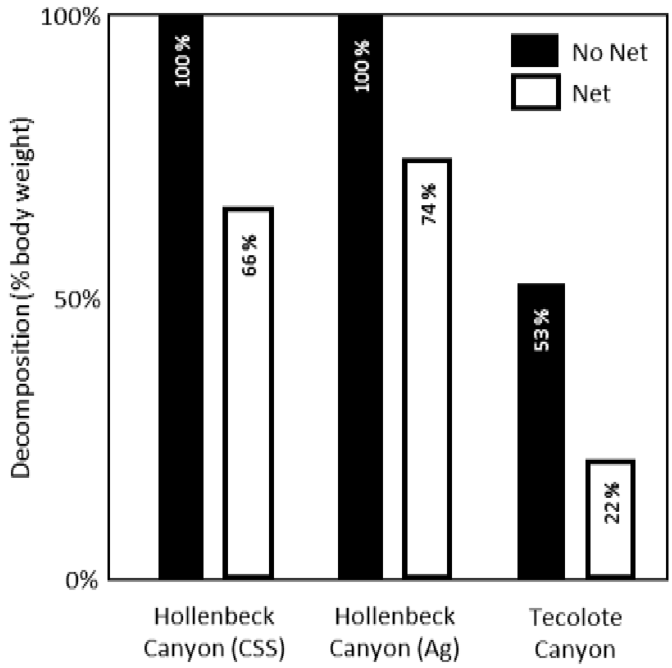

Figure 16. Rat carcass decomposition field trials at the rural Hollenbeck Canyon Wildlife Area and at the urban Tecolote Canyon. The Hollenbeck Canyon trials were conducted within coastal sage scrub (CSS) and agricultural (Ag) habitat.

Table 15. Decomposer insect order-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

	Holland	Coleoptera			Diptera			Hymenoptera			Dermaptera		
Habitat	**Code**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**
Non-native	11xxx				-								
Urban	12xxx	-	-	-	-								
Agriculture	18xxx	+		-									+
Coastal Sage Scrub	32xxx												
Chaparral	37xxx		-				+						
Grassland	42xxx					+				+	-		
Riparian Forest	61xxx		+			+		+					
Riparian Woodlands	62xxx				+						+		
Oak Woodlands	71xxx		+		-	+							
	R^2 =	0.253	0.473	0.398	0.283	0.38	0.25	0.062	*failed*	0.045	0.243	*failed*	0.056

Table 16. Decomposer insect family-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

	Holland	Histeridae (C)			Silphidae (C)			Sarcophagidae (H)		
Habitat	**Code**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**
Non-native	11xxx		-		-			-	-	
Urban	12xxx	-		-	-		-	-		
Agriculture	18xxx				+	+				
Coastal Sage Scrub	32xxx		+			+			+	
Chaparral	37xxx	-	-			-			+	+
Grassland	42xxx						-			
Riparian Forest	61xxx					-				
Riparian Woodlands	62xxx	-						-		
Oak Woodlands	71xxx				+	+			+	
	R^2 =	0.182	0.378	0.177	0.452	0.724	0.756	0.201	0.449	0.166

Table 17. Decomposer insect family/species-habitat analysis. Results from General Linear Models (GLMs) with the positive (+) or negative (-) correlation indicated for the statistically significant habitat variables. A R^2 value in red indicates that data points were identified as outliers or having high leverage, and their removal did not result in a stable model.

	Holland	Platygastridae (H)			Argentine Ant (H)			European Earwig (De)		
Habitat	**Code**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**	**100m**	**1000m**	**5000m**
Non-native	11xxx				+	+				
Urban	12xxx			-			+			
Agriculture	18xxx									+
Coastal Sage Scrub	32xxx		+		-	-				
Chaparral	37xxx									
Grassland	42xxx		+	+				-		
Riparian Forest	61xxx	-			+	+				
Riparian Woodlands	62xxx	-			+	+	+	-		
Oak Woodlands	71xxx									
	R^2 =	0.108	0.233	0.259	0.364	0.565	0.289	0.244	*failed*	0.061

Discussion

Our results demonstrate that there are substantial differences among the insect pollinator and decomposer communities across preserves in western San Diego County. This was an expected result but needed to be documented prior to exploring how these communities are shaped. We suggest that the collecting adequate data for conservation of ecosystem function in these communities is a three step process:

1) Describe (differences in) communities, which is a challenge with insects
2) Determine the main correlates of community composition in these diverse communities
3) Measure how ecosystem functioning is related to changes in the communities

Pollination

The potential pollinator communities associated with San Diego thornmint and Otay tarplant populations were described (cup traps) and initial efforts were made to quantify the visitation rate of each species (flower observations). The 20-minute observations showed that there were few visitors to the thornmint flowers, with bees and flies being the most common visitors. Otay tarplant flowers received many more visitors and both bees and flies were still common. However, beetles were about five times more common than bees and flies. The 1-minute observations described foraging behaviors of those species that visited flowers. Assessing results from both the 20- and 1-minute observations provided an interesting dichotomy in terms pollinator abundance and flower visitation frequency. Some of the rarer flower visitors (e.g. bees: *Osmia*, *Apis mellifera*) tended to move between flowers at a faster rate than some of the species that slowly moved between flowers but were present in very large numbers (e.g. Melyridae, *Exiliscelis californiensis*). Both groups could be important pollinators.

While ecosystem processes like pollination have been occurring for millions of years, it is not readily observed. As a result, it is usually taken as a given that adequate pollination is happening. Largely due to the decline of managed European honey bee populations, pollination and pollinator populations are increasingly being included in conservation efforts. In 2013, Whole Foods and Xerces Society released a story discussing the importance of honey bees and other pollinators for the production of human food. They state that one out of three bites comes from plants that require pollination (Whole Foods 2013). The White House (2015) released a national strategy to protect honey bees and other pollinators, as well as their habitats. And just weeks ago, the United Nations (2016) released a report that highlights a recent study (Garibaldi et al. 2016) that the human food supply may suffer if pollinators are not protected.

There is plenty of evidence that native species are important for the human food supply. For example, it was found that the diversity of native bees, not managed European honey bee hives, resulted in better apple fruit set (Mallinger and Gratton 2015). Native pollinators are also important for maintaining diverse ecosystems as most plants require insect pollination to reproduce. In addition, it is likely that natural areas are providing the habitat to provide the source of pollinators for agricultural areas. Only recently have areas within or around agricultural field been restored to provide wildflower strips for bee foraging (Feltham et al. 2015).

Decomposition

The decomposer communities were described (bucket traps) and initial trials were implemented to assess if decomposing rates differed among the sites (field trial). The insect community captured by the rat baited bucket traps was less diverse than the cup traps; however, nearly all specimens were of species known to be decomposers of animal matter or attracted to carcasses as a predator or parasitoid of decomposers. Two non-native species, the Argentine ant (*Linepithema humile*) and European earwig (*Forficula auricularia*) were among the three most commonly collected species. Their presence may be due to alterations to the native habitat, but they are also likely to be impacting the ecosystem themselves. This is true for the Argentine ant, as they are known to displace native ant species (Holway 1999). These ants may be less valuable to some predators (e.g. horned lizard, Suarez et al. 2000) and they can even prey upon young birds in the nest (Peterson et al. 2004). Less is known about the European earwig's impacts to the southern California ecosystem. A second exotic earwig, the ringlegged earwig (*Euborellia annulipes*), was also captured.

Initial trails also suggest that the decomposition rates will vary across the preserves in western San Diego County. There was one consistent pattern between the insect community and the lower decomposition rate at Tecolote Canyon compared to Hollenbeck Canyon Wildlife Area. All three species of the carrion beetles (Silphidae) were absent from the smaller, urban preserves. Although not known to be a specific target of past collecting efforts, these beetles were observed in historical records from these areas suggesting they have been lost from the current community. This includes (1) *Nicrophorus marginatus* - Mission Valley in 1931; (2) *N. nigritus* - Mission Valley in 1929, Old Town in 1929, Del Mar/Cardiff in 1956; and (3) *N. guttula* - North Island in 1930. These specimens are part of the collection at the San Diego Natural History Museum. The data collected for this study will provide valuable reference data for future conservation efforts.

Results from the bucket traps suggest that our protocol was successful in adequately trapping the decomposer community. Analyses demonstrated the distribution of a beetle parasitoid (Platygastridae) was similar to Coleoptera families, and a fly parasitoid was similar to Diptera families. The lower diversity and reduced bycatch from the bucket traps resulted in easier processing and analyses compared to cup traps. Two of the three most abundant insect families were dominated by a non-native species

Like pollination, decomposition is an "invisible" process that is critical for a diverse and functioning ecosystem. This process retains limiting nutrients within the food webs and allows for energy transfer back to higher trophic levels (Moore et al. 2004). Again, like pollination, decomposition is important for diverse plant and animal communities. Gessman and Chauvet (2002) found that decomposition is a useful metric for assessing ecosystem functioning. Most of the decomposition research relates to leaf litter or carcasses in the context of forensic science. We found little leaf litter in the coastal sage scrub and grassland habitats of San Diego County, and the continued drought conditions resulted in few arthropods in the scant leaf litter that was present.

Future Directions

Sampling for this project resulted in a large and complex data set involving quantifying the insects and relating the community to different elements in the surrounding habitats. We have completed an initial assessment, but further analyses are warranted. The common insect and habitat groups had fairly normally-distributed data; however, the rare groups were right-skewed and/or represented by a low number of specimens/patches or sites. For the rare groups, converting abundance data to presence/absence data was required. The habitat types used for the report were derived by grouping similar Holland classifications. There may be biological reasons to split or combine the habitat types in a different way. For example, Riparian Forests and Riparian Woodlands may have similar insect fauna and combining the riparian habitats would make sense. In addition, phenology could be included in the analysis. The adult life stage of each insect species usually lasts for only a couple weeks to a couple months. If sampling does not occur at the peak of a particular species, a lower abundance will be recorded and associated with the corresponding landscape composition. Our sampling shows that the number of Diptera were higher early in the season, Coleoptera and Hymenoptera plateaued, and few Lepidoptera were captured throughout the season.

We sampled from patches of flowering California buckwheat to include a more widespread assessment of the pollinator communities. This is a common species and present at all sampling sites. The specimens from the buckwheat patches are currently being processed. Identification and analysis of these specimens is ongoing.

With differences in the insect communities clearly demonstrated, more focused pollinator and decomposer quantitative measurements is a natural next step. Options include flower observations, developing insect-flower networks, and carcass processing trials. More focused data collection will allow us to describe how ecosystem functioning is related to changes in the communities. Many of the common species involved with pollination and decomposition have been identified, allowing us to quantify the relative importance of selected species.

In addition to further analyses, future sampling is important so that inter-annual variation can be assessed. This is a necessary first step in assessing the potential impacts of climate change. Additional sampling to include more sites would also allow us to further refine habitat relationships. Finally, having this well-established understanding of the baseline community will facilitate further efforts to obtain funding from local, state, and federal agencies.

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