Western Riverside County
Multiple Species Habitat Conservation Plan
Biological Monitoring Program

2021 Delhi Sands Flower-loving Fly
(*Rhaphiomidas terminatus abdominalis*)

Photo by Taylor Zagelbaum on 12 August 2021

September 2022

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NOTE TO READER:

This report is an account of survey activities conducted by the Biological Monitoring Program for the Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP). The MSHCP was permitted in June 2004. Reserve assembly is ongoing and is expected to take 20 or more years to complete. The Conservation Area includes lands acquired under the terms of the MSHCP and other lands that have conservation value in the Plan Area (called public or quasi-public lands in the MSHCP). In this report, the term "Conservation Area" refers to these lands as they were understood by the Monitoring Program at the time the surveys were conducted.

The Monitoring Program monitors the status and distribution of the 146 species covered by the MSHCP within the Conservation Area to provide information to Permittees, land managers, the public, and the Wildlife Agencies [i.e., the California Department of Fish and Wildlife (CDFW, formerly California Department of Fish and Game) and the U.S. Fish and Wildlife Service]. Monitoring Program activities are guided by defined conservation objectives for each Covered Species, other information needs identified in MSHCP Section 5.3 or elsewhere in the document, and the information needs of the Permittees. A list of the lands where data collection activities were conducted in 2021 is included in Section 8.0 of the Western Riverside County Regional Conservation Authority (RCA) Annual Report to the Wildlife Agencies.

The primary author of this report was the 2021 Delhi Sands flower-loving fly Lead, Tara Graham. This report should be cited as: Biological Monitoring Program. 2022. Western Riverside County MSHCP Biological Monitoring Program 2021 Delhi Sands flower-loving fly Survey Report. Prepared for the Western Riverside County Multiple Species Habitat Conservation Plan. Riverside, CA. Available online: https://www.wrc-rca.org/species-surveys/.

While we have made every effort to accurately represent our data and results, it should be recognized that data management and analysis are ongoing activities. Any reader wishing to make further use of the information or data provided in this report should contact the Monitoring Program to ensure that they have access to the best available or most current data.

Please contact the Monitoring Program Administrator with questions about the information provided in this report. Questions about the MSHCP should be directed to the Executive Director of the RCA. Further information on the MSHCP and the RCA can be found at www.wrc-rca.org.

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INTRODUCTION

The Delhi Sands flower-loving fly (*Rhaphiomidas terminatus abdominalis*; Delhi fly) is federally listed as endangered, and is narrowly distributed in portions of Riverside and San Bernardino Counties in areas with Delhi series soils. The species is known to have occurred within three Core Areas defined by the Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP): Jurupa Hills, Agua Mansa Industrial Center, and Mira Loma (Dudek & Associates 2003). To date, conservation of the species within the MSHCP Plan Area has only occurred at the Teledyne site within the Jurupa Hills Core Area (Figure 1). There are no lands that are currently part of the Conservation Area within the other two Core Areas for this species; however, the Rivers and Lands Conservancy has been actively procuring lands in San Bernardino County in those general areas for Delhi fly conservation.

The Delhi fly has distinctive biological and habitat requirements and faces a number of threats. The life cycle of the Delhi fly includes egg, larval, pupal, and adult stages. Only the adult stage occurs above-ground, when adults emerge to breed during the summer months. The species is restricted to fine, sandy Delhi series soils, usually with wholly or partly stabilized sand dunes and sparse native vegetation. Areas with suitable Delhi fly habitat have been highly affected by anthropogenic activities, including conversion to agriculture, residential and commercial development, surface mining for sand, dumping of trash and cow manure, and damage by off-road vehicles. Invasive exotic plants are also thought to degrade Delhi fly habitat by increasing vegetation cover or by altering soil conditions through dune stabilization and changes in soil moisture (USFWS 1997).

The Delhi fly Conservation Objective 1 states that successful reproduction shall be documented at all Core Areas once a year for the first 5 years after permit issuance and then as appropriate, but not less frequently than every eight years thereafter (Dudek & Associates 2003). Reproductive success is defined in the MSHCP as the presence of pupal cases exuviae or newly-emerged (teneral) individuals. Because Delhi fly is a federally endangered species with an extremely limited distribution within the Plan Area, Monitoring Program biologists have surveyed for Delhi fly within the only accessible Core Area annually since 2005. We describe here the procedure and results of the MSHCP Biological Monitoring Program's 2021 effort to monitor Delhi fly in the Jurupa Hills.

Survey Goals and Objectives

1. Document successful reproduction by Delhi fly at the Teledyne site in the Jurupa Hills Core Area.
    a. Record observation of teneral individuals and/or exuviae.
2. Estimate population density of adult Delhi fly during flight season at Teledyne.
    a. Document occurrences of Delhi fly individuals.
    b. Calculate distance sampling-based estimates of population density that account for animal detectability.

3. Document persistence of the population within appropriate habitat and potential expansion of occupied area as a result of vegetation management.
   a. Record observations of adult individuals to assess potential trends in distribution in response to management activities or other conditions.
4. Gather data regarding Delhi fly resource selections and important distribution covariates including co-occurring insect families within Core Areas.
   a. Record all co-occurring insect families while conducting Delhi fly surveys.
   b. Conduct ground-dwelling arthropod surveys every 5 years.
5. Determine vegetation and soil characteristics occurring across the Teledyne site and compare site characteristics between sampling years.
   a. Conduct vegetation surveys every 5 years.
   b. Record soil moisture and temperature characteristics in the dunes area using the weather station.
6. Monitor the spread of short-pod mustard (*Hirschfeldia incana*) and non-native grasses (Poaceae) across the dune system at the Teledyne site.
   a. Record digital images annually from three photo-stations to document changes in vegetation structure and composition.
7. Monitor the weather conditions that affect the Delhi fly behavior at Teledyne.
   a. Record relative humidity, rainfall, air temperature, soil temperature and soil moisture using the weather station.

METHODS

Study Site Selection

The Teledyne site is located in the Jurupa Hills along the Riverside-San Bernardino County border in the vicinity of Pyrite Street (Figure 1). The study site encompasses 5.84 ha of Delhi series soils which meets USFWS criteria for Delhi fly habitat (USFWS 2008) and is primarily composed of coastal sage scrub vegetation (Dudek & Associates 2003). Common plants found at the site include *Eriogonum fasciculatum*, *Ambrosia acanthicarpa*, *Amsinckia menziesii, Croton californicus, Rhus aromatica, Brassica* spp., and various non-native grasses.

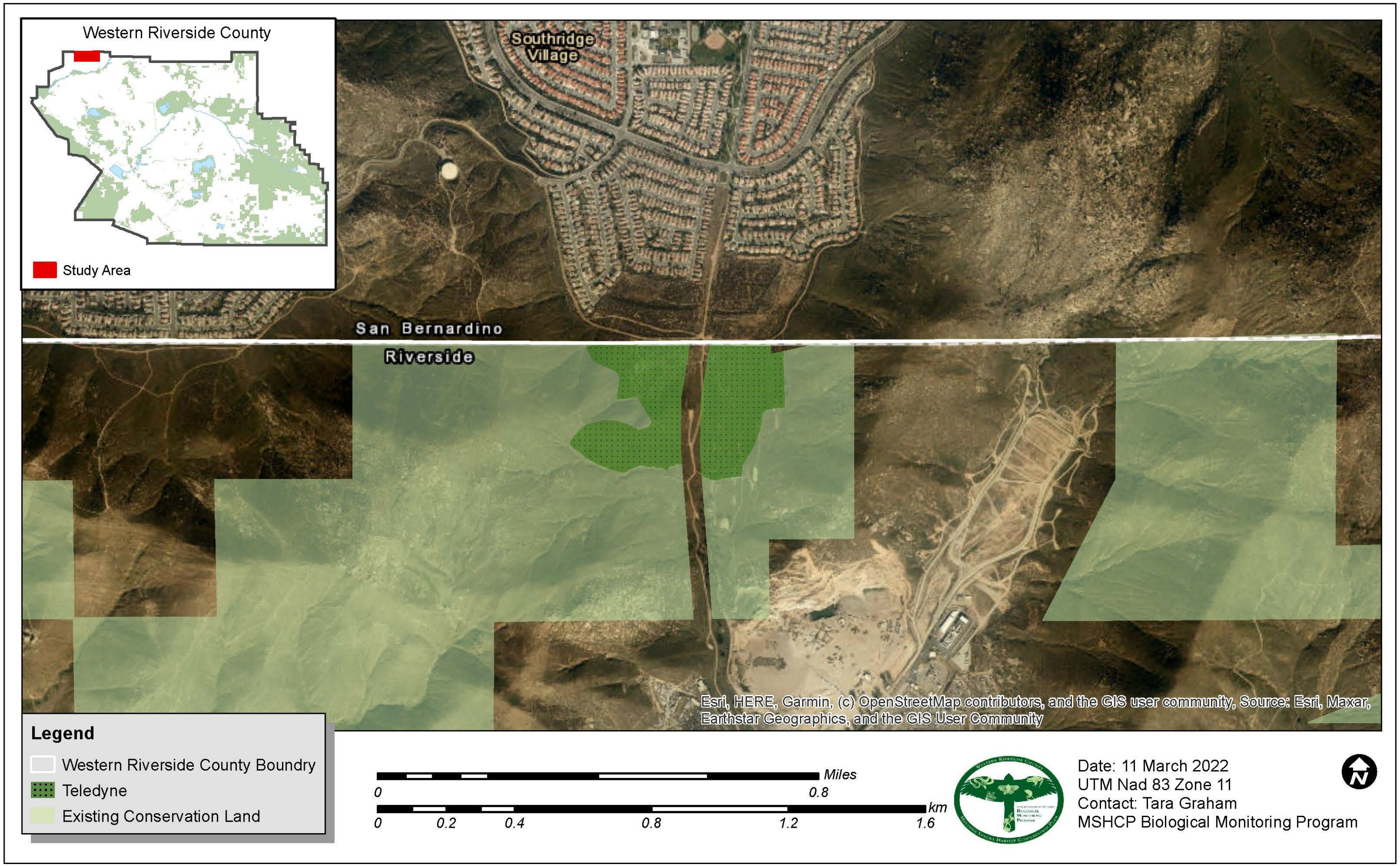

Figure 1. Delhi Sands flower-loving fly Teledyne study location, 2021.

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Protocol Development

Delhi Sands Flower-loving fly surveys

We began surveying for Delhi fly in 2005 following the *Interim General Survey Guidelines for the Delhi Sands Flower-loving Fly* (USFWS 1996). These U.S. Fish and Wildlife Service (USFWS) guidelines were developed to determine presence/absence of Delhi fly by slowly traversing appropriate habitat. We modified the USFWS protocol in 2005 by establishing line-transects and measuring the perpendicular distance between the transect centerline and individual Delhi fly observations, with the goal of estimating population density and detection probability following distance sampling methodology (Buckland et al. 2001). This method was used for surveys conducted from 2005-2010, and 2014 to present. Due to personnel and resource limitations, surveys conducted 2011-2013 were reduced to a general site search to simply document successful reproduction.

The weather conditions are continuously monitored and recorded by a weather station all year-round. The survey protocol used in 2021 is described more completely in the *Western Riverside County MSHCP Biological Monitoring Program Survey Protocol for Delhi Sands Flower-loving Fly,* and is available from the Biological Monitoring Program.

Arthropod Surveys

A pilot study of ground-dwelling arthropods at Teledyne was performed in 2018 to obtain baseline information on the arthropod species present at this site. We adapted our methods from the Coachella Valley Multiple Species Habitat Conservation Plan and Natural Community Conservation Plan Aeolian Sand Communities and Species Monitoring Protocols (CVCC 2012). The Coachella Valley MSHCP used pitfall traps to capture any arthropod species associated with the study area with the ultimate objective of constructing a management model to implement control measures for invasive annual species. We are using the same method to get a better understanding of the complete ecosystem at the Teledyne site including any possible food sources for the Delhi fly while in the larval stage. In 2018, we generated 50 randomly generated points where the pitfall traps would be placed (Figure 2). The survey protocol used in 2021 is described more completely in the *Western Riverside County MSHCP Biological Monitoring Program Protocol for Delhi Sands Flower-loving Fly 2021 Arthropod Surveys*, and is available from the Biological Monitoring Program.

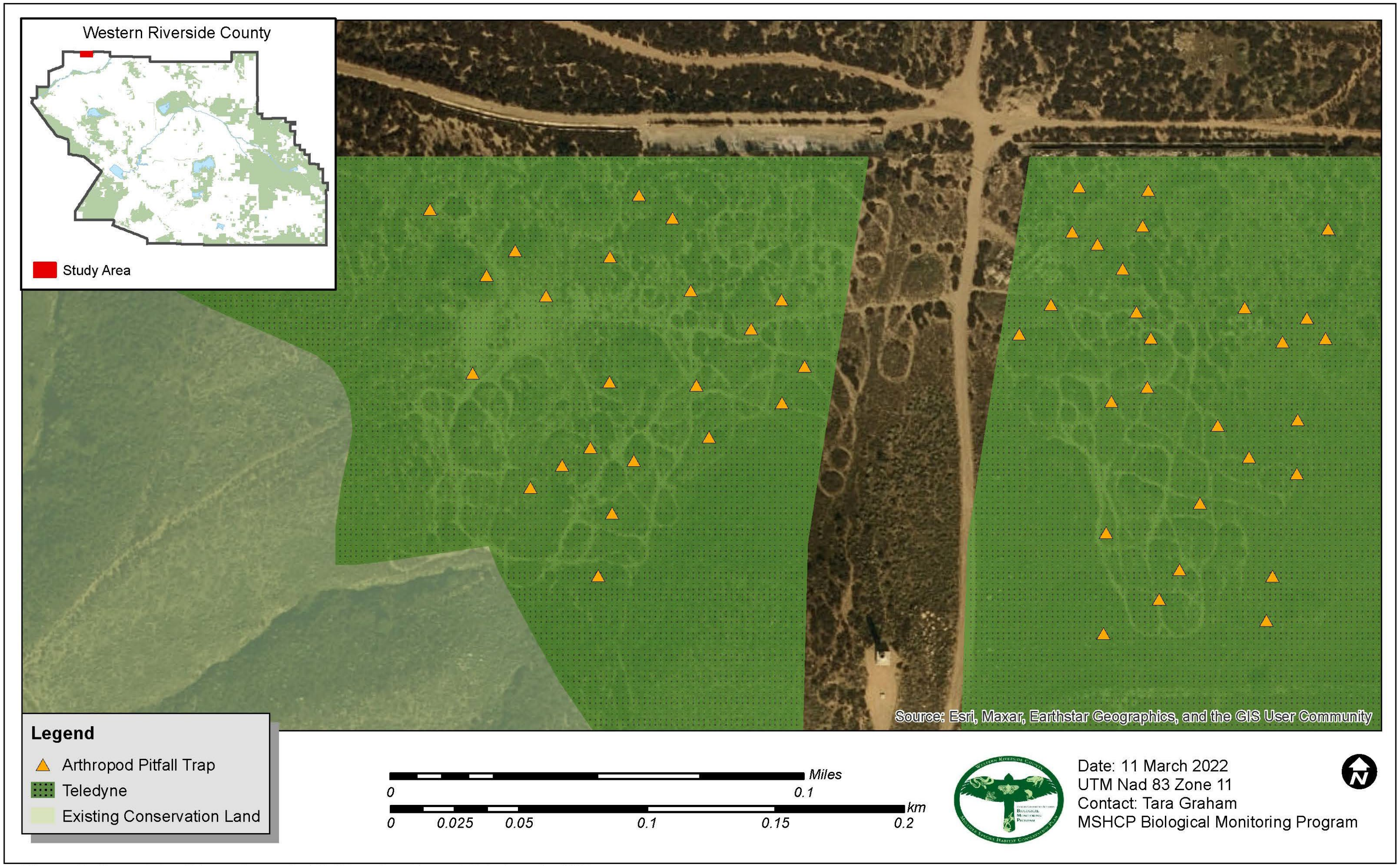

Figure 2. Ground dwelling arthropod pitfall trap locations at Teledyne in 2021.

Vegetation Sampling Survey

In 2008, to determine vegetation and soil characteristics occurring across the Teledyne site and to monitor changes over time, we established four hundred 2.25-m^2 and fifty 100-m^2 vegetation sampling plots. The fifty 100-m^2 sampling plots were designed to calibrate cover estimates and were not sampled in following years. In 2009, to minimize spatial variation between years and thus allow for better year-to-year comparisons of vegetation and soil structure, we re-sampled all four hundred 2.25-m^2 plots, as well as five 2.25-m^2 plots at locations where perched Delhi fly were observed during surveys. In 2010, based on the results of a paired-sample power analysis, the number of plots sampled was reduced to 300. To characterize locations where Delhi fly had been observed, we also sampled one 2.25-m^2 plot at each location where a perched Delhi fly was recorded. It was assumed that these locations better indicated a resource usage decision by a given fly, as opposed to observations made of individuals in flight. In 2016, to characterize locations where Delhi fly exuviae had been observed, we sampled one 2.25-m^2 plot at each location where a Delhi fly exuviae was recorded. Since 2016 vegetation plots are monitored every 5 years. In 2021, we resampled the same randomly distributed points surveyed in 2010 and 2015 that occur within conserved lands. For 2021, vegetation surveys, we surveyed each plot using one 2.25-m^2 plot per point in order to characterize the soil and vegetation characteristics of the conserved lands as a whole and compare findings across years. We also sampled an additional 14 plots where exuviae were found during the survey season along with the existing exuviae plots within conservation (Figure 3). In each sampling plot, we estimated ground cover in the categories of litter, rock, sand, hardpan, basal stem, and "other" (e.g., concrete). The percent cover of the tree, shrub, and herbaceous layers, as well as percent cover of individual shrub species that were strongly dominant within each plot were estimated. Additionally, we estimated percent cover for species/families that are believed to be positively associated with Delhi fly occurrence (*Eriogonum fasciculatum*, *Croton californicus*, *Ambrosia acanthicarpa*, *Heterotheca grandiflora*, and *Stephanomeria* sp. or negatively associated with Delhi fly occurrence (*Brassica/Sisymbrium* sp., and non-native grasses; USFWS 1997). While there is evidence that *E. fasciculatum*, *C. californicus*, and *H. grandiflora* are important resources for Delhi fly (USFWS 2008), the importance of *A. acanthicarpa* and *Stephanomeria* sp. is anecdotal and more research is needed. Finally, we measured compactness (kg/cm^2) of undisturbed soil near the center of each plot and at the center of each quarter of the plot in the 4 cardinal directions using a soil penetrometer (Forestry Suppliers, model 77114). Compaction readings in 2016 were increased to 5 per plot in an effort to increase accuracy. The survey protocol used in 2021 is described more completely in the *Western Riverside County MSHCP Biological Monitoring Program Protocol for Delhi Sands Flower-loving Fly 2021 Vegetation Sampling Surveys*, and is available from the Biological Monitoring Program.

Figure 3. Vegetation sampling plots at Teledyne in 2021.

Survey Plot/Transect Locations

Delhi Sands Flower-loving fly surveys

We established permanent transects at the Teledyne site by first delineating Delhi series soils within the target area as identified by the USFWS (1997). The transects were parallel and spaced 15-m across the delineated area, randomly oriented along a 28° bearing. Transects are between 16 and 222 m in length. However, if a transect traversed dense vegetation that made it logistically impossible to walk the transect without significant damage to vegetation while still observing any Delhi fly, we eliminated those portions of the transect from the survey. The eliminated portions added up to 126 meters in 2021, therefore the total aggregate length of surveyed transects was 4.19 km. We placed fiberglass stakes or a flag on shrubs on the centerline of each transect to ensure there was a visible mark every 30 – 40 m to ensure easy navigation and accurate distance measurements from the transect centerline to observed Delhi fly. We regularly replaced missing markers.

Arthropod Surveys

Ground-dwelling arthropod trap locations were selected using ArcGIS v. 10.5 software (ESRI 2016) and the Hawth's Analysis Tools v. 3.27 extension (Beyer 2006) to randomly distribute 50 pitfall traps across the site using a spatially stratified random sampling design.

Vegetation Sampling Surveys

We used ArcGIS v. 9.3.1 software (ESRI 2009) and the Hawth's Tools extension (Beyer 2004) to randomly distribute the 2.25-m^2 plots and 100-m^2 plots across the site using a spatially stratified random sampling design.

Survey Methods

Delhi Sands Flower-loving fly surveys

We divided the survey area into three sections (aggregate transect length range: 960 – 1838 m) and surveyed each section once or twice a day depending on available personnel. When two observers were available, each observer surveyed whole sections and started from opposite ends of the survey site, usually resulting in at least one section being surveyed twice per survey day. When only one individual was available, the observer surveyed as many whole sections as possible once. We recorded time, general weather description, temperature (°C) in shade 1 m above-ground, and average wind speed (mph) at the start and end of each survey. When we observed a Delhi fly, we immediately marked the initial location of the individual with large metal washers with attached flagging or a pin flag. We ensured accurate distance-to-detection measurements by clearly marking transect centerlines and carefully recording the perpendicular distance between the transect centerline and Delhi fly markers. Observers then recorded transect ID, UTM coordinates, time, sex, activity, substrate if the Delhi fly was perched, age class (1-3) of the detected Delhi fly and photo numbers if photos were taken (Appendix A). Any flies detected during an active survey were recorded on the datasheets; Delhi fly observed outside of an active survey (e.g., before the start time or after the end time of a survey) were recorded as incidental observations. Non-target winged insects were identified to family but distance to detection was not measured. If possible, we took photos of teneral Delhi fly individuals. Surveyors took care to avoid disturbing any individuals that were detected. Exuviae are expected to degrade relatively quickly if not discovered, so their presence in a given survey year is assumed to represent emergence of new individuals in the year of discovery. When Delhi fly exuviae were detected, the surveyors recorded the UTMs of the location, then placed their GPS unit next to the exuviae (to make the exuviae location more apparent in a photograph) and stepped back 4-5 meters to take a photo of the exuviae and the surrounding habitat. The surveyors then collected the exuviae to avoid double counting it in future surveys. The exuviae are stored at the Biological Monitoring Program office to be used in future training.

To monitor the weather conditions that affect the Delhi fly behavior at Teledyne, on 1 June 2017 we installed a HOBO Data Loggers (model U30) weather station in the upper dunes area where most Delhi flies are observed. Data on relative humidity (%), rainfall (inches), air temperature (°C), soil temperature (°C) at a depth of 6 inches, soil moisture (m^3/m^3) at a depth of 1 meter was manually downloaded once a month during the flight season and every 2-3 months outside the flight season depending on the availability of personal. All data is collected every 60 minutes. On 20 December, 2018 we installed a second soil moisture sensor at a depth of 2 meters to getter better information about the moisture layer the larvae live in (Ken Osborne, consultant, personal communication).

Arthropod Surveys

To gather data regarding Delhi fly resource selection, in addition to continuing to recording co-occurring insect families during active Delhi fly surveys, we plan to conduct ground-dwelling arthropod surveys every 5 years. A baseline survey was conducted in 2016 and we conducted them again in 2021. We sampled the terrestrial arthropod community using un-baited, live-capture pitfall traps consisting of one-liter plastic bottles with the upper third of the bottle removed. We inverted the upper portion of the bottle to serve as a tight-fitting funnel, preventing trapped arthropods from escaping. To install each pitfall trap, we dug a hole into the ground, placed the bottle, covered the dirt up to the edges of the bottle, and then inserted the funnel. Completing the set up, we placed a piece of fiberboard measuring 20 cm x 20 cm x 0.5cm over each pitfall trap, which we elevated using three small wooden blocks, providing shade to the trapped arthropods. We divided the randomly generated pitfall trap points into two subsets (n = 25 traps each) to ensure that an entire subset could be checked in a single day. We installed each subset of traps in the evening then checked and removed them the next morning. At the first and last trap that was installed each evening, we recorded time, general weather description, soil temperature (°C) and noted the individual trap number. We recorded the top three vegetation species within a meter of each trap when installing the trap on the first survey day and took a photo of the trap and the surrounding habitat after it was completely installed. When checking traps we recorded time, general weather description, and soil temperature (°C) at the start (first trap) and end (last trap) of each survey and recorded the respective trap number (Appendix A). For each trap, we identified, tallied and photographed the species caught in the traps before releasing them. We also recorded any arthropod species we observed outside, but in the vicinity, of the trap.

Vegetation Sampling Surveys

We summarized data from the percent presence (percentage of plots on which plant species were recorded). Although we only record the 3 most dominant species in each vegetation class, plus the 7 species/families that were presumed to be associated with Delhi fly occurrence, percent presence still provides a useful measure of the distribution of species with substantial percent cover. Likewise, mean percent cover for species not recorded in each plot may be biased slightly low, but we provide the results to give the reader a general sense of the cover of each species. Furthermore, we surveyed 16 additional vegetation plots centered on coordinates where exuviae were observed to explore whether there were differences in vegetation or ground cover characteristics.

The MSHCP Management Program has been actively managing the Teledyne site since 2010 in an effort to increase habitat suitability for Delhi fly (RCA 2020). Management activities have included *E. fasciculatum* transplanting, dead vegetation removal, various intensities of selective weeding, and mechanical sand destabilization. We compared the resampled plots between 2010 (pre-management) and 2015 and 2021 (ongoing-management) to see if management actions resulted in continued significant changes to relevant habitat characteristics and Delhi fly suitability, using paired sample t-tests. The plot data collected during the 3 ongoing-management years (2015, 2016 and 2021) was also summarized and compared to the 1 pre-management year using paired sample t-tests. We expected vegetation characteristics in pre-management plots in 2010 to be significantly different from ongoing-management plots in 2021 as a result of the various management actions, with less significance detected between 2015, 2016 and 2021.

We compared the resampled plots in 2021 to the locations where Delhi fly exuviae were found during our 2021 Delhi fly surveys to see if there were significant differences in habitat characteristics. Since there were different number of plots in each of these sets this data was summarized and compared using Welch's two sample t-tests. We expected the exuviae plots to be significantly different from the resample plots.

Training

Delhi Sands Flower-loving fly surveys

All surveyors studied a Delhi fly-specific training manual prepared by the Biological Monitoring Program, relevant invertebrate field guides, and preserved specimens of co-occurring winged invertebrate species. We placed emphasis on the ability to recognize morphological and behavioral field traits of Delhi fly, and proficiency in identifying all co-occurring winged insects to family. We also trained surveyors to differentiate between adult and teneral individuals in a field setting, and to identify common plant species at the Teledyne site. All surveyors participated in field-based training that involved observing, capturing either with a net or by hand, and identifying co-occurring insects to family. Prior to conducting line-transect surveys independently, surveyors passed the USFWS Delhi fly practical exam.

Arthropod Surveys

An in-house guide, based on the results from 2018, was prepared and used as an identification guide during these surveys. If there was a species that could not be identified in the field, the observer was instructed to take photos, if possible, and use resources back at the office to attempt to identify them. Based on availability, observers who participated in the Delhi fly surveys and therefore familiar with the co-occurring insect families at Teledyne, were paired with those observers who have not participated in the Delhi fly surveys and were instructed to teach those who have not participated previously.

Vegetation Sampling Surveys

Prior to the first sampling survey observers visited the Teledyne site to perform mock surveys under the supervision of the Project lead (Tara Graham) and the Botany lead (Marisa Grillo) These mock surveys included quadrat placement, plant species identification and percent cover estimates.

Data Analysis

Delhi Sands Flower-loving fly surveys

We used distance-sampling methodology and Program DISTANCE© to estimate detection probability and population density of Delhi fly at the Teledyne site in 2021 (Buckland et al. 2001; Thomas et al. 2010). Distance sampling allows for density estimation with incomplete detection of animals (i.e., not all animals present need to be observed to estimate density). The method relies on fitting data to a pre-defined detection function based on the assumption that objects become less detectable with increasing distance from the observer (Buckland et al. 2001). Distance sampling also requires that three assumptions be met: 1) complete detection of subjects on the transect line, 2) subjects are detected at their initial locations, and 3) distances are measured accurately (Buckland et al. 2015). We examined detection histograms (i.e., number of observations per distance category in both ten and twenty equal intervals) across the survey period for spikes in the number of observations away from the transect (which could indicate the observer was not recording the initial location of the observation suggesting violation of assumption 2), and for relatively few observations near the transect centerline in relation to other distance categories (which could indicate the observer did not detect every Delhi fly on the transect or they did not record the initial location of the observation suggesting violations of assumptions 1) and 2). We pooled data across the entire 2021 survey season to fit a detection function, and derived both stratified (i.e., daily) and pooled (i.e., average daily) estimates of population density. From our dataset, we removed any observations that had been measured beyond 160 inches from the transect to avoid fitting detection functions with extended ‘tails.’ Lastly, based on recommendations generated by the DISTANCE software pertaining to our dataset and our visual inspection of the histograms, we grouped observations into ten equal intervals (i.e., 0, 16, 32, 48…160 inches; Buckland et al. 2001). We evaluated the full combinations of uniform and half normal key functions with cosine, simple-polynomial, and Hermite-polynomial series expansions (Buckland et al. 2001). We did not use the hazard-rate key function because this model function frequently overestimates the unknown parameters, specifically the rate of death of the subject of study, unless the detection function curve is tightly matched to the hypothetical curve (Buckland et al. 2001). Key functions determine the basic model shape and models can be made more robust by adding a series of adjustment terms (also called series expansions) to the key function. These series expansions can increase the number of bends in the key function models in various ways to better fit the data (Rexstad EA 2015). We assessed model fit by graphical inspection of the detection function and using a chi-square goodness of fit test with 81 degrees of freedom and an alpha level of 0.05. We excluded models from the candidate set that demonstrated significant lack of fit based on the above criteria. We ranked competing models using Akaike's Information Criterion adjusted for small sample size (AICc).

Arthropod Surveys

Since this was the first complete arthropod survey done at the Teledyne site there is no data from previous years to compare to. We were able to calculate the percentage of times each family or species were found in the pitfall traps and where the traps that had the most or least families and species were located.

Vegetation Sampling Surveys

Summary statistics, including dominant species by mean percent cover, most commonly occurring species, mean soil compactness, and total vegetation cover for each vegetation class will be reported. The vegetation data collected in 2021 will be compared to vegetation data collected previous years to characterize the site as a whole, and to compare areas where management have taken place on-site to unmanaged areas. Vegetation data collected in previous years have been analyzed using logistic regression to develop models predicting the probability of occurrence of Delhi fly in relation to vegetation and soil. Soil compactness measurements obtained with the adapter foot were converted before data analysis took place (Amacher and O'Neill 2004). Following the 2021 data summarization, we extracted data that were collected on the same plots during 2008-2010, 2015-2016 and 2021 Delhi fly vegetation surveys to compare site characteristics between sampling years using two tailed paired t-test analyses. However, we only used the data from the 262 plots located inside conservation and only plots that were within ± one percent of 100 in our analysis.

RESULTS

Delhi Sands Flower-loving fly surveys

In 2021, we observed an adult Delhi fly on-transect on 79 occasions and off-transect on 13 occasions, with observations occurring from 29 June to 12 August (Figure 4). Of those observations, 62 were male, 23 were female and 7 of undetermined sex. Of the 92 individuals observed while conducting surveys, 23 were teneral.

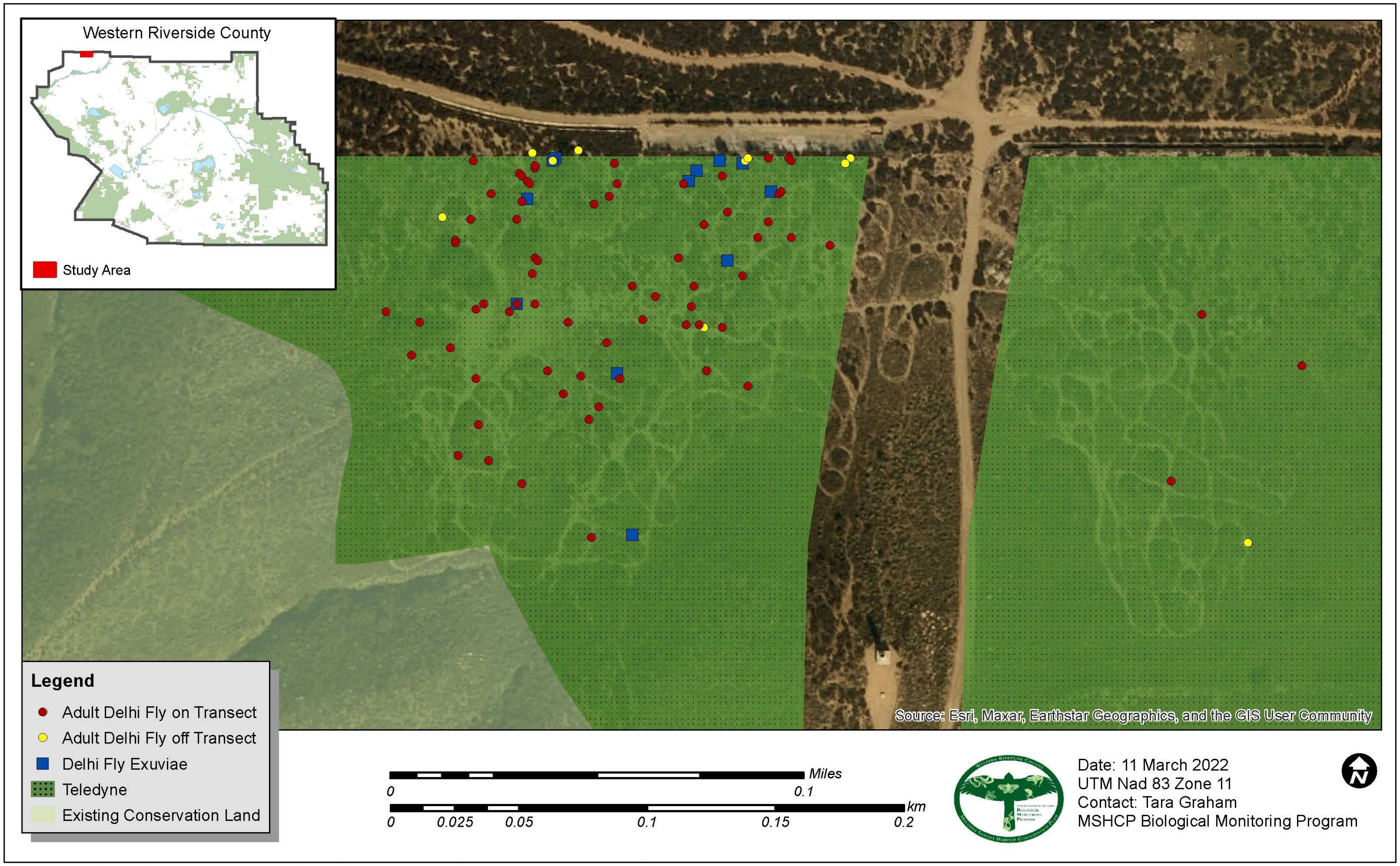

Figure 4. Delhi Sands flower-loving fly adult and exuviae detections at Teledyne in 2021.

The first Delhi fly was detected at Teledyne during a scouting survey on 24 June. We began line-transect surveys on 29 June, and ended the surveys on 23 August after no Delhi fly were observed for four consecutive survey days (Figure 5).

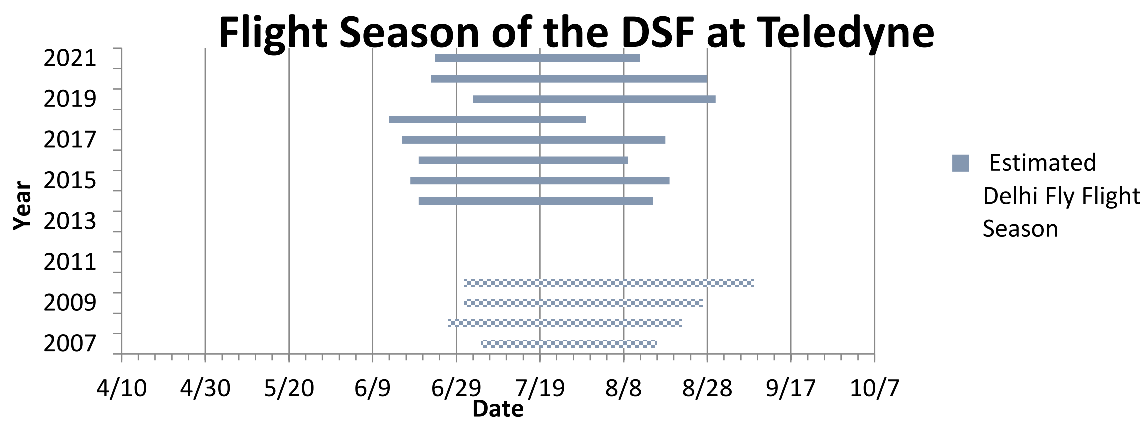

Figure 5. The observed Delhi Sands flower-loving fly flight season from 2007-2021. The checkered lines represent years we did not attempt to observe the first adult Delhi fly before beginning surveys.

Only Delhi fly observations that occurred on-transect resulted in distance measurements and were used for density estimate calculations. In total, we conducted surveys on 29 days between 08:41 h and 15:39 h. We walked a total of 74 km over the course of the 29 survey days which resulted in 1.24 Delhi fly observations per km surveyed (Figure 6).

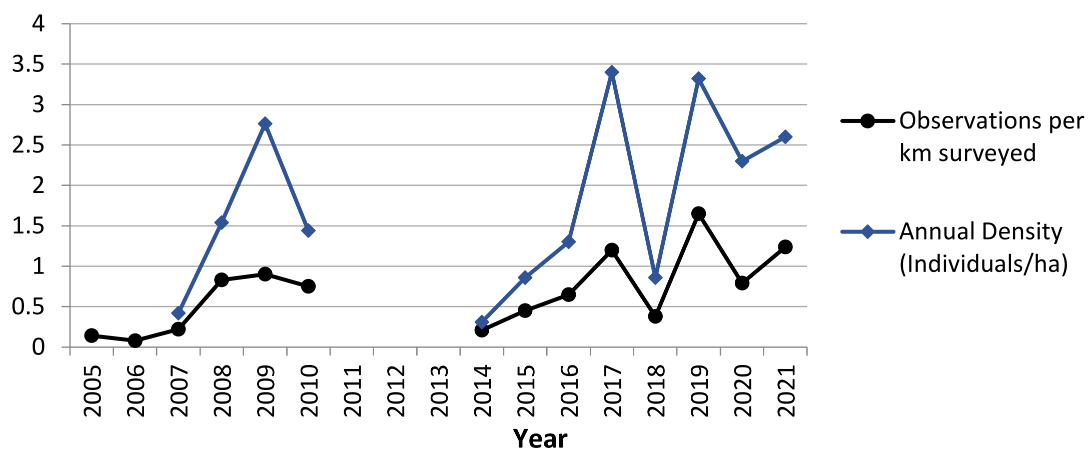

Figure 6. Delhi Sands flower-loving fly observations (per km surveyed) and annual density estimates (individuals per ha) from 2005-2021. Surveys from 2011-2013 were conducted following a different protocol, therefore those data are excluded. From 2005-2006 there were insufficient data to obtain densities, therefore those years are excluded.

The top three performing models (half-normal key function with a cosine polynomial expansion, uniform key function with a cosine polynomial expansion and uniform key function with a hermite polynomial, data used in all models were divided into ten equal intervals; Figure 7) resulted in a chi-square goodness of fit score of 0.676, 0.660 and 0.660 respectively and an AICc value of 326.41, 326.64 and 326.64

respectively (Table 1). We visually checked the detection function curve shape criterion and confirmed an appropriate detection function curve for each model. All of this information together indicates that half-normal key function with a cosine polynomial expansion model was superior to the others and therefore chosen to represent our data. The density estimate of Delhi fly at Teledyne in 2021 was 2.6 individuals/ha (95% CI: 1.8-3.8); (Figure 6) and the detection probability was 0.45 (95% CI: 0.34-0.59). Estimated Delhi fly density peaked on the first survey day (29 June) at an estimated 11.9 individuals/ha, and then oscillated between 7.7 and zero individuals/ha until 16 August when it reached zero individual/ha.

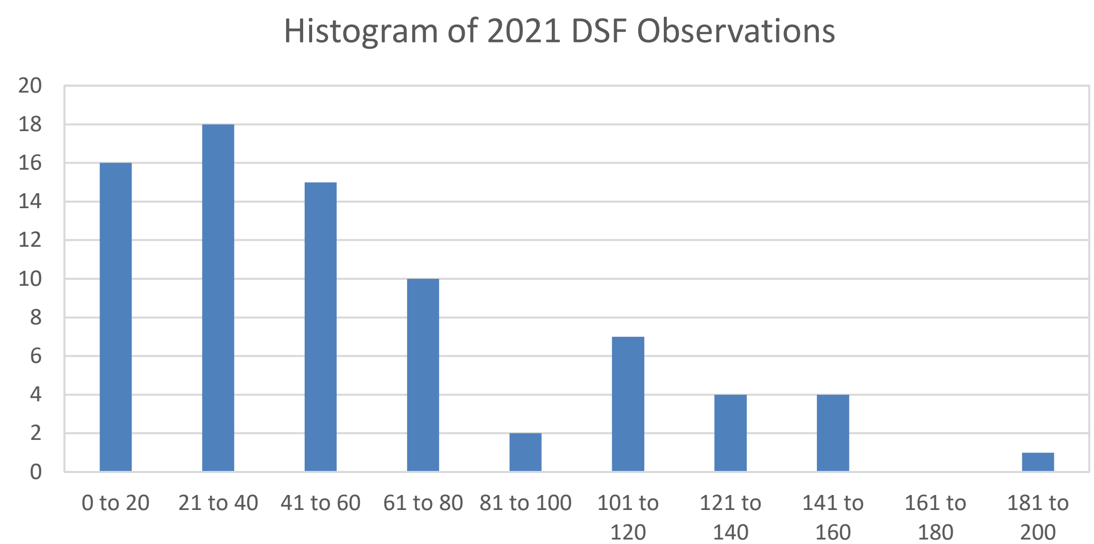

Figure 7. Observations of the Delhi fly showing distance from the transect grouped in 10 equal intervals with all observations over 160 inches removed to eliminate any tails.

Table 1. All models analyzed with their respective AICc and GOF Chi-p values.

Model	AICc	GOF Chi-p
5% Truncation 10 Equal Intervals Half-normal Cosine	326.41	0.676
5% Truncation 10 Equal Intervals Half-normal Simple	327.55	0.430
5% Truncation 10 Equal Intervals Half-normal Hermite	327.55	0.430
5% Truncation 10 Equal Intervals Uniform Cosine	326.64	0.660
5% Truncation 10 Equal Intervals Uniform Simple	328.99	0.518
5% Truncation 10 Equal Intervals Uniform Hermite	326.64	0.660
10 Equal Intervals Half-normal Cosine	326.41	0.676
10 Equal Intervals Half-normal Simple	327.55	0.430
10 Equal Intervals Half-normal Hermite	327.55	0.430
10 Equal Intervals Uniform Cosine	326.64	0.660
10 Equal Intervals Uniform Simple	328.99	0.518
10 Equal Intervals Uniform Hermite	326.64	0.660
20 Equal Intervals Half-normal Cosine	433.35	0.700
20 Equal Intervals Half-normal Simple	434.37	0.585
20 Equal Intervals Half-normal Hermite	434.37	0.585
20 Equal Intervals Uniform Cosine	433.04	0.684
20 Equal Intervals Uniform Simple	435.50	0.562
20 Equal Intervals Uniform Hermite	433.04	0.684
10 Equal Intervals Truncation Beyond 160 Half-normal Cosine	326.41	0.676
10 Equal Intervals Truncation Beyond 160 Half-normal Simple	327.55	0.430
10 Equal Intervals Truncation Beyond 160 Half-normal Hermite	327.55	0.430
10 Equal Intervals Truncation Beyond 160 Uniform Cosine	326.64	0.660
10 Equal Intervals Truncation Beyond 160 Uniform Simple	328.99	0.518
10 Equal Intervals Truncation Beyond 160 Uniform Hermite	326.64	0.660
20 Equal Intervals Truncation Beyond 160 Half-normal Cosine	433.35	0.700
20 Equal Intervals Truncation Beyond 160 Half-normal Simple	434.37	0.585
20 Equal Intervals Truncation Beyond 160 Half-normal Hermite	434.37	0.585
20 Equal Intervals Truncation Beyond 160 Uniform Cosine	433.04	0.684
20 Equal Intervals Truncation Beyond 160 Uniform Simple	435.50	0.562
20 Equal Intervals Truncation Beyond 160 Uniform Hermite	433.04	0.684

A total of 12 exuviae were collected in 2021, all of which were collected during active surveys (Figure 4). Five exuviae were found northeast of the upper dunes, three north of the dunes, one in the dunes, one east of the dunes and two southeast of the dunes. This distribution is similar to the exuviae distribution we observed on-site in 2019 and 2020 with a little more activity south of the dunes.

Arthropod Surveys

We began with the setup process on 17 May and ended the surveys with trap checks on 28 May. We checked the traps on a total of 8 days between the hours of 0810 and 1317 and soil temperatures ranging from 23.9 °C to 30.0 °C. We observed 22 families outside of the traps and 78 species including 32 families in the traps, two of which were lizards and one toad. In addition to the 32 families there were 13 observed arthropods that could not be identified beyond order.

More than twenty-nine families were represented in the pitfall trap captures with the top 5 ranked by percentage of all captures being Araneae, Machilidae, Carabidae, Formicidae and Tenebrionidae. At least 10 of the families caught in the pitfall traps have members that live underground during the larval stage of their lives. (Figure 8).

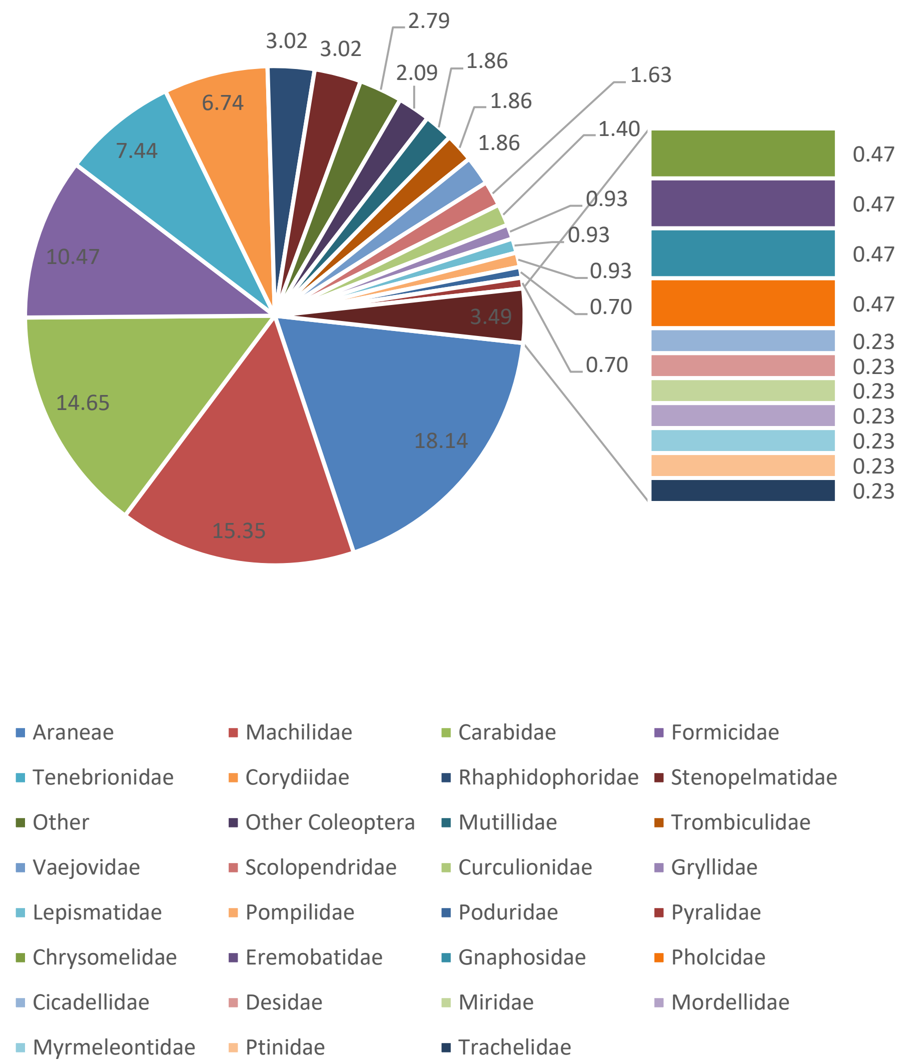

Figure 8. Graph showing the abundance of Arthropods' families captured in 2021.

Vegetation Sampling Surveys

Vegetation sampling took place over 23 days in 2021, beginning 27 September and ending on 5 November (Table 2). Total mean percent cover estimated for the 262 resampled plots had a value of 53.4% (SE ± 1.9).

Table 2. Most common plant species and families recorded across 262 resampled vegetation plots and 12 exuviae plots in 2021. Target species/families are listed in bold; all other species/families were recorded as 1 of the 3 dominant species in at least one plot. Species that are underlined are hypothesized as having a positive association with the Delhi fly. Standard error (SE) is only reported for target species/families.

Plant species/family	Percent presence		Mean percent cover	
	Resampled	Exuviae	Resampled	Exuviae
Poaceae	**82**	**36**	**6.95 (SE ± 0.74)**	**1.10 (SE ± 0.63)**
Amsinckia menziesii	54	14	5.67	0.76
Eriogonum fasciculatum	**39**	**71**	**16.85 (SE ± 1.86)**	**21.64 (SE ± 6.82)**
***Stephanomeria* sp.**	**37**	**7**	**2.87 (SE ± 0.41)**	**0.01 (SE ± 0.01)**
Phacelia ramosissima	26	29	5.78	5.71
Croton californicus	**23**	**21**	**1.92 (SE ± 1.86)**	**1.86 (SE ± 1.71)**
Camissonia sp.	23	7	0.70	0.07
Ambrosia acanthicarpa	**18**	**14**	**1.83 (SE ± 0.39)**	**1.43 (SE ± 1.22)**
Rhus aromatica	16	14	7.13	6.43
Eriogonum gracile	8	0	0.34	0
Encelia farinosa	7	0	2.46	0
Centaurea melitensis	7	0	0.86	0
Lessingia glandulifera	5	0	0.36	0
Erodium cicutarium	5	0	0.07	0
Keckiella antirrhinoides	2	0	0.54	0
Helianthus annuus	2	0	0.43	0
Sambucus nigra ssp. *canadensis*	2	0	0.90	0
Prunus ilicifolia	2	0	1.22	0
Acmispon glabrus	2	0	0.55	0
Artemisia californica	2	0	0.34	0
Unidentified forb/grass	2	0	0.01	0
Salvia mellifera	1	0	0.24	0
Adenostoma fasciculatum	1	0	0.28	0
Corethrogyne filaginifolia	1	0	0.01	0
Deinandrea paniculata	1	0	0.004	0
Eucrypta chrysanthemifolia	1	0	0.02	0
Marah macrocarpus	1	0	0.004	0
Verbesina encelioides	1	0	0.02	0
Ericameria pinifolia	0.38	7	0.05	0.07
Nicotiana glauca	0.38	0	0.13	0
Cryptantha muricata	0.38	0	0.01	0
Cucurbita foetidissima	0.33	0	0.02	0
Heterotheca grandiflora	**0**	**0**	**0.00 (SE ± 0.00)**	**0.00 (SE ± 0.00)**

Mean percent cover values for the 3 vegetation classes within those plots were: shrubs = 29.95% (SE ± 2.1), forbs/grasses = 26.87% (SE ± 1.7), and trees = 2.26% (SE ± 0.8). On the 262 resampled plots included in our analysis, we found the family group Brassicaceae present on 26% of plots and the family group Poaceae present on 82% of plots. The most common individual species were Poaceae (recorded on 82% of plots), *Amsinckia menziesii* (54%), *Eriogonum fasciculatum* (39%), and *Stephanomeria* sp. (37%), Brassicaceae (26%) (Table 2). The dominant individual species, by mean percent cover, were *E. fasciculatum* (17%), *Rhus aromatica* (7.1%), Poaceae (7.0%) and *Phacelia ramosissima* (5.8%), *Amsinckia menziesii* (5.7%; Table 2).

Total mean percent cover estimated on the exuviae plots had a mean value of 34.4% (SE ± 7.0). Mean percent cover values for the 3 vegetation classes within those plots were: shrubs = 28.8% (SE ± 7.1), forbs/grasses = 7.9% (SE ± 4.0), and trees = 0% (SE ± 0). Additionally, we recorded 10 species in a dominant category at least once (Table 2).

On the 12 exuviae plots included in our analysis, we found the family group Brassicaceae present on none of plots and the family group Poaceae present on 36% of plots. The most common individual species were *E. fasciculatum* (recorded on 71% of plots), Poaceae (36%), *Phacelia ramosissima* (29%), *Croton californicus* (21%) and *Rhus aromatica, Amsinckia menziesii*, *Ambrosia acanthicarpa* all on 14.3% of the plots. The dominant individual species by mean percent cover were *E. fasciculatum* (21.6%), *Rhus aromatica* (6.4%), *Phacelia ramosissima* (5.7%), *Croton californicus* (1.9%) and *Ambrosia acanthicarpa* (1.4%; Table 2). Important to note these values are exclusively from plots occupied by Delhi Fly.

Comparison of 2008-2021 Vegetation Data

To compare ground cover and vegetation class cover at the Teledyne site over sampling years, data collected during the 2008, 2009, 2010, 2015, 2016 and 2021 sampling efforts were summarized (Table 3). Only plots that were resampled during each survey effort were extracted and data were examined for integrity. Visual comparisons between years show that the proportion of total mean percent of sand decreased overall on both the resampled plots and the exuviae plots and the total mean percent of litter increased, attributed mostly to an increase in total mean percent of shrubs. The mean soil compactness increased slightly on both resampled and exuviae plots; however, this measurement is not directly comparable to years before 2016 due to the increased compaction readings taken within each plot (Table 3).

Table 3. Comparisons between average ground cover percentages, mean vegetation class cover percentages and mean soil compactness across sites sampled during 2008-2021. Although 300 plots were sampled, not all plot were used in these comparisons. The summarization only includes plots that were resampled each year that vegetation surveys took place, as well as the exuviae plots and only includes plots that had total ground cover totals within ± one percent of 100. Ground compaction measurements were not collected in 2008.

Variable	Exuviae 2021	2021	Exuviae 2016	2016	2015	2010	2009	2008
Ground cover								
Number of plots	13	262	38	256	250	255	243	256
Hardpan (%)	-	0.1	-	-	-	0.4	-	0.1
Loose sand (%)	NA	NA	NA	NA	15.3	31.0	40.7	46.6
Stabilized sand (%)	NA	NA	NA	NA	33.7	6.2	7.5	22.9
Total sand (%)	69.3	35.3	90.6	58.5	49.0	37.1	48.3	69.4
Other bare ground (%)	0.1	0.7	0.04	1.0	0.7	1.4	1.2	0.1
Basal stem (%)	0.4	1.0	0.5	0.8	1	0.6	0.9	0.5
Litter (%)	30.1	62.1	9.0	39.5	48.8	59.3	49.7	29.1
Rock (%)	0.2	0.9	0.1	0.3	0.7	1.3	0.1	0.9
Mean Soil compactness (Kg/cm^2)	0.15	0.41	0.12	0.35	0.42	0.54	0.41	NA
Vegetation classes								
Number of plots	13	262	38	262	264	255	243	256
Forbs/Grasses (%)	7.5	14.9	2.2	6.4	16.9	24.2	20.2	12.6
Shrubs (%)	31.9	30.4	2.6	14.0	18.8	7.1	6.2	4.9
Trees (%)	-	2.3	-	2.6	2.9	2.0	1.7	0.9
Total vegetation (%)	39.4	47.5	4.8	23.0	38.6	33.2	28.0	18.4

Ground cover results for the resampled plots in 2021, in order from highest to lowest mean percent cover, were litter (62.1%, SE ± 1.9), sand (35.3%, SE ± 1.9), basal stem (1.0%, SE ± 0.1), rock (0.9%, SE ± 0.5), other bare ground (0.7%, SE ± 0.4), and hardpan (0.1%, SE± 0.1; Table 3). Mean soil compactness was 0.41 kg/cm^2 (SE ± 0.02; Table 4).

Comparisons between 2010 resampled vegetation plots and 2021 resampled vegetation plots using a paired t-test were done on the vegetation species hypothesized to have positive and negative associations with Delhi fly as well as mean soil compactness (Table 4). Comparisons of *Ambrosia acanthicarpa* (t value=0.89, (df)=261, p = 0.375) between 2010 resampled vegetation plots (M=2.29, SD=5.12) and 2021 resampled vegetation plots (M=1.83, SD=6.33) show a decrease for the mean percent cover and a decrease in the percent present. Comparisons of Brassicaceae (t value=-3.03, (df)=261, p = 0.002) between 2010 resampled vegetation plots (M=1.08, SD=4.78) and 2021 resampled vegetation plots (M=3.08, SD=9.48) show a significant increase for the mean percent cover but there was a decrease in the percent present. Comparisons of *Croton californicus* (t value=-2.22, (df)=261, p = 0.027) between 2010 resampled vegetation plots (M=0.97, SD=2.73) and 2021 resampled vegetation plots (M=1.92, SD=6.41) show a significant increase for the mean percent cover but a decrease in the percent present. Comparisons of *Eriogonum fasciculatum* (t value=-7.73, (df)=261, p = 2.323e-13) between 2010 resampled vegetation plots (M=3.08, SD=14.06) and 2021 resampled vegetation plots (M=16.85, SD=30.16) show a significant increase for the mean percent cover and an increase in the percent present. Comparisons of *Heterotheca grandiflora* (t value=1.79, (df)=261, p = 0.074) between 2010 resampled vegetation plots (M=0.01, SD=0.09) and 2021 resampled vegetation plots (M=0.00, SD=0.00) show a decrease for the mean percent cover and percent present. Comparisons of Poaceae (t value=0.63, (df)=261, p = 0.529) between 2010 resampled vegetation plots (M=6.53, SD=8.17) and 2021 resampled vegetation plots (M=6.95, SD=12.01) show an increase for the mean percent cover and a decrease in percent present. Comparisons of *Stephanomeria* (t value=-2.23, (df)=261, p = 0.07) between 2010 resampled vegetation plots (M=2.00, SD=5.41) and 2021 resampled vegetation plots (M=2.87, SD=6.62) show a significant increase for the mean percent cover and a decrease in percent present. Comparisons between the mean soil compactness (t value=18.81, (df) =261, p = < 2.2e-16) for 2010 resampled vegetation plots (M=0.54, SD=0.88) and 2021 resampled vegetation plots (M=0.40, SD=0.38) show a significant decrease in compactness (Table 4).

Table 4. Results of paired t-test comparisons between target species/families mean percent cover and the mean soil compactness across 262 vegetation sampling plots in 2010 and 2021**.** Species are divided by hypothesized positive and negative associations with Delhi fly, respectively. **Bold** indicates significant differences between sampling years. The number in ( ) indicates the percent a species is present in all 262 plots.

	Mean percent cover (% present)			
Target species/family	**2010**	**2021**	**P-value**	**95% CI**
Ambrosia acanthicarpa	2.3 (45)	1.8 (18)	0.3754	(-0.546, 1.443)
Croton californicus	0.9 (24)	1.9 (23)	**0.0027**	(-1.794, -0.109)
Eriogonum fasciculatum	3.1 (9)	16.9 (39)	**2.323e-13**	(-17.165, -10.196)
Heterotheca grandiflora	0.01 (2)	0.0 (0)	0.0741	(-0.001, 0.021)
Stephanomeria sp.	2.0 (40)	3.0 (37)	**0.0266**	(-1.920, -0.119)
Brassicaceae	1.1 (35)	3.1 (26)	**0.0027**	(-3.305, -0.702)
Poaceae	6.5 (86)	7.1 (82)	0.5289	(-1.987, 1.023)
Mean Soil Compactness (kg/cm²)	0.5	0.4	**< 2.2e-16**	(1.312, 1.618)

Comparisons between 2016 resampled vegetation plots and 2021 resampled vegetation plots using a paired t-test were done on the vegetation species hypothesized to have positive and negative associations with Delhi fly as well as soil compactness (Table 5). Comparisons of *Ambrosia acanthicarpa* (t value=-4.26, (df)=261, p = 2.87e-05) between 2016 resampled vegetation plots (M=0.17, SD=0.64) and 2021 resampled vegetation plots (M=1.88, SD=6.33) show a significant increase for the mean percent cover and no change in percent present. Comparisons of Brassicaceae (t value=-4.57, (df) =261, p = 7.46e-06) between 2016 resampled vegetation plots (M=0.48, SD=1.36) and 2021 resampled vegetation plots (M=3.08, SD=9.48) show a significant increase for the mean percent cover and a decrease in percent present. Comparisons of *Croton californicus* (t value=-3.10, (df)=261, p = 0.002) between 2016 resampled vegetation plots (M=0.71, SD=1.61) and 2021 resampled vegetation plots (M=1.92, SD=6.41) show a significant increase for the mean percent cover and a decrease in percent present. Comparisons of *Eriogonum fasciculatum* (t value=-6.10, (df)=261, p = 3.90e-09) between 2016 resampled vegetation plots (M=7.36, SD=21.59) and 2021 resampled vegetation plots (M=16.85, SD=30.16) show a significant increase for the mean percent cover and an increase in percent present. Comparisons of *Heterotheca grandiflora* (t value=1, (df)=261, p = 0.318) between 2016 resampled vegetation plots (M=0.03, SD=0.49) and 2021 resampled vegetation plots (M=0.00, SD=0.00) show a decrease for the mean percent cover and a decrease in percent present. Comparisons of Poaceae (t value=-5.06, (df)=261, p = 8.02e-07) between 2016 resampled vegetation plots (M=3.11, SD=4.10) and 2021 resampled vegetation plots (M=6.95, SD=12.01) show a significant increase for the mean percent cover and a decrease in percent present. Comparisons of *Stephanomeria* (t value=-6.92, (df)=261, p = 3.508e-11) between 2016 resampled vegetation plots (M=0.03, SD=0.28) and 2021 resampled vegetation plots (M=2.87, SD=6.62) show a significant increase for the mean percent cover and an increase in percent cover. Comparisons between the mean soil compactness (t value=-0.92, (df)=261, p = 0.360) for 2016 resampled vegetation plots (M=0.35, SD=0.35) and 2021 resampled vegetation plots (M=0.40, SD=0.38) show an increase in compactness (Table 5).

Table 5. Results of paired t-test comparisons between target species/families mean percent coverage and the mean soil compactness across 262 vegetation sampling plots in 2016 and 2021. Species are divided by hypothesized positive and negative associations with Delhi fly, respectively. **Bold** indicates significant differences between sampling years. The number in ( ) indicates the percent a species is present in all 262 plots.

	Mean percent cover (% present)			
Target species/family	**2016**	**2021**	**P-value**	**95% CI**
Ambrosia acanthicarpa	0.2 (18)	1.8 (18)	**2.866e-05**	(-2.431, -0.893)
Croton californicus	0.7 (32)	1.9 (23)	**0.002166**	(-1.979, -0.441)
Eriogonum fasciculatum	7.4 (22)	16.9 (39)	**3.904e-09**	(-12.557, -6.425)
Heterotheca grandiflora	0.03 (0.4)	0.0 (0)	0.3182	(-0.030, 0.091)
Stephanomeria sp.	0.03 (2)	3.0 (37)	**3.508e-11**	(-3.644, -2.029)
Brassicaceae	0.5 (44)	3.1 (26)	**7.464e-06**	(-3.739, -1.489)
Poaceae	3.1 (90)	7.0 (82)	**8.02e-07**	(-5.359, -2.356)
Mean Soil Compactness (kg/cm^2)	0.35	0.4	0.3601	(-0.128, 0.047)

Comparisons between 2021 resampled vegetation plots and 2021 exuviae vegetation plots using Welch's two sample t-test were done on the vegetation species hypothesized to have positive and negative associations with Delhi fly as well as soil compactness (Table 6). *Heterotheca grandiflora* was excluded from the comparison since it was not present on any of the plots. Comparisons of *Ambrosia acanthicarpa* (t value=0.22, (df)=14.2, p = 0.83) between 2021 resampled vegetation plots (M=1.83, SD=0.39) and 2021 exuviae vegetation plots (M=1.54, SD=1.31) show a decrease for the mean percent cover and a decrease in percent present. Comparisons of Brassicaceae (t value=5.27, (df)=261, p = 2.91e-07) between 2021 resampled vegetation plots (M=3.08, SD=0.59) and 2021 exuviae vegetation plots (M=0.00, SD=0.00) show a significant decrease for the mean percent cover and a decrease in percent present. Comparisons of *Croton californicus* (t value=0.04, (df)=13.14, p = 0.97) between 2021 resampled vegetation plots (M=1.92, SD=0.40) and 2021 exuviae vegetation plots (M=2.00, SD=1.84) show a decrease for the mean percent cover and a decrease in percent present. Comparisons of *Eriogonum fasciculatum* (t value=-0.83, (df)=13.65, p = 0.42) between 2021 resampled vegetation plots (M=16.85, SD=1.86) and 2021 exuviae vegetation plots (M=23.00, SD=7.21) show an increase for the mean percent cover and an increase in percent present. Comparisons of Poaceae (t value=5.76, (df)=54.96, p = 3.98e-07) between 2021 resampled vegetation plots (M=6.95, SD=0.74) and 2021 exuviae vegetation plots (M=1.18, SD=0.67) show a significant decrease for the mean percent cover and a decrease in percent present. Comparisons of *Stephanomeria* (t value=6.99, (df)=261.2, p = 2.24e-11) between 2021 resampled vegetation plots (M=2.87, SD=0.41) and 2021 exuviae vegetation plots (M=0.01, SD=0.01) show a significant decrease for the mean percent cover and a decrease in percent present. Comparisons between of the mean soil compactness (t value=162.28, (df)=61.50, p = 4.502e-10) for 2021 resampled vegetation plots (M=0.40, SD=0.38) and 2021 exuviae vegetation plots (M=0.15, SD=0.12) a significant decrease in compactness (Table 6).

Table 6. Results of Welch two sample t-test comparisons between target species/families mean percent coverage across 262 resampled vegetation plots and 13 exuviae plots in 2021. Species are divided by hypothesized positive and negative associations with Delhi fly, respectively. **Bold** indicates significant differences between the two types of sampling plots. The number in ( ) indicates the percent a species is present in all 262 plots.

	Mean percent cover (% present)			
Target species/family	**Resampled**	**Exuviae**	**P-value**	**95% CI**
Ambrosia acanthicarpa	1.8 (18)	1.43 (14)	0.8322	(-2.630, 3.220)
Croton californicus	1.9 (23)	1.86 (21)	0.9674	(-4132, 3.976)
Eriogonum fasciculatum	16.9 (39)	21.64 (71)	0.4232	(-22.170, 9.866)
Heterotheca grandiflora	0.0 (0)	0.0 (0)	NA	NA
Stephanomeria sp.	3.0 (37)	0.01 (7)	**2.24E-11**	(2.055, 3.666)
Brassicaceae	3.1 (26)	0 (0)	**2.91E-07**	(1.930, 4.236)
Poaceae	7.1 (82)	1.10 (36)	**3.98E-07**	(3.760, 7.777)
Mean Soil Compactness (kg/cm²)	0.4	0.15	**4.50E-010**	(0.191, 0.352)

Weather Station Data

The Delhi fly larvae most likely lives in the moisture layer that is in the general area of 2 meters below the surface and moves up or down based on environmental conditions, based on the life cycle of other closely related *Rhaphiomidas* species. Once they leave the moisture layer the larvae will not survive long (Ken Osborne, consultant, personal communication). In order to learn what triggers Delhi fly emergence we have looked at the values from the sensors on the HOBO weather station in the 2 days prior to the first Delhi fly observation and in the 2 days prior to the peak density day. In the 2 days prior to the first Delhi fly observation the daily average of the soil temperature (°C) was been between 31.98 and 32.85, the daily average of the soil moisture (m^3/m^3) at a depth of 1 meter was 0.000 on both days and the daily average of the soil moisture (m^3/m^3) at 2 meters was between 0.592 and 0.611. In 2021, the average daily soil temperature (°C) was between 31.98 and 32.85, which is above the high end of the 3-year average which is 30.83. The soil moisture (m^3/m^3) at a depth of 1 meter was 0.000 for both days which is much lower than the 3-year average of 0.316 and the soil moisture (m^3/m^3) at a depth of 2 meters was between 0.592 and 0.611 which is on the above the high end of the 3-year average which is 0.508. In the 2 days prior to the peak density day the daily average of the soil temperature (°C) was been between 34.36 and 34.86, the daily average of the soil moisture (m^3/m^3) at a depth of 1 meter was 0.000 and the daily average of the soil moisture (m^3/m^3) at 2 meters was between 0.603 and 0.614. In 2021, the average daily soil temperature (°C) was between 34.36 and 34.86, which is higher than the 4-year average which is between 33.27 and 33.65. The soil moisture (m^3/m^3) at a depth of 1 meter was 0.000 both days which is on the below the 4-year average which was 0.352 both days and the soil moisture (m^3/m^3) at a depth of 2 meters was between 0.603 and 0.614 which is higher than the 3-year average which was between 0.450 and 0.502 (Figure 9). Prior years data used for comparisons can be found in the Biological Monitoring Program Delhi Sands flower-loving fly Survey Report (years 2005-2020). Prepared for the Western Riverside County Multiple Species Habitat Conservation Plan. Riverside, CA. Available online: https://www.wrc-rca.org/species-surveys/.

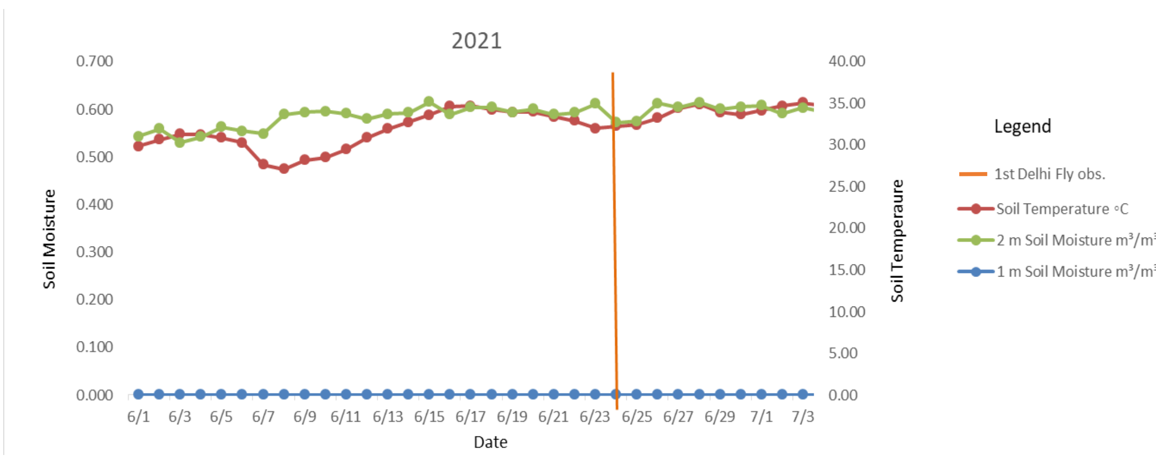

Figure 9. Weather station data for 2021 showing the conditions before the first observations of the Delhi fly.

DISCUSSION

Delhi Sands Flower-loving fly surveys

In 2021, our goals were to document successful reproduction by Delhi fly at Teledyne, estimate population density of adult Delhi fly in 2021 as compared to previous estimates, document persistence of the population within appropriate habitat, gather data regarding Delhi fly resource selection and important distribution covariates, and determine vegetation and soil characteristics of occupied areas. We met the monitoring objective at Teledyne by confirming successful Delhi fly reproduction again in 2021, and documenting 20 teneral individuals and 14 exuviae during active surveys. The first Delhi fly individual was observed on 24 June and the last individual of the flight season was observed at the Teledyne site on 12 August. These observations remain noteworthy as the USFWS Recovery Plan states that the flight season historically did not begin until early August (USFWS 1997) which was later revised to begin 1 July (USFWS 2004). After the late start of the flight season in 2019 (3 July), our data in 2020 and 2021 no longer suggests a distinct temporal shift in the flight season for this species at the Teledyne site, but rather our data shows the end of the flight season at Teledyne is close to a month before USFWS had originally suggested (Figure 5). In 2021, the first observed individual was seen on 24 June which was just 1 day after the first observed individual in 2020. In an effort to accurately detect the start of the flight season, we will continue to start scouting surveys in early June. Continued tracking of environmental parameters over time may help us to identify trends that influence Delhi fly emergence.

Density estimates and observations per km in 2021 increased slightly from 2020. The daily density estimate in 2021 was 2.6 individuals/ha, which is comparable to the density in 2020 (2.3 individuals/ha; Figure 7; BMP 2020). The number of Delhi fly observations per km surveyed was 1.24 in 2021, which is comparable to the 1.20 observations per km surveyed in 2017 (BMP 2020). The total number of survey hours in 2021 was 95.7 and level of survey effort will continue to keep this intensity of survey hours to maintain the sample size to get a more accurate density estimate while continuing to reduce potential impacts on teneral flies, which have been observed emerging from the sandy open spaces along the line transects.

As noted in previous years, we detected most Delhi fly individuals in the western section of the site where soils are generally sandier and looser and vegetation is sparse (Figure 4). Furthermore, surveyors generally detected Delhi flies on the edges of vegetation, rather than in the middle of the open sand dune or in the middle of thicker patches of shrubs or trees. This observed behavior could be due to the added protection the vegetation provides. Habitat management activities by the MSHCP Land Management Program initiated at Teledyne since 2015 (RCA 2020), which includes weeding and maintaining paths through the vegetation, seems to have improved site conditions for the Delhi fly. Potential evidence of this is shown by the Delhi fly's use of the pathways created by the management activities as well as an increase in the density estimates. Density estimates and observations per km increased considerably from the pre-management years with an average density of 1.5 and an average of 0.487 observations per km compared to ongoing-management years with an average density of 1.9 and an average of 0.821 observations per km. However, additional years of surveying are required to confirm whether this is a statistically significant change.

Based on the weather information collected during 2018 to 2021, there is a distinct pattern emerging in the environmental conditions present in the couple of days prior to the Delhi fly emergence. For all 3 years, in the couple of days prior to the first observation of the Delhi fly the soil temperature has been between 28.66 and 32.24 degrees celsius, a very narrow range of 3.58 degrees. The soil moisture at 1 meter has been between 0.462 and 0.474 (m^3/m^3) which is a narrow range of 0.012 (m^3/m^3; BMP 2020). This presents very specific conditions in the 2 days prior to the larvae emerging. The underground values for 2021 show as the soil temperature raises so does the soil moisture at the 2-meter depth, however, at the same time the soil moisture at the 1-meter depth lowers. Further analysis will have to be done to make any definitive conclusions on this (Figure 9).

Arthropod Surveys

In 2021, the top five families based on the percent of all captures (%) in the pitfall traps were Araneae at 18.14, Machilidae at 15.35, Carabidae at 14.65, Formicidae at 10.47, and Tenebrionidae at 7.44. Also included, in smaller percentages, are other Coleoptera, Rhaphidophoridae, Stemopelmatidae, Mutillidae, Gryllidae, Chrysomelidae and Myrmeleontidae (Figure 8). It is important to note since all of the afore mentioned families (except Araneae and Machilidae) have larval stages that survive in the soil, they may be potential food sources for the Delhi fly larvae that are thought to be predacious (Ken Osborne, entomologist, personal communication and Rick Rogers, entomologist, personal communication).

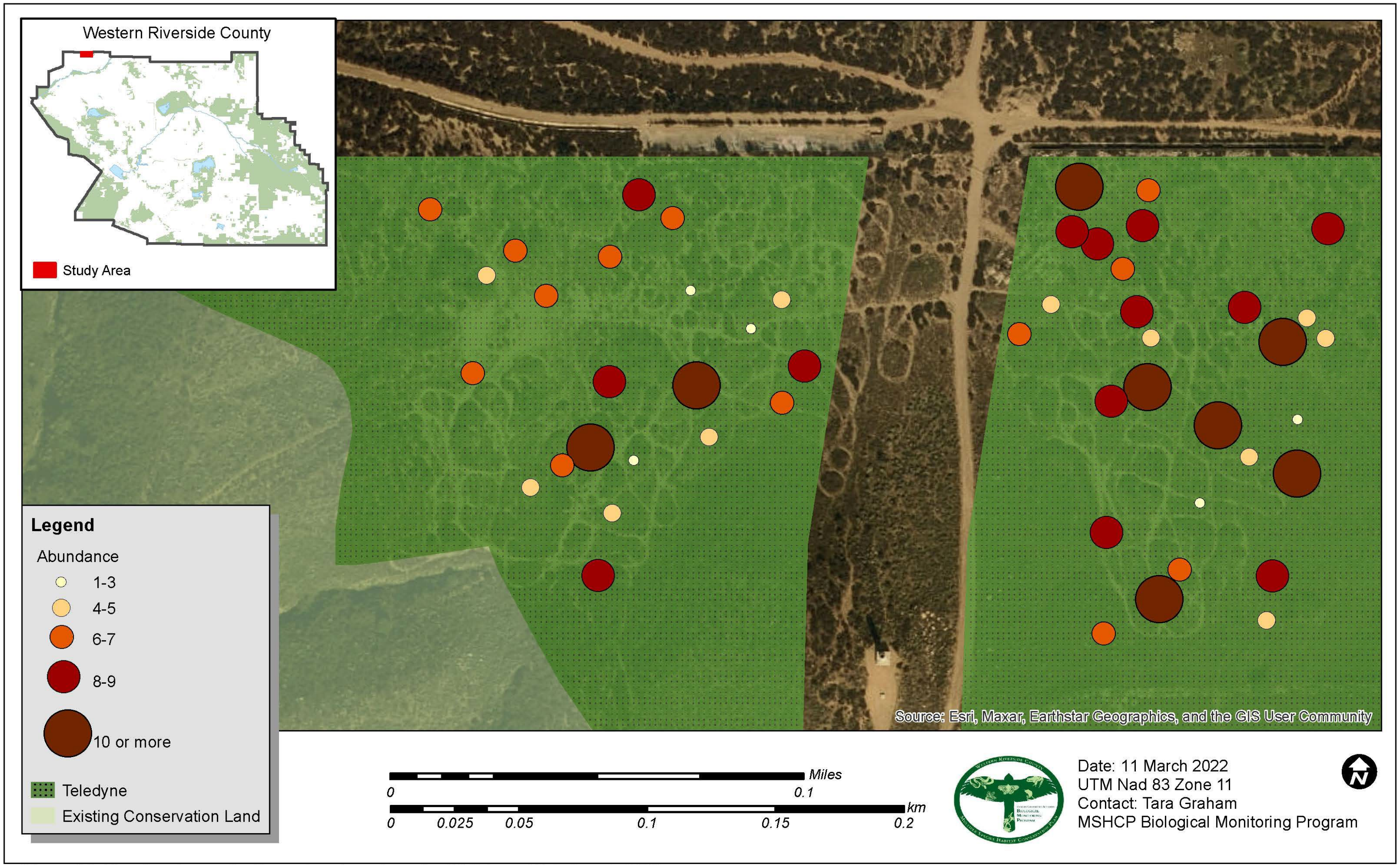

Figure 10. The abundance of arthropod captures in each pitfall trap at Teledyne in 2021.

Vegetation Sampling Surveys

Many of the vegetation metrics tracked from pre- (2010) and ongoing- (2014-2021) management activities show beneficial effects, examples including a decrease in the percent presence of Poaceae, Brassicaceae as well as mean soil compactness, and an increase in the percent presence as well as the mean percent cover of *E. fasciculatum* than would have not been expected without management. Between 2015 through 2016 (ongoing-management years)many of the target species, both positively and negatively associated with the Delhi fly, declined in percent cover which may be attributed to management goals of increasing total percent cover of sand. In 2021, all of the target species, both positively and negatively associated with the Delhi fly, have neared or increased their pre-management mean percent cover, with the exception of *Ambrosia acanthicarpa* and *Heterotheca grandiflora*. However, all of the target species, both positively and negatively associated with the Delhi fly, have a lower percent presence with the exception of *E. fasciculatum* which may be attributed to management goals of increasing total percent cover of sand and selective weeding (Table 7). This also indicates that even though a single plot may have a higher coverage of a particular species, the overall cover of a particular plant may be lower when averaged across all plots than that particular plant's cover in some individual plots.. Comparisons between the 262 resampled plots and the exuviae plots indicated there is significantly less mean percent cover of Brassicaceae, Poaceae and *Stephanomeria* on the exuviae plots than on the plots where exuviae was not located; mean vegetative percent cover overall was also lower on exuviae plots than the resampled plots with the exception of *E. fasciculatum*.

Stabilization of Delhi series soils onsite remains a concern, as consolidated sands reduces suitability for Delhi Fly. The overall mean soil compactness values show the soil is almost 3 times less compact on the exuviae plots, ongoing-management, however data shows a slight increase in 2021.

Dune systems are dynamic where attrition and replenishment of sands is a natural process. When the attrition of sands occurs at a faster rate than replenishment, the dune system erodes away. Based on the data, the overall percentage of total sand has gone down this year in both the resampled and exuviae plots (Table 7) than in prior years. This may be due to the increased percent cover of shrubs in both the resampled and exuviae plots as well as forbs/grass percent cover in the resampled plots (Table 3). It will be important to prevent Delhi series sand from shifting /andor blowing offsite. When comparing the density of the Delhi fly at Teledyne and the mean percent cover of *Heterotheca grandiflora* across the years, there appears to be no dependency of the Delhi fly on this plant species, as had previously been thought (USFWS 2008).

Table 7. Comparisons between target species/families mean percent coverage and the mean soil compactness across 262 vegetation sampling plots in 2010, 2015, 2016 and 2021. Species are divided by hypothesized positive and negative associations with Delhi fly, respectively. **Bold** indicates significant differences between sampling years. The number in ( ) indicates the percent a species is present in all 262 plots.

	Mean percent cover (% present)			
Target species/family	**2010**	**2015**	**2016**	**2021**
Ambrosia acanthicarpa	2.3 (45)	2.3 (40)	0.2 (18)	1.8 (18)
Croton californicus	0.9 (24)	1.4 (32)	0.7 (32)	1.9 (23)
Eriogonum fasciculatum	3.1 (9)	9.9 (30)	7.4 (22)	16.9 (39)
Heterotheca grandiflora	0.01 (2)	0.03 (1)	0.03 (0.4)	0.0 (0)
Stephanomeria sp.	2.0 (40)	0.2 (13)	0.03 (2)	3.0 (37)
Brassicaceae	1.1 (35)	2.1 (61)	0.5 (44)	3.1 (26)
Poaceae	6.5 (86)	4.8 (93)	3.1 (90)	7.1 (82)
Mean Soil Compactness (kg/cm²)	0.5	0.42	0.35	0.4

Recommendations

Future Surveys

The species-specific monitoring objective for Delhi fly states that successful reproduction shall be documented at all Core Areas once a year for the first five years after permit issuance and then as appropriate, but not less frequently than every eight years thereafter. The MSHCP permit was issued in 2004; therefore, further surveys to document successful annual reproduction of Delhi fly are not strictly mandated. However, given the endangered status of the species and the minimal effort required to document successful reproduction at the sole occupied site within the Plan Area, continued monitoring of Delhi fly annually is planned.

Conservation and Management

Evaluating the efficacy of ongoing efforts by the Management Program to improve habitat conditions (RCA 2020) for Delhi fly at Teledyne is essential. Vegetation surveys and ground-dwelling arthropod surveys will continue to be conducted every 5 years to track Delhi fly habitat conditionsWe plan to continue to conduct the line-transect study in 2022, as opposed to the area searches done in 2011 – 2013, to monitor potential effects of management activities and Delhi fly population fluctuations. Vegetation and soil characteristics will continue to be monitored in conjunction with ongoing management actions conducted as described by the Delhi Sands flower-loving fly Habitat Management Plan (Marchant 2005) and Delhi Sands flower-loving fly Habitat Management Update (RCA 2020). Monitoring of the weather conditions at the Teledyne site will continue to further learn about the needs of the Delhi fly.

We plan on conducting both the vegetation and arthropod surveys in 5 years, as well as the annual monitoring of mustard plants through photos.

We will also be performing late afternoon surveys to observe and collect data on the resources the female Delhi fly utilizes for oviposition (USFWS 1997).

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APPENDIX A.

Datasheets Used During Arthropod and Delhi fly Surveys

2021 Arthropod Pitfall Trap Setup

Page ____ of _____

Date: ________________ **Teledyne Site**

Recorder ______________ Photographer______________

** 0 = clear or few clouds; 1 = partly cloudy; 2 = overcast;
3 = fog or smoke; 4 = light drizzle

	Time	Soil Temp ºC & Trap #	Weather
Start :			
End :			

Pitfall #	Top Veg Species 1	Top Veg Species 2	Top Veg Species 3	JPEG ID	Notes
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

Delhi Flys seen outside of a pitfall trap

Time	UTM East	UTM North	♀ or ♂	Activity/Behavior	Substrate	Age	JPEG ID	Notes

Data Entered: _________________ Data Proofed: ___________________

2021 Arthropod Pitfall Trap Setup

Page ____ of _____

Date: ________________ **Teledyne Site**

Recorder ______________ Photographer______________

** 0 = clear or few clouds; 1 = partly cloudy; 2 = overcast;
3 = fog or smoke; 4 = light drizzle

	Time	Soil Temp ºC and Trap #	Weather*
Start :			
End :			

Pitfall #	Top Veg Species 1	Top Veg Species 2	Top Veg Species 3	JPEG ID	Notes
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					

Delhi Flys seen outside of a pitfall trap

Time	UTM East	UTM North	♀ or ♂	Activity/Behavior	Substrate	Age	JPEG ID	Notes

2021 Arthropod Pitfall Trap Survey Species List

Insects or Insect Families Identified:

Coleoptera
- [ ] Chrysomelidae – Leaf Beetles
- [ ] Coccinellidae – Ladybird Beetles
- [ ] Curculionidae – Snout and Bark Beetles
- [ ] Meloidae – Blister Beetles
- [ ] Ripiphoridae – Wedge Beetles
- [ ] Scarabaeidae – Scarab Beetles
- [ ] Tenebrionidae – Darkling Beetles

Diptera
- [ ] Apioceridae – Flow er Loving Fly
- [ ] Asilidae – Robber Fly
- [ ] Bombyliidae – Bee Fly
- [ ] Calliphoridae – Blow Fly
- [ ] Conopidae – Thick-headed Fly
- [ ] Muscidae – House Fly
- [ ] Mydidae - Mydas Fly
- [ ] Oestridae – Bot Fly
- [ ] Sarcophagidae – Flesh Fly
- [ ] Stratiomyidae – Soldier Fly
- [ ] Syrphidae – Syrphid Fly
- [ ] Tabanidae – Horse and Deer Fly
- [ ] Tachinidae - Parasitic Fly
- [ ] Tephritidae – Fruit Fly

Hemiptera
- [ ] Cicadidae - Cicadas
- [ ] Largidae - Bordered Plant Bug
- [ ] Lygaeidae - Seed Bug
- [ ] Pentatomidae - Stink Bug
- [ ] Reduviidae - Assassin Bug
- [ ] Scutelleridae - Shield-backed Bug

Hymenoptera
- [ ] Bethylidae - Parasitic Wasp
- [ ] Chrysididae – Cuckoo Wasp
- [ ] Crabronidae - Sand Digger Wasp
- [ ] Formicidae – Ants
- [ ] Ichneumonidae - Parasitoid Wasps
- [ ] Mutillidae – Velvet Ant
- [ ] Pompilidae – Spider Wasps
- [ ] Scoliidae - Scoliid Wasp
- [ ] Sphecidae – Thread-w aisted Wasps
- [ ] Vespidae – Paper, Potter Wasp, Hornet, ...

Bees
- [ ] Apidae – Bumble Bees, Honey Bees
- [ ] Halictidae – Sw eat Bees
- [ ] Megachilidae - Leaf Bees

Lepidoptera
- [ ] Hesperiidae – Skippers
- [ ] Lycaenidae – Coppers, Hairstreaks and Blues
- [ ] Noctuidae – Night Moth
- [ ] Nymphalidae - Brushfooted Butterfly
- [ ] Pieridae – Whites and Sulfurs
- [ ] Pyralidae – Pyralid Moth
- [ ] Sesiidae - Clearw ing Moths

Odonata
- [ ] Anisoptera – Dragonfly
- [ ] Zygoptera – Damselfly

Orthoptera
- [ ] Acrididae – Grasshoppers
- [ ] Gryllidae – Crickets

Mantodea
- [ ] Mantidae – Mantises

Neuroptera
- [ ] Chrysopidae – Green Lacew ing
- [ ] Myrmeleontidae – Antlion

- [ ] Other ______________________________

2021 Delhi Sands Flower Loving Fly Survey

Data Entered: ____________________ Data Proofed: ____________________

Date: ______________ Section: __________ **Teledyne Site**

Purpose: Data Collection Survey __________ Scouting Survey ___________

Observer(s) ______________________________

Method: Line Distant Transect ____________ Untimed Area Search ____________

* mph

** 0 = clear or few clouds; 1 = partly cloudy; 2 = overcast; 3 = fog or smoke; 4 = light drizzle

	Time	Temp °C	Avg Wind*	Weather**	Notes
Start :					
End :					

Age Code

0: Pupa E: exuviae U: Unknown

1: fuzz entirely covers dorsal thorax = teneral (note wing margin wear)

2 : fuzz covers ≥ half dorsal thorax (note wing margin wear)

3 : fuzz covers < half dorsal thorax (note wing margin wear)

Activities/Behaviors

Perched: indicate substrate

Interspecific Interaction: (different species) describe interaction

Intraspecific Interaction: (same species) describe interaction

Nectaring: record plant species, or take sample

Oviposition: *describe site, record soil temp!!! Tell lead right away.*

Emerging **Grooming** **Cruising**

Mating **Agonistic** **Cruising to Perched (C→P)**

DSF on transects (During the survey start and end times AND on a transect.)

Transect #	Distance (in)	UTM East	UTM North	Time	Waypoint	♀ or ♂	Activity/Behavior	Substrate	Age	JPEG ID	Notes

DSF off transects and all Exuviae (All Exuviae and adult DSF during the survey start and end times but NOT on a transect.)

Time	UTM East	UTM North	♀ or ♂	Activity/Behavior	Substrate	Age	JPEG ID	Notes

Notes: ____

Insects or Insect Families Identified:

Coleoptera

- [ ] Chrysomelidae – Leaf Beetles
- [ ] Coccinellidae – Ladybird Beetles
- [ ] Curculionidae – Snout and Bark Beetles
- [ ] Meloidae – Blister Beetles
- [ ] Melyridae - Soft-winged Flower Beetles
- [ ] Mordellidae - Tumbling Flower Beetles
- [ ] Ripiphoridae – Wedge Beetles
- [ ] Scarabaeidae – Scarab Beetles
- [ ] Tenebrionidae – Darkling Beetles

Diptera

- [ ] Apioceridae – Flower Loving Fly
- [ ] Asilidae – Robber Fly
- [ ] Bombyliidae – Bee Fly
- [ ] Calliphoridae – Blow Fly
- [ ] Conopidae – Thick-headed Fly
- [ ] Muscidae – House Fly
- [ ] Mydidae - Mydas Fly
- [ ] Oestridae – Bot Fly
- [ ] Sarcophagidae – Flesh Fly
- [ ] Stratiomyidae – Soldier Fly
- [ ] Syrphidae – Syrphid Fly
- [ ] Tabanidae – Horse and Deer Fly
- [ ] Tachinidae - Parasitic Fly
- [ ] Tephritidae – Fruit Fly

Hemiptera

- [ ] Cicadidae - Cicadas
- [ ] Largidae - Bordered Plant Bug
- [ ] Lygaeidae - Seed Bug
- [ ] Pentatomidae - Stink Bug
- [ ] Reduviidae - Assassin Bug
- [ ] Scutelleridae - Shield-backed Bug
- [ ] Miridae - Plant Bug

Hymenoptera

- [ ] Bethylidae -Flat Wasp
- [ ] Chrysididae – Cuckoo Wasp
- [ ] Crabronidae - Sand Digger Wasp
- [ ] Formicidae – Ants
- [ ] Ichneumonidae - Parasitoid Wasps
- [ ] Mutillidae – Velvet Ant
- [ ] Pompilidae – Spider Wasps
- [ ] Scoliidae - Scoliid Wasp
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- [ ] Noctuidae – Night Moth
- [ ] Nymphalidae - Brushfooted Butterfly
- [ ] Pieridae – Whites and Sulfurs
- [ ] Pyralidae – Pyralid Moth
- [ ] Sesiidae - Clearwing Moths

Odonata

- [ ] Anisoptera – Dragonfly
- [ ] Zygoptera – Damselfly

Orthoptera

- [ ] Acrididae – Grasshoppers
- [ ] Gryllidae – Crickets

Mantodea

- [ ] Mantidae – Mantises

Neuroptera

- [ ] Chrysopidae – Green Lacewing
- [ ] Myrmeleontidae – Antlion

- [ ] Other ____________________