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Effects of Large-scale Wildfires on the Scorpion and Solifugid Communities of the San Diego MSCP Region

Data Summary

Prepared for:

San Diego Association of Governments

Effects of Large-scale Wildfires on the Scorpion and Solifugid Communities of the San Diego MSCP Region

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Sacramento, California
2010

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ABSTRACT

To investigate the role of large-scale wildfires on the scorpion and solifugid species within San Diego County of southern California, we examined specimens that had been collected from four study sites distributed across the region from both before and after the 2003 wildfires: 1) Santa Ysabel Preserve, 2) Rancho Jamul Ecological Reserve-Hollenbeck Canyon Wildlife Area, 3) Little Cedar Ridge, and 4) Elliott Chaparral Reserve. In October and November of 2003, large-scale fires burned approximately 130,000 ha of San Diego County. We collected data to assess fire impacts on the local solifugid and scorpion communities using drift fence arrays with pitfall traps. Sampling prior to the fires was conducted between May 1998 and June 2003. Post-fire sampling was conducted between January 2005 and September 2007 with the objective of identifying impacts of wildfire on the scorpion and solifugid communities. We calculated monthly detection frequencies of each species to test for differences in seasonal activity patterns between scorpions and solifugids. We compared total species richness, rates of species accumulation, and average species richness detected per sample occasion between pre- and post-fire sample periods to describe major differences in the pre- and post-fire datasets. To test for the effects of wildfire on the community, we compared pre- to post-fire differences in the average species richness per sample occasion between burned and unburned plots, as well as modeled the effects of vegetation, plot condition (burned or unburned), and their interaction on the species richness measures for post-fire periods. We also tested for associations between vegetation types and individual scorpion and solifugid species and for the two most dominant species, constructed site occupancy models to compare occupancy among sites, vegetation types, and between burned and unburned plots.

Seven scorpion and 14 solifugid species were detected across all of our trapping efforts. The scorpions *Vaejovis puritanis* and *Anuroctonus pococki pococki* were the most commonly detected species, occurring in 14.6% and 8.9% of the sample collections, respectively. The most abundant solifugid was *Eremochelis andreasana*, which we found in 1.7% of the samples. The majority of the species that we observed were only found in 1% or less of the samples that we collected. Of all of the species collected, three scorpions, *A. p. pococki, V. puritanis*, and *Superstitionia donensis*, and three solifugid species, *Ammotrechula wasbaueri*, *E. andreasana*, and *Eremochelis kastoni*, were detected at all four study sites. Our monthly detection frequencies showed that scorpions and solifugids reached their peak activity levels at different times of the year. Solifugids were most active in June while scorpions reached peak activity in August. Species richness and rate of species discovery increased in post-fire samples compared to pre-fire. The difference in average species richness per sample occasion between pre- and post-fire samples did not vary between burned and unburned plots. In the post-fire period, species richness per sample occasion for scorpions and solifugids varied by vegetation type but not plot condition, meaning there was a measured effect of vegetation but not fire on the average number of species detected. Approximately half of the scorpions and solifugids tested had a positive association between detection and vegetation type. Occupancy analyses revealed that the scorpions *A. p. pococki* and *V. puritanus* varied by site. *A. p. pococki* also varied by vegetation, but neither species varied by condition (i.e., burned or unburned) or across years.

The overall absence of a negative effect of wildfire on the scorpion and solifugid communities in our analyses of pre- and post-fire sample data is not surprising given the biology

of both scorpions and solifugids is well suited to surviving both the short and long-term effects of fire. Both species groups are nocturnally active and readily use below-ground retreats during the daytime needing less shade cover. Scorpions and solifugids largely inhabit xeric environments, with seasonal peaks in activity occurring during the hottest and driest periods of the year. Both species-groups are comprised of generalist predators that have a unique physiology allowing them to store large quantities of energy for extended periods of times, enabling them to survive the prolonged periods of food deprivation often associated with the weeks and months immediately following a wildfire.

INTRODUCTION

Wildfires have long been a part of the southern California landscape. Native wildlife communities have existed with some variation of this fire regime and have various survival strategies (Hanes 1971; Vogl and Schorr 1972; Keeley and Keeley 1984; Keeley and Fotheringham 2001). Keeley et al. (1999, 2004) have stated that large landscape-level fires occurred in the past and are likely to occur into the future as long as southern California experiences episodes of severe fire weather (e.g., fast, dry winds). Despite fire suppression efforts and management plans, large and small wildfires continue to occur from both natural ignition sources and those associated with the increasing human population (Keeley et al. 1999, 2004). This has been reinforced by the findings of Wells et al. (2004) that have shown that there has been an increase in the frequency at which coastal sage scrub has burned over the past century. The intervals between fires have been substantially reduced when compared to historic levels. Increased fire frequency can cause the conversion of shrublands (e.g., chaparral and coastal sage scrub) to grasslands (Zedler et al. 1983; Keeley 2005), which may have a cascading affect on the animals living in these environments.

Direct and indirect effects of fire can have both negative and positive consequences on local invertebrate species and communities. Negative effects of fires may include direct mortality, loss of suitable habitat, and the loss of plant and animal food resources (Warren et al. 1987, Smith and Morton 1990, Shaffer and Laudenslayer 2006). An additional undesirable effect would be the increased potential for the conversion of a highly diverse scrub and chaparral into less diverse grasslands. For some species fire may have positive impacts. Species that are able to escape and survive the immediate dangers associated with fires may prefer the open, disturbed habitats of the post-fire environment and benefit from the new opportunities (Warren et al. 1987).

In October and November of 2003, large-scale fires swept across southern California, burning over 300,000 ha of wildlands. This included nearly 130,000 ha burned in the Cedar and Otay Fires in San Diego County. In addition to the loss of nearly 5,000 structures and 15 human fatalities (California Department of Forestry and Fire Protection, 2003), these large fires impacted local wildlife communities in a region already recognized as being one of the most at risk areas for loss of biodiversity (Mittermeier et al., 1998). The first large habitat reserve created in San Diego County, the Multiple Species Conservation Plan (MSCP) (City of San Diego 1997) was directly in the footprints of these two fires. Half of the protected lands within the MSCP were affected by the fires, and some protected habitats were entirely within the fire perimeters.

There are very few studies that have examined the impacts of wildfire on scorpions and solifugids. The studies that have been conducted and studies that have examined the effects of wildfire on other arthropods show that the varied responses of arthropods to burning are based on life habits, phenology, and interactions with non-arthropods (Warren et al. 1987; Smith and Morton 1990). Warren et al. (1987) developed models to explain the varied responses to fire by dividing the pre- and post-fire environmental conditions into three phases. Many of the burrowing arthropods survive the first phase, which Warren et al. termed the combustion phase. Immediately after burning, the lack of shade and shelter results in the surface soil becoming hotter and drier, accompanied by a change in soil chemistry. This "shock" phase has varied effects on the arthropod community; many are not able to survive the short period of xeric conditions. The last phase is recovery where lush post-fire growth may attract large numbers of smaller arthropods which are preyed upon by the scorpions and solifugids. However, no monitoring data on scorpion and solifugid communities in coastal San Diego has been collected prior to this study.

Concern over the recovery of these habitats and the species within them motivated our efforts to conduct this research. From 1998 to present, we have been collecting data on scorpions and solifugids in the San Diego region at several locations, many of which have been impacted by the 2003 fires. These data are detection and non-detection data and have been collected to determine the presence of terrestrial arthropods during all seasons of the pre- and post-fire conditions while not conducting specific counts or abundance estimates of any one specific taxon. With the detailed data on vegetation and animal communities that we had collected previously within the 2003 fire footprints, we were in a unique position to address this concern.

The primary objective of this study was to increase our understanding of the short term response of scorpions and solifugids to wildfire in southern California. Through intensive sampling in burned and unburned areas coupled with comparisons to pre-fire sampling results, we expected 1) to learn whether there were significant short term impacts of wildfire on the scorpion and solifugid communities, 2) to determine which taxa are most responsive to the different fire phases, and 3) to provide background and baseline information for further examinations into long term impacts caused by large, high frequency wildland fires and any resultant vegetation community type conversion.

Scorpion and Solifugid Background and Natural History—Scorpions and solifugids are two orders of arthropods in the class Arachnida; the Scorpiones and Solifugida[1]. Arachnida also includes spiders, whip-scorpions, ticks and harvestmen; 13 orders in total (Harvey 2002). All arachnids have four pairs of legs, lack the antennae found in other arthropods, and have a two section body plan with a cephalothorax and abdomen. The scorpion and solifugid species range in size between 1 and 13 centimeters (Cloudsley-Thompson 1958). Scorpions can be distinguished from other arachnids by a combination of characters. The familiar scorpion body pattern includes large pedipalps with stout chelae (claws) at the front end and a long narrow back

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[1] Cladistic approaches to the higher level taxonomy of these groups is only beginning with many taxonomists placing them at the order level and others considering them to be subclasses or even classes of the Chelicerata next to Arachnida (Fet, et. al., 2000).

end with a terminal sting (Barnes 1963). A more thorough description of scorpions would also note a distinct division of the abdomen into the wide, basal mesosoma and the thin, distal metasoma. The long, thin metasoma is what gives the scorpion the appearance of having a tail. At the end of the metasoma is a somewhat curved and pointed telson (venom gland) bearing an aculeus or sting (Preston-Mafham 1991, Prendini 2006). Solifugids, a somewhat less familiar group, lack the thin metasoma, telson and poison gland of the scorpion, but have exceptionally large chelicerae (mouthparts or mandibles) relative to any of the other arachnids (Muma 1962, Kaston 1972). Solifugids also have unique sensory racquet organs (malleoli) on the ventral surfaces of the hind legs (leg IV) (Harvey 2002).

Typically nocturnal, scorpions and solifugids can be present in great numbers in suitable habitat. They can be found globally in tropical and subtropical environments. Within the U.S. they inhabit arid and semi-arid regions where they act as the top predators of the arthropod community (Muma 1951, Polis 1990). Scorpions and solifugids feed voraciously on many arthropod species, some of which are considered to be pests (Polis 1990). In turn, the scorpions and solifugids are consumed by many vertebrate taxa including reptiles, amphibians, birds and small mammals (Preston-Mafham 1991).

Scorpions spend the majority of their daylight hours underground in burrows that they typically dig themselves. The subterranean shelters allow them to escape the heat of the day and avoid excessively dry weather. While in their burrows, scorpions thermoregulate by actively moving forward and backward within the burrow to either raise or lower their body temperatures (Polis et al. 1986, Preston-Mafham 1991). Closer to the burrow entrance at the

A California swollenstinger scorpion (*Anuroctonus p. pococki*) with its large pedipalps and characteristic bulb between the aculeus and the telson.

surface of the ground the temperature is usually higher; while deeper in the ground the conditions remain cooler. Scorpions typically emerge from their daytime retreats at night in search of prey. Prey is detected with special sensory organs in the tarsi (the distal part of the limbs), pedipalps and pectines (large paired sensory organs on the underside of the mesosoma). Scorpions attack and subdue their prey with the clawed pedipalps and venomous sting. The prey are then torn into small pieces to be digested in a pre-oral cavity before entering the gut (Polis 1990, Prendini 2006). Unlike many other arachnids, scorpions have internal fertilization and the eggs develop within the female's body. As the young scorpions hatch and emerge, they climb onto the mother's back. They remain there for up to two weeks where their mother protects them until they have their initial molt, after which time they leave. Additionally, all scorpions fluoresce under ultraviolet light, making them easy to observe at nighttime with the aid of a handheld fluorescent light. See the appendix for descriptions of scorpion species detected.

Solifugids prefer regions where the soil is bare and broken. They are thermophillic, preferring high temperatures, and are rarely found in cold or temperate climates. Throughout the winter months, they hibernate, becoming active in hotter months. They are voracious feeders, often eating insects, spiders, scorpions and small lizards until their abdomens are fully distended

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A large solifugid in a defensive display with raised pedipalps and large open chelicerae.

(Muma 1951). They have even been observed to kill and eat mice and small birds (Preston-Mafham 1991). One species found in this region feeds specifically on bees, entering bee hives in search of prey (Muma 1967). Most species are nocturnal, hiding under stones, woody debris or in crevices during the day. Only a few smaller species are diurnal. Solifugids typically find prey by sight and touch. They are capable climbers and will go up trees after prey items if necessary. They use their pedipalps to aid in locomotion which allows them to climb over shrubs and over large objects (Muma 1967). They are capable of also climbing up glass and out of the plastic buckets used as pitfall traps. Solifugids thoroughly masticate and macerate their prey using the large chelicerae, which they can move in both vertical and horizontal planes. The prey is reduced to a soft pulp which is then pressed against the mouth opening where it is ingested. They are very fast for their size and are attracted to artificial lights. Running rapidly towards flashlights or lanterns, solifugids have a reputation of appearing aggressive. Typically only one clutch of eggs is produced per season, but it may contain as many as 200+ eggs. The young may hatch as soon as 1 to 3 days afterwards, but can take up to 3 weeks to become motile (Preston-Mafham 1991).

The malleoli on the ventral surface of the hind legs of a solifugid.

Scorpions and solifugids account for over 1,270 and 1,080 species respectively world wide (Harvey 2002). The highest scorpion diversity in the United States is found in the extreme southern and southwestern portions of the country (Polis 1990) with the solifugid diversity in the region being equivalent or greater. San Diego County contains the highest diversity of scorpions along the west coast, with at least fifteen species identified from the county including observations from this study (Polis 1990; Fet et al 2000). Only recently has understanding solifugid diversity really begun, with new species being described each year (Brookhart and Cushing 2005). Currently, over 100 species of solifugids are known from the U.S. (Preston-Mafham 1991). With the high diversity and unique biology of these creatures and the roles they fulfill within the ecosystem, it is important to understand how the scorpion and solifugid communities respond to large scale alteration in the fragmented landscape of San Diego.

METHODS

Study areas

This research was conducted at four separate study areas within San Diego County, California: Elliott Chaparral Reserve, Little Cedar Ridge, Rancho Jamul Ecological Reserve-Hollenbeck Canyon Wildlife Area and Santa Ysabel Preserve (figure 1).

Elliott Chaparral Reserve was centered at 32.89217°N and 117.09460°W, with an average elevation of 195 meters. Major vegetation communities were chaparral and coastal sage scrub, dominated by chamise (*Adenostoma fasciculatum*), California buckwheat (*Eriogonum fasciculatum*), and annual, non-native grasses (*Avena* and *Bromus*). Elliott Chaparral Reserve

was located at the western end of the Cedar Fire, which completely burned the site in October 2003. Prior to the Cedar Fire, the majority of the reserve burned in 1944 or 1945 (California Department of Forestry and Fire Protection 2006). This site was managed by the Nature Reserve System of the University of California at San Diego (UCSD).

Little Cedar Ridge was located on the northern slopes of Otay Mountain near the international border in southern San Diego County and was managed by the Bureau of Land Management (BLM) as part of the Otay Mountain Wilderness. The Otay Mountain Wilderness encompassed approximately 6,800 ha and ranged in elevation from 250 to 1,000 m. Our study area covered a small portion of the wilderness centered at 32.62078°N and 116.86202°W with an average elevation of 400 meters. The majority of vegetation was characterized as chaparral and coastal sage scrub. Dominant plants included chamise, Tecate cypress (*Cupressus forbesii*), annual, non-native grasses, and California buckwheat. The entire area burned during the Otay Fire in October 2003. No record of previous fire could be found for the area (California Department of Forestry and Fire Protection 2006).

Rancho Jamul Ecological Reserve and Hollenbeck Canyon Wildlife Area (collectively referred to as Rancho Jamul) were located 6 km north of Little Cedar Ridge. Both properties were managed by the California Department of Fish and Game. Rancho Jamul Ecological Reserve was located at 32.67873°N and 116.85431°W, with an average elevation of 250 m. It covered approximately 1,500 hectares. Some southern portions of this site burned during the Otay Fire of 2003. Hollenbeck Canyon Wildlife Area covered 1,450 ha and was untouched by the 2003 wildfires. Both areas encompassed a diversity of vegetation communities, including native and non-native grasslands, coastal sage scrub, and upland and riparian woodlands dominated by oaks, sycamores, and willows. In addition to natural vegetation communities, there were extensive, fallow agricultural fields. Dominant plant species at the site included annual, non-native grasses, California buckwheat, California sagebrush (*Artemisia californica*), coast live oak (*Quercus agrifolia*), western sycamore (*Platanus racemosa*), laurel sumac (*Malosma laurina*), and San Diego sunflower (*Viguiera lacini*ata). Three plots on the Hollenbeck Canyon Wildlife Area were burned in the 1996 Honey Fire, seven years prior to the initial, pre-fire surveys conducted in 2003. Based on the level of vegetation cover at these plots after seven years of regeneration, we classified each as unburned for our analyses. One other plot burned in 1968. No other fire records were found for the remaining study plots at this site (California Department of Forestry and Fire Protection 2006).

At an average elevation of 1,078 m, Santa Ysabel Preserve was the highest of our four study sites and was located near the small town of Santa Ysabel in the northern portion of San Diego County. The study plots were centered at 33.11984°N and 116.65840°W. The area supported oak and pine woodlands, native and non-native grasslands, chaparral, coastal sage scrub, and riparian woodlands. Dominating the various vegetation communities were coast live oak, annual, non-native grasses, chamise, Engelmann oak (*Quercus engelmannii*), and white sage (*Salvia apiana*). This 1,500 ha site was managed by the Parks and Recreation Department of the County of San Diego. The preserve represented the northeastern extent of the Cedar Fire, which consumed a portion of the site in 2003. One plot at Santa Ysabel Preserve burned in 1938, two others burned in 1929 and no recorded fires were found for the remaining plots at this site (California Department of Forestry and Fire Protection 2006).

Environmental conditions were relatively uniform across all four study sites. Elliott Reserve, Little Cedar Ridge, and Rancho Jamul all experienced similar weather patterns and temperatures. Average July maximum temperatures ranged from 28°C to 29°C. Average January low temperatures fell between 5°C and 6°C. Annual precipitation averaged between 28 and 31 cm. At Santa Ysabel Preserve, the average July high was 33°C; the average January daily low temperature was 1°C, and the average annual rainfall was 53 cm. Temperature and precipitation data are 30 year averages for 1966 through 1995 compiled by Franklin (2001) from data collected from 104 to 136 climate stations across southern California.

Scorpion and solifugid sampling

We established 63 pitfall trap arrays (figure 2) in San Diego County, as part of a larger, multi-taxa project aimed at looking into the effects of wildfires. Each array consisted of seven pitfall traps (five gallon buckets) connected by drift fencing to form three arms radiating from a center pitfall trap (Fisher et. al 2008). Wooden feet were attached to the bucket lids such that the lids could be inverted to shade the buckets during the sample occasion and allow animals moving along the ground to fall into the buckets. In between sample occasions, the lids were flipped over to securely close the buckets. Ground dwelling macro-invertebrates were captured incidentally by the pitfall arrays. Each time these arrays were sampled for herpetofauna, a subsample of the invertebrates were collected and placed in 70% ethanol for future identification. Each sample contained only a subset of each species (between two and eight individuals) from each array to the extent to which the species could be differentiated in the field.

Sampling locations were classified into four general vegetation communities based on the pre-fire vegetation (figure 3). We conducted 50-m vegetation transects (Sawyer and Keeler-Wolf 1995) at each array between 1995 and 2002, as described by Fisher et al. (2008). Each transect consisted of 100 data points taken at 0.5 m intervals where all plant species were recorded (see methods in Fisher et. al 2008). Using the plant species documented along transects, we classified sample plots as grassland, woodland/riparian, chaparral (CHAP), or coastal sage scrub (CSS). Post fire vegetation surveys were performed in spring 2005 and spring 2006 to assess the recovery of the vegetation surrounding each plot.

We sampled invertebrates prior to the fires between March 2001 and June 2003 at Rancho Jamul and Santa Ysabel Preserve; between May 1998 and April 2001 at Elliott Reserve and between June 1998 and March 2001 at Little Cedar Ridge. During the pre-fire sampling, the invertebrate collection was incidental to the herpetofauna and subsets of the trapped invertebrates were collected. Post-fire sampling was conducted between January 2005 and September 2007 at all study sites except Rancho Jamul which was sampled from November 2003 to September 2007 (see table 1). We collected the first post-fire samples 14 months following the fires. Samples were collected five times per year prior to the fires and ten times per year after the fires. Each sample occasion consisted of ten consecutive nights prior to the fires and four consecutive nights post-fire, after which the traps were closed. During the post-fire sampling, the invertebrate taxa were more thoroughly sampled with more attention to the collection of scorpion and solifugid taxa.

We brought the samples to the laboratory for sorting and identification. Scorpion and solifugid specimens were separated from the other invertebrates and stored in 95% ethanol. Specimens were identified to species where possible. The scorpion samples were identified by Michael Soleglad (Associate Editor, Euscorpius), Robin Keith (United States Geological Survey), and Chris Brown (USGS). We use the taxonomy of Fet et al. (2000) for all scorpion species with the exception of the recently described *Anuroctonus p. pococki* for which we use Soleglad and Fet (2004). Solifugids were identified by Paula Cushing (Denver Museum of Nature and Science) and Jack Brookhart (DMNS). Voucher specimens of the scorpions are stored at the USGS San Diego Field Station, San Diego, CA or with Michael Soleglad, Borrego Springs, CA. Solifugid specimens are stored at the Denver Museum of Nature and Science.

Statistical analyses

Prior to conducting any analyses we first converted all count data to detection and non-detection data (1, species detection; 0, no species detection) for each individual species. We used the detection/non-detection data in our analyses of seasonal activity patterns, species richness, and site occupancy.

In order to describe and compare activity patterns between scorpions and solifugids, we calculated the monthly detection frequency for each sampled species. The detection frequency for an individual species equals the total number of sample occasions with a detection divided by the total possible number of detections (i.e., the product of the total number of arrays sampled and the total number of sample periods for a given month). We used a t-test to check for a difference in the peak month of activity (i.e., the mode of the sample) between scorpions and solifugids.

To test for a difference between pre- and post-fire sample periods as well as an effect of plot condition (burned or unburned) on the average scorpion and solifugid species richness, we calculated the average number of scorpion and solifugid species detected per sample occasion per array (or plot). We used a repeated measures ANOVA to test for an effect of sample period (pre- or post-fire) and an interaction of sample period and plot condition (burned or unburned) on the average species richness across the four sampled sites. To compare differences in rates of species discovery between the pre- and post-fire sample periods, we calculated the logarithmic slope of the species accumulation curves (over an equal number of sample occasions) for the two sample periods. We made this comparison for each site separately, indicating a simple increase or decrease in the rate of species accumulation.

Post-fire analyses—We used hierarchical linear modeling analyses in SYSTAT 12 to model the effects of vegetation, condition, and their interaction on the average number of species detected per sample occasion and the cumulative species richness per array for the post-fire period. We included site as a random effect in all models to account for the within site correlation structure of the data. We used Second-order Akaike Information Criterion (AICc) to assess model fit of multiple hypotheses for each response variable. We included a null model (intercept plus random effect 'site') in the model set to evaluate the explanatory power of the variables relative to the mean value.

To test for associations between vegetation types and individual scorpion and solifugid species, we used G-tests. The G-test is a likelihood ratio test similar to a Chi-square test but utilizes the natural logarithm and gives an additive G-value as the test statistic. This test can be more precise for medium sized samples and utilized in more complex designs such as repeated goodness-of-fit. We only included species that were detected a minimum of eight times during the post-fire period in the analyses. We also did not include the two most dominant species sampled in the study as they were the focal species of our occupancy analyses which has greater power to test for associations with vegetation types for larger sample sizes.

For the two most frequently detected species in our samples, we constructed site occupancy models to compare occupancy between sites, among vegetation types, between conditions (burned and unburned) and across years. We constructed single-species, multi-season log-likelihood models of site occupancy implemented in program PRESENCE to compare changes in occupancy estimates. PRESENCE uses information on the probability of detection to estimate annual rates of site occupancy and annual rates of local extinction as a measure of annual population turnover (Mackenzie et al. 2002, 2003). Use of detection probability in the estimation process is particularly important for species with low detection probabilities (i.e., species that are rarely detected in surveys although they are present) because naïve estimates of occupancy for these species often underestimate true rates of occupancy. Program PRESENCE is a particularly robust program for estimating site occupancy, as it allows for flexibility in the study design, which is important for large scale, multi-year monitoring projects with variable sampling efforts between years and across sites.

In order to evaluate the importance of site, vegetation type, condition, and year on occupancy and the effect of season on detection probability, we built a series of occupancy models that included the site covariates: 'site' to test for a site effect (i.e., differences in occupancy rates between Little Cedar Ridge, Elliott Chaparral Reserve, Rancho Jamul, and Santa Ysabel Preserve); 'vegetation' to test for an effect of the different vegetation types (chaparral, coastal sage scrub, grassland, and woodland/riparian) on occupancy; 'condition' to test for an effect of fire on occupancy; and 'year' to test for variation in occupancy rates across years. We included 'season' as a sample covariate to correct for variation in the timing of sampling across sites and between years. The 'season' covariate captured differences in detection probability between peak (July, August, September, and October) and off-peak (March, April, May, June, and November) activity periods for both taxonomic groups. Note, sample occasions occurring during the winter months of December, January, and February were excluded from the analysis due to the rarity of scorpion and solifugids in the collections during this time period. We evaluated and weighted models using Aikaike' Information Criterion (AIC) as described by Burnham and Anderson (2002). Site and sample covariates that improved model fit relative to the null model were added together in increasing complexity.

RESULTS

Community description—A total of 7 scorpion and 14 solifugid species were detected during the multi-year study (table 1). In general, both scorpions and solifugids were infrequently captured throughout the study period. Out of a total of 2,342 sample occasions for the entire study period that includes both the pre- and post-fire sample periods, the two most frequently detected species, the scorpions *Vaejovis puritanis* and *Anuroctonus p. pococki*, were detected on 342 (14.6%) and 209 (8.9%) occasions, respectively. The next most dominant species was the solifugid, *Eremochelis andreasana*, detected on 39 (1.7%) occasions. Note numerical results presented in table 1 refer to the post-fire period only.

Fourteen species (or two-thirds of the total species captured) were detected less than 1% of the time. Of these, seven species were detected less than or equal to 0.1% of the time. Of the total species detected, three scorpions, *A. p. pococki, V. puritanis*, and *Superstitionia donensis*, and three solifugid species, *Ammotrechula wasbaueri*, *E. andreasana*, and *Eremochelis kastoni*, were detected at all four study sites. On average, scorpions and solifugids were detected about 50% more frequently from Little Cedar Ridge (average number of specimens collected per plot per sample occasion = 0.45), than Elliott Chaparral Reserve (0.31), Rancho Jamul (0.31), or Santa Ysabel Preserve (0.30).

Using the mode (in the statistical sense) of detection frequency for each species as our replicate, we show the solifugids, on average, peak in activity in June (average value = 6.2, with 1 = JAN, 2 = FEB, 3 = MAR, etc.) while scorpions peak in late summer, during the month of August (8.1) (t-test; $t_{19} = 4.377$, $P \leq 0.001$; Fig. 4).

Pre- to post-fire comparisons—We detected eight species (five scorpions and three solifugids) in the pre-fire samples. All eight species detected in the pre-fire samples were also detected in post-fire samples. On three occasions, species detected at specific sites in pre-fire samples were not detected in post-fire samples from those same sites (see table 1). Thirteen species were detected post-fire but not detected pre-fire.

We found an increase in the average number of species detected per sample occasion between pre- and post-fire periods (Repeated Measures ANOVA: Period, $F_{1,61} = 33.492$, $P < 0.001$). The increase did not vary by condition (Repeated Measures ANOVA: Period*Condition, $F_{1,61} = 0.032$, $P = 0.859$).

The species accumulation rate (i.e. rate of species discovery) over an equal number of sample periods was greater post-fire relative to pre-fire for three of the four sites (logarithmic slope of the species accumulation curves for the pre-fire and post-fire periods, respectively, were 2.63 and 5.72 for Little Cedar Ridge, 1.68 and 3.12 for Elliott Chaparral Reserve, and 0.40 and 4.97 for Santa Ysabel Preserve). Rancho Jamul showed a slight decrease in the slope from pre-fire (2.06) to post-fire (1.64). Note; see figures 5 through 16 for species accumulation curves for all sites and sample periods.

Post-fire analyses—Results of the hierarchical modeling show the average number of scorpion and solifugid species detected per sample occasion in the post-fire period varied by

vegetation type, not condition (table 2). That is, we found no effect of fire, but we did find an effect of vegetation type on the average number of species detected per sample occasion. The average number of species detected per sample occasion was greatest in chaparral (mean = 0.36, SE = 0.14, n = 16) and coastal sage scrub (0.38, 0.13, 19) plots and lowest in woodland/riparian (0.25, 0.18, 15) and grassland (0.21, 0.12, 13) plots. Hierarchical models of cumulative species richness for scorpions and solifugids did not vary by vegetation type or condition (i.e., we found no effect of fire or vegetation type on the cumulative species richness; table 2).

The results of the G-tests for vegetation association show that three scorpions, *Superstitionia donensis, Paruroctonus silvestrii,* and *Pseudouroctanus andreas*, have a positive association with chaparral and coastal sage scrub (table 3). The solifugid, *Eremochelis andreasana*, shows a positive association with chaparral. The solifugid, *Eremobates williamsi*, appears to be less frequently detected in grassland than other sampled vegetation types.

Site occupancy—Occupancy analysis of the post-fire detection data for the scorpion, *Anuroctonus p. pococki*, resulted in two top-ranked models. The highest ranking model accounted for 53% of the total model weights and included both 'site' and 'season' in its model structure (table 4). According to this model, annual site occupancy varied by site with occupancy estimates of 84.5% (SE = 11.1), 28.1% (13.7), 28.2% (9.8), and 74.8% (8.6), for Little Cedar Ridge, Elliott Chaparral Reserve, Rancho Jamul, and Santa Ysabel Preserve, respectively. Estimated annual local extinction rate was 5.0% (3.9) and the probability of detection varied by season with the detection rate at 29.6% (2.8) during peak activity (July, August, September, and October) compared to 6.9% (1.3) during the months of least activity (March, April, May, June, and November).

The second highest ranking model for *A. p. pococki* included the site covariates 'site' and 'vegetation' as well as the sample covariate 'season' in its model structure. According to this model, occupancy varied by both site and vegetation. Occupancy was estimated at 89.4% (11.7) and 82.7% (13.3) in chaparral and coastal sage scrub, respectively, at Little Cedar Ridge. Occupancy was 36.1% (17.0), 29.5% (16.8), and 10.9% (8.5) in chaparral, coastal sage scrub, and grassland arrays, respectively, at Elliott Chaparral Reserve. Occupancy was 41.0% (14.3), 16.0% (0.1), 24.6% (12.4) in coastal sage scrub, grassland, and woodland/riparian plots, respectively, at Rancho Jamul. Occupancy was 93.7% (7.2), 88.5% (12.2), 51.1% (22.5), 68.6% (12.1) in chaparral, coastal sage scrub, grassland, and woodland/riparian, respectively, at Santa Ysabel Preserve. Estimated annual local extinction rate was not estimated and the probability of detection varied by season with the detection rate at 29.2% (2.7) during the months of peak activity (July, August, September, and October) compared to 6.9% (1.3) during the months of least activity (March, April, May, June, and November). The inclusion of the site covariates 'condition' and 'year' in model structure did not improve model fit (i.e., lead to lower AIC scores), suggesting that occupancy did not vary between conditions (impact versus reference) or across the three years (2005, 2006, 2007) of post-fire sampling.

Occupancy analysis of the post-fire detection data for the scorpion, *Vaejovis puritanus*, resulted in a single top-ranked model. The highest ranking model with 98% of model weights included the site covariate 'site' and sample covariate 'season' in model structure (table 5). Annual site occupancy estimates varied by site, with occupancy equaling 75.0% (11.0), 82.6%

(12.0), 83.8% (6.3), and 23.6% (7.9), for Little Cedar Ridge, Elliott Chaparral Reserve, Rancho Jamul, and Santa Ysabel Preserve, respectively. The local annual extinction rate equaled 10.1% (4.0) and the probability of detection during the peak months of activity equaled 40.6% (2.8), compared to 8.1% (1.3) during the months of least activity. Similar to the results for *Anuroctonus p. pococki*, the inclusion of 'condition' and 'year' in model structure did not improve model fit (i.e., lead to lower AIC scores), suggesting that occupancy did not vary between conditions or across years.

DISCUSSION

To increase our understanding of the short-term response of scorpions and solifugids to large-scale wildfire in southern California, we used pitfall traps to sample scorpion and solifugid species presence at four sites (Little Cedar Ridge, Elliott Chaparral Reserve, Rancho Jamul, and Santa Ysabel Preserve) over a 32-month period, 14 to 46 months post-fire. Sampled plots at each of the four sites were associated with a USGS regional herpetofaunal monitoring project (Fisher et al. 2008) and provided multiple years of pre-fire scorpion and solifugid capture data for comparison with post-fire samples.

In total, we detected 21 scorpion and solifugid species during the study period. This represents a significant portion of the scorpion and solifugid diversity present in the southwestern United States (Polis 1990; Fet et al 2000; Brookhart and Brookhart 2006). For solifugids the total number of genera (5) and species (14) detected across the four study sites is comparable to solifugid diversity across the major deserts of the southwestern U.S. and northwestern Mexico. The Sonoran Desert is known to support 11 genera and 82 species of solifugids; the Chihuahuan Desert supports 8 genera and 32 species; the Great Basin Desert, 7 genera and 18 species; and the Mojave Desert, 4 genera and 28 species (Brookhart and Brookhart 2006). Solifugid inhabit xeric environments, including deserts, grasslands, and sand dunes (Schmoller 1970). There are currently 33 species known to be present in the xeric habitats of California, specifically sage, steppe, grassland, and chaparral (Brookhart and Brookhart 2006).

Although we detected a large number of species, the majority of the species that we observed were rarely encountered, with almost two-thirds occurring in less than 1% of the post-fire samples. Even though it is widely recognized by ecologists that most species in plant and animal communities are rare (Gaston 1994), our sampling design may have biased collection efforts towards larger specimens. Unlike the smaller scorpions and solifugids, which were able to escape through the small drain holes or by climbing the sides of the buckets (Muma 1967, C.W.B. pers. obs.), the larger specimens appeared to be genuinely trapped upon falling into the buckets, thus potentially explaining some of the difference in capture rates among species.

Both the scorpions and solifugids exhibited distinctive seasonal activity patterns during our study, with activity peaking in early summer for solifugids and late summer for scorpions. This is consistent with previously published information on these species groups (Muma 1967, Preston-Mafham 1991) and makes biological sense as both groups are largely thermophillic, becoming most active during the warmest times of the year.

In general, cursory comparisons between pre- and post-fire samples showed little evidence of community turnover and an absence of an effect of fire. All eight species detected in pre-fire surveys were detected in post-fire surveys, indicating no major shifts in community composition between periods. We did see an overall increase in average number of species detected per sample occasion between pre- and post-fire sample periods (we used the average number of species detected in our analysis to account for variation in the number of sample occasions per sample periods). Interestingly, the increase in the number of species detected were consistent across both burned and unburned arrays, suggesting the difference between sample periods was independent of condition (i.e., wildfire had no effect). In addition to the observed increase in average species richness per sample occasion between pre- and post-fire periods, the rate of species discovery (i.e., slope of species accumulation curves) increased pre-to post-fire for three of the four sites.

Although we see increases in the rate of species discovery and total species richness between periods (8 species pre-fire to 21 species post fire), whether fire had a positive effect on the scorpion and solifugid diversity is not necessarily clear from our data. Although we detected a large increase in diversity, and for three of the four sites, a large difference in the rate of species discovery, the absence of a measurable difference between burned and unburned arrays suggests that the reason for the large differences between sample periods is unrelated to fire. Other factors (such as weather) that universally affect all of the sampled locations may have changed between the pre-and post-fire periods and thus explain much of the observed difference in capture rates across species.

Another possible explanation for the observed pre- to post-fire difference relates to the sample effort employed to collect invertebrates between the two sample periods. Although the method of collection (pitfall) and the location of arrays did not change from pre- to post-fire periods, it is possible that the effort employed to collect invertebrates each sample period may have changed. If field collectors spent more time searching pitfall buckets for invertebrates during the post-fire period, then rare specimens of scorpions and solifugids would be more common in post-fire samples.

One reason to suspect that effort may have changed between pre-and post-fire samples, is that prior to the wildfires, invertebrate collection efforts were largely considered to be incidental to the capture of amphibian and reptiles at the sampled arrays. Following the wildfires, we defined a specific research question centered on the invertebrate response to fire, thus elevating the importance of invertebrate collection. This combined improved search image likely resulted in more thorough and comprehensive 'searching' the buckets for specimens. The difference in the duration of a sample occasion, from ten nights during pre-fire samples to four nights during the post-fire period, may have influenced the composition of species available to researchers at the close of each sample occasion.

Analyses specific to the post-fire period—In the post-fire period we found the average number of scorpion and solifugid species detected per sample occasion varied by vegetation type, but not condition. That is, we found no effect of fire on the community, but we did find an effect of vegetation type on the number of species detected per sample occasion.   The average number of species detected per sample occasion was greatest in chaparral and sage scrub, and

lowest in woodland and grassland plots. We also found that cumulative species richness per plot did not vary by condition or vegetation type, although there was a trend of increased richness in chaparral and sage scrub plots versus woodland and grassland plots.

For the two most dominant species in the scorpion and solifugid assemblage, occupancy analyses showed no effect of condition (i.e., wildfire had no detectable effect) or year (i.e., occupancy remained stable across years) on the likelihood of occupying a site in the post-fire period. For both of the species, *Anuroctonus p. pococki* and *Vaejovis puritanus*, analyses showed occupancy to vary across the four sampled sites. *Anuroctonus p. pococki* was common at Little Cedar Ridge and Santa Ysabel Preserve (both had occupancy estimates at 75% or above), but not Elliott Chaparral Reserve and Rancho Jamul (occupancy for both sites was 28%). *Vaejovis puritanus* was not widely distributed across Santa Ysabel Preserve (with occupancy less than 25%), compared to >75% occupancy at Little Cedar Ridge, Elliott Chaparral Reserve, and Rancho Jamul. *Vaejovis puritanus* was less sensitive to vegetation type than *A. p. pococki*. *Anuroctonus p. pococki* consistently occupied chaparral and scrub arrays at higher rates than they did woodland or grassland arrays regardless of site. Both species showed a strong effect of seasonality, with activity levels increasing 4-fold in the late summer and early fall.

In general, neither in our comparisons between pre- and post-fire sample periods nor across burned and unburned plots in the post-fire period did we find a negative effect of wildfire on the scorpion and solifugid community. An absence of an effect of fire makes sense given the biology of the species, and has been reported before for scorpions (Smith and Morton 1990). The 2003 fires occurred in October and November, past the peak of activity for scorpions and solifugids. Scorpions and solifugids readily use underground retreat sites for shelter, thus they are likely to survive the combustion phase of the fire. They are most active in the hottest and driest periods of the year, thus the loss of moist and cooler micro-climates associated with leaf litter and woody debris is not likely to affect them as it might other arthropods.

Scorpions and solifugids have a unique physiology that allows them to store large amounts of energy for extended periods of time. With adequate reserves they can go several months without eating, allowing them to survive the shock phase that follows a wildfire. Scorpions and solifugids are voracious, generalist predators of smaller invertebrates. Because the emergent vegetation that follows the first winter rain following a wildfire supports a high abundance of herbivorous insects, scorpions and solifugids would have access to a large prey base, allowing them to sustain their numbers through the first couple of years following the wildfire.

Additional Note on Taxonomic Value of this Study

This study has been a great asset to the understanding of scorpion and solifugid diversity, taxonomy and biology. All specimens of the scorpion species (*Pseudouroctonus williamsi*) were retained by the identifying expert to aid with current efforts to revise the Vaejovidae (Soleglad and Vandergast, pers. comm.). For the solifugids, to date 28 species from 10 genera have been detected by USGS pitfall trap studies in southern California including over 50 sites beyond this study. From these specimens, at least two new species are being or have been described with potential for a third. Undescribed females for four species of *Eremochelis* were detected. Two species of *Hemerotrecha* previously known from only one type specimen each were both detected. Additional specimens have also added data to the possible synonimization of two species (Wood and Brookhardt, pers. comm.).

Acknowledgements

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Tables

Table 1. Species capture rate (as a percentage of the total number of sampled occasions) by site and condition (impact and reference) for the post-fire sample period. Boxed numbers indicate the species were detected in pre-fire samples.

Family	Species	Little Cedar Ridge Impact	Elliott Chaparral Reserve Impact	Santa Ysabel Preserve Impact	Santa Ysabel Preserve Reference	Rancho Jamul Impact	Rancho Jamul Reference	Total
Scorpiones								
Chactidae	*Anuroctonus p. pococki*	12.8%	1.7%	15.8%	14.6%	2.9%	3.2%	8.4%
Superstitioniidae	*Superstitionia donensis*	1.6%	1.0%	0.6%	3.3%	-	-	1.0%
Vaejovidae	*Paruroctonus silvestrii*	4.9%	-	-	-	-	-	0.7%
	Pseudouroctonus andreas	3.3%	-	-	1.3%	0.7%	-	0.8%
	Pseudouroctonus williamsi	-	-	-	1.7%	-	-	0.4%
	Serradigitus g. gertschi	-	-	0.3%	-	-	1.1%	0.2%
	Vaejovis puritanus	8.6%	22.0%	1.5%	2.1%	17.1%	20.4%	12.0%
Solifugae								
Ammotrechidae	*Ammotrechula borregoensis*	-	0.3%	-	-	-	-	0.1%
	Ammotrechula wasbaueri	0.8%	1.7%	0.3%	-	0.4%	0.4%	0.6%
Eremobatidae	*Eremobates icenogelei*	-	-	-	-	-	0.7%	0.1%
	Eremobates kastoni	2.9%	-	0.3%	-	-	-	0.5%
	Eremobates papillatus	0.8%	0.3%	-	-	-	-	0.2%
	Eremobates scopulatus	-	0.3%	-	-	-	-	0.1%
	Eremobates vicinus	0.4%	-	-	-	-	-	0.1%
	Eremobates williamsi	-	-	3.9%	2.9%	-	-	1.2%
	Eremochelis andreasana	3.3%	1.7%	4.5%	-	-	1.1%	1.8%
	Eremochelis kastoni	3.7%	1.3%	0.9%	0.4%	1.4%	0.4%	1.3%
	Eremochelis striodorsalis	-	-	4.5%	1.7%	0.4%	0.4%	1.3%
	Eremocosta calexicensis	-	-	-	-	-	0.4%	0.1%
	Eremocosta titania	0.4%	-	-	-	-	-	0.1%
	Hemerotrecha californica	-	0.3%	-	-	-	-	0.1%
Total sample occasions		243	300	336	240	280	280	1679
(# arrays)		(9)	(10)	(14)	(10)	(10)	(10)	(63)

Table 2. Results from the hierarchical linear modeling analyses comparing the effects of different hypotheses (i.e., vegetation, condition, and their interaction) on the response variables describing scorpion and solifugid average and cumulative species richness.

Response Variable[a]	Model[b]	ΔAICc	w_i	K	LL
Average Number Species Detected Per Occasion[1]	Vegetation	0.0	0.93	6	35.52
	Null	6.0	0.05	3	28.96
	Condition	8.0	0.01	4	29.11
	Condition*Vegetation	9.0	0.01	10	36.38
Cumulative Species Richness[1]	Null	0.0	0.54	3	-111.50
	Condition	1.7	0.23	4	-111.19
	Vegetation	1.7	0.23	6	-108.82
	Condition*Vegetation	9.8	0.00	10	-107.46

[a]Key –[1]Site included as a random effect in all models.

[b]Null model includes the intercept plus a random effect of site. The explanatory variables include the fixed effects of vegetation, condition and their interaction.

ΔAICc - Difference in AICc values between each model and the low-AICc model; when comparing the relative fits of a suite of models, differences in AICc values among models indicate relative support.

w_i - AICc model weight; weights have a probabilistic interpretation: of these models, w_i is the probability that model i would be selected as the best-fitting model if the data were collected again under identical conditions.

K - Number of parameters in the model.

LL - Log-likelihood scores.

Table 3. Vegetation associations of scorpion and solifugid species as measured by the cumulative number of detections per vegetation type[a] (significance results from G-Test).

Species	Vegetation Type				
	Chaparral	Coastal Sage Scrub	Grassland	Woodland	Sig.[b]
Scorpiones					
Superstitionia donensis	6	10	1	0	***
Paruroctonus silvestrii	5	7	0	0	***
Pseudouroctanus andreas	5	7	1	1	*
Solifugae					
Ammotrechula wasbaueri	3	4	2	1	NS
Eremobates kastoni	5	2	0	1	NS
Eremobates williamsi	7	8	1	8	*
Eremobates striodorsalis	4	3	4	10	NS
Eremochelis andreasana	19	3	5	5	**
Eremochelis kastoni	6	8	5	3	NS
Total # of sample occasions (freq.)	429 (0.26)	516 (0.31)	358 (0.21)	376 (0.22)	

[a] Does not include *Anuroctonus p. pococki*, *Vaejovis puritanus*, or any species with less than eight detections.

[b]G-test: * = P < 0.05; ** = P < 0.01; *** = P < 0.001; NS = P > 0.05

Table 4. Occupancy models for *Anuroctonus p. pococki*. Summary of model selection procedure for post-fire models of site occupancy.

Model	ΔAIC^a	w_i^b	K^c	$-2*LL^d$
ψ(site)ε(·)p(season)	0.00	0.53	7	750.41
ψ(site, vegetation)ε(·)p(season)	0.29	0.46	10	744.70
ψ(vegetation)ε(·)p(season)	10.03	0.00	7	760.44
ψ(·)ε(·)p(season)	12.70	0.00	4	769.11
ψ(condition)ε(·)p(season)	14.64	0.00	5	769.05
ψ(year)ε(·)p(season)	22.39	0.00	6	774.80
ψ(·)ε(·)p(·)	82.16	0.00	3	840.57

[a]Difference in AIC values between each model and the low-AIC model; when comparing the relative fits of a suite of models, differences in AIC values among models indicate relative support.
[b]AIC model weight; weights have a probabilistic interpretation: of these models, w_i is the probability that model i would be selected as the best-fitting model if the data were collected again under identical conditions.
[c]Number of parameters in the model.
[d]Negative two times log-likelihood estimate.
ψ-Occupancy (probability the site is occupied)
ε-Rate of extinction
p-Probability of detection
(·)-Value held constant

Tables 5. Occupancy models for *Vaejovis puritanus*. Summary of model selection procedure for post-fire models of site occupancy.

| Model	ΔAIC	w_i	K	$-2*LL$
ψ(site)ε(·)p(season)	0.00	0.98	7	902.29
ψ(site, vegetation)ε(·)p(season)	7.47	0.02	10	903.76
ψ(vegetation)ε(·)p(season)	31.53	0.00	7	933.82
ψ(·)ε(·)p(season)	33.73	0.00	4	942.02
ψ(year)ε(·)p(season)	35.09	0.00	6	939.38
ψ(condition)ε(·)p(season)	35.22	0.00	5	941.51
ψ(·)ε(·)p(·)	165.74	0.00	3	1076.03

Note: symbols are the same as earlier tables.

# FIGURES
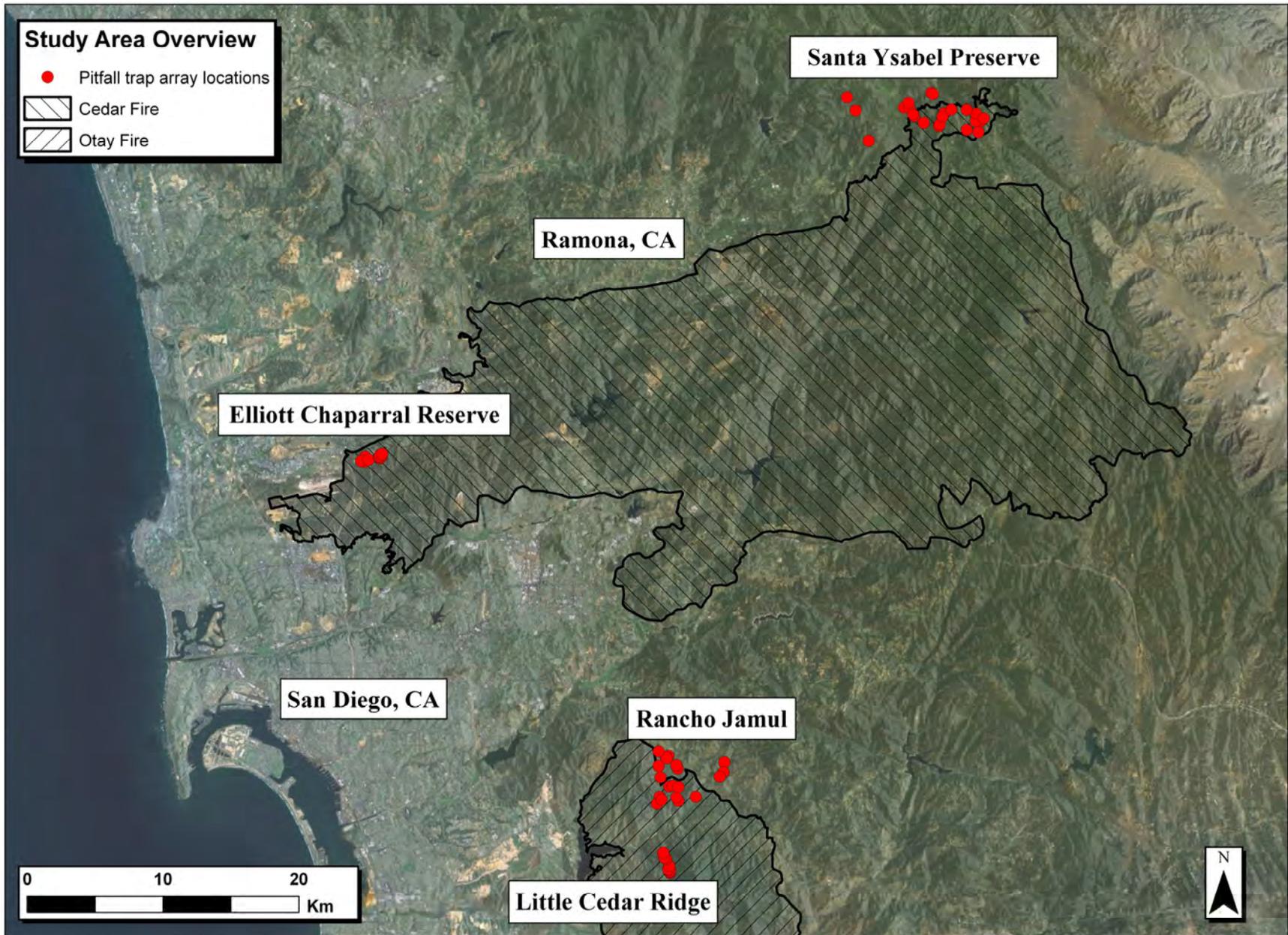
**Figure 1. Schematic of the study areas.**
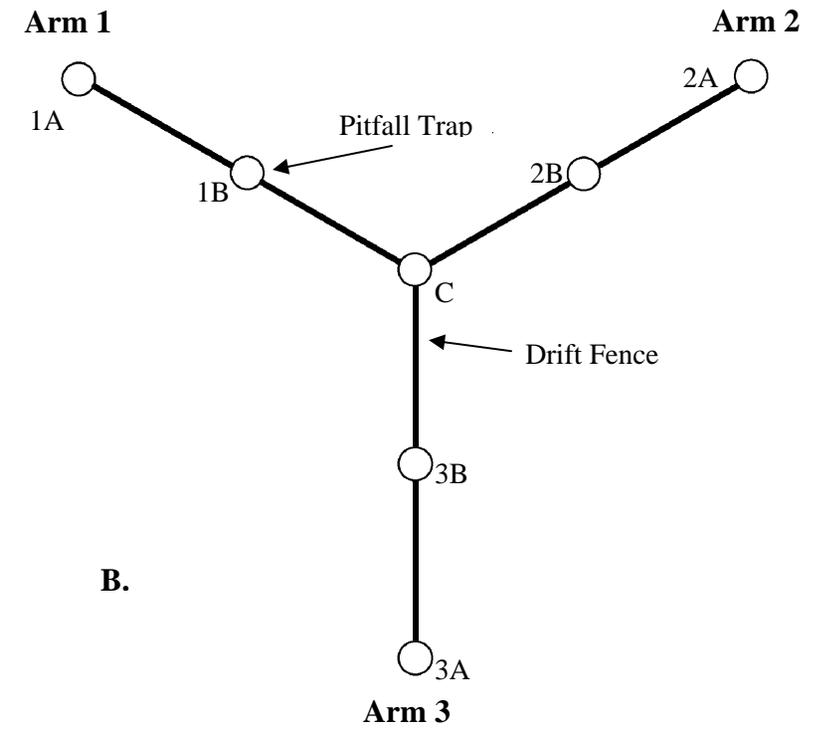
Figure 2. Study plot design. The pitfall trap arrays consisted of seven pitfall traps (five gallon buckets) connected by drift fencing to form three arms radiating from a center pitfall trap. **(A)** A pitfall trap array at Little Cedar Ridge. **(B)** Diagram of pitfall trap array illustrating trap placement. **(C)** View of an open (active) pitfall trap array looking along an arm with a pitfall trap in the foreground.
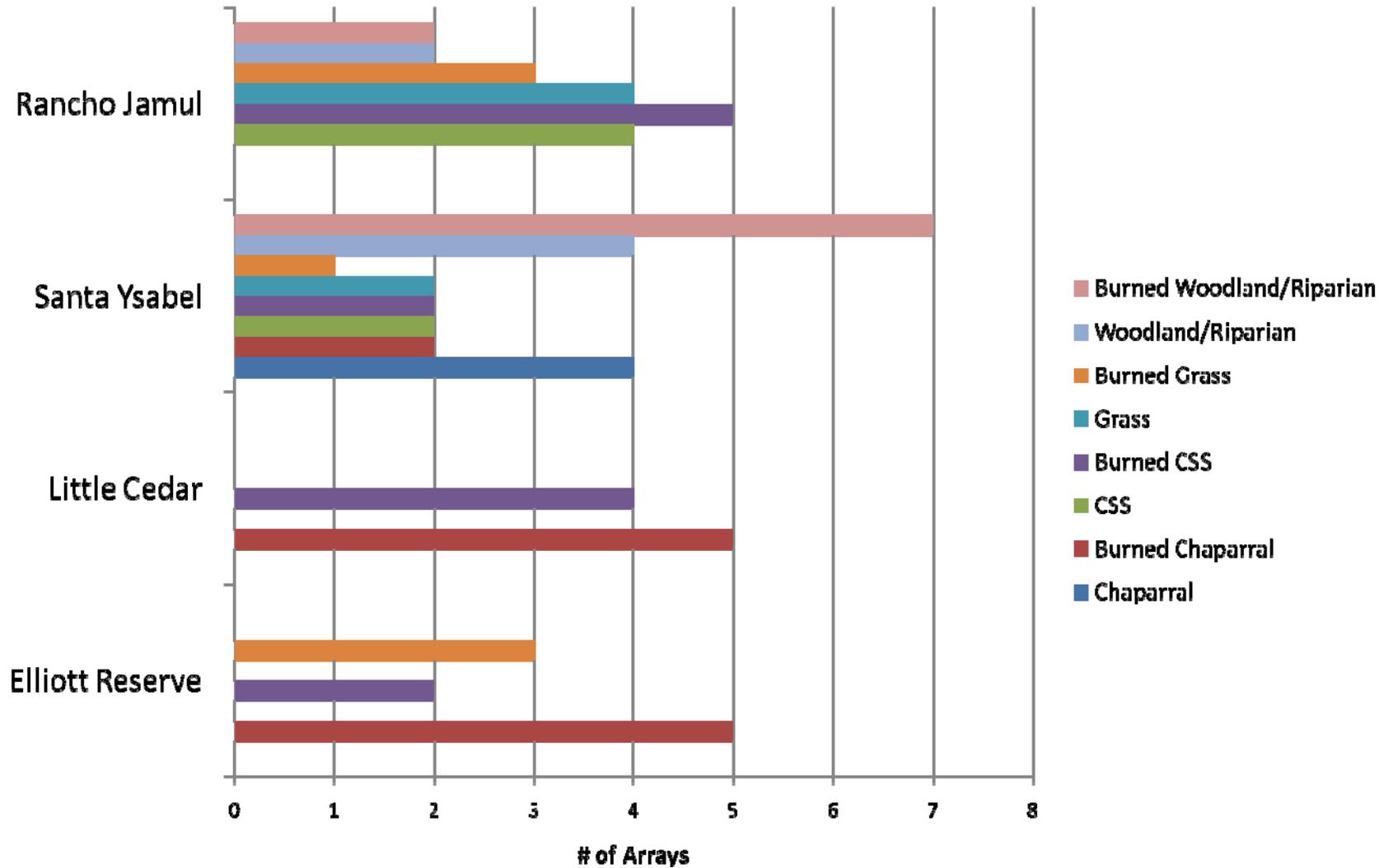
Figure 3. Vegetation composition by site. Of the four sites, Santa Ysabel Preserve is the most diverse with eight different vegetation types represented across sampled plots. Both Little Cedar Ridge and Elliott Chaparral Reserve are the least diverse sites with only two and three vegetation types represented. Variation in vegetation composition between sites confounds our ability to explain the causes for variability in the scorpion and solifugid community between sites.

Figure legend (right side of chart):

- *Ammotrechula borregoensis*
- *Ammotrechula wasbaueri*
- *Hemerotrecha californica*
- *Eremochelis kastoni*
- *Eremochelis striodorsalis*
- *Eremochelis andreasana*
- *Eremobates williamsi*
- *Eremobates papillatus*
- *Eremobates kastoni*
- *Eremobates icenogelei*
- *Eremobates scopulatus*
- *Eremobates vicinus*
- *Eremocosta titania*
- *Eremocosta calexicensis*

Species richness by month:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
--	--	--	--	5	8	7	5	4	1	1	--

A.

Figure 4. Monthly activity patterns of the (A) Solifugae and (B) Scorpiones. "Detection Frequency" equals the total number of sample occasions with a detection divided by the total possible number of detections (i.e., the product of the total number of arrays sampled and the total number of sample periods). For the scorpions, "Detection Frequency" is square-root transformed.
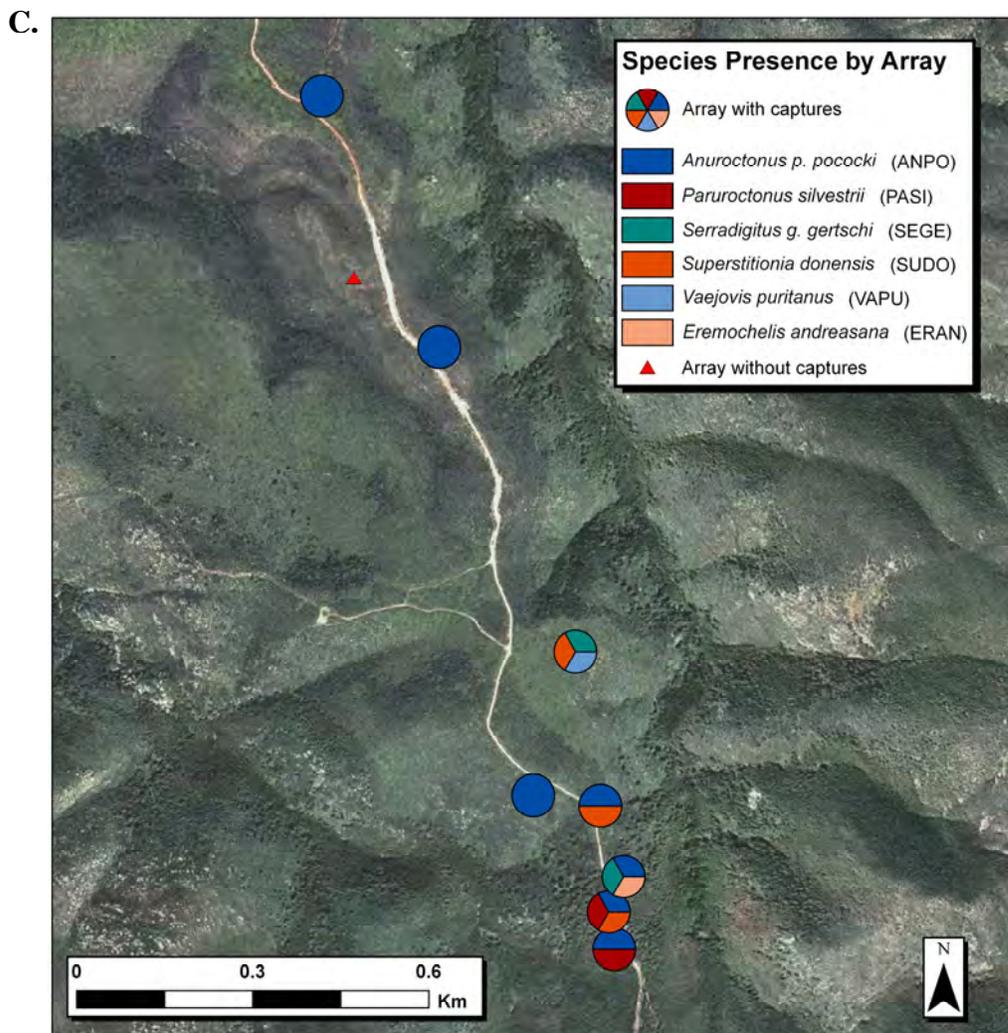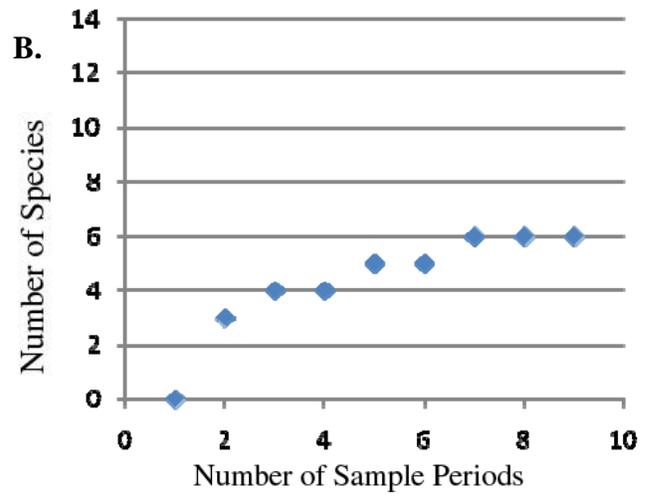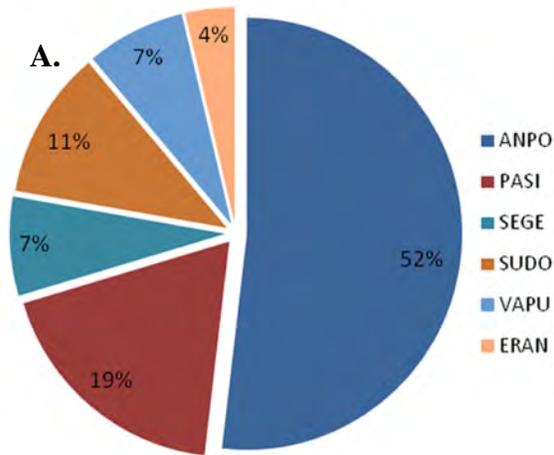
Figure 5. Pre-fire species composition at Little Cedar Ridge (all arrays impacted). (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
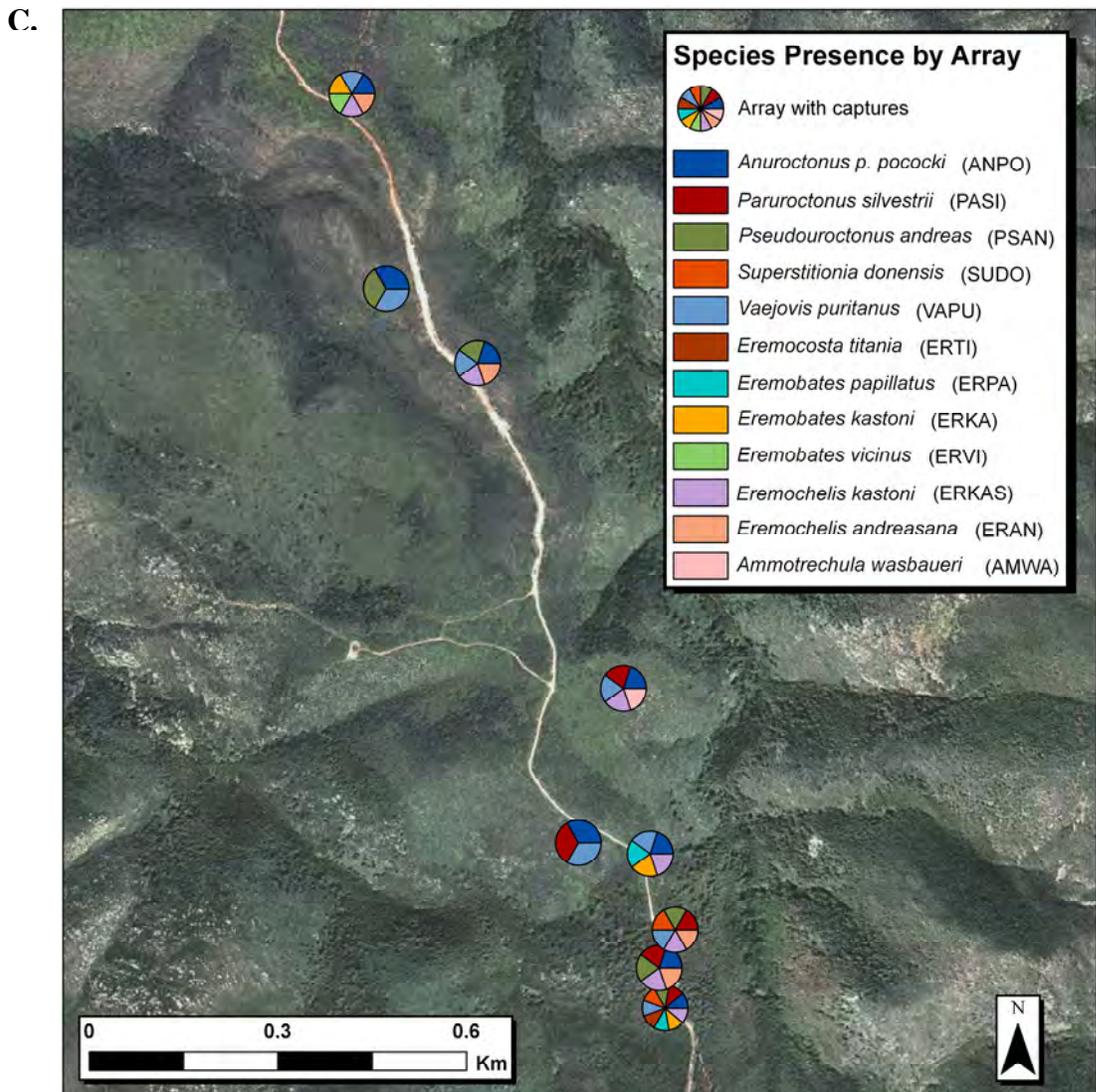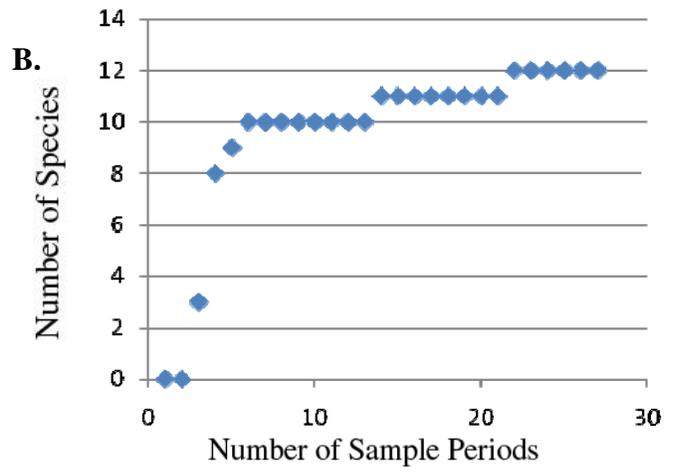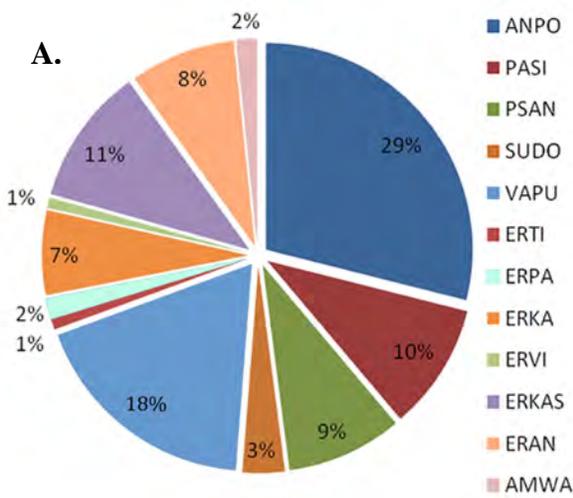
Figure 6. Post-fire species composition at Little Cedar Ridge (all arrays impacted) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).

A. Pie chart showing: 6% ANPO, 3% SUDO, 75% VAPU, 17% AMWA

B. Scatter plot of Number of Species vs. Number of Sample Periods

C. Aerial map with legend:

Species Presence by Array
- Array with captures
- *Anuroctonus p. pococki* (ANPO)
- *Superstitionia donensis* (SUDO)
- *Vaejovis puritanus* (VAPU)
- *Ammotrechula wasbaueri* (AMWA)
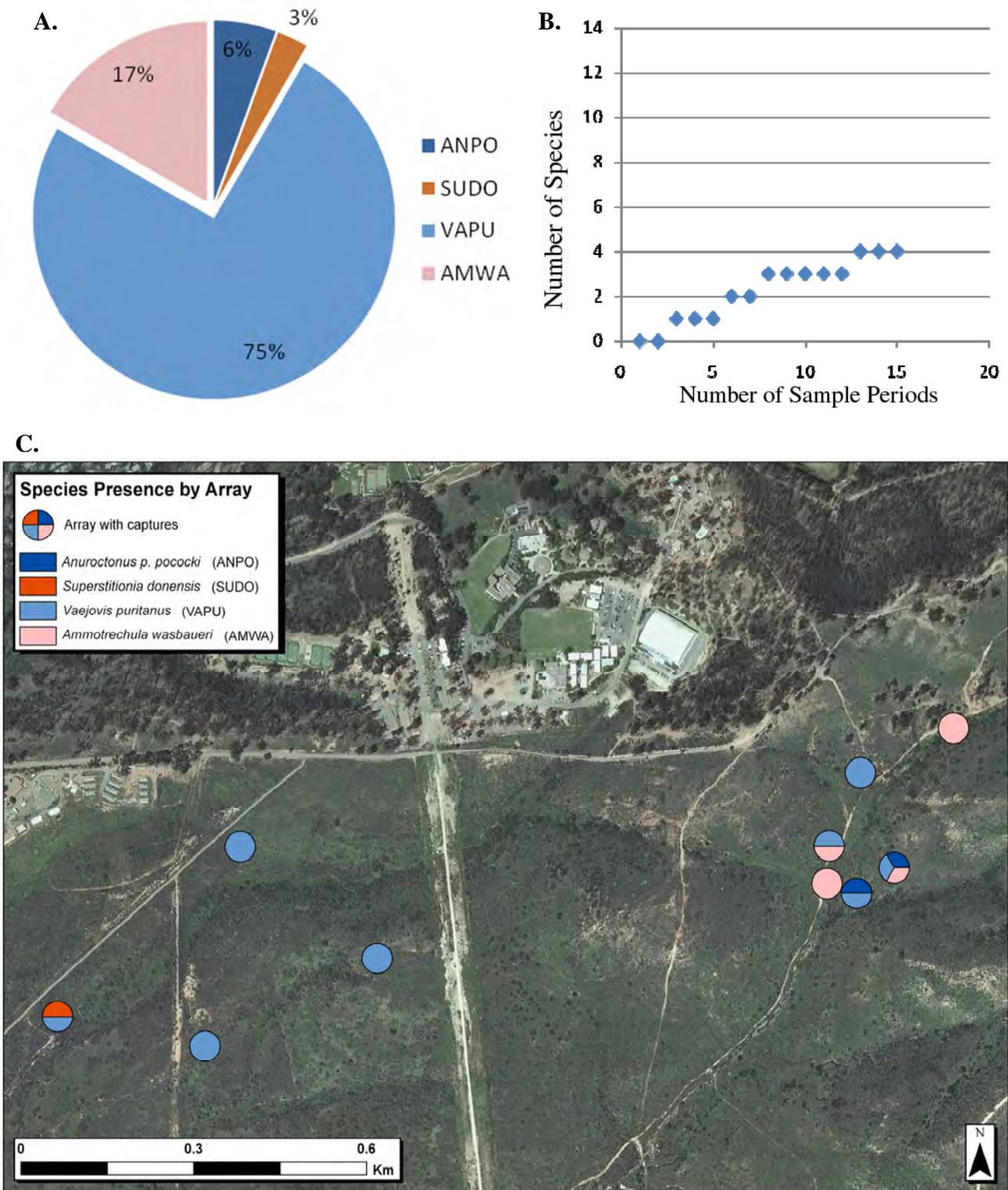
Figure 7. Pre-fire species composition at Elliott Chaparral Reserve (all arrays impacted)
(A.) Species composition and proportions for the entire site. (B.) Species accumulation rate.
(C.) Species presence by array (symbols do not represent the proportion of detections).

A.

- ANPO
- SUDO
- VAPU
- ERPA
- ERSC
- ERKAS
- ERAN
- AMBO
- AMWA
- HECA

75%, 3%, 5%, 5%, 1%, 1%, 4%, 1%, 5%, 1%

B.

Number of Species vs Number of Sample Periods

C.

Species Presence by Array

Array with captures

Anuroctonus p. pococki	(ANPO)
Superstitionia donensis	(SUDO)
Vaejovis puritanus	(VAPU)
Eremobates papillatus	(ERPA)
Eremobates scopulatus	(ERSC)
Eremochelis kastoni	(ERKAS)
Eremochelis andreasana	(ERAN)
Ammotrechula borregoensis	(AMBO)
Ammotrechula wasbaueri	(AMWA)
Hemerotrecha californica	(HECA)
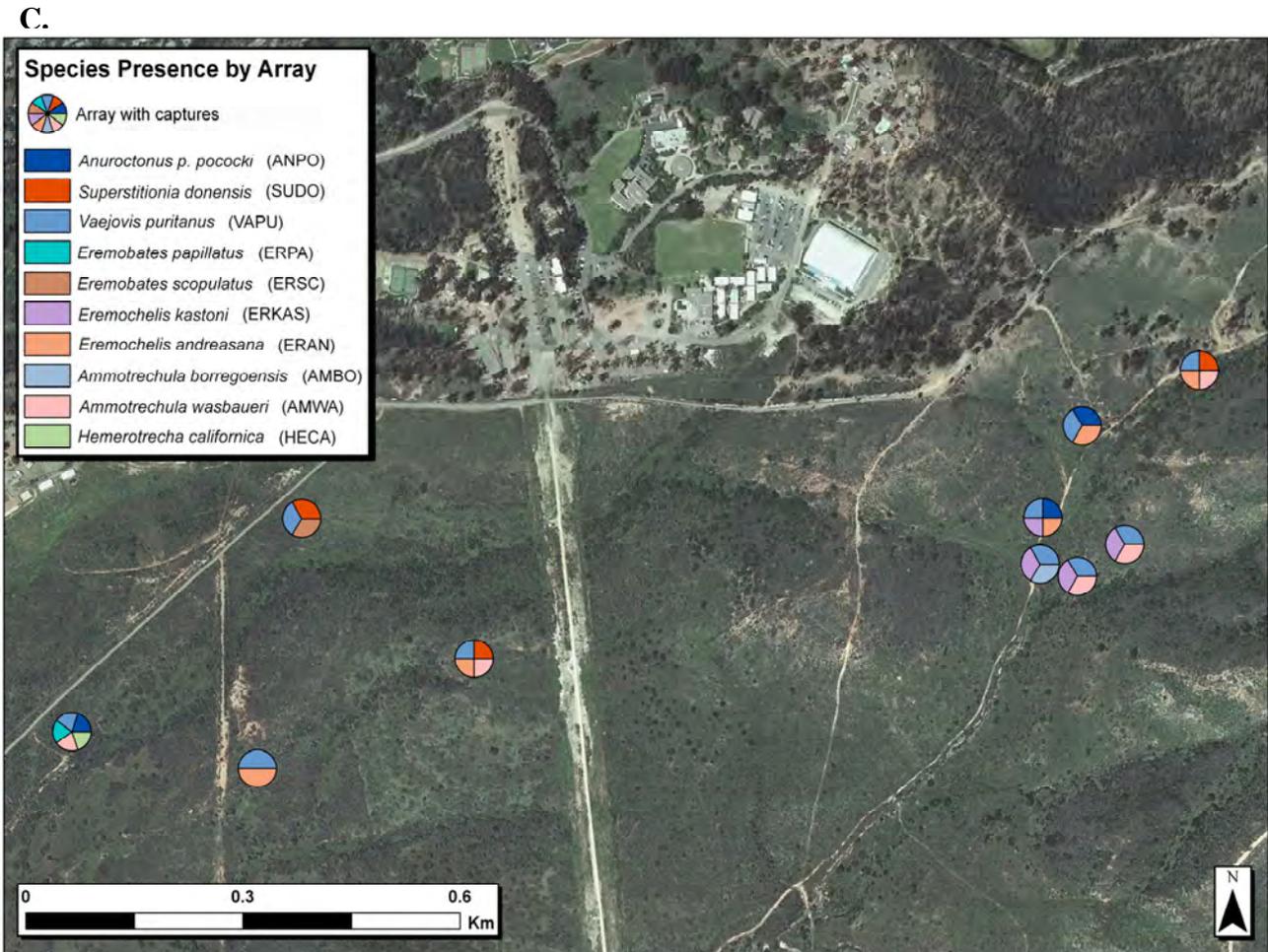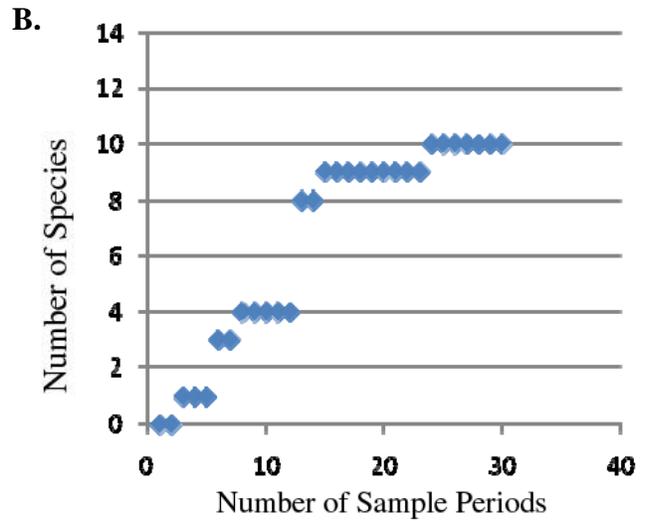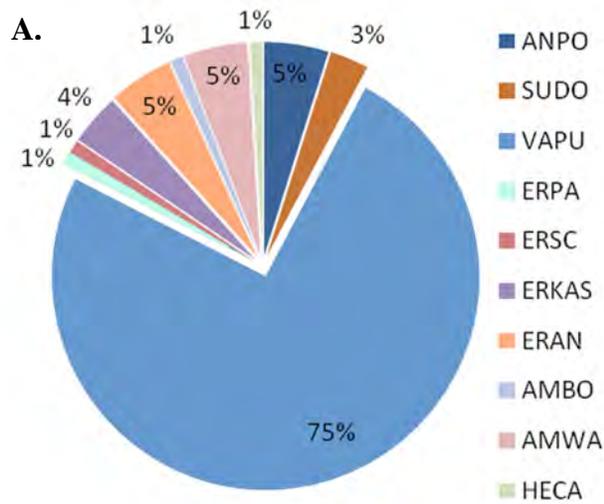
Figure 8. Post-fire species composition at Elliott Chaparral Reserve (all arrays impacted)
(A.) Species composition and proportions for the entire site. (B.) Species accumulation rate.
(C.) Species presence by array (symbols do not represent the proportion of detections).
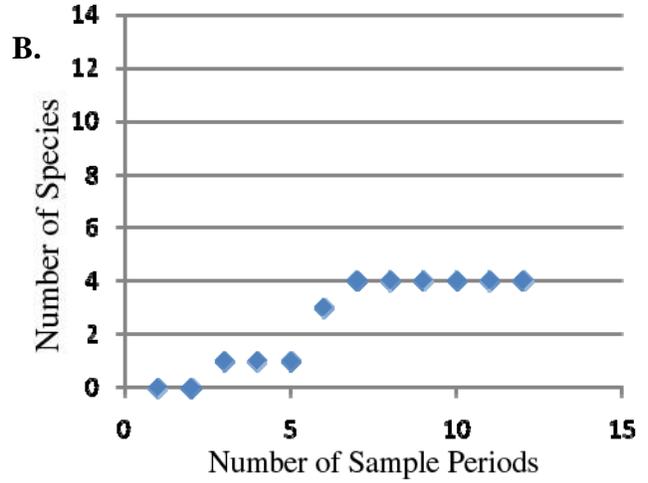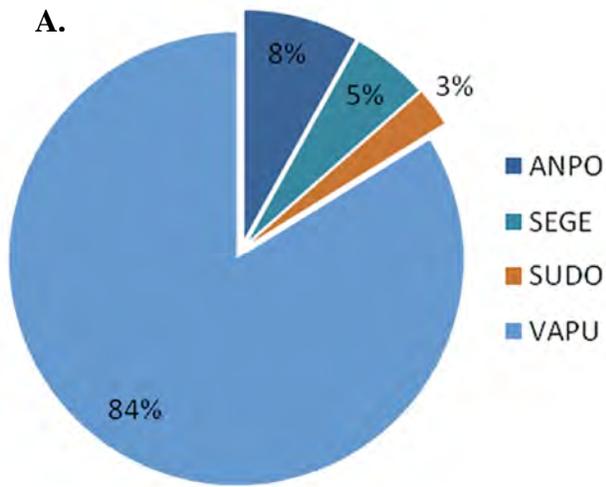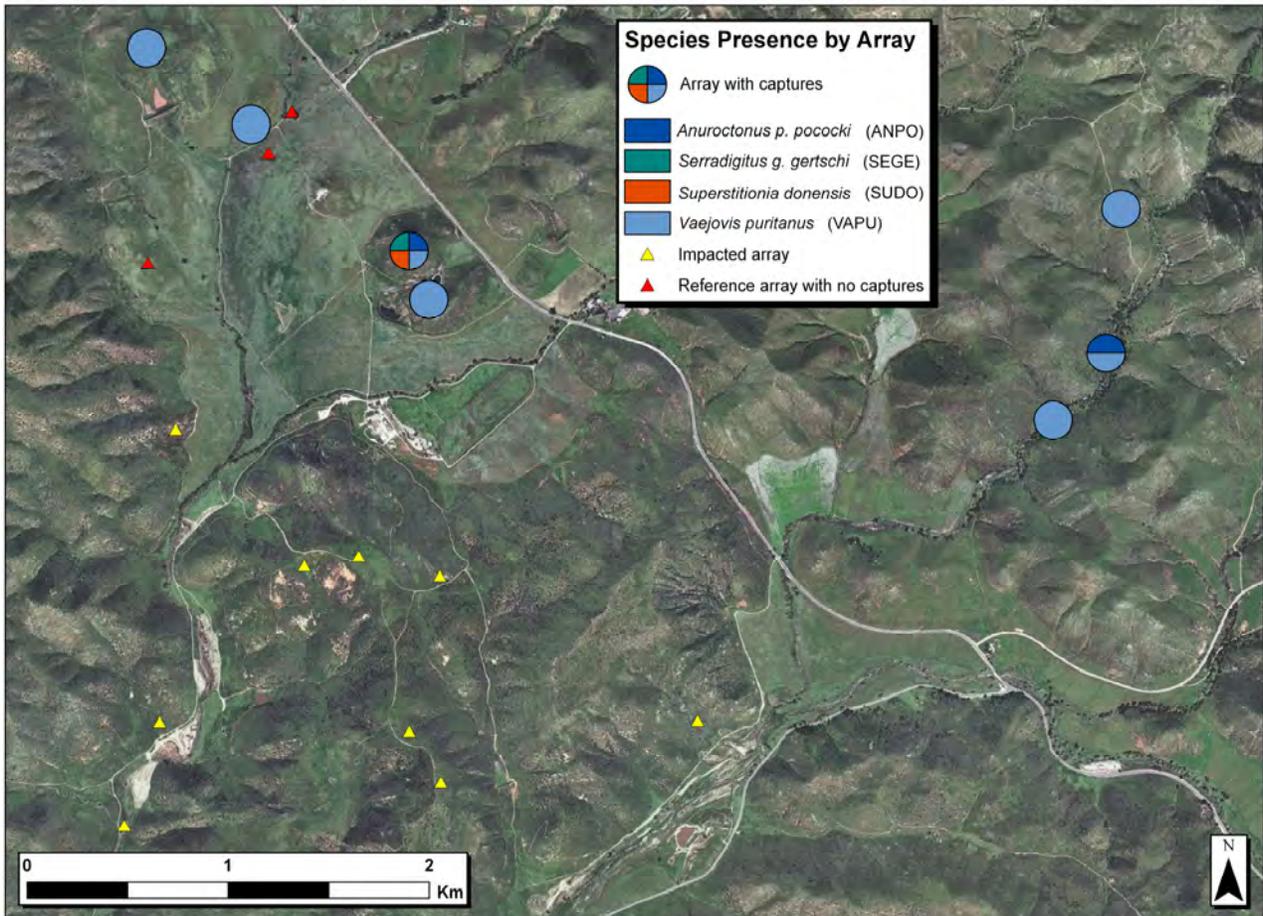
Figure 9. Pre-fire species composition at Rancho Jamul (reference arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
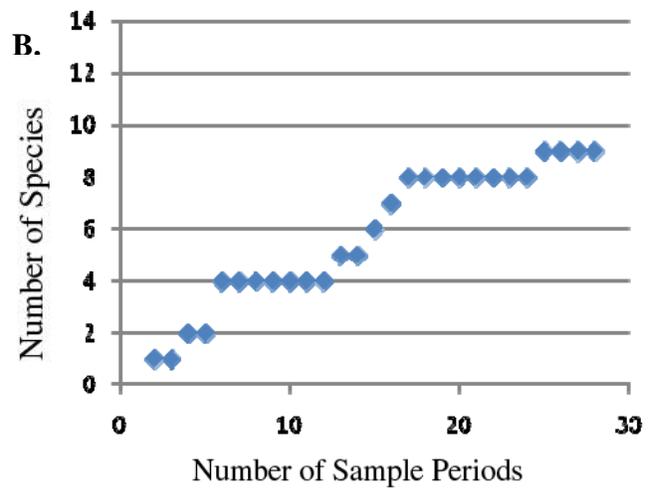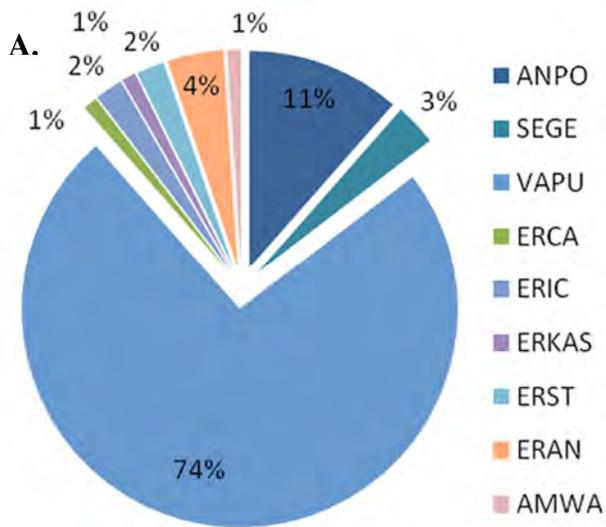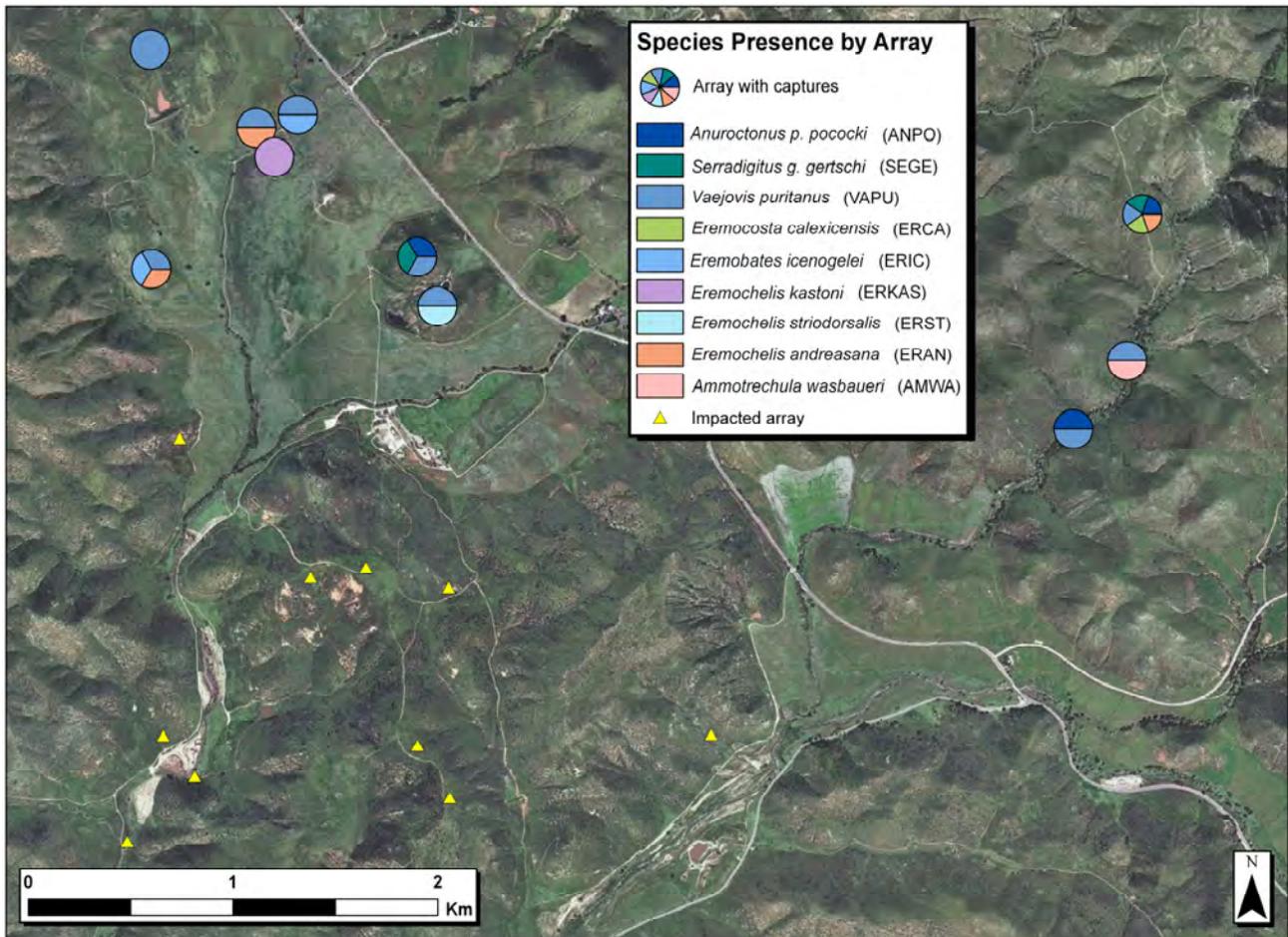
Figure 10. Post-fire species composition at Rancho Jamul (reference arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
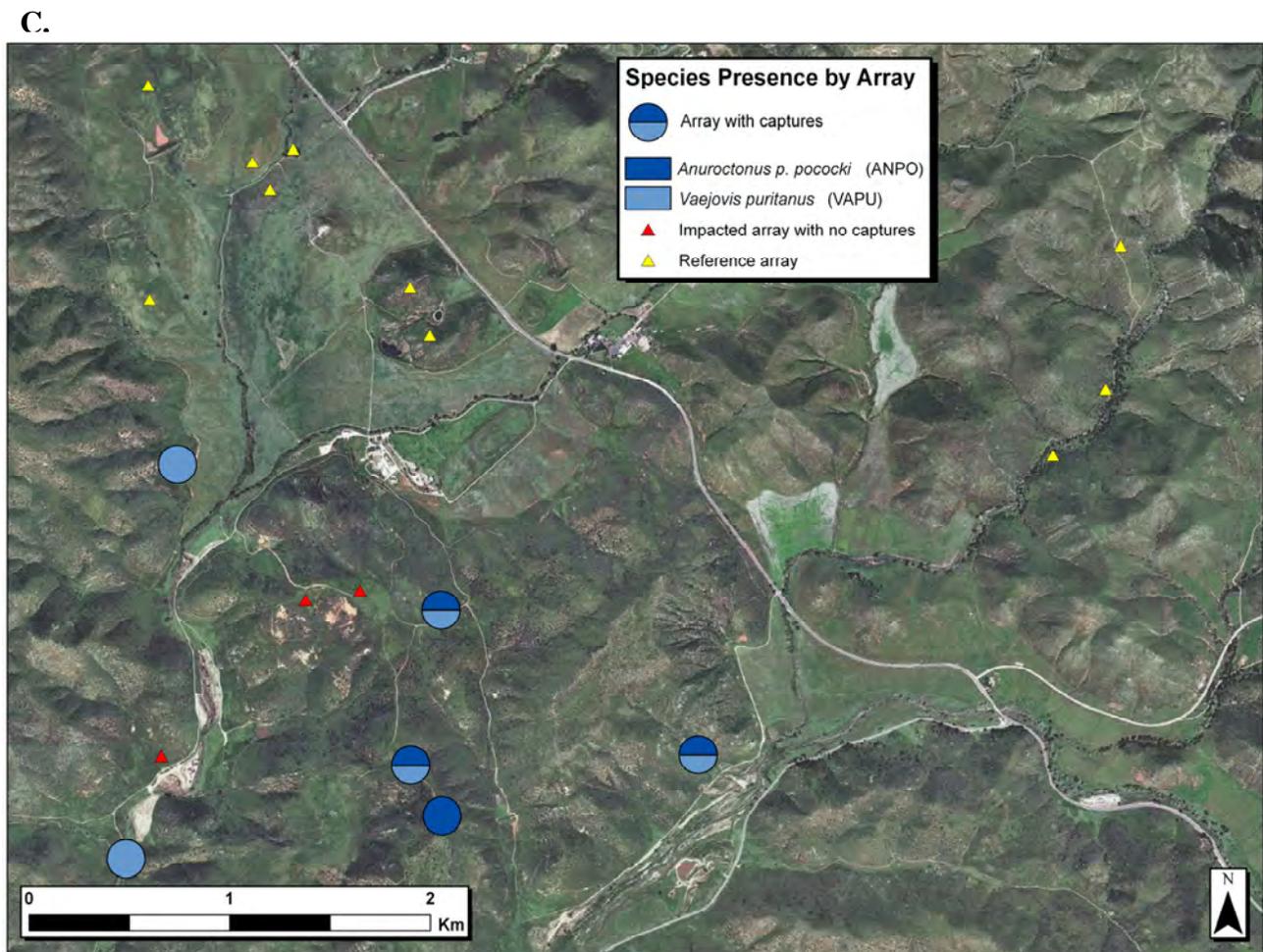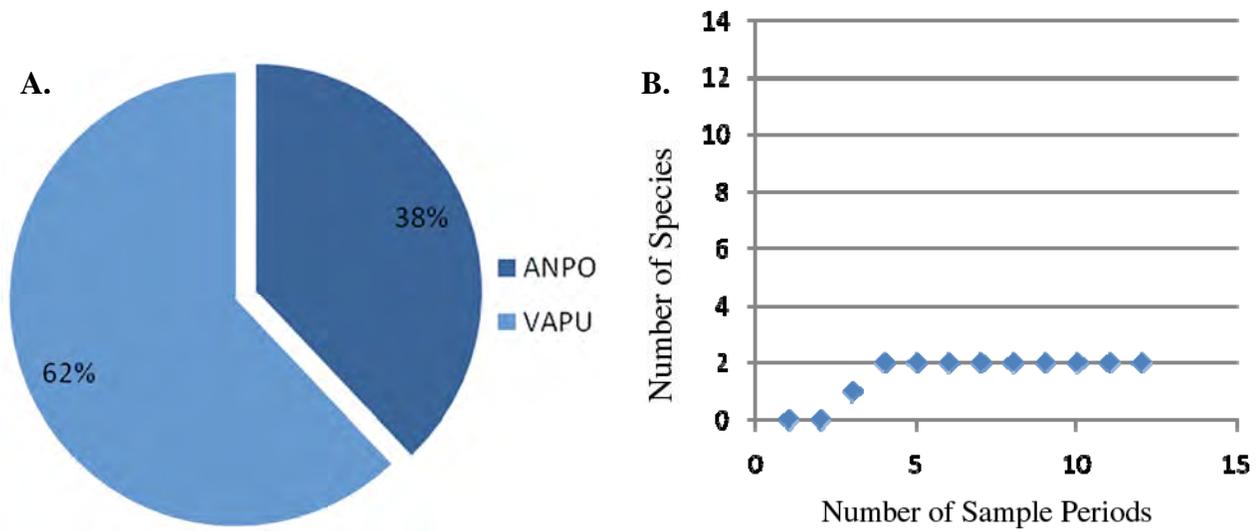
Figure 11. Pre-fire species composition at Rancho Jamul (impacted arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
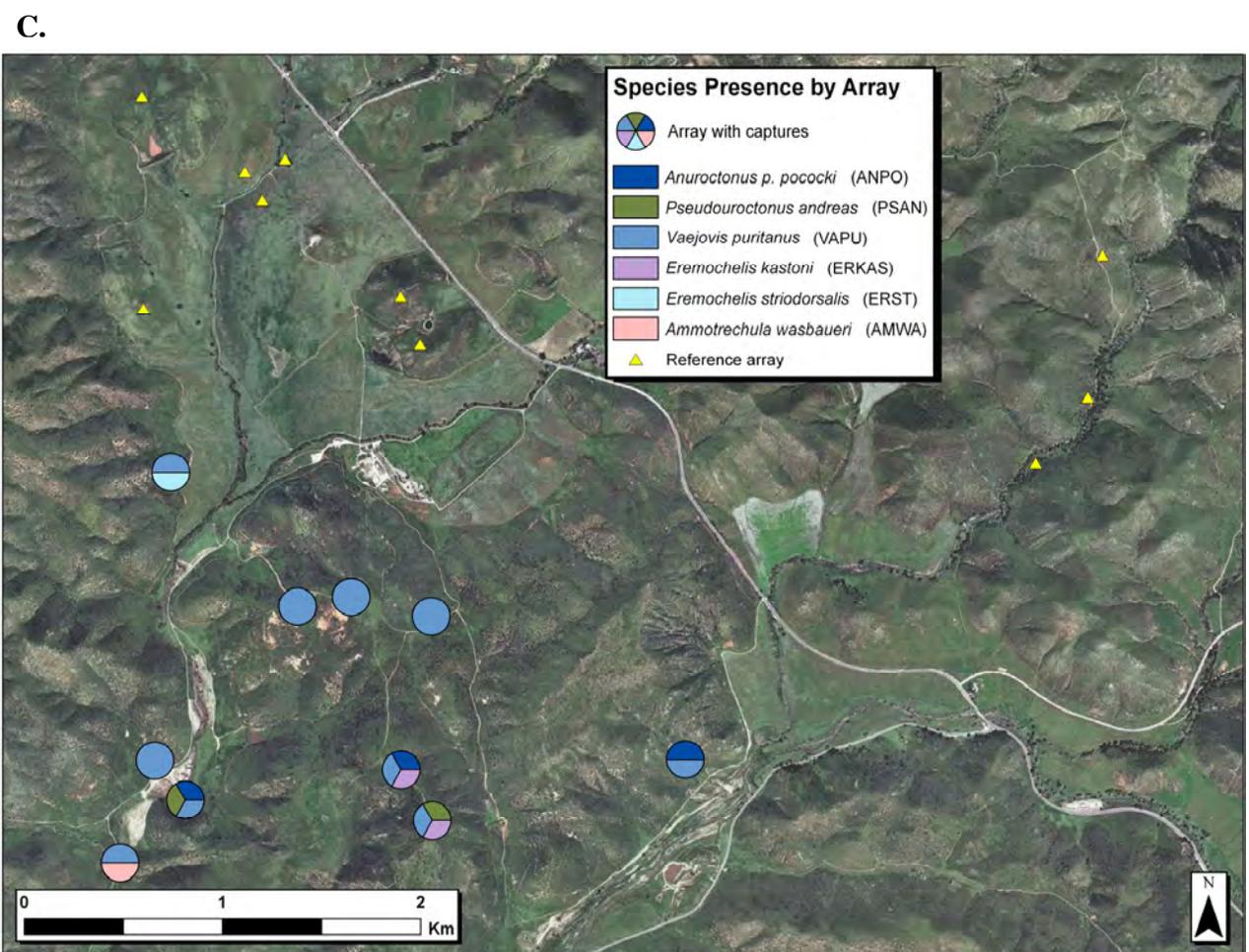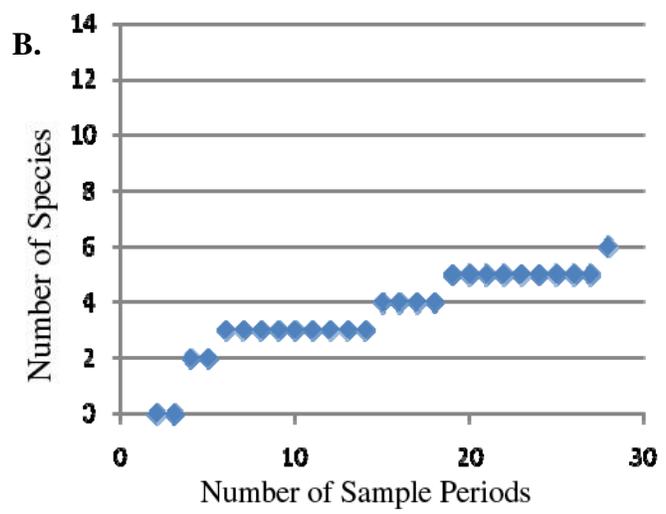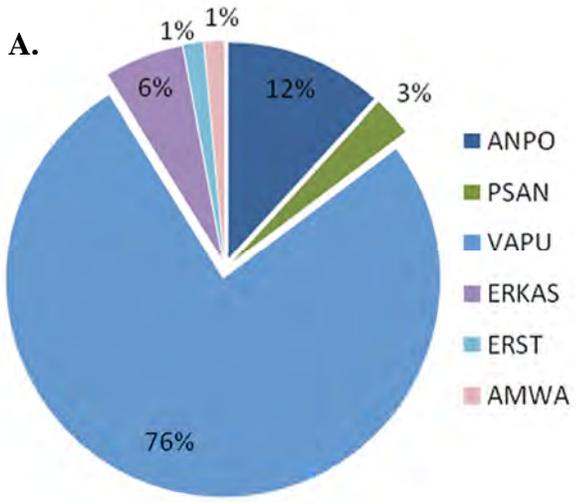
Figure 12. Post-fire species composition at Rancho Jamul (impacted arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
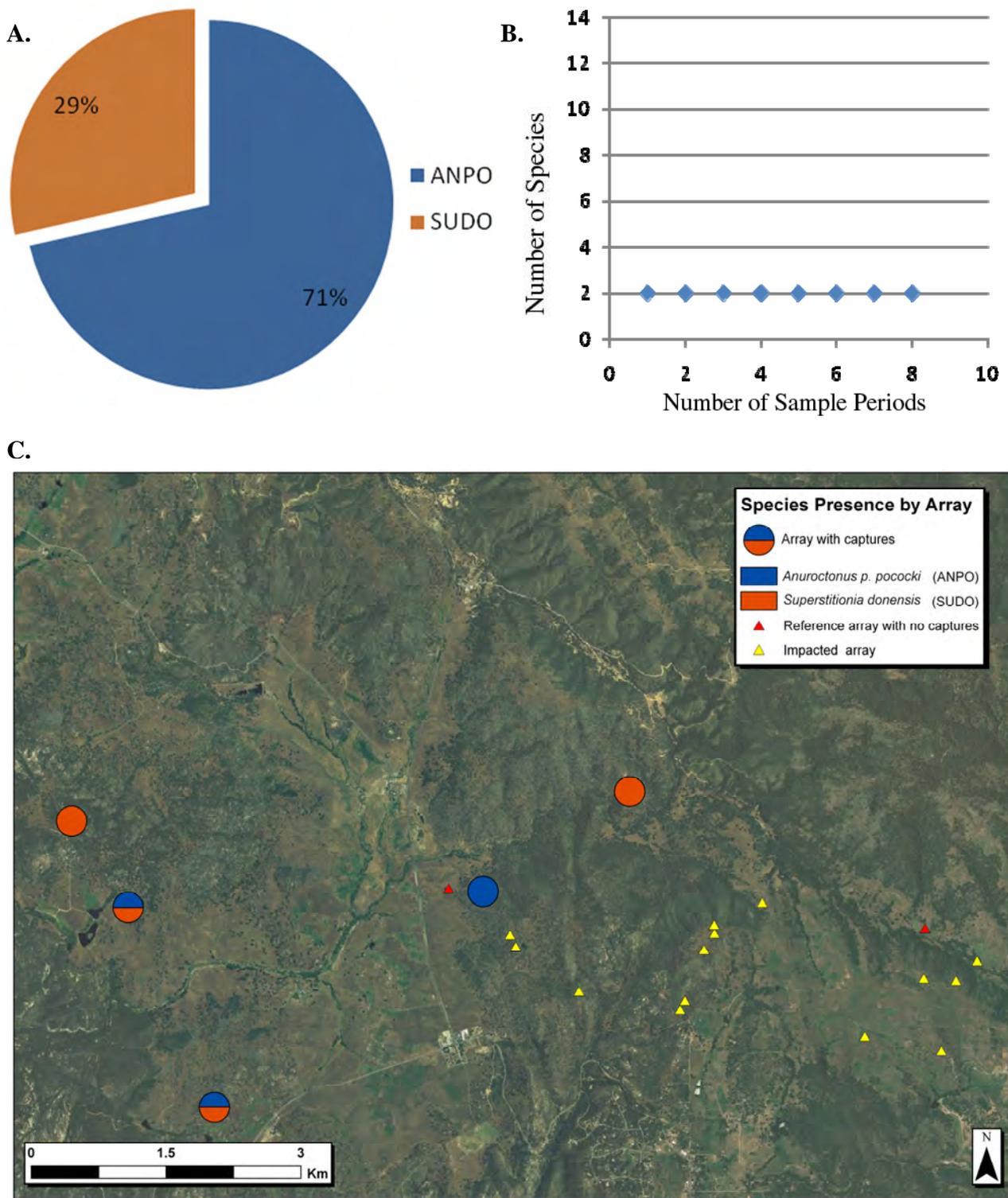
Figure 13. Pre-fire species composition at Santa Ysabel Preserve (reference arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).

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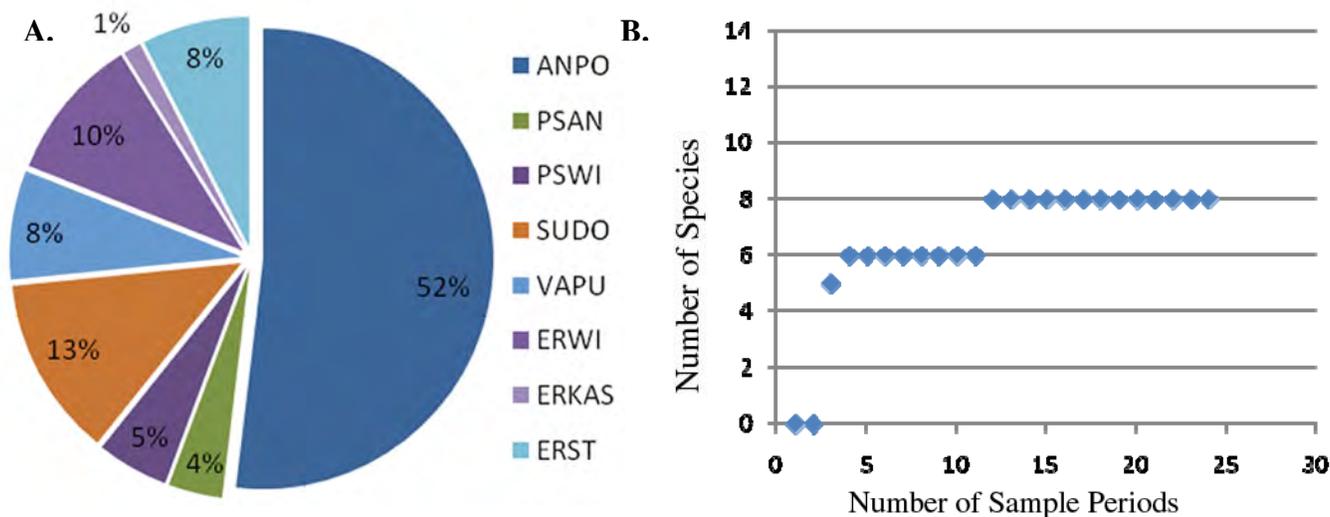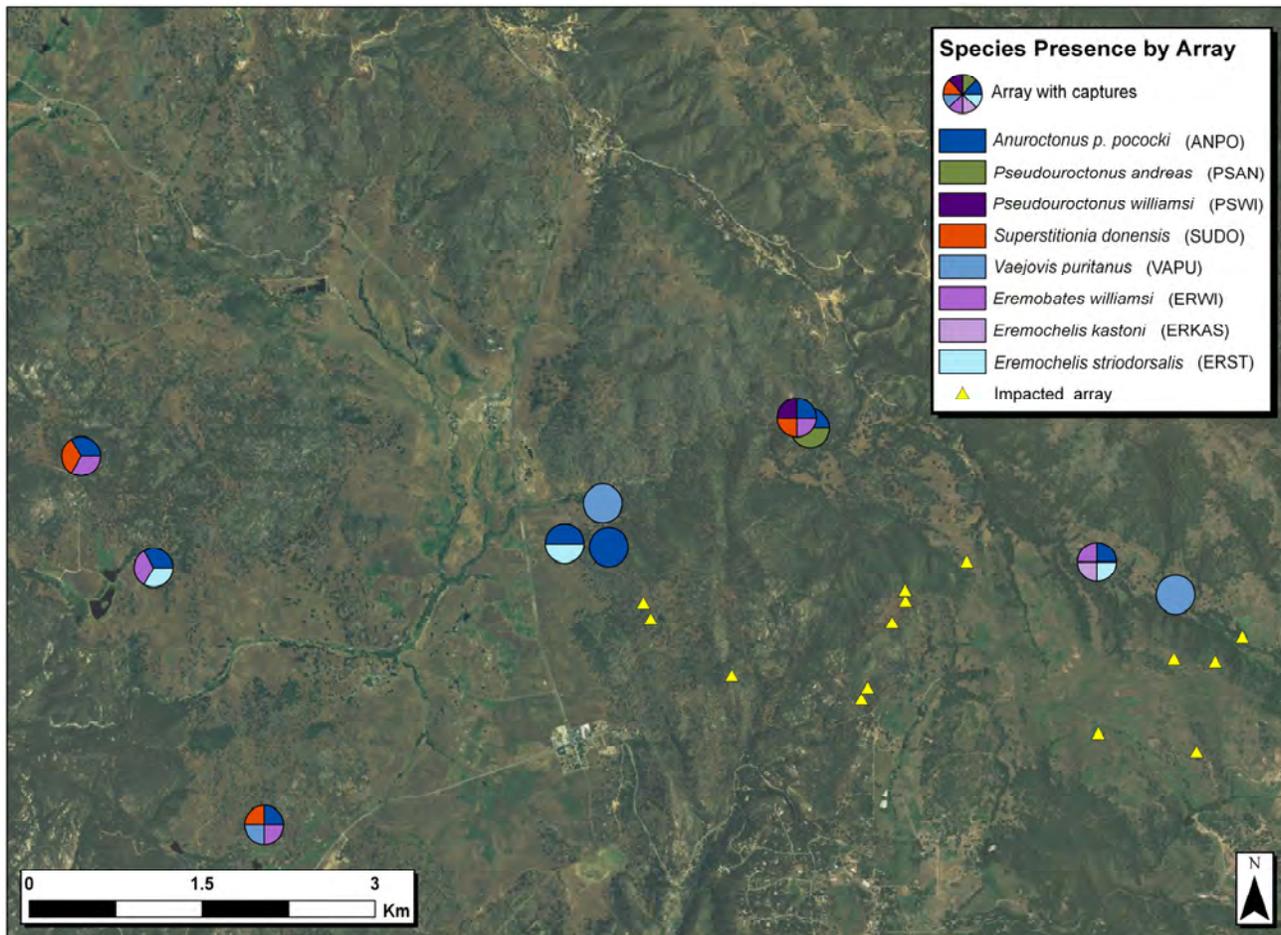
Figure 14. Post-fire species composition at Santa Ysabel Preserve (reference arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
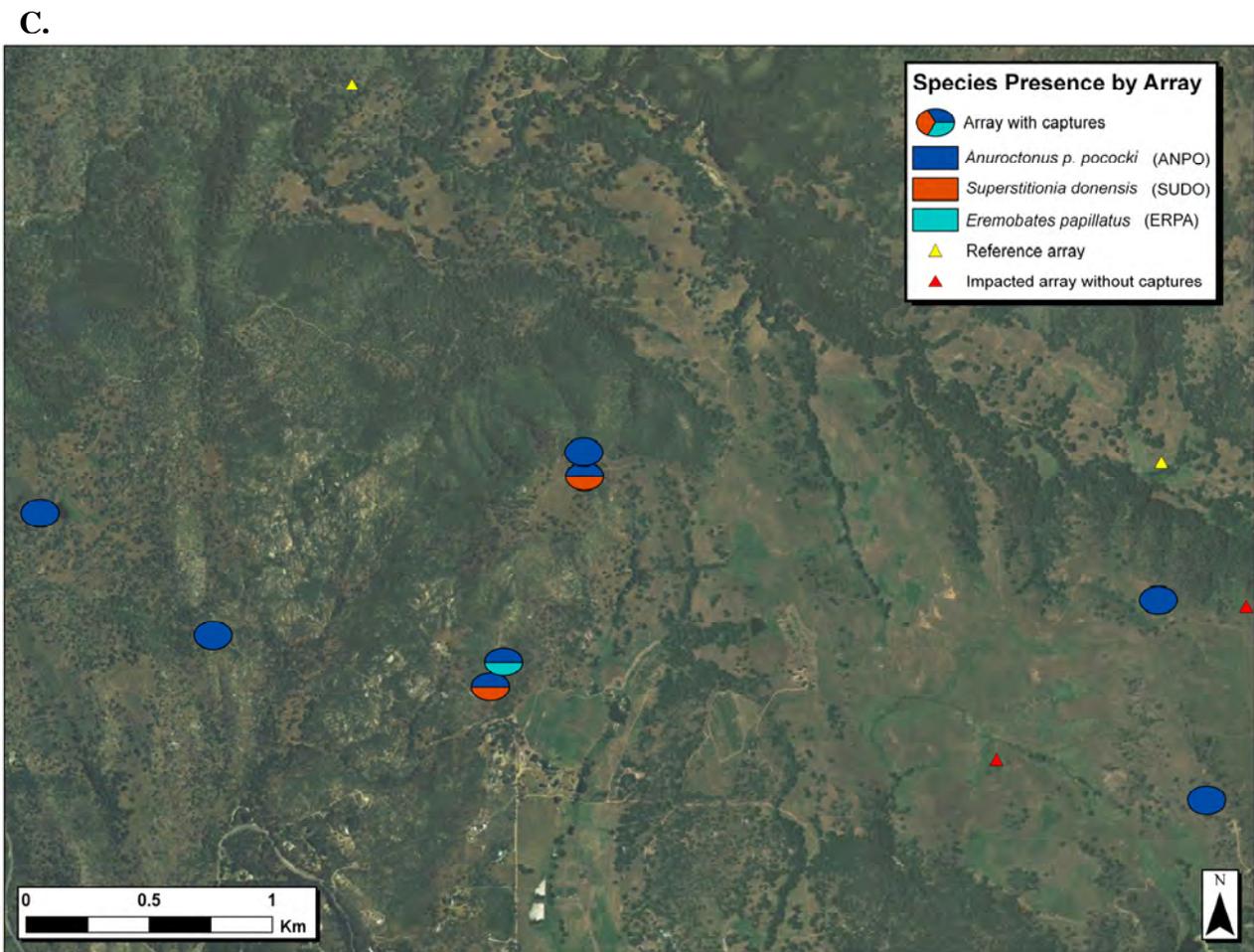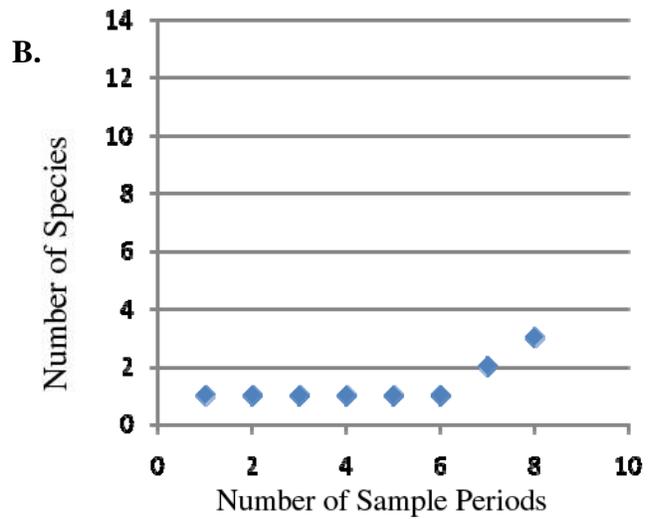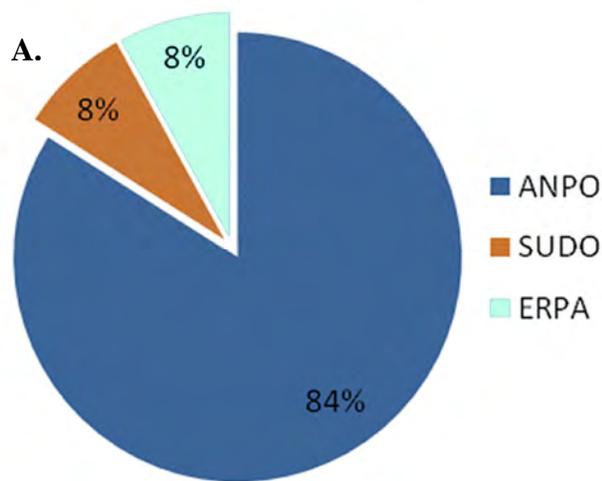
Figure 15. Pre-fire species composition at Santa Ysabel Preserve (impacted arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).
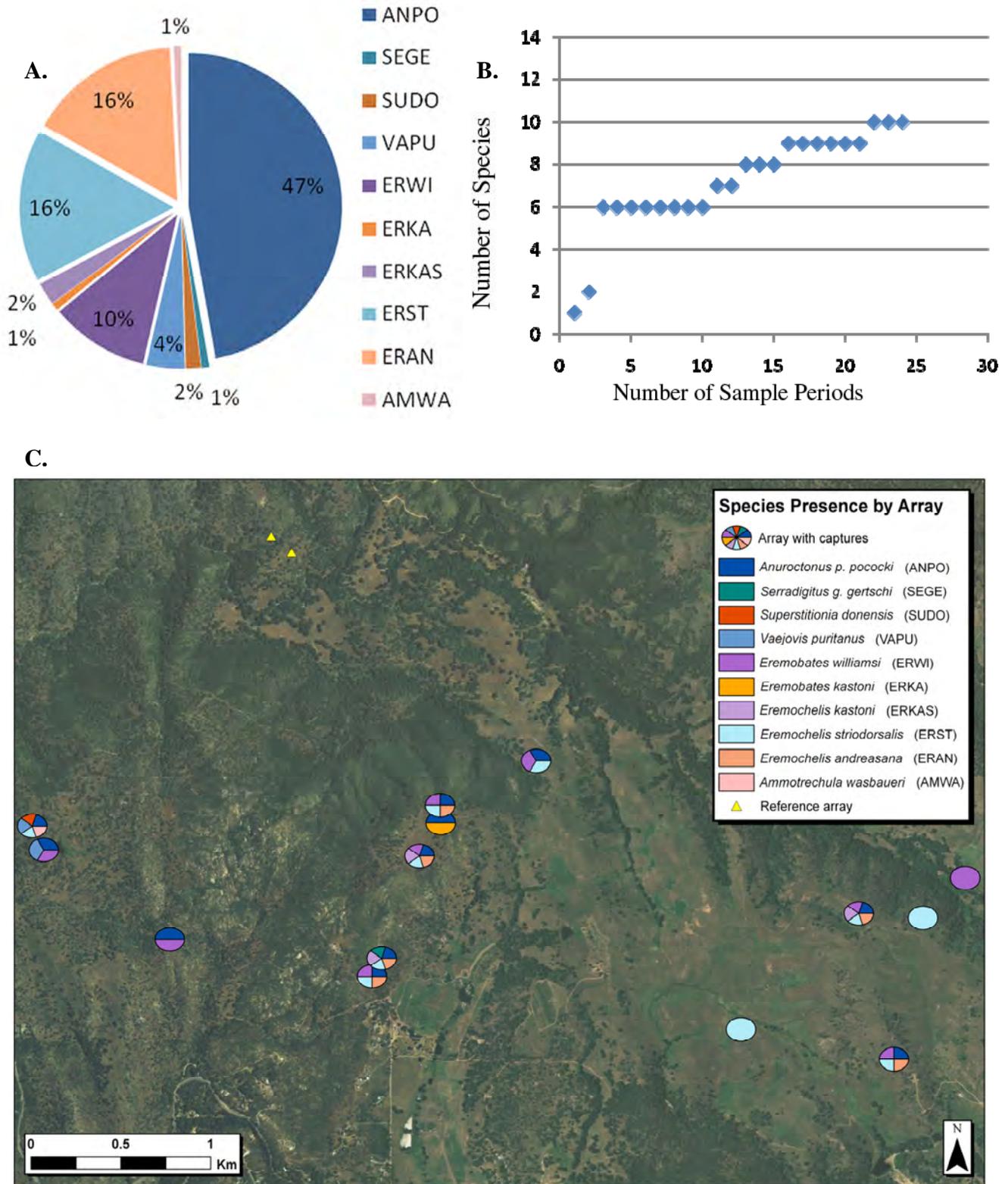
Figure 16. Post-fire species composition at Santa Ysabel Preserve (impacted arrays) (A.) Species composition and proportions for the entire site. (B.) Species accumulation rate. (C.) Species presence by array (symbols do not represent the proportion of detections).

Appendix I

Scorpion Species Accounts

Introduction

This photo guide includes the common scorpions observed in the pitfall trap arrays in coastal San Diego County. The photos are from actual specimens collected for this study and the full body photos have 1cm bars for scale. This guide does not include all species which may be found in the region as some species are difficult to detect using our sampling methods. We use the taxonomy of Fet et al. 2000 for all species with the exception of the recently described *Anuroctonus p. pococki* for which we use Soleglad and Fet 2004.

Chactidae

This family is currently undergoing revision and includes genera that have been placed historically in the Vaejovidae or the Iuridae. Since we are using the species description from Soleglad and Fet 2004 for *Anuroctonus p. pococki* we are also using it for the inclusion of this genus within Chactidae.


1 cm (2.8x)

Note the female lacks distinctive bulge on the telson between the vesicle and aculeus.

Anuroctonus pococki pococki (**California swollenstinger scorpion**): This is the largest species detected during our studies and represents nearly one third of all scorpions captured. Males of this species have a distinctive bulge on the telson (terminal segment of the tail) between the vesicle and aculeus (sting).

Superstioniidae

This small family includes four genera and nine species limited to southern North America (Fet et al. 2000). Most of the species are troglobites (cave dwellers) from wet subtropical caves of Mexico, many of the species lacking eyes.

Superstitionia donensis **(Superstition Mountain scorpion):** This species, from its own subfamily *Superstitioniinae*, is widely distributed widely from New Mexico through California and into Mexico. It was the most commonly detected of the smaller scorpions and was found at all of the study sites. There are type specimens from several locations including the Superstition Mountains of Arizona; near Tucson, Arizona; near Bishop, California and San Diego County, California.

Vaejovidae
This large and diverse scorpion family consists of 10 genera, 146 species and 35 subspecies (Fet et al. 2000).

Paruroctonus silvestrii (**California common scorpion**): This species was only detected at the Little Cedar Ridge study site, but was detected in relatively large numbers for the small scorpions, being the third most frequently detected scorpion at the site. This species is known from southern California and Baja California Norte. The holotype is from Sierra Madre, Los Angeles County, California.

1 cm (8.0 x)

Pseudouroctonus andreas (**pictured**) **and *P. williamsi*:** These small scorpions were detected fewer than twenty times across the study. *P. williamsi* is typically larger bodied and darker than *P. andreas* and has the first segment of the metasoma being longer than its width in contrast to *P. andreas*. *P. andreas* is known from southern California and Baja California Norte with a holotype specimen from Andreas Canyon near Palm Springs, Riverside County, California. *P. williamsi* is known from California with the holotype specimen from Mission Gorge, San Diego County, California.

Serradigitus gertschi gertschi (**sawfinger scorpion, no pictures available**): This small scorpion was detected fewer than ten times across the study. This species is known from California, Baja California Norte and Baja California Sur with several type specimens from San Diego County, California, including the holotype from near San Ysidro.

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1 cm (2.8x)

Vaejovis puritanus: One of the larger species, this was the most frequently detected scorpion during this study and was detected at all study sites. This long, slender species is characteristically fast and active and can be difficult to capture without the use of pitfall traps or other containing device. This species is known from southwestern California, Baja California Norte and Baja California Sur. Type specimens are from Santo Tomas, Baja California Norte, Mexico and Jacumba, San Diego County, California.