

Effect of the 2013-2015 California Drought on Small Mammal Abundance and Diversity in  
Chaparral, Oak Woodland and Riparian Habitats

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## **Abstract**

Long-term biodiversity surveys are a useful tool for assessing the impacts of stochastic events on wildlife and their communities. A recent stochastic event to affect the state of California is the historic 2013-2015 drought. This drought, described as a one-in-one-thousand year event, brought precipitation to a historic low; the statewide rainfall reaching 34% below average (Swain et al. 2014). While humans are feeling the impact of this water shortage, the effects on native ecosystems and wildlife populations are poorly documented. Baseline small mammal biodiversity data collected in 2011, before the drought, allows us the opportunity to study the impacts of the drought on populations of small mammals, which are important indicators of ecosystem health. In this study, we compare small mammal abundance and diversity in chaparral, oak woodland, and riparian habitats measured before and during the drought. Here we show that there was an overall reduction in small mammal abundance and in species diversity during the drought. Not all habitat types were affected equally. The abundance of small mammals in oak woodland habitats was the most negatively affected by the drought. Abundance in chaparral habitats was least impacted by the drought, and evidence suggests that chaparral was the preferred habitat type during drought-stress conditions. While most species of small mammals declined in abundance, a few did increase, likely due to increased niche availability. These results shed light on the dramatic effects that a major drought can have on natural ecosystems, and the varied responses by different species in different habitat types. As the frequency and intensity of stochastic events increase due to climate change, it is important to understand the effects they may have on natural systems in order to better prepare and manage for them.

## **Introduction**

The Los Padres National Forest is a 1.75 million acre stretch of forest in the South Coast and Transverse Ranges within Monterey, San Luis Obispo, Santa Barbara, Ventura and Kern counties of California. Approximately 48%, or 875,000 acres, of this National Forest has been designated as wilderness areas; regions of moderately undisturbed natural habitat. The Los Padres National forest provides permanent or temporary habitat for about 468 species of fish and wildlife. It is important habitat for 23 threatened and endangered animals and an additional 20 animals that are considered sensitive. It also supports three threatened and endangered plants and 71 sensitive plant species (Forest Service n.d.). This habitat is becoming increasingly important as urbanization and agriculture continue to reduce available habitat for native and endemic species across the state.

A portion of the forest, the Santa Lucia Wilderness, consists of 18,679 acres of the Santa Lucia Mountain Range and is located inland of the cities of Arroyo Grande and San Luis Obispo, San Luis Obispo County, CA. The diverse topography of the area results in a variety of habitat types. The dominant (most extensive) habitats in the area are chaparral, oak woodland, and riparian.

We chose to conduct this study in the areas surrounding the Hi Mountain Condor Lookout (Condorlookout.org), a retired USFS fire lookout that has been restored to act as a field-research station and interpretive center. The Lookout is an important resource for researchers to access the three representative habitat types of the Santa Lucia Wilderness and provides for more intensive efforts than would otherwise be possible.

The chaparral habitat in the Hi Mountain area is characterized by woody shrubs with sclerophyllous leaves; primarily a mosaic of *Adenostoma fasciculatum*, *Ceanothus cuneatus* and

*Arctostaphylos glauca*. Most of the chaparral in the vicinity of Hi Mountain has not recently been affected by wildfire so the vegetation remains in dense stands. These stands are primarily on south facing slopes. The oak woodland habitat in the Hi Mountain area is dominated by a sparse over-story of *Quercus douglasii*, *Q. lobata* and *Q. agrifolia* and an understory of grasses dominated by *Avena spp.* and *Bromus spp.* The riparian habitat is characterized by *Q. agrifolia* and *Platanus racemosa*, an understory of grasses similar to the oak woodland habitat, and thick stands of *Toxicodendron diversilobum*.

The effects of historic wildfire on the vegetation have been studied in this area, but little is known about the affects of the California drought and its impacts on biodiversity. Since 2003, California Polytechnic State University, San Luis Obispo, along with the US Forest Service, in collaboration with the Morro Coast Audubon Society has been collecting baseline biodiversity data from the Hi Mountain area. Baseline data and continued sampling of species abundance and richness allow us to observe temporal changes in biodiversity. These observed changes can reflect more deterministic natural fluctuations in population trends (such as due to succession), or effects due to stochastic events.

A recent stochastic event to hit California is the historic 2013-2015 drought. In 2013, the statewide precipitation in California was less than 34% of average and was lower than any previous year in the 119-year observational record (Swain et al. 2014). By 2015, the cumulative rainfall deficit has been described as a one-in-a-thousand-year event (Sinclair and Krebs 2002). Long-term surveys of small mammal abundance spanning the years before and during the drought should shed some light on the effects that this major stochastic event has had on the biodiversity of the Santa Lucia Mountains. Small mammals play a major role in the ecosystem in which they live. They impact vegetation structure through consumption and dispersal of seeds,

and are important food sources for a wide variety of predator species (Converse et al. 2006). Therefore, any fluctuation in the species richness and abundance of small mammals is an important indicator of the overall biodiversity and productivity of the ecosystem.

Population growth rates in vertebrates are primarily affected by three factors: top-down control by predators, bottom-up control by food (or more generally “resource”) availability, and social interactions between competitors and conspecifics. However, bottom-up control determined by resource availability tends to be the primary and universal factor affecting vertebrate populations (Sinclair and Krebs 2002). This pattern has been reported in many studies, including a paper by Abbott et al. on the abundance of *Peromyscus boylii* which found that the population densities and distributions of rodents were related to seasonal and year-to-year availability of acorns, seeds, and berries (Abbott et al. 1999). Another small mammal study supported this conclusion as well, implicating that precipitation, habitat structure, and food resources are the ultimate environmental factors that influence population dynamics (Kuenzi et al 1999).

Precipitation and its effect on the presence of annual vegetation have been shown to affect the reproduction, and therefore population dynamics of desert rodents (Beatley 1969). This is likely applicable to Hi Mountain small mammal populations, but the effects may not be equal in all of the habitat types in the area, or across species. A study on the effects of drought on closely related tree species found that species that occur in drier, more seasonally variable habitats tended to have higher water-use efficiency than species from wetter habitats, and therefore held up better in drought-response experiments (Savage et al. 2010). Part of this drought-tolerance can be explained by differences in root structure. In a study on grassland plant species, Morecroft et al. found that deeper-rooted species tend to be more drought tolerant than

species with shallow roots (Morecroft et al. 2004.). These results suggest that habitats consisting of different plant species with varying root structure and resultant drought tolerance would have variable responses to drought. Plants in chaparral habitats are well adapted to xeric conditions. Their adaptations include a thick cuticle layer of sclerophyll on their leaves and vertical orientation of leaves to reduce water loss by transpiration. Chaparral plants also make two sets of roots; a deep tap root, and secondary growth of a mat of fine roots near the surface to collect moisture from coastal fog (Ornduff et al. 2003). These adaptations make chaparral species very drought-tolerant. Riparian species, however, are very dependent on water and tend to be lush where water is abundant, but less so where water is intermittent (Ornduff et al. 2003). Indeed, the Santa Lucia range is the transition between Black Cottonwood and Sycamore, and this transition is attributed to weather and precipitation.

Baseline small mammal abundance and diversity data was taken in the summer of 2011, before the drought began. Follow up data was taken in summer 2014 and again in summer 2015, in the middle and later years of the drought. In this study, I will compare the three years of data in order to assess the impacts of the multi-year, sustained drought on the small mammal populations in three dominant habitat types of the Hi Mountain area. I predict that overall, abundance and diversity of small mammal populations in all of the habitat types will decline across both time steps (2011-2014 and 2014-2015) resulting in an overall deficit across the span of this study. Furthermore, I predict that the decline will not be equal in each of the three habitat types. I expect that small mammals in the chaparral habitat, which contains plant species that are adapted to more xeric environments, and thus most resistant to drought stress will experience the smallest impact on their populations. I predict that small mammals in riparian habitats, consisting of highly water-dependent vegetation will show the largest decline due to the drought. I predict

that the small mammals in oak woodland habitat, which has plants that are intermediate in water needs and xeric adaptations, will show a moderate decline in abundance compared to the other two habitat types.

## **Methods**

### Experimental Design and Plot Selection

The study is based on thirty study plots in the Hi Mountain area that were randomly selected by Dr. Francis Villablanca and the first group of Hi Mountain interns in 2003. Because the experimental design and plot utilization has been consistent since 2003, the same study plots were used for the three years of this project. In 2003, a group of research students used ArcView, a geographic information system software to create a vegetation map of the Hi Mountain area of the Los Padres National Forest (Saldo 2014). Based on these maps, the researchers concluded that the three most common (based on percent coverage) habitat types were chaparral, riparian, and oak woodland, with plant communities designated following *California Vegetation* (Holland and Keil, 1995).

They then subdivided the habitats into one hectare plots and, using the query function in ArcView, eliminated any plots which were within 150 meters of a road, were straddling habitat boundaries, or which were too steep to access (Pell 2011). Out of the remaining plots, they randomly selected 25 plots in each habitat type, after confirming that they did fit the selection criteria (Pell 2011). Only the first ten plots in each habitat type were used for this study. One of the chaparral study plots, C5, that was used in 2011 and 2014 sampling was inaccessible to 2015 interns due to local suspicious activity in the area, so only the remaining nine chaparral plots were sampled in 2015.

## Data collection

Small mammal trapping took place during the summer (July-August) in 2011, 2014, and 2015. Study plots were a 3 x 3 grid with stations at 20m intervals, with the traplines that composed the grid oriented in the cardinal directions. Interns navigated to the plot center using a handheld GPS device. Once arriving at the plot center, we identified all of the nine stations and re-flagged them as needed. We cut back overgrown vegetation on some of the trails to plot centers and individual stations when necessary to access the station. Each of the 30 study plots was then trapped for three consecutive nights.

On the first night of trapping, we set out two H.B. Sherman XL traps at each station in the study plot. The traps were set open, a small handful of oats was tossed into the back of the trap and more oats were strewn in a small trail leading up to the trap entrance to lure the animals in. Dirt and leaf litter were piled on top and around the sides of the trap for thermoregulation during the night. The traps were set and baited a few hours before sunset on each of the three trapping nights.

Every station was checked soon after sunrise each morning after the nights that traps were set. Empty traps were shut and remained closed all day. Traps that contained animals were closed after the animal was removed and remained shut during the day; on the third morning the traps were removed.

Animals captured in traps were removed by holding the opening of a plastic bag tightly around the entrance to the trap, then locking the trap door in the open position and inverting the trap in one fluid motion to deposit the animal into the bag. The opening to the bag was then pinched off and the trap removed.

To weigh the animal, we dumped out any remaining bait and debris, attached a Pesola scale to the bag, measured the weight in grams, and then subtracted the weight of the bag (10g) to obtain the mass of just the animal. The rodent was then removed from the bag to identify its species and either read or attach an ear tag (fingerling – American Stamp Company) with an individual identification number. If the animal was not a recapture, and thus was unmarked, a new ear tag was administered using pliers and the number was recorded. We then recorded the animal's sex and breeding condition. Animals were released at the site of capture.

More data was needed for individuals that were identified as belonging to the genus *Peromyscus* in order to be sure of the species; for these animals we used a small ruler to measure length (in millimeters) of head and body, length of tail, length of ear, and length of hind foot. We also recorded whether or not the tail was bicolored or tufted and whether the animal was docile or not. The latter was determined by how much the animal squirmed or attempted to bite the handler.

#### Data Review

The field data was entered into a spreadsheet in Microsoft Excel. The data was reviewed for errors such as misidentified species or inconsistencies in sex or breeding conditions for the same individual on different days. The body measurements recorded in the field were used to clear up any unidentified animals in the genus *Peromyscus*. *Peromyscus californicus* was identified by weighing at least 35 grams, and having a tail length that was 130% the length of its head and body. *Peromyscus truei* was identified by having ears that are longer than the hind foot. *Peromyscus boylii* was identified by ear length shorter than their hind foot, tails that are generally slightly longer than their head and body (105%-110%), and weigh at least 18 grams.

*Peromyscus maniculatus* was identified by weighing less than 18 grams and having tails that are about 90% of their head and body length.

There were many unidentified individuals in the genus *Neotoma*. *Neotoma bryanti* was characterized as having a distinctly bicolored tail and a small body weight compared to the other species. In 2015, this species was identified by the old name *N. lepida*, a synonym for *N. bryanti*, so I combined the data and labeled it all *N. bryanti* (Patton 2008). There has also been recent taxonomic revision of *Neotoma fuscipes* (Matocq and Murphey 2007, Matocq 2002). In the field, *Neotoma macrotis* males were identified by their floretted baculum; otherwise they were recorded as *Neotoma fuscipes* (Matocq and Murphey 2007, Matocq 2002). Females were not easily identifiable in the field, so were recorded as *Neotoma sp.* However, in reviewing the data, most of the individuals captured in 2011 were *Neotoma macrotis*. I therefore binned all woodrats (other than *N. bryanti*) as *N. macrotis*. The boundary zone between these species is most often a riparian corridor, so overlap could potentially occur and should be the subject of future investigation.

## Data Analysis

### 1. Schnabel Population Estimate

Because my capture numbers were so low for most species (see below), I was not able to generate an accurate population estimate for each species individually. Instead, I combined all species in each habitat type and I used the Schnabel method to generate a population estimate and confidence intervals for the entire small mammal population in each habitat type.

The Schnabel method is an equation for population estimation using mark-recapture data that spans more than two sampling events. It solves for the estimated population size using the

relative numbers of animals captured and recaptured (see Figure 9). I then calculated 95% confidence intervals for this estimate.

I compared my population estimates to the estimates from the 2014 and 2011 data for each habitat type. I calculated the percent change over each of the two time steps (2011-2014 and 2014-2015) as well as the overall change over the entire length of the study. A graph was also created to depict the changes in population size visually.

## 2. Tabular Analysis

In order to address species level patterns (rather than plant community level) I used the minimum-number-known-alive (aka the number of unique individuals captured) to compare species abundance in each habitat across the three sampling years. I recognize the limitations of this method (Pocock et al. 2004) and use it here to demonstrate qualitative patterns. I created three tables (Tables 1, 2, 3); one for each habitat type, summarizing all the species of small mammals and the minimum-number-known-alive in the three sampling events. The total number of animals for each habitat type was calculated to provide an overall summary of population size in each habitat and for each year. I also created three graphs (Figures 6, 7, and 8) to compare these numbers visually.

Although some of the sample sizes were too small for a statistical significance test, there were some dramatic trends worth noting. I categorized the trend of changes in minimum-number-known-alive across the two time steps for each species in each habitat type and created a table (Table 5) for comparison. The qualitative trends considered were: a decline across both time steps (D); a decline to local extinction in either 2014 or 2015 (Ex); an initial decline in the first time step followed by a secondary increase in the second time step (SI); and a haphazard

change or random trend (H). Individual species patterns were thus placed into one of these trends.

Figures were also made depicting the number of animals captured and recaptured on each night (Figure 3, 4, and 5) in order catch any potentially unusual patterns, such as a preponderance of trap shy animals on night two or three.

## **Results**

### Overall abundance by habitat

In 2011, the population estimate ( $N$ -hat) for chaparral habitat species pooled was 173.53 individuals with a 95% confidence interval (C.I) of 159.91 to 194.03; in 2014  $N$ -hat was 48.39 (95% C.I. 44.07-58.83); in 2015, the population estimate was 71.11 (95% C.I. 48.66-131.94). There was a 72% decline from 2011 to 2014 and then a 47% increase from 2014 to 2015. There was an overall decline of 59% from 2011-2015.

In 2011, the population estimate for oak woodland species pooled was 237.64 (95% C.I. 220.57-262.27); in 2014 it was 47.20 (95% C.I. 42.96-57.52); in 2015, it was 86.63 individuals (95% C.I. 61.43-146.89). There was an 80% decline from 2011 to 2014 but then an 84% increase from 2014 to 2015. The overall decline from 2011-2015 was 64%.

In 2011, the population estimate for riparian species pooled was 229.79 (95% C.I. 213.13-253.93); in 2014 it was 60.32 (95% C.I. 55.16-71.89); and in 2015 it was 47.65 (95% C.I. 31.93-93.86). There was a 74% decrease from 2011 to 2014 and an additional 21% decrease from 2014 to 2015. Overall, there was a 79% decline from 2011-2015.

Thus, when we consider all species across all habitat types in the Hi Mountain area, there was a dramatic decrease in population size, approximately 75-80%, in the first time step (2011-

2014). In the second time step (2014-2015), there was a secondary increase in the population size in chaparral habitats (47%), and a larger secondary increase in oak woodland habitats (84%). In riparian habitat, the population size continued to decline (21%) in the second time step. The overall deficit from 2011-2015 is about 60-80% across all three habitat types (see Figure 2).

#### Trends in species richness by habitat

The summary of species richness by habitat type is presented in Table 4. In riparian and oak woodland habitats, there was a decline in species richness across each time step (2011-2014 and 2014-2015). The largest decline in species richness occurred in the oak woodland habitat. In chaparral habitat, there was an increase in species richness across both time steps.

#### Trends in species abundance by habitat

The species abundance in each habitat type is summarized by Tables 1, 2, and 3 and is represented visually in Figures 6, 7, and 8 respectively. The trends over time for each species in each habitat type are categorized in Table 5. The trends identified overall were: a species declines across both time steps (D); a decline to local extinction in either 2014 or 2015 (Ex); an initial decline in the first time step followed by a secondary increase in the second time step (SI); and a haphazard change or random trend (H).

In the riparian habitat, two species declined (*P. boylii* and *P. californicus*); four species declined to extinction by 2015 (*N. macrotis*, *M. californicus*, *P. maniculatus*, and *R. megalotus*); *N. bryanti* had a haphazard trend; and 2 species had a secondary increase (*C. californicus*, and *P. truei*). However, *P. truei* had a very small increase compared to *C. californicus*.

In oak woodland habitats, three species declined (*N. macrotis*, *P. boylii*, and *P. californicus*); six species declined to extinction (*D. venustus*, *N. bryanti*, *M. californicus*, *P. maniculatus*, *P. truei* and *T. merriami*); *D. heermanni* had a haphazard trend; and two species

had a secondary increase (*C. californicus* and *R. megalotus*). However, *R. megalotus* had a very small increase compared to *C. californicus*.

In chaparral habitats, three species declined (*C. californicus*, *D. venustus*, and *P. californicus*); one species declined to extinction (*P. maniculatus*); and five species had secondary increases (*D. heermanni*, *N. bryanti*, *N. macrotis*, *P. boyllii* and *P. truei*). However the increases in *D. heermanni*, *N. bryanti* and *P. boyllii* were very small compared to the substantial increases in *P. truei* and *N. macrotis*.

The oak woodland habitat had the largest number of species to decline or go extinct and the smallest number of species showing a secondary increase (9:2). Riparian was the intermediate habitat type (6:2). Chaparral had the lowest number of species to decline or go extinct and the largest number of species showing secondary increases (4:5).

## **Discussion**

I hypothesized that the total small mammal populations in Hi Mountain would decrease across both time steps in all habitat types in response to the historic California drought. The estimate total population did show an overall decline from 2011-2015 in all habitat types; however, contrary to my hypothesis, there was actually an increase in the total estimated population size in the second time step, 2014-2015, for both chaparral and oak woodland habitats. Comparisons of minimum-number-known-alive for individual species in each of the three habitats revealed that while most species had significant declines in abundance, several showed a secondary increase from 2014 to 2015. These trends sometimes varied with habitat type within a particular species. Overall, populations in the chaparral habitats were the least

negatively affected, as predicted. However, the habitat type that was the most negatively affected was oak woodland, which was not predicted (riparian was the predicted community).

### Population estimates

The population estimates for all species combined calculated from mark-recapture data revealed that overall, from the pre-drought, baseline year (2011) to the end of the drought (2015) there was a dramatic reduction in total small mammal populations in all three habitat types. The overall percent declines ranged from 59-79% (average 67.33%). The largest overall decline in population size was in the riparian habitat (79%) and the smallest decline was in chaparral habitat (59%); the oak woodland decline was intermediary (64%). This is the pattern that was predicted due to the characteristically drought-tolerant physiology of chaparral plants and the water dependency of riparian plant species.

However, it is interesting to note the differences in the changes when each time step is observed independently. In the first time step, 2011-2014, there was a 75-80% decrease in the total estimated population size in all three habitats. In the second time step, 2014-2015, the changes were much more variable. The small mammal population in riparian habitats continued to decline in the second time step (21% from 2014), but in chaparral and oak woodland habitats, there was actually an increase (47 and 84% respectively). The secondary increase in the total population size was not the expected trend and was not predicted.

A possible explanation may be the fact that rainfall data from the Salinas Dam Station near Hi Mountain in Santa Margarita, CA indicates a slight increase in precipitation from 2014 to 2015 (see Figure 10). Though this slight increase (only 2.90cm) is still well below average for the area, it may have yielded a slight increase in the food availability for these animals, and some relief from bottom-up population regulation. However, the increase is so slight, and not

necessarily representative of rainfall at the exact study location, so we can not draw a definitive conclusion based on this information.

Another possible explanation is due to the fact that the population estimates were calculated using different methods in 2014 than the methods used in the other two years. In 2011 and 2015, the population sizes were estimated using the Schnabel equation for mark-recapture data. In 2014, the program MARK was used to estimate population size. Because of the difference in methods, the comparison between 2014 and 2015 may be inaccurate. However, because the same methods were used in 2011 and 2015, the overall change in population size from pre-drought to end-of-drought years is still valid, and reveals a significant decline.

### Species richness

By 2015, both oak woodland and riparian habitats showed a sharp decline in species richness, each losing approximately half of the species observed in the pre-drought baseline year. On the other hand, the number of species encountered in chaparral habitats increased in each time step. This increase suggests that these species previously occurred in other habitats, but during the drought, began to use chaparral habitat instead. The former habitats used by these species may have experienced a greater reduction in habitat quality due to drought stress than chaparral. Chaparral plant species are characteristically very drought tolerant, therefore the food and cover provided by these plants would have remained relatively abundant. Indeed, the cover in this plant community would have been the most static given the shrubby nature of the community overall. These results suggest that during drought conditions, chaparral habitat is the preferred habitat for small mammals, even those that rarely occur in chaparral during average rainfall years. This conclusion is further supported by the fact that in 2011, chaparral had the lowest species richness, but in 2015, not only had the species richness increased in chaparral, it

was higher than the species richness in either of the other two habitats. It is unknown whether this shift towards chaparral habitats is due to a greater availability of food or cover, or if it is due to other factors. Another potential consideration is the fact that recent research has shown that many mammal species have shifted their ranges to higher elevations in response to global warming (Rowe et al. 2010). Overall, the chaparral habitat studied was on hillsides at higher elevations than both oak woodland and riparian habitats, so this phenomenon may be playing a role in the shift of populations toward chaparral habitat. Further investigations assessing the weight of these many potential factors are necessary to determine the likely cause.

#### Trends in species abundance by habitat

Due to the low trap success for most of these species, I was not able to calculate accurate population estimates for individual species. Instead, I compared the minimum-number-known-alive for each species in each habitat. While minimum-number-known-alive is theoretically proportional to the population size, it is generally an underestimate of the true population size (Pocock et al. 2004). However, because it is proportional, it offers a precise comparison between years (McKelvey 2001). Because the study question is relative in nature, precision is more important than accuracy, so this metric is valuable in assessing trends across the years.

*Peromyscus sp.* was included in the species counts and in the graphs and trend table. This category does not represent a separate species; rather, it reflects potential noise in the other four species in the genus *Peromyscus*. These individuals were not identifiable to species in the field (due to young age) and may potentially belong to the species *Peromyscus boylii*, *P. californicus*, *P. maniculatus*, or *P. truei*.

Overall, species abundance in riparian habitats was negatively affected during this drought. Most of the species declined in abundance (66.7%), and almost half fell to extinction

(44%). This decline in so many of the original species suggests that riparian habitats around Hi Mountain were seriously degraded during the drought years. There were two species that experienced increases during the drought (*C. californicus*, and *P. truei*). The increase in *P. truei* was very small (1 individual), and may be variable due to the unidentified *P. sp.* The increase in *C. californicus* was much larger. The characteristic cheek pouches of *C. californicus* may allow it to be a more effective forager than any of the other species, and thus outcompete other species when food availability is low. Alternatively, this trend may suggest that *C. californicus* is capitalizing on the increase in niche availability due to the decline and extinction of so many other species. This trend may be caused by a combination of these two factors.

A large majority of the species in oak woodland habitats declined in abundance (75%), and half (50%) of them were not present at all in 2015 traps. These widespread declines shared by so many species suggest serious drought stress in oak woodland habitats. Seeds from the herb and grass-dominant understory of oak woodlands are usually an important food supply for small mammals. Plants with shallower roots, such as oak understory species, have been shown to be less resistant to drought (Morecroft 2004). Declines in species abundance, and an inferred pattern of plant drought stress suggest that bottom-up control is an important factor regulating small mammal populations. There were two species that increased in abundance in oak woodlands (*R. megalotus* and *C. californicus*). The increase in *R. megalotus* was very small, and may be due to low detection probability. The increase in *C. californicus* abundance was very large and actually surpassed the pre-drought numbers from 2011. This is likely due to a huge increase in niche availability due to the dramatic reduction of all other species in oak woodlands.

Chaparral had the fewest species declines, with only one species going extinct (*P. maniculatus*). However, only one individual *P. maniculatus* was captured in each previous year,

so the lack of them in 2015 could be due to low trapping success, or it may be variable due to the noise reflected in the *P. sp.* category. The majority of species found in chaparral habitats showed an increase (55.6%), and this was the habitat with the most increases. Three of these five species (*P. boylii*, *D. heermanni*, and *N. bryanti*) were not present in chaparral before the drought. Though this may be due to low trapping success, it also may suggest that drought-tolerant chaparral plants provide preferable habitat during dry years. Certainly these trends reveal that chaparral was the habitat that experienced the least negative effect due to the historic California drought.

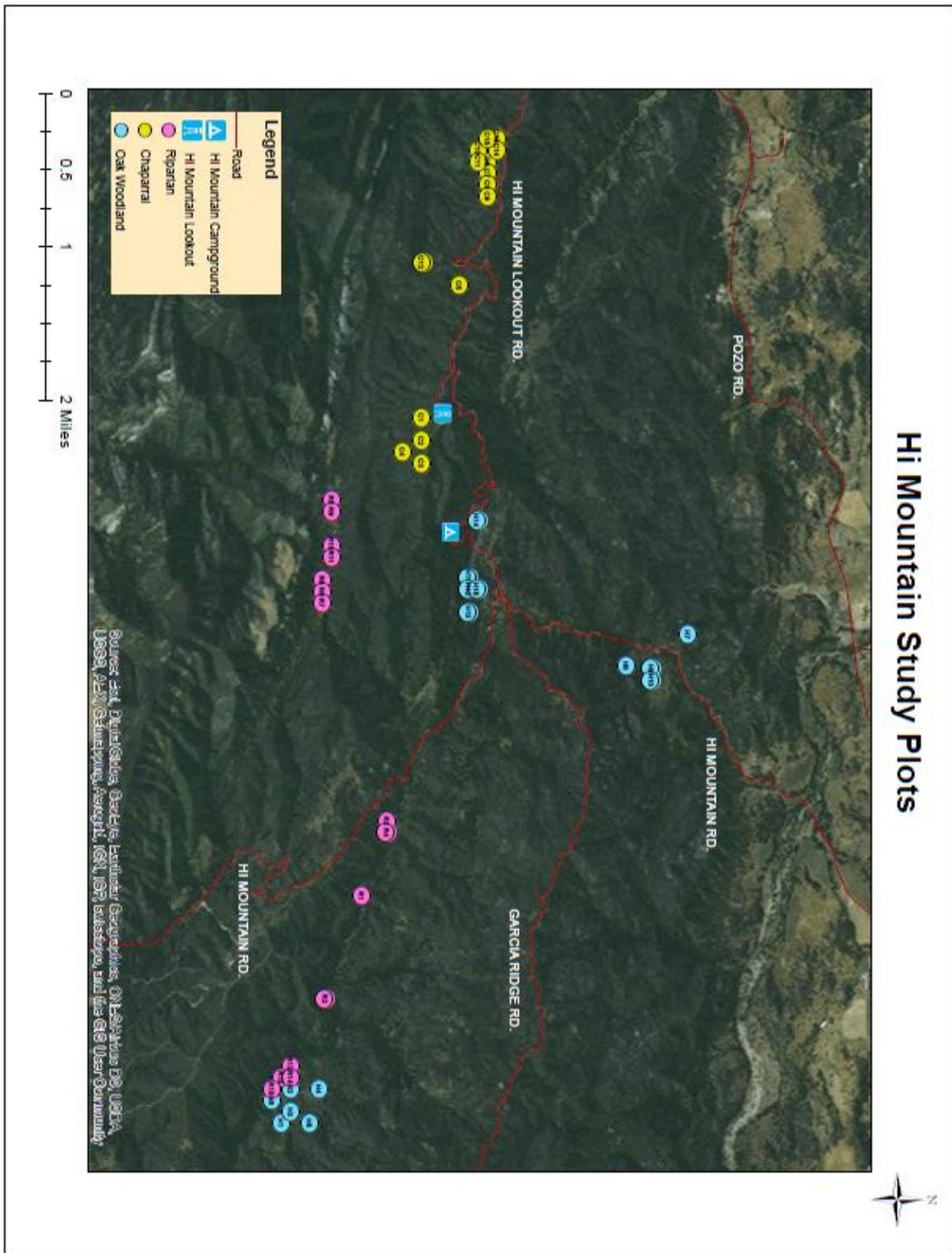
#### Future investigations

Long-term biodiversity surveys are incredibly important for demonstrating fluctuations in ecosystem diversity and health in response to temporal variation in the environment. In this study, monitoring the biodiversity in the Hi Mountain area of the Santa Lucia Mountains from 2011-2015 has allowed us to compare trends in small mammal abundance in the context of the historic California drought. Increases in rainfall due to El Niño conditions in 2016 have brought the drought pattern to an end (or closer to an end). Small mammal data collected in 2016 will be very important in assessing the ability of these ecosystems to recover after a drought. Though our study range was relatively small, these results may be informative of the effects of the drought on small mammal populations in similar environments. These results shed light on the varying degrees to which a major drought affects populations of small mammals in different habitats. Stochastic events such as this drought are increasing in frequency and intensity due to climate change (Swain 2014). Thus, it is increasingly important to understand the effects these events will have on our native ecosystems. Further investigations on a variety of different ecosystems and taxa would be valuable. This kind of research can help inform management decisions by

providing information about which species and habitat types may be the most vulnerable to stochastic events. This would allow us to better manage and conserve important biodiversity.

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**Figure 1.** Updated map of Hi Mountain study plots in riparian, chaparral, and oak woodland habitats made in ArcMAP 10.2.2 by Elizabeth Saldo with the assistance of Robert Vaughan.

Species	2011	2014	2015
<i>Peromyscus boylii</i>	0	2	2
<i>Peromyscus truei</i>	31	4	10
<i>Peromyscus maniculatus</i>	1	1	0
<i>Peromyscus californicus</i>	0	0	12
<i>Peromyscus sp.</i>	1	3	1
<i>Dipodomys heermanni</i>	0	0	1
<i>Dipodomys venustus</i>	7	4	1
<i>Chaetodipus californicus</i>	20	11	6
<i>Neotoma bryanti</i>	0	0	2
<i>Neotoma macrotis</i>	41	7	15
<b>Total individuals</b>	135	47	50

**Table 1.** Summary of species caught in Chaparral habitat plots in each year of surveys. Values are number of individuals.

Species	2011	2014	2015
<i>Peromyscus boylii</i>	33	17	15
<i>Peromyscus truei</i>	40	0	0
<i>Peromyscus maniculatus</i>	11	0	0
<i>Peromyscus californicus</i>	32	5	4
<i>Peromyscus sp.</i>	7	5	2
<i>Dipodomys venustus</i>	2	0	0
<i>Dipodomys heermanni</i>	0	1	0
<i>Chaetodipus californicus</i>	30	8	40
<i>Neotoma macrotis</i>	10	5	1
<i>Neotoma bryanti</i>	5	1	0
<i>Microtus californicus</i>	7	0	0
<i>Reithrodontomys megalotus</i>	5	0	1
<i>Tamias merriami</i>	1	1	0
<b>Total individuals:</b>	183	43	63

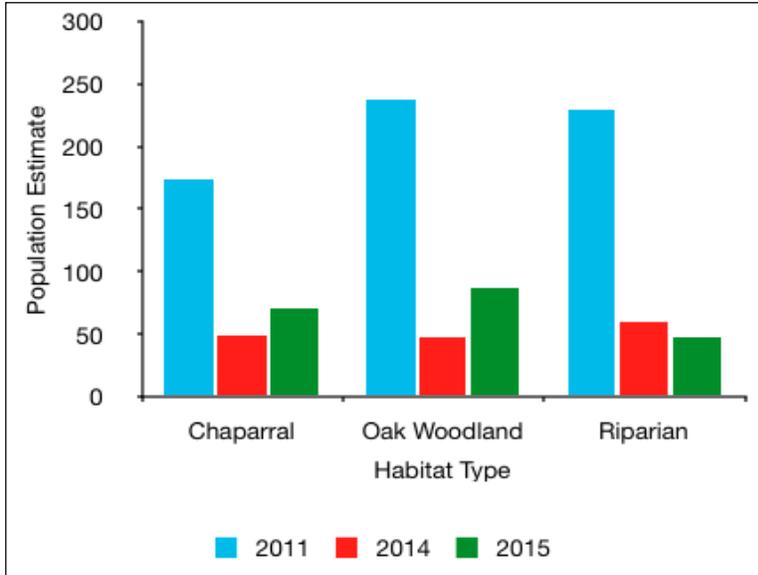
**Table 2.** Summary of species caught in Oak Woodland habitat plots in each year of surveys. Values are number of individuals.

Species	2011	2014	2015
<i>Peromyscus boylii</i>	63	28	17
<i>Peromyscus truei</i>	4	0	2
<i>Peromyscus maniculatus</i>	17	0	0
<i>Peromyscus californicus</i>	29	4	4
<i>Peromyscus sp.</i>	5	10	1
<i>Chaetodipus californicus</i>	17	3	14
<i>Neotoma macrotis</i>	17	3	0
<i>Neotoma bryanti</i>	5	10	1
<i>Microtus californicus</i>	3	1	0
<i>Reithrodontomys megalotus</i>	13	0	0
<b>Total individuals:</b>	173	59	39

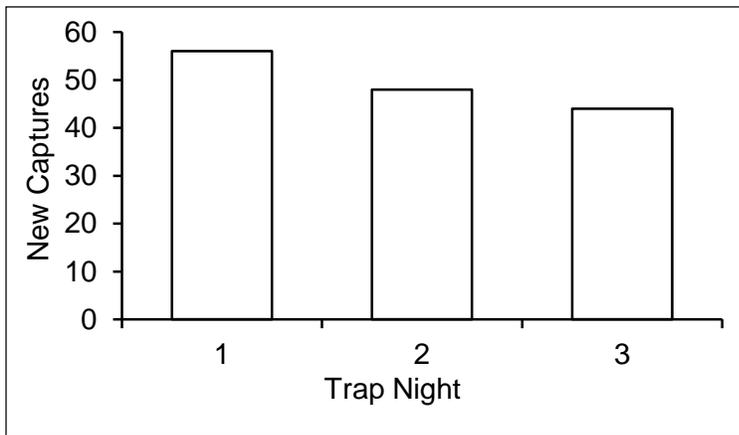
**Table 3.** Summary of species caught in riparian habitat plots in each year of surveys. Values are number of individuals.

Habitat type	2011	2014	2015
Riparian	9	6	5
Chaparral	5	6	8
Oak Woodland	11	7	5
<b>Habitats Combined</b>	11	10	9

**Table 4.** Comparison of species richness by habitat each year, as well as total species richness across all habitats.



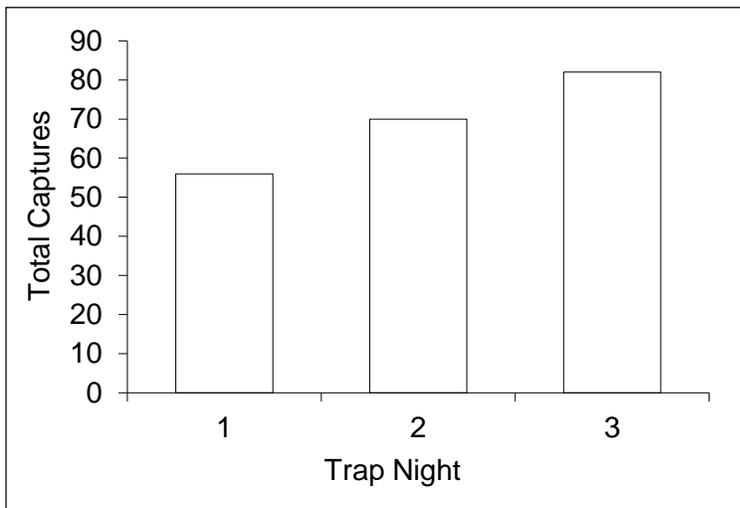
**Figure 2.** Population estimates for each habitat type by year. Blue bars represent summer 2011, red bars represent summer 2014 and green bars represent summer 2015.



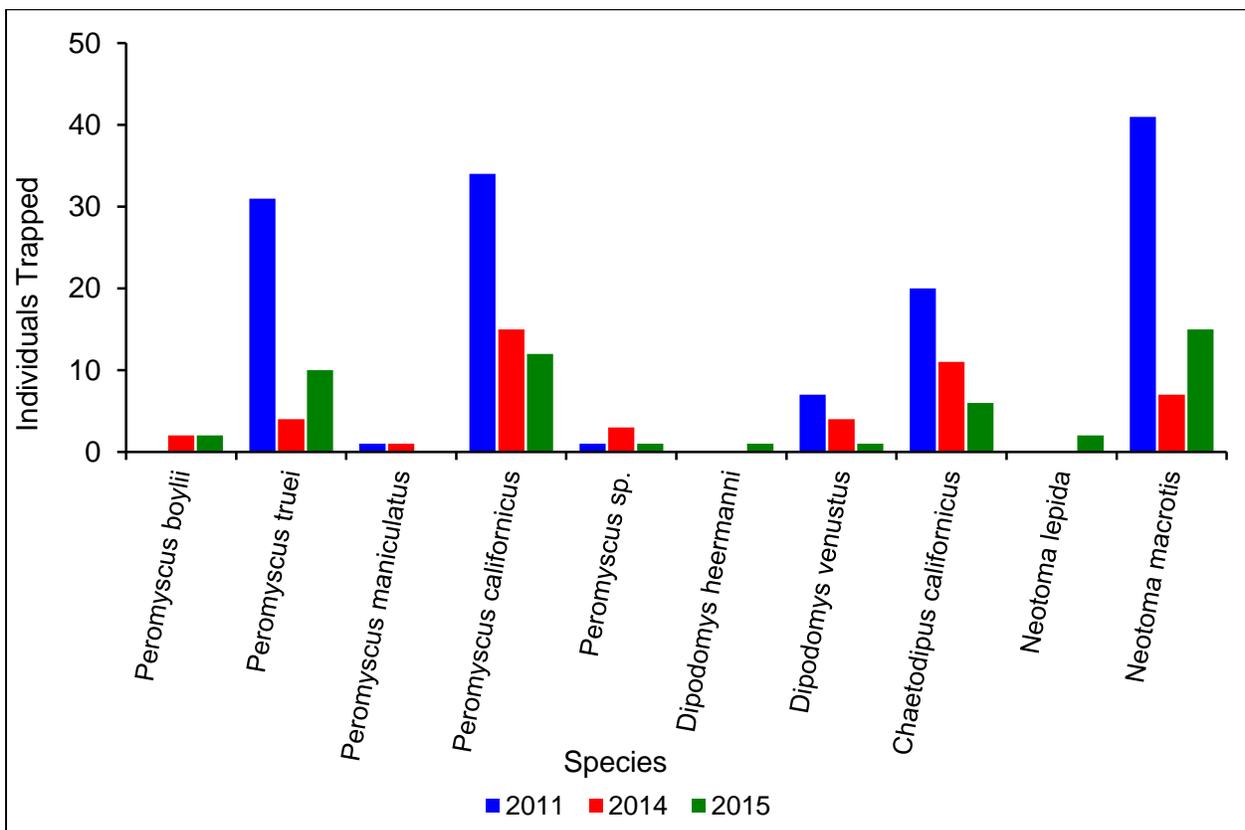
**Figure 3.** Number of new captures in 2015 across all plots combined per trap night.



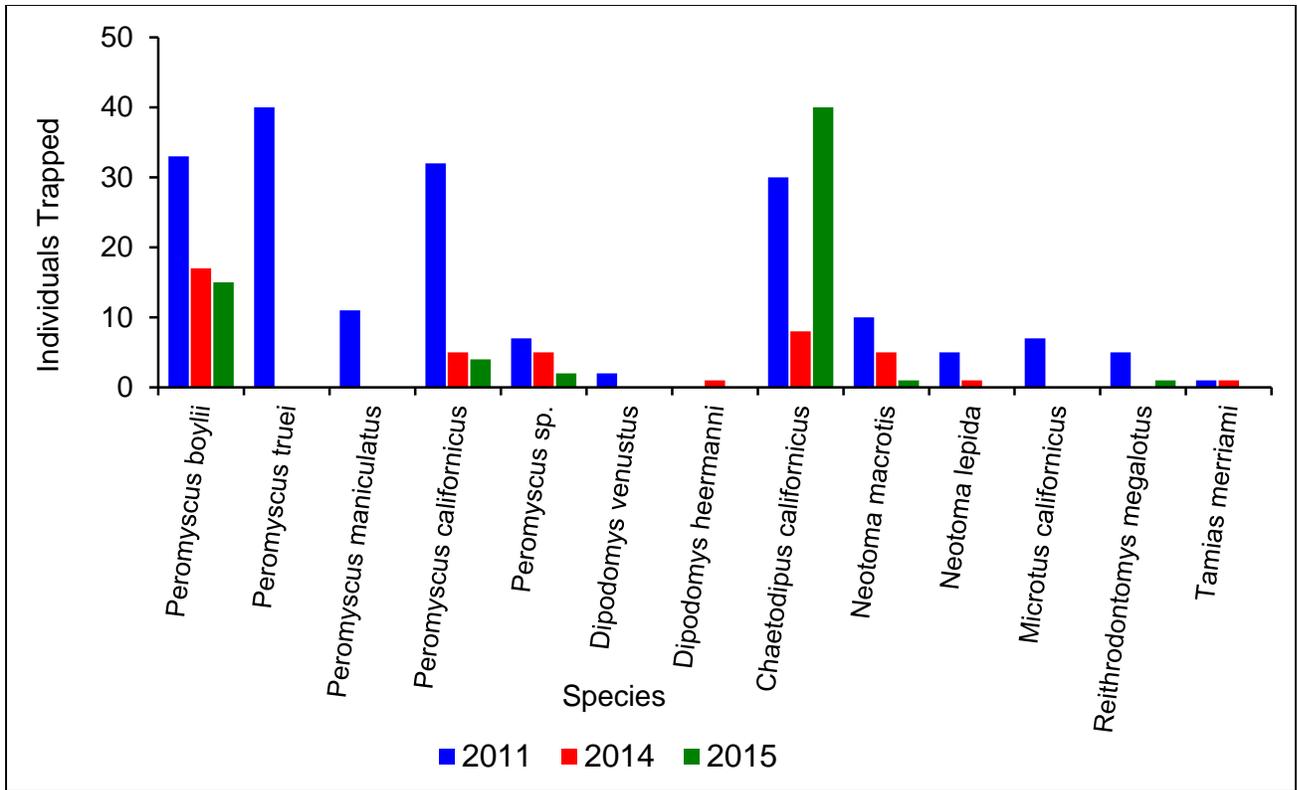
**Figure 4.** Number of 2015 recaptures across all plots on the second and third trap nights.



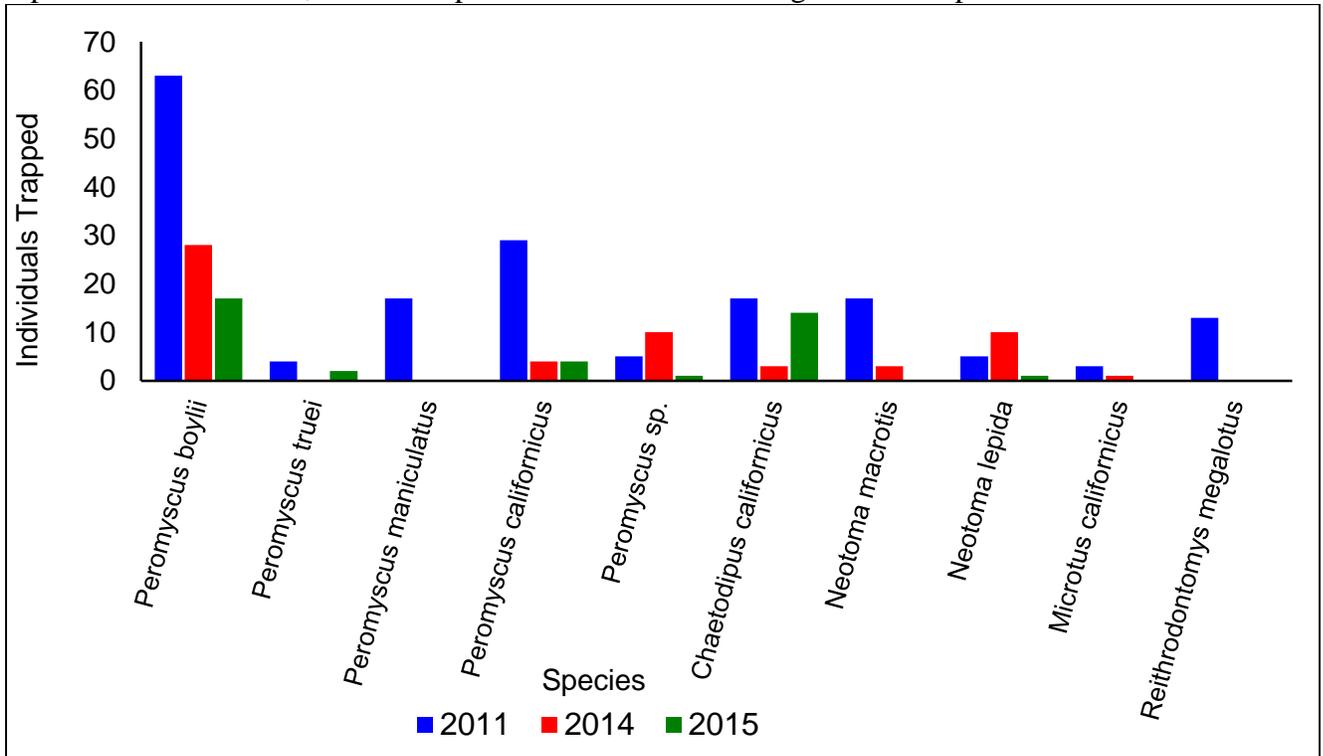
**Figure 5.** Number of total 2015 captures across all plots per trap night. Trap Night 1 represents captures and Trap Nights 2 and 3 represent captures and recaptures combined.



**Figure 6.** Number of individuals per species captured in Chaparral plots. Blue bars represent summer 2011, red bars represent summer 2014 and green bars represent summer 2015.



**Figure 7.** Number of individuals per species captured in Oak Woodland plots. Blue bars represent summer 2011, red bars represent summer 2014 and green bars represent summer 2015.



**Figure 8.** Number of individuals per species captured in Riparian plots. Blue bars represent summer 2011, red bars represent summer 2014 and green bars represent summer 2015.

Species	Riparian	Oak Woodland	Chaparral
<i>Chaetodipus californicus</i>	SI	SI	D
<i>Dipodomys heermanni</i>	N	H	SI
<i>Dipodomys venustus</i>	N	Ex	D
<i>Neotoma bryanti</i>	H	Ex	SI
<i>Neotoma macrotis</i>	Ex	D	SI
<i>Microtus californicus</i>	Ex	Ex	N
<i>Peromyscus boylii</i>	D	D	SI
<i>Peromyscus californicus</i>	D	D	D
<i>Peromyscus maniculatus</i>	Ex	Ex	Ex
<i>Peromyscus truei</i>	SI	Ex	SI
<i>Peromyscus sp.</i>	H	D	H
<i>Reithrodontomys megalotus</i>	Ex	SI	N
<i>Tamias merriami</i>	N	Ex	N

**Table 5.** Summary of the ‘minimum-number-known-alive’ population trends by species and habitat. ‘D’ indicates a decline in the minimum-number-known-alive of that species across each time step; ‘Ex’ indicates that the number declined to local extinction in that habitat in either 2014 or 2015; ‘SI’ indicates that the number of individuals decreased in the first time step (2011 to 2014) but had a secondary increase in 2015; ‘H’ indicates a haphazard change, or no real trend; ‘N’ indicates that the species was never present in that habitat.

$$N = \frac{\sum_{i=1}^m M_i C_i}{\sum_{i=1}^m R_i}$$

**Figure 9.** The Schnabel equation used for population estimates based on mark-recapture data with more than two mark-recapture events. Image from Olmos 2013, <http://www.ipedr.com/vol68/005-ICLLL2013-A00017.pdf>

Station Name and no.		Salinas Dam # 719												*** All units are in inches ***	
Water Year	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	Total		
2015-2016	0.94	0.00	0.00	0.00	1.30	1.38	5.78	0.71							
2014-2015	0.00	0.00	0.00	1.02	0.39	3.98	0.20	2.32	0.00	0.55	0.12	0.00	8.58		
2013-2014	0.00	0.00	0.00	0.08	0.04	0.16	0.00	4.17	2.17	0.83	0.00	0.00	7.44		
2012-2013	0.00	0.00	0.00	1.02	1.89	4.72	1.14	0.39	0.67	0.00	0.28	0.00	10.12		
2011-2012	0.00	0.00	0.00	1.34	2.91	0.12	2.32	0.31	2.92	2.60	0.00	0.00	12.52		
2010-2011	0.00	0.00	0.00	1.42	2.24	11.26	2.17	4.65	7.17	0.12	0.83	0.55	30.39		
2009-2010	0.00	0.00	0.51	5.63	0.00	4.37	8.15	4.41	1.06	3.11	0.20	0.00	27.44		
2008-2009	0.00	0.00	0.00	0.08	0.55	0.94	0.24	2.01	0.94	0.31	0.04	0.12	5.24		
2007-2008	0.00	0.04	0.00	0.47	0.08	1.65	5.12	1.34	0.04	0.04	0.00	0.00	8.78		
2006-2007	0.08	0.08	0.08	0.16	0.04	1.73	0.98	3.19	0.16	0.39	0.00	0.00	6.89		
2005-2006	0.00	0.00	0.16	1.26	0.28	2.68	6.06	2.09	5.20	5.16	1.10	0.00	23.98		

**Figure 10.** Rainfall data from the Salinas Dam Station near Hi Mountain in Santa Margarita, CA. In the 12 months before the 2011 season of trapping (July 2010-June 2011) there was 30.39 inches (77.19 cm) of rain. In the 12 months before the 2014 trapping season there was 7.44 inches (18.90 cm) of rain. In the 12 months before the 2015 trapping season, there were 8.58 inches (21.79 cm) of rain. Data provided by the San Luis Obispo County Public Works recording rain station (<http://www.slocountywater.org/weather/alert/precipitation/pdf/719%20Salinas%20Dam%20Precipitation%20Data.pdf>).

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