# Project Report 2015

## An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County

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## EXECUTIVE SUMMARY

We report on the fifth year's progress in a multi-year program with the goal of developing a strategy to support the recovery of Western burrowing owls (BUOW; *Athene cunicularia hypugaea*) and their grassland ecosystem in San Diego County. Current BUOW management is dependent on continued human intervention and may not be self-sustaining. Because the California ground squirrel (*Otospermophilus beecheyi*) is a keystone species that helps engineer California grassland ecosystems and provides critical resources for BUOW, re-establishment of this species is a crucial component of any sustainable recovery plan for BUOW and the larger ecosystem.

The main components of the program in 2015 consisted of work on both BUOW and California ground squirrel. For squirrels, we continued monitoring two previously established studies: (1) the experimental manipulation of grassland habitat structure and squirrel translocation to better support the persistence of ground squirrels, and (2) a pilot manipulation of natural squirrel dispersal into newly grazed pasture, using the addition of cover piles to attract squirrels into unoccupied habitat. In 2015, BUOW efforts continued to focus on understanding the ecological drivers and anthropogenic threats influencing BUOW population performance in San Diego County, as well as development of a new habitat suitability model for BUOW. These efforts were conducted collaboratively with California Department of Fish and Wildlife, San Diego Management and Monitoring Program, and other agency partners.

**Replicated experimental squirrel translocations and vegetation structure management**. The re-establishment of ground squirrel populations on potential recovery sites for BUOW was the focus of our first three years of management by science, and reported on in detail previously. We implemented a squirrel translocation program employing soft-release protocols that address ecological needs and species life-history characteristics, and manipulated vegetation structure at three sites: Rancho Jamul Ecological Reserve, the Sweetwater parcel of the San Diego National Wildlife Refuge, and Lonestar Ridge West Mitigation parcel on Otay Mesa.

The results have consistently shown that the combination of squirrel translocation and vegetation treatment together supports higher levels of squirrel activity than the use of either management strategy alone. Within the squirrel release plots, mowed areas had large numbers of burrows, whereas few squirrel burrows were located in the unmowed control sub-plots. Apparently, the conditions produced by mowing encouraged squirrels to colonize treated areas. However, this was only the case at translocation release plots; when no squirrels were released, few squirrel burrows were found in the mowed plots. Although the 4$^{th}$ year of the experiment was marked by declining numbers of burrows in all plots, the significant treatment interaction persisted.

Squirrel observations indicated that of the four pairs of plots initiated in 2011, two appear unused in the past year. For the two persisting plots (both at RJER), higher numbers of

individuals were detected in 2015 compared to 2014, and the burrows on the plots showed signs of recent digging activity. Of the two pairs of plots initiated in 2012, ground squirrel colonies not only persisted, but they were more successful at three years post release when compared with the 2011 plots.

The declines in squirrel burrowing activity suggested that the end of active translocation and mowing has either impacted squirrel numbers, or impacted habitat suitability for squirrels through vegetation structure, or both. The finding through observations and retrapping of persistent squirrel numbers indicates that squirrels are present, and suggests that current fluctuations in vegetation structure as grazing is established may be having an impact on squirrel activity. Inter-annual variation in climatic factors and predation pressure may also influence squirrel populations.

**Pilot study for encouraging natural squirrel dispersal.** Following the implementation of grazing at Rancho Jamul, we monitored the creation of burrows on the periphery of a large squirrel colony. Baseline conditions were characterized by thick invasive grasses not favored by squirrels, which were opened up by grazing. In the second season of monitoring, the total number of burrows detected within the transects was similar to 2014. However, there was a pattern of increasing density within the woodpile transects nearest to the source population. The evidence shows moderate levels of dispersal and burrow creation following grazing, and moderate support for the hypothesis that provision of cover for predator evasion increases colonization. The second year of monitoring confirmed that BUOW habitat may be created slowly through vegetation management alone, provided a large enough colony of squirrels is in close proximity.

**Baseline monitoring of BUOW population dynamics to inform management strategies for San Diego County.** Three principle studies have been implemented since 2013: (1) BUOW nesting and foraging ecology, using camera traps to monitor reproduction, survival, and prey delivery at nest burrows and data loggers to monitor microclimatic conditions at natural and artificial burrows; (2) BUOW population ecology using leg bands and DNA analysis for individual identification; and (3) BUOW spatial ecology using GPS data loggers to monitor home range movements during the breeding season. These studies were selected to work in combination so that the sum of the results can provide greater insights than if they were each conducted in isolation.

In 2015, we monitored 37 nesting attempts, and again found that fledging success was variable across our study sites. Reproductive success (in terms of numbers fledged) was lower in 2015 compared to 2013, but the differences between all three years of systematic monitoring were not significant. The potential continuing downward trend in population performance needs to be monitored, particularly in light of the continuing drought conditions. There was no single leading cause of juvenile mortality; infanticide (a potential indicator of food limitation) and depredation each accounted for about half of the mortality seen in camera trap photos. Productivity (both in terms of the maximum number of emergent chicks and the number fledged) was positively related to the number of prey deliveries per day and negatively related to the proportion of invertebrates delivered. Food limitation is likely driving variation in reproductive success and occurrences of infanticide.

These results are consistent with past years and point to management opportunities that focus on improving habitat and prey base. Additional productivity data gathered in 2016 will help to assess the impact of the habitat changes occurring at Lonestar.

While we did not find a statistically significant difference between natural and artificial burrows in the maximum numbers of chicks or fledglings in 2015, we found that natural burrows had a significantly higher fledging rate than artificial burrows when data were combined across years (2013-2015). We also found that burrow microclimate differed by burrow type with natural burrows buffering against fluctuating outside conditions better than artificial burrows. Architectural differences between natural and artificial burrows may account for the differences in microclimate, but our results from 2015 remain inconclusive. A field experiment testing different burrow designs and comparing the conditions to natural burrows will be conducted in 2016. We speculate that differences in microclimate and their effects on egg and/or chick survival may be contributing to differences in reproductive output and will further investigate this hypothesis in 2016.

Our on-going banding effort has allowed us to document movements, site fidelity, recruitment, survival, and other facets of BUOW population dynamics and natural history. We used parameter estimates we obtained from band resighting to conduct a population viability analysis which indicated that the Otay Mesa BUOW population is operating as a sink. Current reproduction and survivorship are insufficient to sustain the population without high levels of immigration. Management efforts to establish multiple viable population nodes in San Diego County are imperative to prevent the extirpation of this species. These results are discussed further in the draft Implementation Plan. In 2015 as an in-kind contribution, we initiated genetic analyses of blood and feather samples collected in 2013 and 2014. Through genetic sexing, we confirmed the sexes of 48 birds and identified the sexes of 76 birds. We examined sex ratios and found no effect of year or burrow type on sex distribution in chicks. Parentage analysis allowed us to confirm the family groups identified in the field as well as elucidate information about unbanded parents and multi-year breeding pairs. In addition, genetic analyses also demonstrated that the BUOW in San Diego are generally seasonally monogamous, as we found no evidence of extra-pair copulations. We examined the heterozygosity and inbreeding coefficient of the Otay Mesa BUOW population and compared these values to published results of populations in other locations. We found a comparable amount of heterozygosity to other populations and low inbreeding indicating there is a healthy amount of immigration and emigration.

Our GPS results and home range estimates for 2015 were similar to those of 2014; we found that 90% of all locations were within 660 m of the respective burrow. These results illustrate the importance of the habitat immediately surrounding the breeding burrow both in terms of its foraging quality and the potential hazards to BUOW. The siting of artificial burrows, habitat restoration, and other management activities should take into account the habitat, food availability, and risks of disturbance or other negative impacts to BUOW within a small (500-600 m radius of breeding burrow) spatial scale. The high degree of philopatry exhibited by BUOW (evidenced by our band resights and a male that was tracked in both 2014 and 2015) highlight the importance of understanding BUOW spatial ecology when siting artificial burrows and when using passive relocation as a mitigation measure.

**Development of a new habitat suitability model for BUOW.** Evaluating and identifying potential BUOW recovery nodes is critical since the breeding population has been reduced to a single small population, posing considerable risk of local extinction in San Diego County. Additional sites could help lower this risk and help increase BUOW population size. In 2015, a landscape-scale habitat suitability model was developed for San Diego County. Based on occupancy records in publicly available databases, the model indicates that BUOW are recorded more frequently in lower elevation sites with warmer and drier spring conditions. They are also found in sites with higher land area of coastal sage scrub, grassland, and agricultural land uses at 1 km scale. The suitability model indicates that suitable habitat conditions (based on climatic, topographic, and land use factors) should be abundant across western San Diego County. However, most of these areas have already been developed. The model shows that only a small proportion of existing conserved parcels contain suitable conditions for BUOW. Further details and maps are provided and discussed in the draft Implementation Plan report.

**Draft Implementation Plan for BUOW.** The development of a conservation strategy and research plan is essential to address the complex and numerous threats to BUOW and provide an integrative tactical solution to achieve a stable and viable BUOW population in this region. Much data has been collected over the last 5 years through this collaborative adaptive management and research program. This year represented a transition towards applying the findings and lessons learned from our research activities to the development of a management plan. In conjunction with this annual report, we have developed a draft Implementation Plan for BUOW as a separate document. The plan includes population viability estimates, key factors for establishing new breeding sites, optimal relocation techniques for both ground squirrels and BUOW, critical areas within the MSCP needed for protection, comparisons of management strategies, and management recommendations. We expect further advancement and refinement of the Implementation Plan in 2016.

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## INTRODUCTION

The native grasslands of the western United States, and California in particular, are among the most endangered ecosystems in the temperate world (Samson & Knopf 1996). In California approximately 90% of species listed in the Inventory of Rare and Endangered Species can be found in grasslands (Barry et al. 2006). Grasslands support both high wildlife abundance and diversity and are one of the signature ecosystems of the west. In California, 86% of grasslands are held in private ownership because they are so favorable for human uses such as grazing, agriculture and housing developments (Davis et al. 1998). It is not surprising then that the remaining grasslands support a number of species of conservation concern. One of California's more notable grassland species is the charismatic and highly visible western burrowing owl (*BUOW, Athene cunicularia hypugaea*). Another prominent grassland species, the California ground squirrel (*Otospermophilus beecheyi)*, is abundant and common, but generally undervalued even though it is an integral component of this ecosystem and is known to exert a strong positive interaction on BUOW.

Because the California ground squirrel is a "keystone" species that helps engineer California grassland ecosystems and provides critical resources for BUOW, re-establishment of this species is a crucial component of any recovery plan for BUOW and the larger ecosystem. Ground dwelling squirrels influence the structure and composition of the grassland ecosystem, both directly as prey and indirectly through burrowing and foraging activities, suggesting a high level of interaction (Kotliar et al. 2006).

In 2011, the San Diego Zoo Institute for Conservation Research (ICR) and the Institute for Ecological Modeling and Management (IEMM) initiated a program to assist in the recovery of BUOW and their grassland ecosystem in San Diego County. Using an adaptive management approach (Walters 1986; Schreiber et al. 2004; Nichols & Williams 2006), ICR/IEMM collaboratively launched a multi-year study to restore ecological function to grassland communities in San Diego County by re-establishing ground squirrels and, ultimately, BUOW.

### *Project goals*

The overarching objective of this project is to facilitate the reestablishment of ecosystem processes in order that the ecosystem in which the BUOW is found is less reliant on repeated human intervention. Our aim is to create suitable BUOW habitat through the ecosystem engineering activity of ground squirrels that will be self-sustaining.

Results from year one of this multi-year program were mixed and indicated that modifications to the translocation protocol were necessary to improve release success of relocated squirrels (Swaisgood & Lenihan 2012). Our results also highlighted the need to understand how soil characteristics affect squirrel establishment and retention. In year two (2012), we modified the protocols developed for ground squirrel translocation in 2011 and initiated data collection for a ground squirrel habitat suitability model. Although work was focused on refining the ground squirrel translocation methodology, we opportunistically monitored BUOW and continued pilot work using camera traps at owl nest burrows. In year three (2013), we expanded our research on BUOW, monitoring their nesting and foraging ecology at artificial and natural burrows, through the use of camera traps, direct observations, and habitat surveys. We also initiated a capture and banding effort to allow for identification of individuals. In year four (2014), we continued to monitor squirrel translocation outcomes and began a pilot project examining ways to encourage natural ground squirrel dispersal. We also continued our research efforts on BUOW, focusing on potential factors that may affect their reproduction and survival. This included GPS tracking of owl foraging movements during the breeding season to gain a better understanding of their habitat use and spatial movement patterns. By obtaining a better understanding of the factors regulating population dynamics of BUOW, in terms of reproduction, survival, recruitment, and movement patterns, the results from this research will help inform the effective long-term management of BUOW in San Diego County. In 2015, we continued with all aspects of our research from 2014 and developed a strategic management plan to help conserve BUOW in the region using results from this research.

The goals for 2015 were to:

1. Continue monitoring of squirrel translocation outcomes from 2011 & 2012 translocations;
2. Monitor natural ground squirrel dispersal into managed habitat at Rancho Jamul Ecological Reserve;
3. Examine BUOW nesting and foraging ecology by:
    - Using camera traps at active breeding burrows to document parental care, prey provisioning, predation/predators, and other visitors,
    - Comparing results from natural and artificial burrows,
    - Monitoring condition of artificial burrows;
4. Examine BUOW population ecology through:
    - Banding and collecting genetic material from owls,
    - Monitoring reproductive output;
5. Examine BUOW spatial ecology using GPS dataloggers;
6. Develop a comprehensive strategic management plan using data collected from the previous four years of research.

***Personnel***

*Principal Investigators:*
Lisa Nordstrom, Ph.D., Debra Shier, Ph.D., Ron Swaisgood, Ph.D.

*Field Team—Squirrel monitoring:*
Field Organizer: JP Montagne (ICR in-kind contribution)

*Volunteers:* Angelica Aguilar Duran, Sara Alhawi, Marion Berry, Chelsea Betancourt, Martha Cruz, Michelle Dewey, Amy Downey, Ramon Esquer, Kathleen Esra, Gloria Marselas, Shanda McDonald, Erica Mills, Ed Mitchell, Lisa Muscato, Susan Naibkhyl, Lowry Pierich Jr., Jimmie Presley, Frances Sims, Katrina Stenson, Nate Tauzer, Taylyn Wokmunskie; 226 total hours.

*Field Team—BUOW monitoring:*
Field Organizer: Colleen Wisinski, M.S.
Expert Advisors: Jeff Lincer, Ph.D. (BUOW), Mathias Tobler, Ph.D. (software, data management; ICR in-kind contribution)
Field Technicians: Stephanie Gobert, Kira Marshall
Volunteers from San Diego Zoo Global (ICR in-kind contribution): Annabelle Bernabe, Kathleen Esra, Carina Graham, Kate Lambert, Gloria Marselas, Sara Meszaros, Subashini Sudarsan, Tasha Thompson; ~700 total hours
Genetic Analyses (ICR in-kind contribution): Heidi Davis, Taylor Haines

*Habitat Suitability Modeling:*
Field Organizer: Susanne Marczak
Data Analysis: Sarah McCullough Hennessy, Ph.D.

***Permits***

Fieldwork was conducted under the California Department of Fish and Wildlife (CDFW) Scientific Collecting Permits of Colleen Wisinski (SC-11839), Jeff Lincer (SC-1606), and JP Montagne (SC-11422). BUOW banding and bleeding were conducted under the Federal Bird Banding Permit of Jeff Lincer (20242) with Colleen Wisinski (20242-A) as a subpermitee. This project was approved by SDZG's Internal Animal Care and Use Committee (IACUC) and operates in accordance with all IACUC provisions under Projects #11-017, #12-002 and, #14-009.

# LONG-TERM MONITORING OF CALIFORNIA GROUND SQUIRREL TRANSLOCATIONS

## *Introduction*

As a means to improve grassland habitat for BUOW and other species of concern, in 2011 we initiated the development of a scientific, ecologically relevant strategy for relocating California ground squirrels. Long-term success is contingent upon our ability to translocate California ground squirrels to the restoration sites in numbers sufficient for a population to establish itself at an ecologically functioning threshold where squirrels serve as ecosystem engineers (Kotliar et al. 2006; Soule et al. 2003). Many translocation programs are unsuccessful or marginally successful because of high mortality (O'Bryan & McCullough 1985, Jones & Witham 1990) and post-release dispersal away from the release site (review in Stamps & Swaisgood 2007). For this squirrel species, Salmon & Marsh (1981) noted, "Our experience has been that California ground squirrels released into an area will rarely stay." In one translocation study, 83% of California ground squirrels relocated in a hard release without acclimation immediately abandoned the release site (Van Vuren et al. 1997). Post-release monitoring, attention to release group composition, and ecologically relevant modifications to the post-release habitat and social environment can have profound effects on the success of translocation programs (Stamps & Swaisgood 2007; Swaisgood 2010). These factors were incorporated into our own translocation project, which met with mixed success. However, we increased squirrel persistence by making carefully documented and controlled alterations to the release strategy, following adaptive management procedures.

Detailed reports on outcomes and methodologies of translocations as part of this project can be found in previous annual reports. In 2015, we monitored persistence of squirrels at six experimental plots in two release sites to continue our assessment of minimum survival and retention at two plots established in 2012 and record colony persistence at four plots established in 2011. We also monitored the persistence of squirrel ecosystem engineering effects at the same plots as another indicator of squirrel persistence and to track current burrow availability for both squirrels and owls.

## *Methods*

### Plot size and layout

Pairs of circular plots were established based on similar vegetation community, soil type, slope, and aspect as well as proximity. Each circular plot was 100 m in diameter, with an area of 7854 $m^2$ (1.94 acres). Each plot was divided evenly into three equal wedge-shaped subplots. The subplots received one of three treatments: control, mowing, and mowing plus augering. Squirrels were translocated into one plot from each pair (Figure 1-1). This design allowed us to separate the direct effects of vegetation manipulation from the ecosystem engineering effects of ground squirrels.

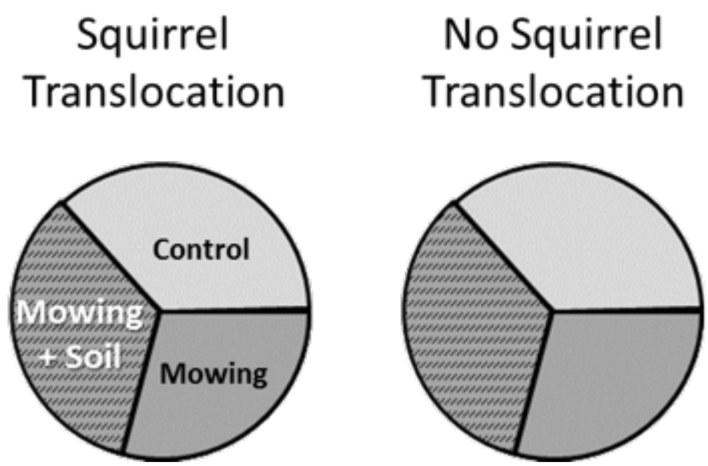



**Figure 1-1. Paired design of the habitat enhancement/squirrel translocation experiment.**

**Treatment methods**

**Treatment 1: Mowing and thatch removal.** Mowing and thatch removal was conducted without motorized equipment to minimize soil compaction and surface disturbance. Vegetation treatments occurred in May, at the end of the growing season for annual grasses but before grasses were dried out. Vegetation was mowed to a height of 7.5 – 15 cm using handheld weed-whackers, and the resulting thatch was raked and removed from the site. There was no evidence of soil disturbance from mowing or thatch removal.

**Treatment 2: Mowing and thatch removal plus soil decompaction.** Soil decompaction was implemented by augering 20 holes per subplot to produce a density of one hole every 10 $m^2$. Holes were drilled to ~0.3 m depth on a 45 degree angle with a one-person handheld auger fit with a 6 in. auger bit.

**Squirrel translocation procedures**

California ground squirrels were captured for relocation from source sites at North Island Naval Base Coronado (NBC) and at local ranches in Pine Valley and Jamul. The target number was 30-50 squirrels released per plot. The target release group for one pie comprised a minimum of three adult males and six adult females, plus their weaned pups, and attempts were made to maintain familiar social groups of individuals.

ICR biologists performed a health check and recorded age, sex, weight and reproductive condition for each squirrel. Individuals were marked with standard ear tags, radio-frequency identification (RFID) tags, and unique dye markings for individual identification. A subset of adult squirrels was equipped with VHF radio-collars to allow tracking and monitoring of individual squirrels post-release.

When squirrels were transferred to the acclimation burrows, the experimental plots in 2011 were surrounded with a battery-powered electric-tape fence to deter predation attempts by coyotes. Squirrels were provided with food and water bottles. After one week, acclimation cages were removed, and the squirrels were monitored with observations, radio-tracking, re-trapping, and camera traps to measure squirrel retention on site, movements off site and survivorship.

A second year of translocations was conducted to supplement the initial squirrel populations. The supplemental translocations occurred in August (in contrast to the June timing of the 1st year translocations). In the second year, woody debris piles were added to the plots to provide additional cover.

**Study sites and plot locations**

***Study sites***

The study was planned for three sites in southern San Diego County: Rancho Jamul Ecological Reserve, the Lonestar Ridge West parcel on Otay Mesa, and the San Diego-Sweetwater National Wildlife Refuge. After the first year of the study, the Lonestar site was discontinued and additional pairs of plots were added at Rancho Jamul.

***Plot nomenclature and location data***

Site codes were assigned to denote whether plots were located at Rancho Jamul (RJER), or Sweetwater (SWTR). The plots are labeled with a unique name, plus a letter denoting which of the paired plots was the control (C, "Control") or the squirrel translocation (G, "Ground squirrel") plot (See Table 1-1 for GPS locations).

**Table 1-1. Final plot locations (UTM coordinates reported in projected coordinate system NAD1983 Zone 11N).**

| Site | Plot | Elevation (m) | Easting | Northing |
|---|---|---|---|---|
| Rancho Jamul | RJER JE-C | 832 | 512823.5110 | 3617500.8735 |
| | RJER JE-G | 834 | 512740.9191 | 3617655.3768 |
| | RJER JW-C | 870 | 512169.7722 | 3617351.9940 |
| | RJER JW-G | 843 | 512149.1849 | 3617576.5499 |
| | RJER JS-C | 771 | 512546.2182 | 3616321.7555 |
| | RJER JS-G | 760 | 512614.0000 | 3616179.2598 |
| | RJER JC-C | 842 | 512385.5666 | 3617027.1563 |
| | RJER JC-G | 834 | 512263.0544 | 3616527.6144 |
| | RJER JB-C | 759 | 512579.1138 | 3615943.9042 |
| | RJER JB-G | 736 | 512541.3664 | 3615716.0390 |
| Sweetwater | SWTR SE-C | 676 | 503004.8305 | 3617329.0047 |
| | SWTR SE-G | 616 | 503047.2489 | 3617443.9296 |

**Assessment methods**

***Long-term post-release monitoring — 2011 and 2012 plots***

We monitored persistence of squirrel colonies at the four release plots established in 2011: Sweetwater East (SE) located in Sweetwater, Jamul South (JS), Jamul West (JW), and Jamul East (JE) in Rancho Jamul. These plots received no translocations or habitat manipulation since 2012. We observed each release plot three consecutive days for three hours between 8AM and 12PM.

We also monitored minimum retention at Jamul Baja (JB) and Jamul Central (JC) with the same trapping methods and procedures as 2014 (Wisinski et al. 2014). These two plots were established in 2012 and received no translocations or habitat manipulation since 2013.

***Burrowing activity***

Observers walked a grid pattern through each subplot and recorded California ground squirrel activity. Burrows with an opening of at least 7 cm at the point of maximum diameter were recorded as probable California ground squirrel burrows. Burrow locations were marked with GPS, and the size and shape of both the burrow entrance and the burrow apron were recorded. If scat was found around the burrow or on the apron, it was identified to species and recorded. The condition of the burrow entrance (i.e. clear, cobwebbed, collapsed) was recorded, as well as other field notes about burrow condition and use.

**Statistical analysis**

Squirrel capture results were not statistically analyzed due to very low capture numbers during the 2014 capture-release monitoring at the 2011 plots.

For burrowing activity, a repeated measures analysis was conducted utilizing all six pairs of plots. Since four pairs were begun in 2011 and two pairs were begun in 2012, the variable representing time in the repeated measures model is a categorical variable representing the number of years into the experiment (Years 1-4). The structure of the repeated measures model takes into account the additional variance from initiation of plots in two different years by use of a categorical variable representing each set of paired plots. This variable accounts for pair-level variance from both the site and year the plot was initiated.

## *Results*

**Minimum long-term persistence — 2011 plots**

We monitored colony persistence on the four 2011 plots during May 10th through 24th, after three years without active management. We detected fifteen squirrels through observation: 9 at JE and 6 at JW (Table 1-2; Figure 1-2). At SE and JS, no squirrels were detected. Examination of burrows revealed no recent activity.

**Minimum long-term persistence — 2012 plots**

We conducted capture-release trapping surveys on May 25th through June 6th at the two 2012 plots. Capture numbers for JC were unchanged from the previous year, but number of squirrels at JB increased more than three-fold from the previous year (Table 1-2; Figure 1-2). We captured 64 individual squirrels: 51 at JB and 13 at JC. Seven individuals were translocated in 2013 (JB = 4, JC = 3). Five squirrels were adults captured and marked as juveniles in 2013 (JB = 4, JC = 1). Sex ratios were skewed at both plots with more than twice as many female squirrels (JB: 36 females and 15 males; JC: 9 females and 4 males).

**Table 1-2. Total number of squirrels captured during long-term monitoring.** The first and second years followed initial and supplemental translocations. We used the same trapping protocol for the third year, while the fourth year we monitored instead with an observational scan method. Additional evening trapping is separated and in italics.

| Time of capture | Type of release | JB | JC | JE | JS | JW | SE | Total |
|---|---|---|---|---|---|---|---|---|
| **Morning** | 1st Year (Initial) | 0 | 8 | 6 | 7 | 6 | 5 | **32** |
| | 2nd Year (Supplemental) | 15 | 10 | 14 | 5 | 11 | 7 | **62** |
| | 3rd Year (Retention) | 40 | 13 | 1 | 0 | 1 | 3 | **58** |
| | 4th Year (Observation) | * | * | 9 | 0 | 6 | 0 | **15** |
| ***Evening*** | *1st Year (Initial)* | *0* | *2* | - | - | - | - | ***2*** |
| | *2nd Year (Supplemental)* | *1* | *3* | *9* | *7* | *0* | *2* | ***22*** |
| | *3rd Year (Retention)* | *11* | *0* | *0* | *0* | *0* | *0* | ***11*** |

** 4th year observational scan monitoring of JB and JC is scheduled for June 2016.*

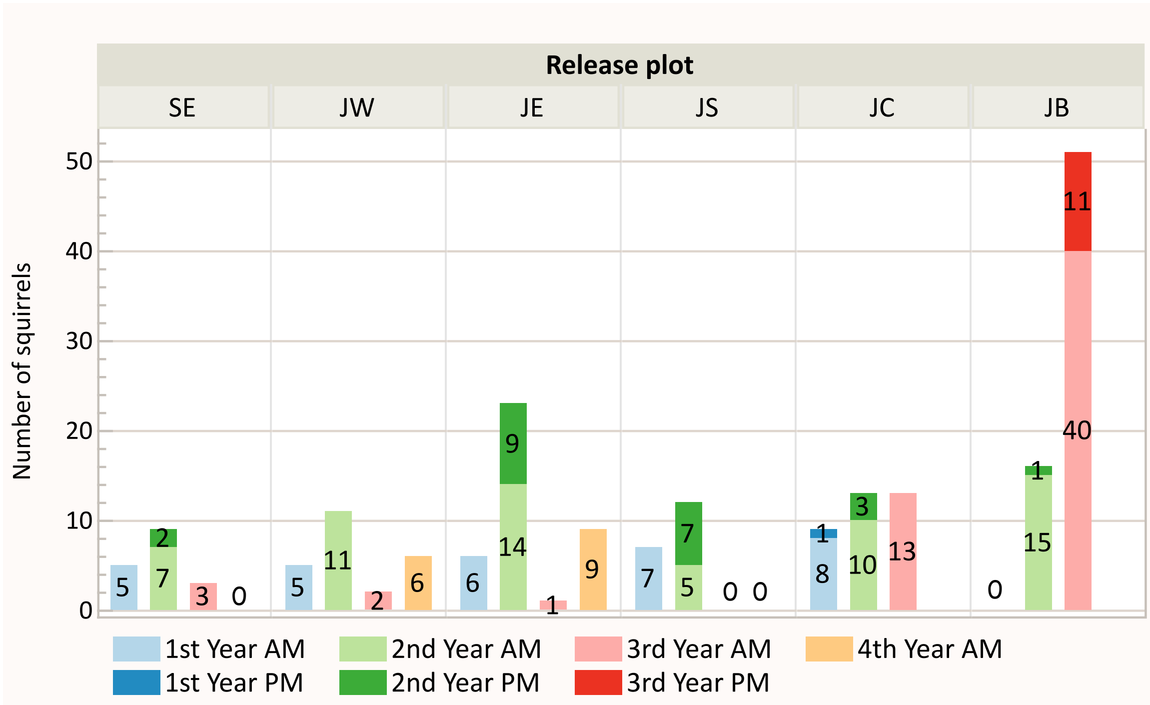



**Figure 1-2. Summary of the number of squirrels captured on each plot.** These numbers include translocated individuals, their progeny and immigrants from local populations. After 2011, we increased sampling by adding an evening session, therefore there are no values for Year 1 PM for SE, JW, SE and JS. All long-term monitoring was scheduled in June to maximize capture probability of juveniles prior to dispersal; therefore trapping took place twelve months after initial translocation (1st Year), and nine months after the supplemental translocation (2nd Year).

**Squirrel burrowing activity**

The spring 2015 timepoint represents an interval of 18 months since final 2013 supplemental translocation for JC and JB plots. For the remaining pairs of plots, the 2015 spring sample represents activity 30 months after final 2012 supplemental translocation. In spring 2015, squirrel activity continued to be largely concentrated in the plots that received squirrel translocation, with 98% of burrows found on the plots that received translocated squirrels (Figure 1-3). The number of burrows decreased in all translocation plots. Decreases were generally greater in the plots with the longer interval since last treatment, with exceptions. The greatest decrease observed was consistent with this pattern (88%, JS), but the smallest decrease measured was also in a 2011 plot (26%, SE). The decrease observed at JE (40%) was comparable to the decrease observed in the two 2012 plots (45%, JC and 36%, JB). The overall number of burrows in control plots dropped further between spring 2014 and 2015.

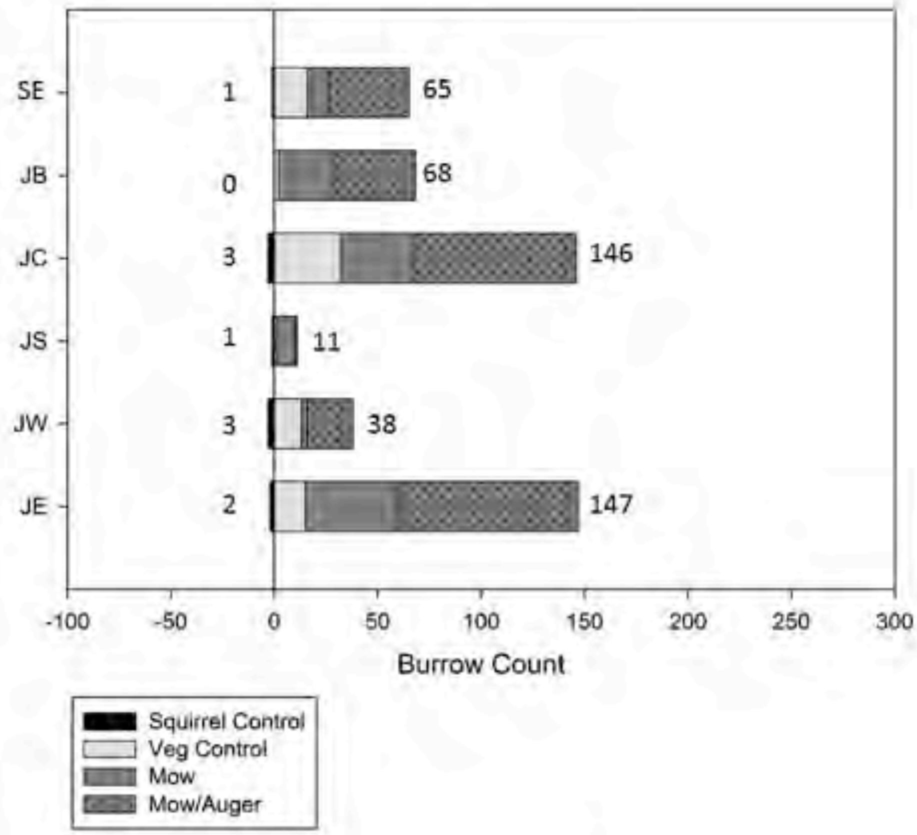



**Figure 1-3. 2015 squirrel activity by plot pair, measured as the number of burrows equal to or greater than 7 cm diameter.** For JC and JB, the March 2015 sample represents activity levels 18 months after final 2013 supplemental translocation. For the remaining pairs of plots, the March 2015 sample represents activity 30 months after final 2012 supplemental translocation.

The proportion of squirrel burrows continued to be higher in the subplots receiving vegetation treatments than the control subplot (Figure 1-3). Quantifying the total area of ground surface disturbance, derived from the apron areas measured at each burrow, is another useful metric of squirrel activity. Summing the individual apron areas within each treatment subplot gives one number per subplot that can be used as a proxy for squirrel activity within each subplot. Before creating this proxy measurement, we assessed the distribution of individual apron areas in all subplots. Out of 485 burrows, 332 burrows included an apron. Of those burrows with aprons, 49% had an apron area smaller than 0.2 $m^2$ (Figure 1-4). Maximum observed apron area was just under 4.0 $m^2$. The distribution exhibits right (positive) skew due to the relatively low proportion of burrows with large aprons. The creation of a large apron requires time and effort, and not all burrows are developed to this extent. In response to the observed skewness, the proxy estimate of squirrel activity was treated with a square root transformation for all analyses.

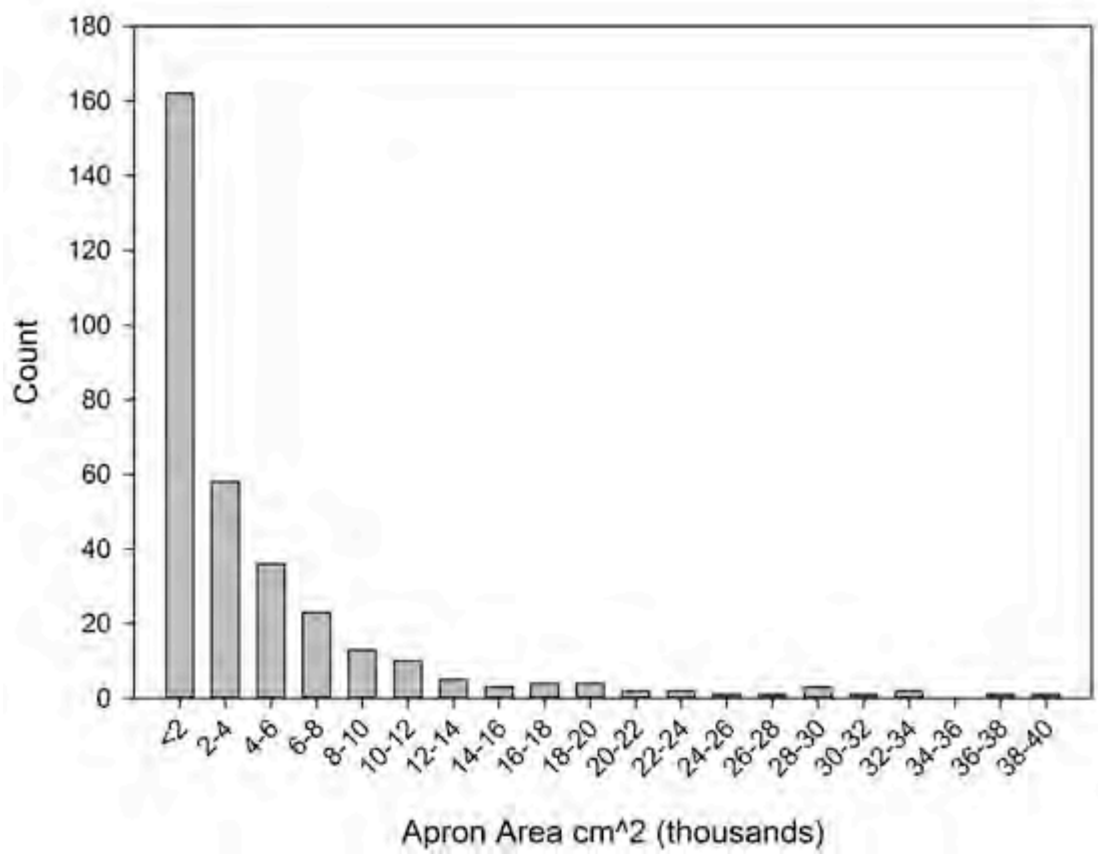



**Figure 1-4. Histogram of individual apron areas in all subplots, with apron area measured in thousands of $cm^2$ (n=332). Burrows with no apron were excluded.**

The results from the repeated measures model indicate that the interaction of squirrel translocation and vegetation treatment continued to be highly significant through the spring of year 4 ($p<0.01$, Table 1-3). The combination of both mowing and squirrel translocation are supporting squirrel activity levels. The separation in activity level between the subplots with mowing only and with the addition of augering also continued into the 4th year of the experiment. Also worth noting is that disturbance area decreased for the first time in the course of the experiment in spring of year 4, across all vegetation treatment subplots (Figure 1-5).

**Table 1-3. Generalized linear repeated measures model results from burrowing activity, measured as apron area, sampled during 2011-2015 (n=6).** The data were square root transformed. Analysis includes time points for year 1 post –translocation, year 2 pre- and post-supplemental translocation, and year 3 and 4 spring timepoints. All interactions were modeled.

| **Treatment Effect** | Apron area | | | |
|---|---|---|---|---|
| | df | $\Delta R^2$ | F | P |
| **Between Subjects** | | | | |
| Squirrel | 1 | 0.93 | 129.54 | <0.01 |
| Pair | 5 | 0.03 | 0.91 | 0.54 |
| *Error* | 5 | 0.04 | | |
| **Within Subjects** | | | | |
| Time | 4 | 0.44 | 18.96 | <0.01 |
| Time x Squirrel | 4 | 0.29 | 12.69 | <0.01 |
| Time x Pair | 20 | 0.15 | 1.27 | 0.30 |
| *Error* | 20 | 0.12 | | |
| Veg | 2 | 0.47 | 29.36 | <0.01 |
| Veg x Squirrel | 2 | 0.38 | 23.55 | <0.01 |
| Veg x Pair | 10 | 0.08 | 0.94 | 0.54 |
| *Error* | 10 | 0.08 | | |
| Veg x Time | 8 | 0.13 | 1.88 | 0.09 |
| Time x Veg x Squirrel | 8 | 0.08 | 1.16 | 0.34 |
| Time x Veg x Pair | 40 | 0.44 | 1.28 | 0.22 |
| *Error* | 40 | 0.35 | | |

The interaction between time and squirrel translocation observed at previous timepoints also continued to be significant ($p<0.01$). The time variable represents the repeated annual fall and spring measurements conducted in each subplot since the initiation of the experiment. The variable incorporates both variation across year and across seasons, treating the passage of time as a linear, nonhierarchical effect. Thus the interaction found includes such patterns as the staggered initiation of plots in 2011 and 2012, and the seasonal timing of translocations across the two year treatment plan.

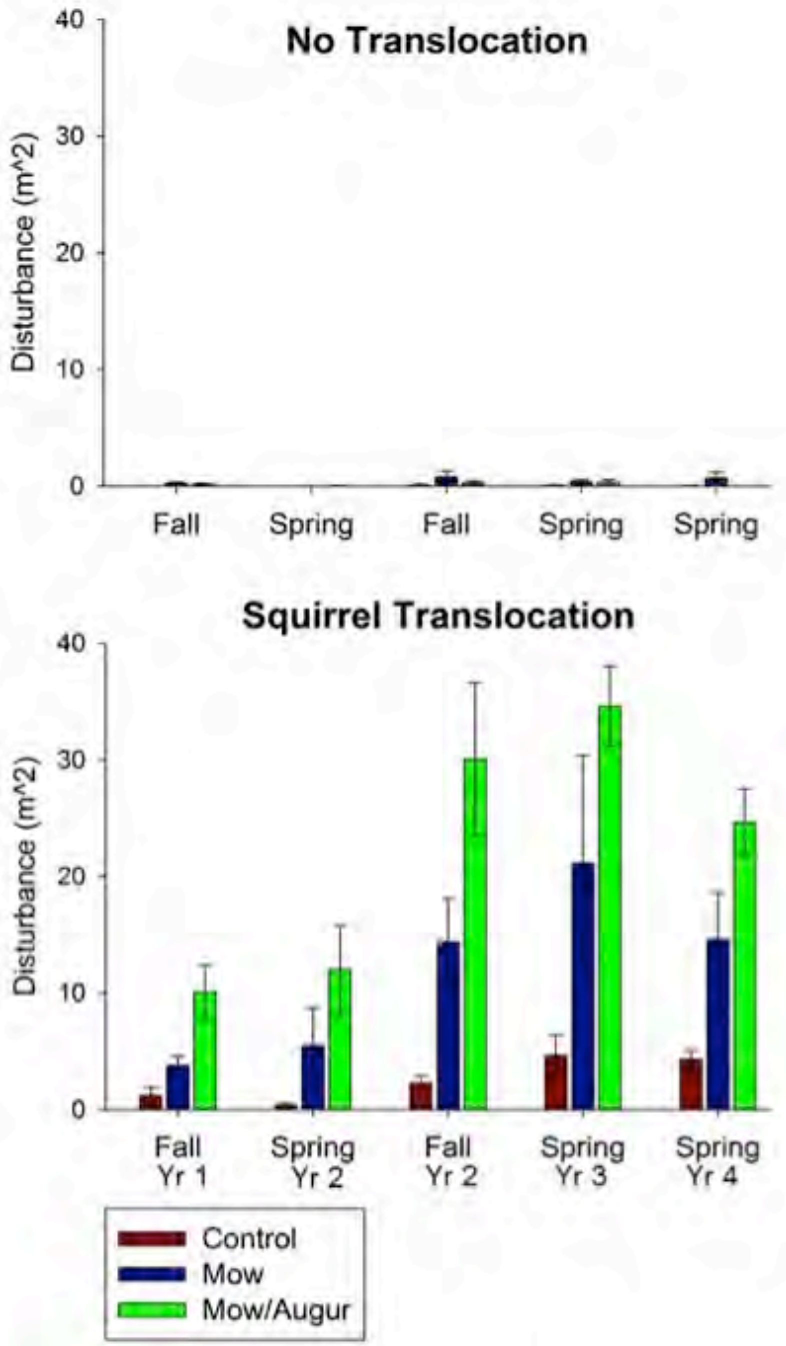



**Figure 1-5. Overall ground surface disturbance (derived from the apron areas measured at each burrow) as a proxy for squirrel activity during 2011-2015 (n=6).** Activity levels at both translocation and control plots are presented.

***Discussion***

For most extant Californian grassland communities, ongoing vegetation management is required to maintain the low habitat structure needed by both squirrels and owls. The Rancho Jamul plots experienced a shift in management regime in 2015 from targeted mowing to widespread grazing. Grazing was implemented both as a means of controlling exotic annual grasses, and to reduce residual dry matter to increase the foraging efficiency of birds of prey. In 2015, there was an observable grazing footprint on most of the plots in terms of vegetation height and soil disturbance. While some squirrel burrows showed signs of trampling by cows, our current data support the conclusion that squirrels are resilient to this type of disturbance. There could potentially be secondary effects through reduced forage for squirrels, but these are more difficult to evaluate during the ongoing drought conditions. We also recognize that the grazing plan will be implemented on a provisional basis as long as the drought persists. During non-drought conditions, grazing would be expected to provide vegetation management effects that are compatible with squirrel habitat requirements. Successfully striking a balance between squirrel activity and grazing at Rancho Jamul would validate the management recommendations developed from the findings of this program, and support future efforts to manage for BUOW through squirrel reestablishment and vegetation management.

**Year 4 treatment effects on squirrel burrowing activity**

The burrow counts and surface disturbance measures have consistently shown that the combination of squirrel translocation and vegetation treatment together supports higher levels of squirrel activity than the use of either management strategy alone. Within the squirrel release plots, mowed areas had large numbers of burrows, whereas few squirrel burrows were located in the unmowed control treatments. Apparently, the conditions produced by mowing encouraged squirrels to colonize treated areas. However, this was only the case at translocation release plots: when no squirrels were released, few squirrel burrows were found in the mowed plots.

Although the 4th year of the experiment was marked by declining numbers of burrows in all plots, the significant treatment interaction persisted. The positive signal associated with auger treatment also persisted through this round of data collection.

**Population status at experimental plots**

The primary monitoring objective for 2015 was to determine the persistence of squirrel colonies at the release sites after 18 or 30 months without any active habitat management or additional translocations. In terms of the plots established in 2011, the Sweetwater plots appear unused in the past year. After indications in 2014 of squirrel movement north of the plot, the 2015 monitoring found no squirrels present. At Jamul, two of three 2011 release plots (JE and JW) are

persisting. Higher numbers of individuals were detected in 2015 compared to 2014, and the burrows on the plots showed signs of recent digging activity.
Ground squirrel colonies not only persist at the 2012 plots, JB and JC, but they were more successful at 3 years post release when compared with the 2011 plots. The high numbers of squirrels detected at plot JB is particularly impressive. The squirrels occupied half of the treatment areas within the plot, and also expanded beyond the perimeter of the plot. Potential factors contributing to the persistence of squirrel colonies at the Jamul plots include: effects of the new grazing management regime on vegetation structure and/or predator behavior, and drought effects on avian and terrestrial predators. In terms of seasonal variation, spring 2015 conditions were cooler and wetter than 2014. Although we scheduled monitoring for the same date range each year, the local average temperature in May was 62.8°F in 2015 compared to 68.9 °F in 2014. Likewise, the total monthly precipitation was 1.13 inches in 2015, compared to zero inches in 2014 (*http://www.ncdc.noaa.gov/data-access*).

However, the declines in squirrel burrowing activity suggested that the end of active translocation and mowing has either impacted squirrel numbers, or impacted habitat suitability for squirrels through vegetation structure, or both. The finding through observations and retrapping of persistent squirrel numbers indicates that squirrels are present, and suggests that current fluctuations in vegetation structure as grazing is established may be having an impact on squirrel activity.

**Implications for conservation and management**
California ground squirrels (and other burrowing mammals elsewhere) play a key role in engineering grassland ecosystems (Reichman and Seabloom 2002, James and Eldridge 2007), and deserve consideration during conservation planning and policy. While it may not be possible to increase ground squirrel activity at large scales, it is realistic to return them to targeted, protected reserve lands as a key component of restoring more functional grasslands.

The theoretical best-case scenario of an intrinsically self-sustaining ecosystem after reintroduction of the ecosystem engineer (Byers et al. 2006) was not realistic due to established exotic seedbanks at all of our sites. Therefore we adjusted our restoration goal to shifting the site to a more sustainable hybrid state through reintroduction of the ecosystem engineer (Hobbs et al. 2009). It is now evident that a realistic hybrid state would consist of dominant exotic grass cover, active human management of grass structure, burrowing squirrels, and breeding owls. The potential stability of this hybrid ecosystem is uncertain but will be influenced by abiotic and biotic indirect effects of the ecosystem engineer (Byers et al. 2006). For example, possible undesired biotic effects include increased exotic grass growth on abandoned burrows from increased nutrient levels and soil temperature (Schiffman 2007).

Managers might best leverage the findings of this experiment by identifying target sites where owl occupancy is desired, and where either component of vegetation management and squirrel presence is already in place. Since both were necessary for significant burrow habitat creation, managers could seek opportunities to create the combination in locations where, for example, vegetation density is already kept low by grazing or other disturbance, or in locations with an existing squirrel population. Adding vegetation management to a site with a small population of resident squirrels may increase the size of the colony and squirrel activity levels.

This work was done as part of an ongoing active conservation effort, and was designed as part of an adaptive management framework (Sabine et al. 2004, Nichols and Williams 2006). The experimental design allowed us to test various management alternatives against one another (for example, translocating squirrels vs. natural squirrel colonization and different forms of habitat management). The results indicate clear lessons learned, and inform both future management actions and future research questions to further refine management protocols.

Clearly our results show that active squirrel translocation was needed at the restoration sites where we worked, but different starting conditions regarding the proximity and abundance of squirrel populations may be more conducive to natural squirrel colonization provided vegetation management creates favorable habitat. Future work can test this hypothesis and explore the potential for this more cost-effective solution to ecosystem engineer recruitment in some prescribed circumstances. Our results also indicate to managers that ongoing vegetation management is likely required to retain a more open habitat structure, but alternatives to mowing, for example grazing and fire, may be evaluated with regard to efficacy for squirrel establishment. Our study also did not rule out an ecosystem engineering role for squirrels on vegetation management. Future projects could explore whether larger number of squirrels established for longer periods of time help maintain more open habitat or alter the competitive balance in the plant community in favor of native grasses and forbs. Finally, the long-term goal of re-establishing BUOW to these restored habitats is the next and most important goal to validate our approach to restoration.

# MONITORING NATURAL DISPERSAL OF CALIFORNIA GROUND SQUIRRELS INTO THE BURROWING OWL HABITAT MANAGEMENT AREA (BOHMA) AT RANCHO JAMUL ECOLOGICAL RESERVE

### *Introduction*

Rancho Jamul Ecological Reserve has set aside a Burrowing Owl Habitat Management Area (BOHMA) where BUOW have been soft-released into artificial burrows and efforts have been made to improve the landscape to retain owls after release. The goal of this effort is to continue improving the habitat by encouraging the natural dispersal of California ground squirrels from an existing adjacent colony through vegetation treatment and the addition of protective cover. Beginning in 2014, CDFW conducted a new form of vegetation treatment in conjunction with systematic placement of woodpiles allowing us to address the following questions: (1) Does vegetation management through grazing influence natural dispersal of California ground squirrels?; (2) If natural dispersal occurs, which age cohort is dispersing?; and (3) Does the placement of woodpiles in managed habitat expedite natural dispersal?

### *Methods*

The BOHMA has been periodically grazed by cattle to reduce non-native grasses and forbs since early 2014. If natural dispersal of ground squirrels can be facilitated through vegetation management via grazing, information on which age cohort disperses into managed habitat will enable us to determine the ideal time of year for these vegetation treatments. Adult squirrels may disperse after breeding in early spring while juveniles disperse in early to mid-summer (Holekamp 1984). Should new burrows be documented during the spring surveys, we can assume adult ground squirrels are dispersing because there are no juveniles this time of year. However, if we document new burrows during the August/September survey, we would assume that juveniles are digging these burrows.

Furthermore, observations from ground squirrel settlement following translocation indicate that squirrels use woodpiles for cover while establishing new burrows. Our working hypothesis is that squirrels will be more likely to disperse and colonize if they can excavate burrows in or near cover thereby reducing predation risk during the period in which they are establishing burrows. To address this question, CDFW installed sixteen woodpiles on the BOHMA February 2014 (Figure 2-1).

In 2015, CDFW continued to control non-native vegetation by grazing cattle, and we monitored squirrel dispersal with CDFW partners using the methods outlined in our 2014 report (Swaisgood et al. 2015). We conducted surveys on April 24$^{th}$ and October 30$^{th}$, 2015.


**Figure 2-1. Map of the BOHMA with transects.** There are 32 transects in the BOHMA divided equally across four distances (50m, 150m, 250m, & 350m) from the source population of squirrels in the lower left section of the map. Half of the transects are centered on woodpiles (yellow) and half are control transects (orange).

### *Results & Discussion*

We recorded a total of 44 individual burrows during 2015 surveys. This total includes 18 burrows found in areas outside of transects, where none were found in 2014. If we exclude those, then 26 burrows were found within transects (Table 2-1). Seven of the burrows identified during the spring survey were still detected again during the fall survey, while four other burrows were first recorded in 2014. Although the total number of burrows found within transects are similar between years, there is a pattern of increasing density within woodpile transects at the 50m distance (Figure 2-2). A potential distribution trend towards woodpiles W-5 and W-7 appears to exist (Figure 2-3). However, a third year of surveys is needed to better address whether the woodpiles are attracting squirrels into the BOHMA.

This experiment was designed to pilot test the hypothesis that colonization could occur from natural squirrel dispersal, given an adequate population base. This alternative to squirrel translocation is attractive as it could be a more cost-effective solution to ecosystem engineer recruitment in some prescribed circumstances. To date, the experiment has recorded slow dispersal rates. In terms of dispersal distance, few squirrels are dispersing beyond the 50 m transect. These data could be used to support protocol modifications to enhance the dispersal rate. The finding of few squirrel burrows beyond the 50 m cover piles suggests that the current configuration may be spaced too widely for squirrels to easily utilize the "rungs" of the ladder configuration as intended. Alteration to a corridor-type configuration may provide the squirrels with the connectivity they need to colonize beyond 50 m.

In both years, more burrows were detected during fall surveys than during spring. The timing of the fall surveys coincides with the dispersal of juveniles at the end of breeding season, suggesting that juveniles are occupying the grazed habitat rather than adults. Encouraging juvenile dispersal into unoccupied habitat should then be the focus of management activities. In the experimental translocation plots, we observed a pulse of burrowing activity after disturbances such as vegetation mowing, as fossorial mammals quickly occupied newly available habitat. The timing of grazing by parcel is dependent on vegetation conditions and availability of the grazers, and by necessity occurs over a fairly wide window of time. However, shifting the timing of treatments including cover piles from winter to summer could be advantageous. As we plan to establish a second experimental replicate in 2016, these first two years of results provide direction for refinements to improve the current protocol.

**Implications for conservation and management**

Overall, while encouraging natural dispersal by ground squirrels may be part of an important long-term strategy for managing protected areas for BUOW, our results indicate that relying on natural dispersal, even when encouraged with vegetation management and provision of cover, will not be a good management tool when BUOW habitat needs to be created more quickly. Given the current small population size for BUOW in San Diego County, and the population viability models indicating that this population is in jeopardy of being extirpated, more active management techniques such as squirrel translocation and artificial burrow creation will be necessary to quickly improve habitat for BUOW at designated recovery nodes where ground squirrels are currently absent or at densities too low to serve their appropriate ecosystem function.

**Table 2-1. Burrow counts for BOHMA surveys.** Total number of ground squirrel burrows found within transects for each survey session. Burrows found outside of transects are totaled in parentheses.

| Distance | Transect | Spring 2014 | Fall 2014 | Spring 2015 | Fall 2015 |
|---|---|---|---|---|---|
| 50m | woodpile | 2 | 7 | 8 (4) | 13 (4) |
| | control | 1 | 2 | 0 (1) | 2 (9) |
| 150m | woodpile | 0 | 3 | 0 | 1 |
| | control | 1 | 3 | 0 | 0 |
| 250m | woodpile | 0 | 0 | 0 | 0 |
| | control | 0 | 0 | 0 | 1 |
| 350m | woodpile | 0 | 1 | 0 | 0 |
| | control | 0 | 1 | 1 | 0 |
| | **Annual total** | **21** | | **26 in transect, 44 total** | |

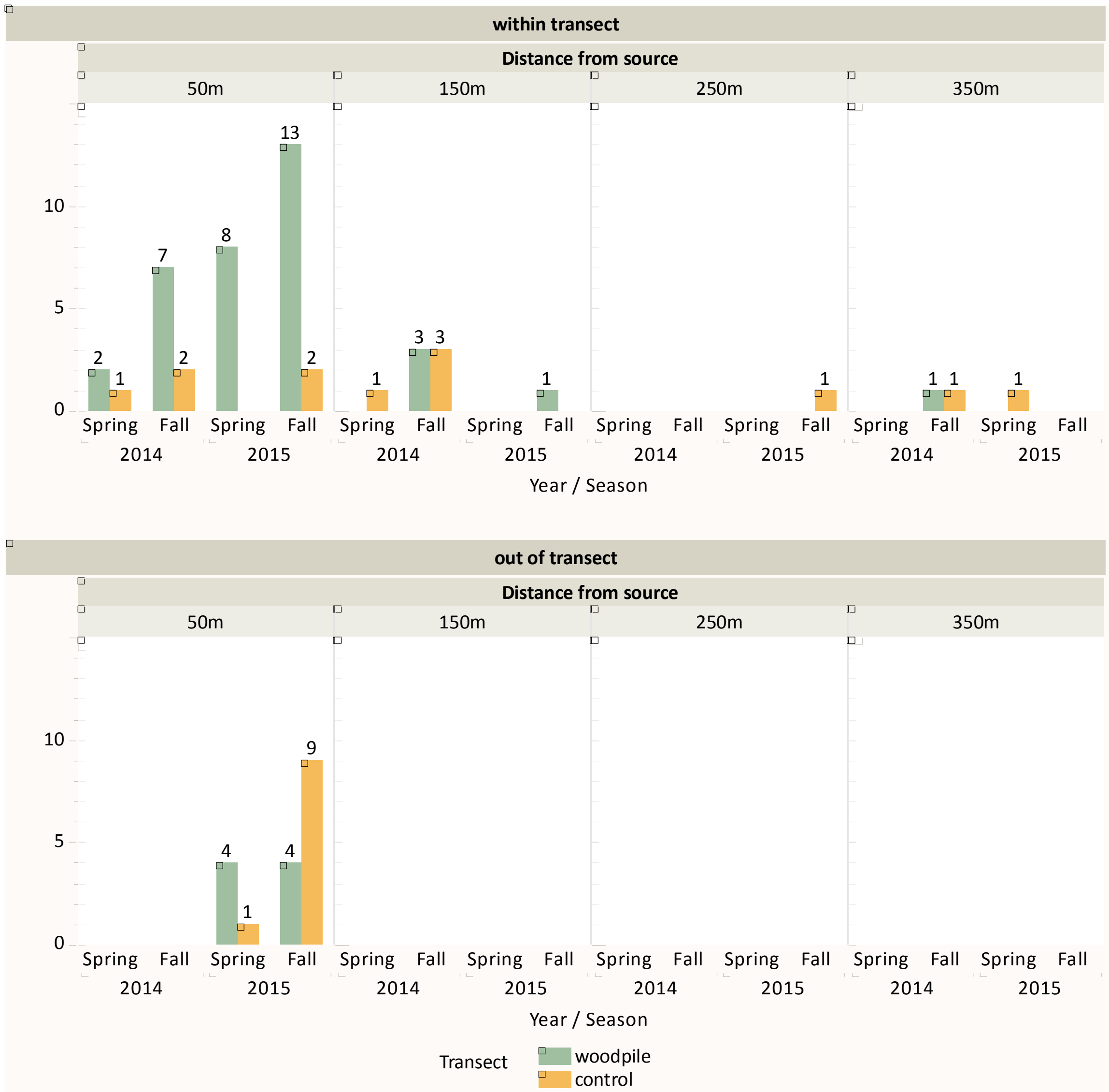
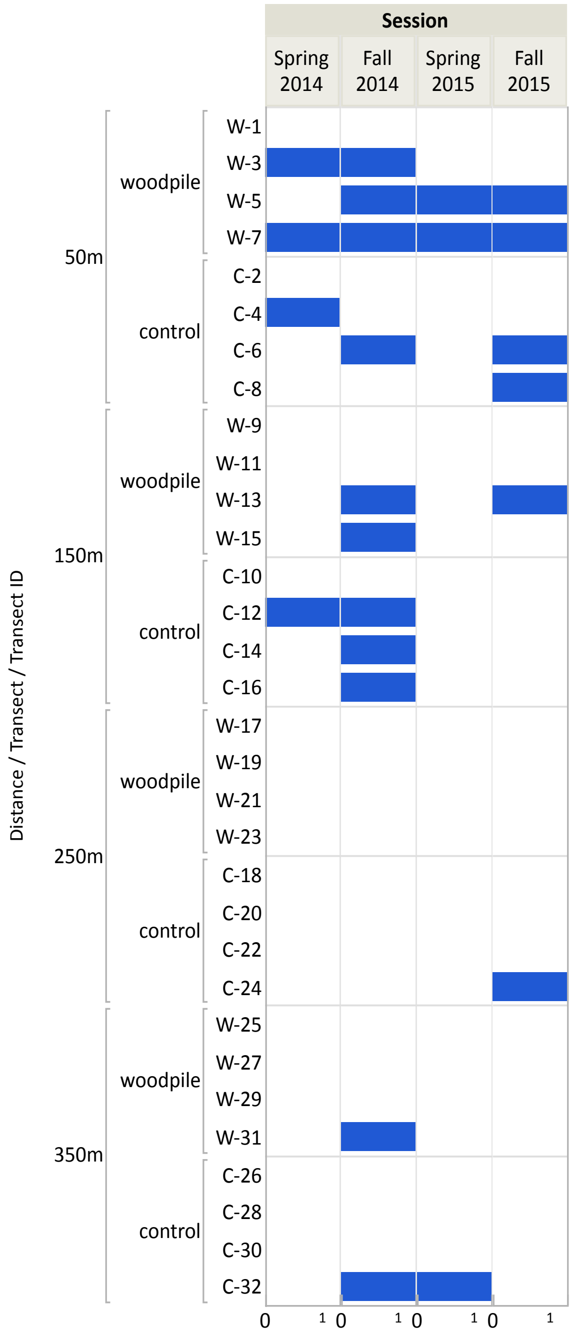



**Figure 2-2. Summary of number of burrows detected for each survey.** The top graph displays the total number of squirrel burrows found within woodpile (green) and control (orange) transects at increasing distances from the source population for the four survey sessions in the spring and fall of 2014 and 2015. The bottom graph displays additional burrows recorded opportunistically outside of any transects.



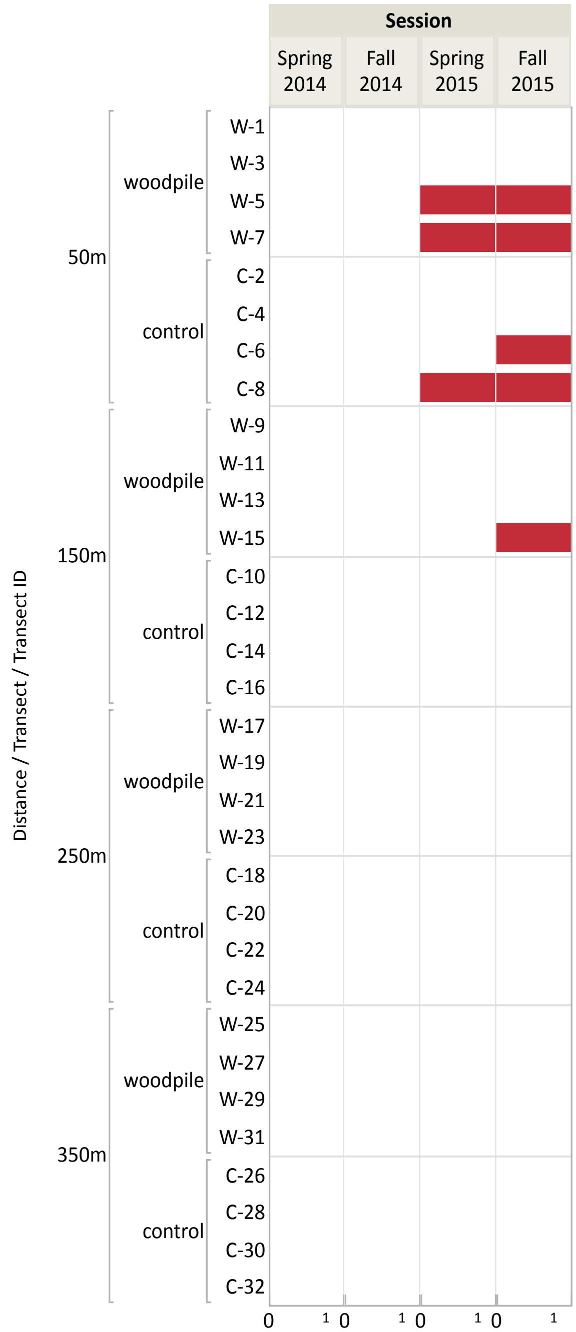




**Figure 2-3. Presence of burrows at each transect.** In the left figure, blue boxes indicate which transects had burrows within the transect during each session. Each transect is numbered 1 through 32 and prefaced with a "W" for woodpiles and "C" for controls. We also recorded squirrel burrows found outside of transects, shown in red in the figure on the right.

# BURROWING OWL NESTING AND FORAGING ECOLOGY

## *Introduction*

Working with the BUOW partnership, SDSU IEMM developed a conceptual model explaining possible factors regulating BUOW population dynamics. Among the most fundamental variables identified in this model are burrows, habitat type (vegetation), prey abundance and availability, and predation. In 2011 and 2012, we conducted a pilot project to test the utility of using camera traps to document BUOW reproductive ecology and population dynamics. We found that camera traps placed at the nest burrow entrances allow us to count chicks to determine reproductive success, track prey deliveries by adult owls, and identify prey items. Due to our success with the pilot project, in 2013 we made this research the focus of much greater effort. In 2014 and 2015, we continued to monitor BUOW nesting and foraging ecology using a variety of tools, including camera traps, color banding, and GPS telemetry.

We established camera traps at a number of natural and artificial burrows at sites with varying habitat characteristics. Understanding the relative productivity of BUOW at different locations and habitat types is a critical first step for better management. These data will be especially important for assessing the viability of management actions involving establishment of artificial burrows. Current BUOW management practices focus strongly on the installation of artificial burrows to encourage occupancy and breeding in an area. However, artificial burrows are often placed in available areas with minimal consideration of the immediate habitat characteristics or potential foraging areas. It has been hypothesized that artificial burrows may sometimes serve as an ecological trap, drawing owls in to nest in areas that do not otherwise provide sufficient resources or expose the owls to greater risk of predation. By comparing productivity and prey provisioning at artificial and natural burrows, we can gain a better understanding of how artificial burrows are functioning as a management tool for BUOW.

Artificial and natural burrows may also differ with regard to microclimate inside the burrow, microhabitat immediately surrounding the burrow, or the landscape features and habitat quality in the owl's home range. To address these possibilities, we used data loggers placed inside and immediately adjacent to burrows to monitor temperature and humidity variables and conducted habitat surveys of the vegetation surrounding artificial and natural burrows. These variables are explored with regard to their potential effects on nesting success and offspring viability.

We also continued to build on our previous banding efforts. Color-banding, which allows for individual recognition of the birds, is helping to increase our knowledge of survival, recruitment, and movement of BUOW through resighting via camera trap photos and on-the-ground observations. During our banding effort, we also collected genetic material and stored it at ICR's Frozen Zoo. In 2015, we began to conduct genetic analyses on samples collected since 2013 to determine the sex of each individual and relatedness among individuals. We also examined the population genetics of the BUOW of San Diego County and compared them with other populations in the United States. BUOW genetic analyses were provided by ICR as an in-kind contribution.

In addition, we continued to examine the spatial ecology of BUOW in 2015. While band re-sighting is instrumental for understanding recruitment and site fidelity, it alone cannot provide the level of spatio-temporal data needed to understand BUOW movement patterns, home range size, and resource use in this region. Due to recent technological advances creating GPS units small enough to be used on BUOW, we were able to use telemetry to help fill these knowledge gaps. Information gained from this research has been incorporated into the BUOW recovery plan to help guide site selection, identify key foraging or other critical habitat areas, and inform management actions.

## *Methods*

### Study sites

The study sites were all located on public lands and conservation areas in San Diego County within Management Unit 3 of the Management Strategic Plan (San Diego Management and Monitoring Program 2013). We focused on five priority sites that were identified in 2013 for monitoring BUOW nesting and foraging ecology (Figure 3-1); site selection is described in the 2013 annual report (Wisinski et al. 2014):

1. Brown Field Municipal Airport, managed by City of San Diego Airports;
2. Lonestar Ridge West Mitigation Site, managed by California Department of Transportation;
3. Johnson Canyon/Lonestar Ridge East Mitigation Site, managed by California Department of Transportation;
4. Poggi VOR, managed by Federal Aviation Administration; and
5. Lower Otay Reservoir Burrowing Owl Management Area (LORBOMA), managed by City of San Diego Public Utilities.

Brown Field Municipal Airport (Brown Field; N 32° 34’ 18.84”, W 116° 58’ 46.67”) is characterized by managed non-native grassland habitat with highly disturbed human use areas. California ground squirrels occur in relatively high numbers and create natural burrows for the owls to occupy. All nest burrows that we monitored at Brown Field were natural burrows. Lonestar Ridge West Mitigation Site (Lonestar; N 32° 34’ 43.61”, W 116° 58’ 01.85”) is a newly restored vernal pool and BUOW mitigation site. The site contains 75 artificial burrows (25 plastic, 25 wood, and 25 starter holes) with some natural burrows onsite, particularly along the perimeters. Lonestar is characterized by sparse, mostly native, vegetation with some patches of non-native grass. In 2015 a major effort was made to establish native grassland in the southern portion of the site with high success as of the end of the year. The Johnson Canyon/Lonestar Ridge East Mitigation Site (Johnson Canyon; N 32° 34’ 56.48”, W 116° 57’ 15.83”) is a more established mitigation restoration site characterized by coastal sage scrub vegetation with patches of non-native grasses. The site contains 21 artificial burrows. Poggi VOR (Poggi; N 32° 36’ 37.14”, W 116° 58’ 44.80”) is characterized by managed non-native grassland habitat and contains a high number of ground squirrels and a high density of natural burrows. LORBOMA (N 32° 37’ 17.05”, W

116° 54’ 55.96”) is an artificial burrow site characterized by coastal sage scrub habitat with some areas of native and non-native grass. The site contains 23 artificial burrows.

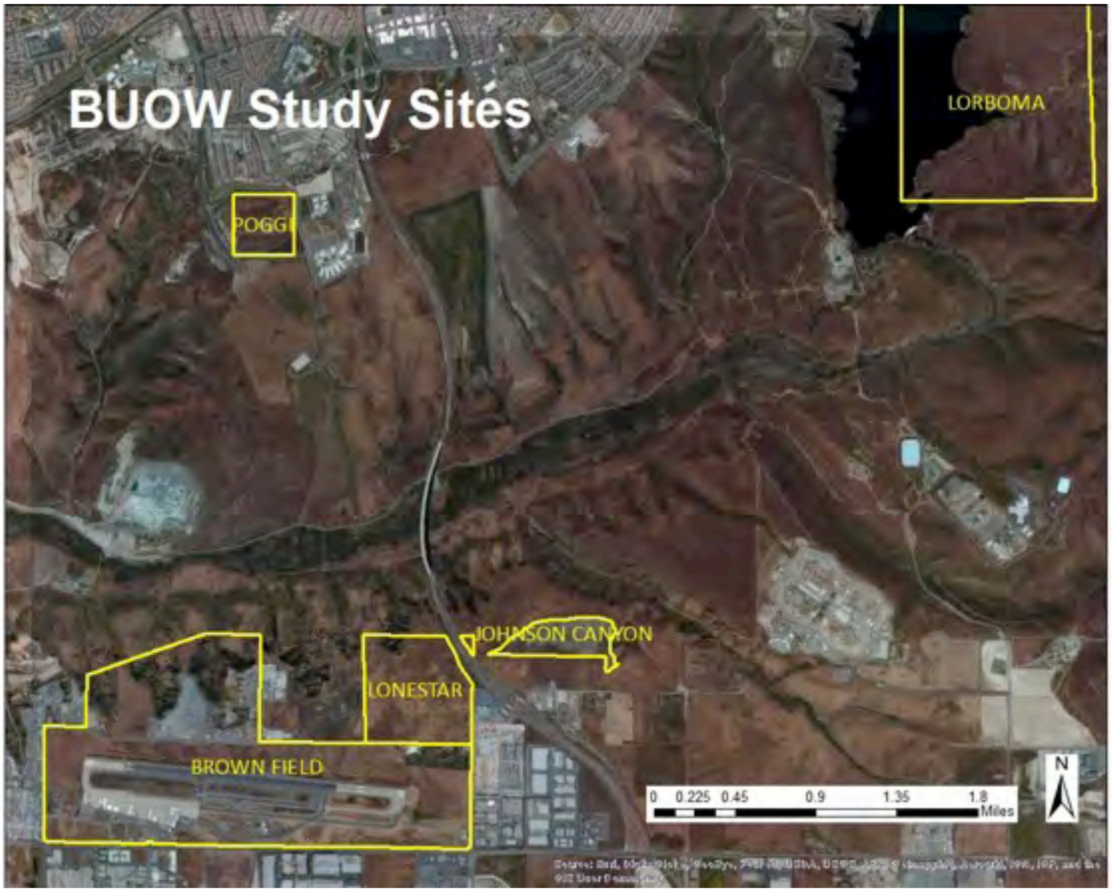



**Figure 3-1. Map of the 2015 BUOW study sites.**

**Nest monitoring**

In 2013, we compiled known natural and artificial burrow locations within Management Unit 3 from previous years’ data, eBird, CNDDB, California Department of Fish and Wildlife (CDFW), and CalTrans. We surveyed all of these known locations, which included all areas with artificial burrows except the Sweetwater Authority property, to determine the status of each burrow (active, inactive, need for maintenance) and used this list to determine which burrows to monitor throughout the breeding season. We focused on burrows on public lands and obtained the necessary permissions to access these areas. Five areas were identified as priority sites for monitoring. In 2015, we continued to work at these five sites.

All known nest burrows at the 5 study sites were checked weekly and were monitored using camera traps. However, after nest abandonment at Poggi and LORBOMA, these two sites were checked less frequently. The number of owls seen, sex and age class of the owls, and the presence of ground squirrels or predators were recorded for each nest visit. In addition, incidental BUOW sightings and sign at squirrel translocation plots at Rancho

Jamul Ecological Reserve were recorded throughout the study period. We opportunistically checked artificial burrows in Management Unit 3 to collect data on BUOW use and condition of the burrows. These data were added to our database and will help inform our on-going assessment of artificial burrows in San Diego County.

**Camera trapping**

We set cameras at burrow entrances (usually 1 for natural burrows and 2 for artificial burrows) when we confirmed the presence of eggs or chicks. In 2015, all nest burrows received camera traps, including two burrows that were located under the helicopter pads at Brown Field. However, to insure safety without impeding normal airport activities, we had to install the cameras at ground level. This compromised our ability to detect prey deliveries, but we were still able to collect productivity and predation data from these burrows.

We used Reconyx® PC900 remote camera systems to monitor the entrances of occupied nest burrows. We used a Bushnell® Natureview camera with an adjustable focal length lens after the original Reconyx camera failed at one of the burrows. Each camera was placed 1-3 m from the burrow entrance approximately 0.5-0.75 m above the ground and focused on the entrance and apron area of the burrow. As in 2014, we placed the cameras at an angle (as close to perpendicular as possible) to the entrance to allow for better identification of prey items brought by the owls. We set the cameras to take 3 pictures per motion-triggered event with a 30-second rest period in between trigger events. We changed camera batteries and retrieved SD data cards once per week to coincide with the weekly nest visit. We added or moved cameras if the juveniles moved to a satellite burrow.

**Camera trap data processing**

All camera trap photos were organized by burrow and date. We used Adobe® Bridge to examine all of the photos for the presence and type of prey items and the presence of non-BUOW visitors (including predation events and humans) and to tag each photo with pertinent information (see Appendix 1 for protocol with full keyword list). We recorded each independent prey delivery, predation, or burrow visit event. Events were considered independent if 1) it was clear that the subsequent prey delivery contained a different item, or 2) more than an hour elapsed between visits by other species (e.g. rabbits). Predation events were much more discrete and easier to identify as independent. For each day, we recorded the maximum numbers of adults and juveniles, respectively, along with the identities of any banded owls. We re-examined all tagged photos a second time for quality control.

**Analysis of camera trap data**

Using the daily maximum juvenile counts, we determined the maximum numbers of chicks (post-emergence to fledging) and the maximum numbers of fledglings (present after 45 days of age) at each burrow. We used 2-sample t-tests to test for differences in productivity by burrow type. We also examined the types of prey delivered by burrow type using non-parametric Mann-Whitney U tests. For these analyses, we used the total number of prey deliveries divided by the number of photo days to standardize between burrows and the proportions of bird, herpetofauna, invertebrate, mammal, and unknown prey; we examined prey deliveries from camera set-up date to fledging or failure date to account for the high variability in the duration of camera deployment (i.e. successful nests had cameras running for a much longer period of time). In addition, we examined daily prey deliveries from chick emergence through 3 weeks post-emergence at each burrow to more closely examine the relationship between prey deliveries and fledging success. We excluded any burrows where no chicks emerged or where no prey deliveries were captured on camera during the 3-week period. We did not include site differences because 2 of the 5 sites had no nests and a third site had only 3 nests (one of which failed before any eggs hatched). We also excluded the data from any burrows where we were not able to confirm that eggs had been laid. Where appropriate, we reexamined the 2013 and 2014 data (recalculated as described above) to compare between all three years.

**Banding**

During the nestling and fledgling stages of the breeding season, we captured, banded, and took genetic samples (blood and/or feathers) from BUOW at or near their nest burrows. We used one-way door traps at the burrow entrances as our primary capture technique for juveniles and adult females. We included the use of call/playback to capture adult males as part of the spatial ecology monitoring. Bow nets were used to capture dispersing fledglings. Standard morphometric measurements were taken for each bird. Blood samples were taken from the brachial vein; in the case of very small nestlings, body feathers were taken. All blood, feather, and tissue samples are being stored in the Frozen Zoo® at the Beckman Center, San Diego Zoo Institute for Conservation Research. Unbanded owls received two aluminum bands: a USGS band and a green alphanumeric Acraft band.

**GPS dataloggers**

To identify foraging areas, we affixed GPS dataloggers to a subset of adult males during the nestling period. We focused on this breeding stage and sex to increase the chances of recapturing tagged individuals (to retrieve the data) since breeding males are very territorial and do most of the hunting during this period. Consequently, telemetry data for males would be most informative for understanding foraging movements. Additionally, the females develop a brood patch, which interferes with the harness attachment. We used PinPoint 100 GPS units from Lotek/Biotrack. The units weighed 4.2 – 5g and were attached with a Teflon ribbon harness that weighed ~0.6g. If a bird was unbanded, we only affixed a USGS band (not an auxiliary band) at the time of GPS tag attachment to reduce the weight of all attachments. We did not collect genetic samples from any birds at the time of GPS tag attachment to reduce stress. In order to keep all attachments under 5% of body weight, we were restricted to tagging males weighing over 136g (if previously unbanded) or 168g (if banded). Upon recapture, GPS tags were removed, color bands were added (if necessary), and genetic samples were taken. The original tags (purchased in 2014) were able to log ~100 locations so were set up to take locations every 1.5 hours from 8:15 PM to 5:15 AM over an approximately 2-week period. We also received two new tags (as a result of malfunctions in 2014) with updated firmware that allowed the units to take up to 376 locations. Due to the increased capacity, we set these units to take locations every 0.5 hours from 8:00 PM to 6:00 AM over an approximately 3-week period.

Each location reading (latitude and longitude) taken by the GPS units was accompanied by the date and time, the number of satellites used by the tag to determine the location, and a degree of precision (DOP) estimate.

**Analysis of GPS data**

Based on the beacon test we conducted in 2014 (see Swaisgood et al. 2015), we removed all bird locations with >3 DOP and ≤3 satellites for home range analysis. We used the adehabitatHR package in R to calculate home ranges for each bird using both minimum convex polygons (MCP) and fixed kernel density estimation (KDE).

**Artificial burrow modifications**

Early in 2015, we modified 12 artificial burrows (6 wooden and 6 plastic) at Lonestar to make the chambers accessible from above. The modifications were made to allow for easy installation of iButton dataloggers before the breeding season without disturbing owl nesting. Burrows were randomly selected for modification from a subset of burrows that had been used for breeding in previous years to increase the chances of occupancy and modifications were modeled after Johnson et al. 2010. During excavation of the burrows, we found that a large proportion of the burrows were filled in or had blockages (see Appendix 4). As a result, in late 2015 (after the breeding season), we worked with CalTrans to modify the remaining artificial burrows at Lonestar and all of the artificial burrows at Johnson Canyon to allow for better assessment of burrow conditions and maintenance to ensure functionality for the owls in the future.

**iButton dataloggers**

We used Hygrochron Temperature/Humidity Logger iButtons (model DS1923-F5#) to add to our existing small dataset. In 2014, we found that natural burrows do a better job of buffering outside conditions than artificial burrows. We hypothesized that these differences were a result of the 2-entrance design of the artificial burrows, which created a pass-through for convection heating and cooling. In 2015, we attempted to investigate this by adding door flaps (similar to walk-in freezers) to one tunnel entrance inside the burrow chamber that would allow the owls to pass in or out but would block most airflow. This design (versus blocking one entrance and making it inaccessible) gave the owls the advantage of having multiple escape routes into the burrow while allowing us to answer whether the lack of buffering observed at artificial burrows was due to unrestricted airflow into the burrow chamber.

At Lonestar, we placed the iButtons in the selected burrows (see “Artificial burrow modifications” above) in early March to avoid disrupting breeding activity. We also randomly assigned half of the wooden and plastic burrows, respectively, to the door-flap treatment group. The burrows were assigned as follows: wooden with door (LS 23, LS 107, LS 133), plastic with door (LS 97, LS 112, LS 129), wooden without door (LS 42, LS 105, LS 160), and plastic without door (LS 146, LS 166, LS 193). We placed iButtons in three natural burrows at Brown Field that had been occupied by BUOW (though not necessarily for breeding) in 2013 or 2014 (Gailes, Cul du Sac, and Lycoming) and one squirrel burrow near two breeding burrows. We also placed an iButton in a natural burrow on the periphery of Lonestar, but need to exclude it from analysis because it became completely buried. The iButtons that were inserted into the burrows were placed inside small Whiffle balls to protect them from any animals using the burrows. The outside iButtons were placed on a ~0.5m-high stake at ~1m from the burrow entrance; each stake had a sunshade to prevent the iButtons from receiving direct sunlight. Temperature and humidity readings were taken automatically once per hour. The iButtons were removed in mid-July (14$^{th}$-17$^{th}$).

**Analysis of iButton data**

We truncated the data to include only the period of 6 June to 5 July, 2015 to coincide with the same period we examined in 2014. To examine burrow microclimate, we calculated the average daily temperature and humidity, and the average daily coefficient of variation for temperature and humidity from inside each burrow. To measure the buffering effect, we calculated the average daily difference between the inside and outside temperature and humidity at each burrow. We tested whether the respective mean values differed by burrow material type (natural, plastic, wood) using ANOVA. We used the truncated data set from the artificial burrows only to compare the burrows that had door flaps to those that did not using the same set of metrics.

**Genetic sexing**

BUOW juveniles and adults are monomorphic during the non-breeding season, making sexing in the field impossible. To identify the sex of each individual, we utilized two molecular techniques in tandem. In bird species, the females are heterozygous (ZW) for the sex chromosomes while the males are homozygous (ZZ). The chromodomain- helicase DNA binding gene (CHD) is a gene located on the avian sex chromosome. This highly conserved gene differs slightly in genetic sequence and in size by 4 base pairs on the Z (395 base pairs) and W (399 base pairs) chromosomes, allowing for differentiation between male and female.

***<u>Genetic sexing with enzyme digest</u>***

The first sexing technique used was CHD amplification followed by enzyme digest. DNA was isolated from blood or feather samples obtained during trapping. The CHD gene from both the Z and W chromosomes was amplified using polymerase chain reaction (PCR) with primers P2 and P8 (Leppert et al. 2006). These alleles only differ by 4 base pairs, a size difference that cannot be distinguished with gel electrophoresis, so we employed an enzyme digest to make these distinguishable. Samples were digested with *Hae III*, a restriction enzyme specific to GG/CC sites. This cuts the CHD-W allele into two smaller fragments while leaving the CHD-Z allele unaltered. Following digestion, PCR products were visualized on a 2.5% agarose gel. The presence of two bands (the large, uncut CHD-Z allele and smaller CHD-W fragments) indicated a female, while one band indicated a male.

***Genetic sexing with fluorescent PCR***
We also employed a second method that did not require restriction digest. DNA was isolated from blood or feather samples and the CHD gene was amplified using PCR with primers P2 and P8 along with a 6-FAM-labeled primer that fluoresces blue to allow for size-based detection of PCR product. We visualized the CHD amplicons using a 3130xl Genetic Analyzer, which is capable of discerning the 4 base pair difference. Two fluorescent peaks indicated ZW (female), while one fluorescent peak indicated ZZ (male).

***Analysis of genetic sexing results***
Individuals with molecular sexing results from at least one of the two methods were included in the analysis. Sex ratio of juveniles was calculated for 2013 and 2014 separately. Because chi-square analysis showed these did not differ from the expected ratio and no effect of year was seen, data were pooled across years. We then compared sex ratios of pooled data between artificial and natural burrows using the chi-square test to determine if burrow type correlated with sex ratio alterations.

**Genotyping and Population Genetics**

***Microsatellite genotyping***
To individually identify owls, we used DNA isolated from blood or feather samples to perform microsatellite analysis. We analyzed 28 previously published microsatellite loci (Korfanta et al. 2002, Macias-Duarte et al. 2010, Faircloth et al. 2010) using multiplex PCR reactions of six to eight loci per multiplex. Multiplexes were designed using the program Multiplex Manager and adjusted by eye. In addition to the 28 forward and reverse primer pairs, we used the universal primer PCR method (Ge et al. 2014). We modified four universal primers from Vartia et al. (2014) by labeling these with different dyes [T3 labeled with PET (red), M13 with NED (yellow), NeoR with VIC (green), and Hill with 6-FAM (blue)]. This allowed us to amplify up to 8 unique loci per multiplex in a two-step PCR. First, the forward and reverse primers amplify the loci of interest; then the fluorescently-labeled universal primer with a complimentary sequence being incorporated into the PCR product in later cycles. Microsatellites were checked for null alleles using MICROCHECKER and for Hardy-Weinberg equilibrium and/or linkage disequilibrium using GENEPOP in order to exclude loci that introduce bias or are physically linked on chromosomes. After data-trimming, 19 microsatellite loci were usable in the genotyping data.

***Analysis of microsatellites for population genetics***
Microsatellite genotype data were input into the program CERVUS to identify any duplicate samples in the data. The program was then utilized to calculate the expected ($H_e$) and observed ($H_o$) heterozygosity values as well as the inbreeding coefficient ($F_{IS}$) of the population. These were averaged over the 19 loci used for analysis. These values were compared to literature from other geographic regions to determine genetic health of the San Diego County BUOW population (Korfanta et al. 2005).

***Analysis of parentage***
The genotyping results from the 19 analyzable loci were input into COLONY to verify observed parentage and determine missing parent information. COLONY uses the maximum likelihood method to determine the most likely parent of each offspring based on the genotypes observed in the population.

## *Results & Discussion*

### Nest monitoring
During the 2015 breeding season, we located and monitored 37 BUOW nests or burrows weekly from mid-March through September (Table 3-1, Figure 3-2). We opportunistically checked burrows located on private land, but did not monitor them for breeding. We confirmed breeding (by presence of eggs or chicks) at 30 of the 37 burrows. We were not able to confirm breeding at the other burrows for two main reasons: (1) in most cases, we were not able to confirm the presence of eggs in natural burrows, so if a failure occurred before chick emergence, we could not confirm whether breeding had taken place; or (2) if a burrow occurred on private land, we observed it from the nearest road and only revisited it as time allowed during the rest of the season.

We found that fledging success (percent of burrows where we confirmed at least one juvenile had fledged) for first nesting attempts was highly variable. Apparent fledging success was 75% at Brown Field (6/8), 55% at Lonestar (6/11), and 67% at Johnson Canyon (2/3). Poggi and LORBOMA each had one nest that failed. We recorded 8 renesting (or late) attempts (5 at Lonestar, and 3 at Brown Field), but only one of the renests (at Lonestar) was successful. The variability in fledging success is likely due to the continuing and worsening drought conditions in the region. Food limitation is likely driving much of the variation in productivity and the severity of the limitation is probably very localized (even within a site, as evidenced by our 2014 and 2015 foraging range results). The vegetation at Lonestar saw significant growth in 2015 due to a very labor-intensive effort by CalTrans and TierraData (their subcontractor) to establish a native grassland area on the southern half of the site. However, reproductive success at Lonestar was still variable with the most productive burrows on the edges of the site.

The wide range of variation in fledging success points to considerable potential for management actions to enhance population performance. This variation between sites suggests that there are factors, such as food or predation, that differ among sites; when fully understood these factors or the habitat covariates that give rise to them, may be targeted for management action to facilitate higher reproductive output, potentially providing surplus animals to disperse and colonize other sites. Where productivity is low, these sites may attract owls to nest but may act as an ecological sink population. Here habitat improvements may be required or it may be desirable to deter BUOW from nesting there. Further research is needed to determine underlying causal variables for varying fledging success, but we have already begun to make some inroads into understanding potential drivers of the system (see below).

**Banding**
We banded BUOW during the period of 9 May to 3 September. We captured a total of 82 BUOW (Table 3-2, Appendix 3). We took blood and feather samples from every bird that was captured. The owls we captured represented 25 families (including 2 birds translocated by CalTrans, with 43 of them caught at natural burrows and 39 of them caught at artificial burrows.

As a result of our on-going banding effort, we continued to document movements, site fidelity, and recruitment. With the capability of identifying individuals, we were able to document multiple instances of burrow and/or mate switching after apparent nest failure. We recorded two cases of mate loss followed by re-nesting with a new mate, at least seven cases of burrow and/or mate switching, and four cases of nest abandonment (presumably because of nest failure) followed by disappearance of one or both mates. Together, these situations indicate that nesting is a dynamic process and requires marked animals to fully understand.

As an example, we observed one case in which owls from four different nests experienced nest failure and switched mates before renesting. Originally, two owls banded as adults in 2014 (F: "06 over Y", M: "63 over X") initiated nesting at LS 47. All chicks were depredated and the nest failed on 11 May. At LS 114, "00 over Y," a male banded as an adult in 2014, nested with "80 over X," a female banded as a chick in 2014. A skunk depredated the eggs, newly hatched chicks, and "80 over X". Nearby at Brown Field, "20 over Y" (a male banded as an adult in 2014) paired with "03 over Y" (a female banded as a fledgling in 2014) at Runway, but apparently none of their eggs hatched. A fourth pair at Tripad North consisted of "88 over X," a male banded as an adult in 2014 and his daughter from 2014, "92 over X." Breeding was likely, but not confirmed. After all four of these nests failed, some of the males moved to nearby burrows and some remained at their original breeding burrows while the females moved to nest with new mates. After this shuffle, at LS 47, "63 over Y" and "03 over Y" (from Runway) renested but the nest failed before fledging. "00 over Y" moved from LS 114 to LS 102 and was joined by "06 over Y" from LS 47, but they abandoned the nesting attempt during the egg-laying stage. After moving from Runway to BCS, "20 over Y" attracted "92 over X" from Tripad North. She disappeared on June 29 and breeding was unconfirmed. Finally, "88 over X" remained at Tripad North and did not attract a new mate. We would not have been able to discern this very complicated series of movements and mate switches without having a banded population of BUOW.

Using banding return rates, we can estimate juvenile recruitment rate and site fidelity for adults. In 2015, the return rate for adults was approximately 85%, with 23 of the 27 adults banded in 2014 resighted. By contrast, only 16% (6/38) of the juveniles banded in 2014 were resighted in 2015, suggesting high mortality, high dispersal rates from natal territory, or both. We have been able to use this resight data to inform survival and recruitment rates for population viability analysis and to model both adult and juvenile survival. With a high proportion of the population banded in 2014 and 2015 (especially adults), we should be better able to estimate immigration rates in 2016. This information will allow us to refine our population viability analysis [see BUOW Implementation Plan (ICR 2016)].

**Table 3-1. Breeding success at all BUOW nests located in the Otay Mesa area during the 2015 breeding season.**

| **Burrow**[1] | **Site** | **Breeding** | **Successful**[2] | **# Fledged**[3] | **Notes** | **Previously Banded Birds**[4] |
|---|---|---|---|---|---|---|
| **1. Euc 17 Fence** | Lonestar | Y | Y | 1 | | M: 72 over X<br>F: 12 over Y |
| **2. LS 159** (A)[5] | Lonestar | Y | Y | 2 | | |
| **3. LS 146** (A) | Lonestar | Y | N | 0 | | M: 46 over X |
| **4. LS 133** (A) | Lonestar | Y | Y | 1 | | M: 70 over X |
| **5. LS 114** (A) | Lonestar | Y | N | 0 | Nest depredated by skunk | M: 00 over Y<br>F: 80 over X |
| **6. LS 201** (A) | Lonestar | Y | N | 0 | | M: 73 over X |
| **7. LS 185** (A) | Lonestar | Y | Y | 5 | | M: 34 over X |
| **8. LS 13** (A) | Lonestar | Y | Y | 2 | | M: White AA<br>F: 35 over Y[6] |
| **9. LS 47** (A) | Lonestar | Y | N | 0 | | M: 63 over X,<br>F: 06 over Y |
| **10. LS 44 (A)** | Lonestar | Y | N | 0 | | F: 99 over X |
| 11. LS 52/53 (A)[7] | Lonestar | Y | Y | 2 | Nest discovered late | M: 04 over Y |
| 12. LORBOMA 49 (A) | LORBOMA | Y | N | 0 | Egg seen in burrow chamber, female never seen | M: 69 over X |
| **13. Poggi** | Poggi | Y[8] | N | 0 | Breeding and nest failure confirmed by photos of adult eating egg at burrow entrance (14 Apr) | |
| **14. Gravel Lot** | Brown Field | Y | Y | 3 | | M: 32 over X<br>F: 07 over X |
| **15. FBO Lot** | Brown Field | Y | Y | 1 | | |
| **16. Tripad North** | Brown Field | Likely[9] | N | 0 | | M: 88 over X<br>F: 92 over X |
| **17. Tripad South** | Brown Field | Y | Y | 1 | | M: 89 over X<br>F: 94 over X |
| **18. India** | Brown Field | Y | Y | 6 | | M: 79 over X<br>F: 83 over X |
| **19. Old Schoolhouse** | Brown Field | Y[8] | N | 0 | Breeding and nest failure confirmed by photos of adult eating egg at burrow entrance (26 Apr) | M: 78 over X<br>F: 97 over X |
| **20. La Media Stop Sign** | Brown Field | Y | Y | 3 | 39/Y might be a second mate of 68/X, may have contributed eggs to nest | M: 68 over X<br>F: B over E |
| **21. Gorilla** | Brown Field | Y | Y | 3 | | F: 77 over X |
| **22. Runway** | Brown Field | Y[8] | N | 0 | Breeding and nest failure confirmed by photos of ground squirrel eating eggs at burrow entrance (17, 20, 31 May) | M: 20 over Y<br>F: 03 over Y |
| **23. JC 6** (A) | Johnson Canyon | Y | Y | 3 | | |

*Table 3-1 continued.*

| Burrow[1] | Site | Breeding | Successful[2] | # Fledged[3] | Notes | Previously Banded Birds[4] |
|---|---|---|---|---|---|---|
| **24. JC 15** (A) | Johnson Canyon | Y[10] | N | 0 | C/C was also observed copulating with a male at JC 16 (not clear if it was the same male we later captured there) | M: 86 over X<br>F: C over C |
| **25. JC 18** (A) | Johnson Canyon | Y | Y | 3 | | F: 52 over X |
| 26. Satellite Array East (A) | Sat Array | Unk[11] | n/a | n/a | | M: 71 over X<br>F: 87 over X |
| **Renests/Late Nests** | | | | | | |
| **a. Old Schoolhouse** | Brown Field | Likely[9] | N | 0 | | M: 78 over X |
| **b. LS 102** (A) | Lonestar | Y | N | 0 | | M: 00 over Y<br>F: 06 over Y |
| **c. LS 47** (A) | Lonestar | Y | N | 0 | | M: 63 over X<br>F: 03 over Y |
| **d. LS 23** (A) | Lonestar | Y | N | 0 | Nest depredated by opossum | F: 99 over X |
| **e. LS 3** (A) | Lonestar | Y | N | 0 | | M: 71 over X<br>F: 87 over X |
| f. Lonestar Mound[7] | Lonestar | Y | Y | 2 | Male banded before breeding season; nest discovered late | M: 25 over Y[12]<br>F: C over C |
| g. Cul du Sac Hydrant[7] | Brown Field | Y | ?[13] | 1?[13] | Might be female from FBO Lot; nest discovered late | M: 15 over Y |
| **h. BCS** | Brown Field | Unk[11] | n/a | n/a | | M: 15 over Y<br>F: 92 over X |
| **Non-breeding** | | | | | | |
| **i. Cul du Sac Hydrant** | Brown Field | N | n/a | n/a | Female not present until 21 June | M: 15 over Y |
| **ii. Heritage and Datsun** | Brown Field | N | n/a | n/a | Never observed a female at the burrow | M: 31 over X |
| iii. JC 16 (A) | Johnson Canyon | Unlikely | n/a | n/a | GPS'd because mistaken for the JC 18 male | |
| iv. Starbuck | Brown Field | Unlikely | n/a | n/a | Camera set up to assess breeding status | |

[1]Bold indicates burrows with cameras.
[2]Nests were considered successful if 1 or more juveniles fledged (reached 45 days of age).
[3]At burrows without cameras, the # fledged is a minimum based on weekly visit data. For burrows with cameras, the # fledged is the maximum number of juveniles seen on camera after the estimated fledge date (30 days after the first emergence date).
[4]All alphanumeric bands are green unless otherwise specified; green bands are aluminum, white bands are plastic.
[5](A) indicates artificial burrows.
[6]35 over Y was previously White X5.
[7]Cameras set up late or not ideally positioned.
[8]Breeding was confirmed through camera trap photos of BUOW or ground squirrels carrying eggs out of the respective burrows.
[9]Breeding likely but unconfirmed.
[10]Eggs found in chamber during burrow modification on 8 October 2015.
[11]Breeding status unknown; not enough information to determine whether breeding was likely.
[12]Male banded before breeding season as part of translocation.
[13]Juvenile was depredated by a Cooper's hawk around fledging age (based on camera trap photos). We were not able to estimate fledging date because emergence date or wing chord length were not known.

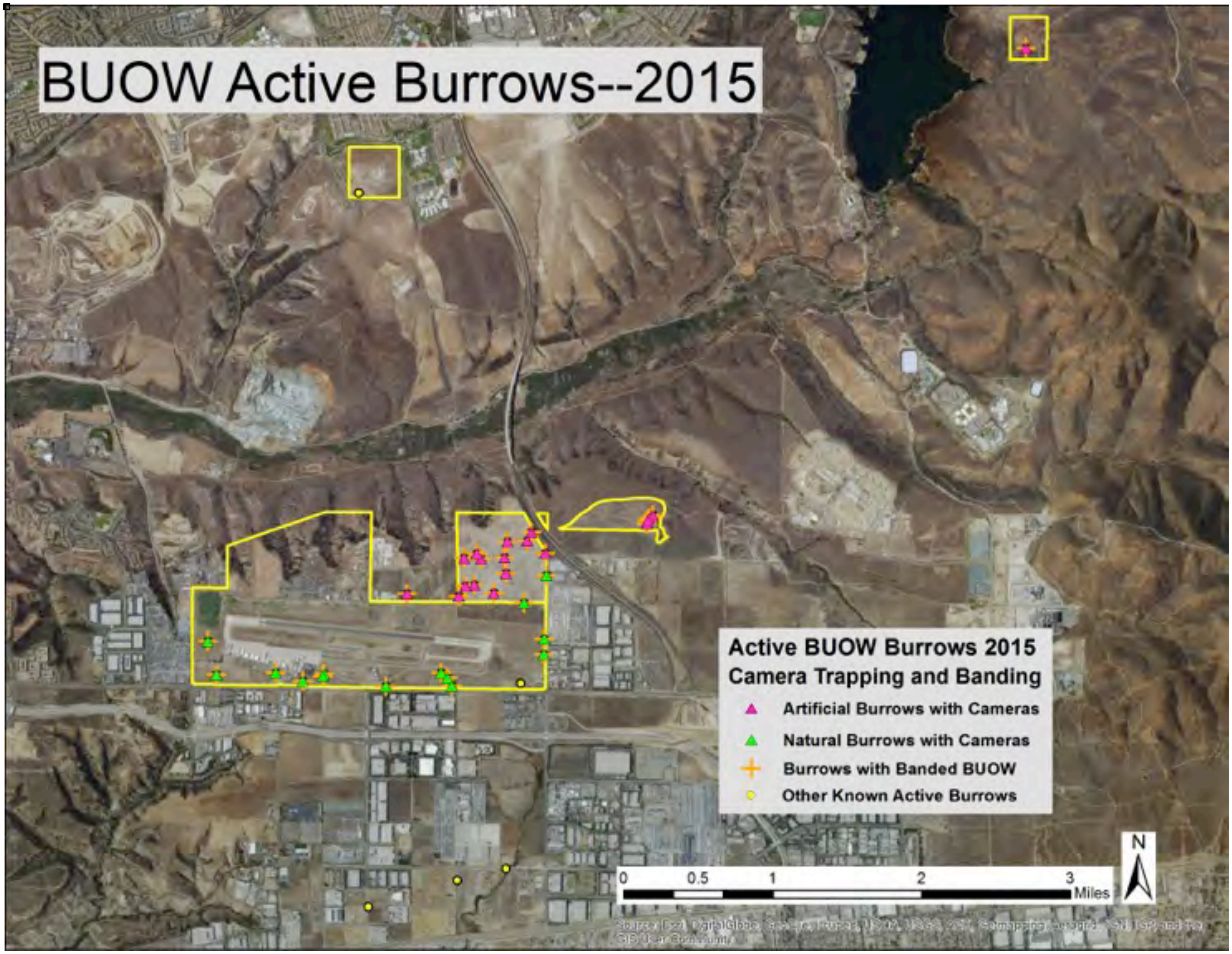



**Figure 3-2a. Map of all active BUOW burrows found in 2015.**

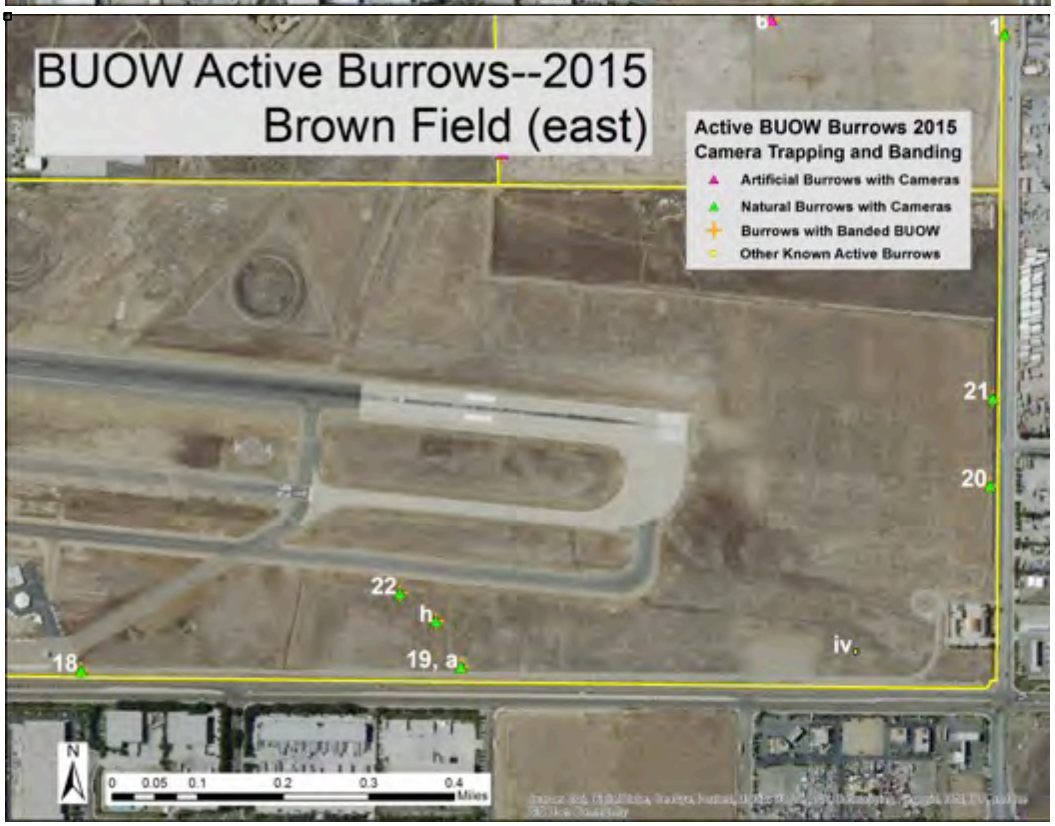
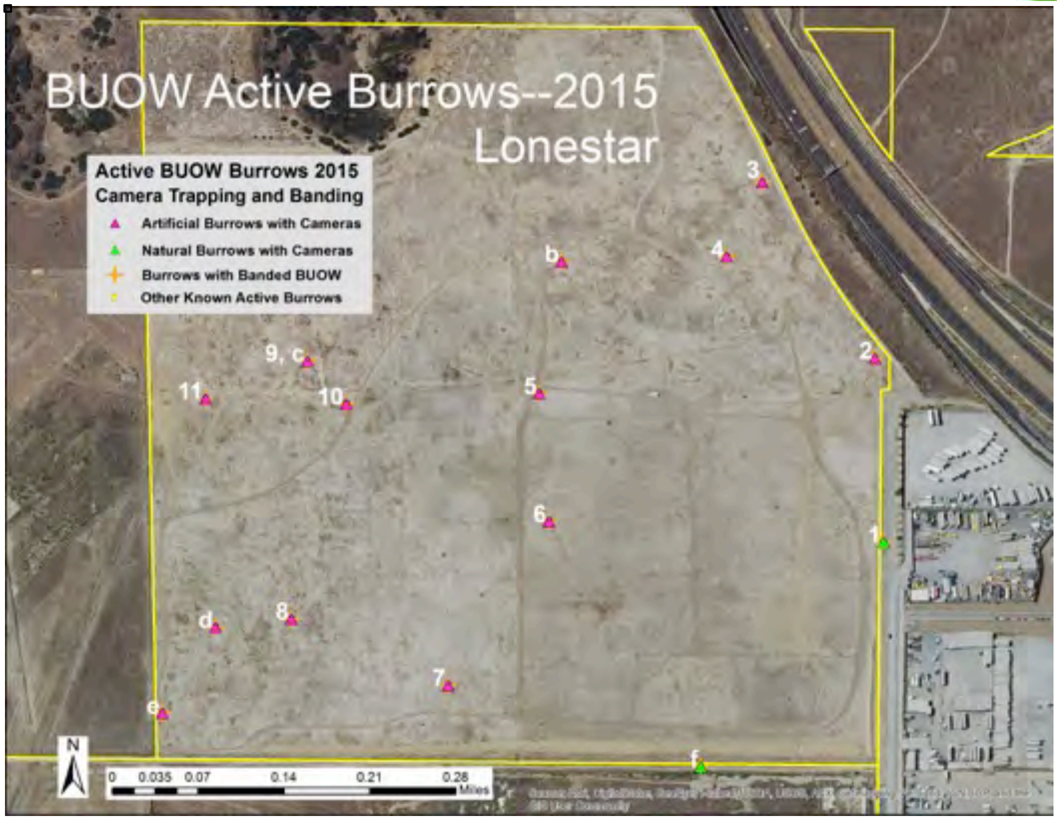




**Figure 3-2b. Map of active BUOW burrows found in 2015.** Numbers refer to Table 3-1.



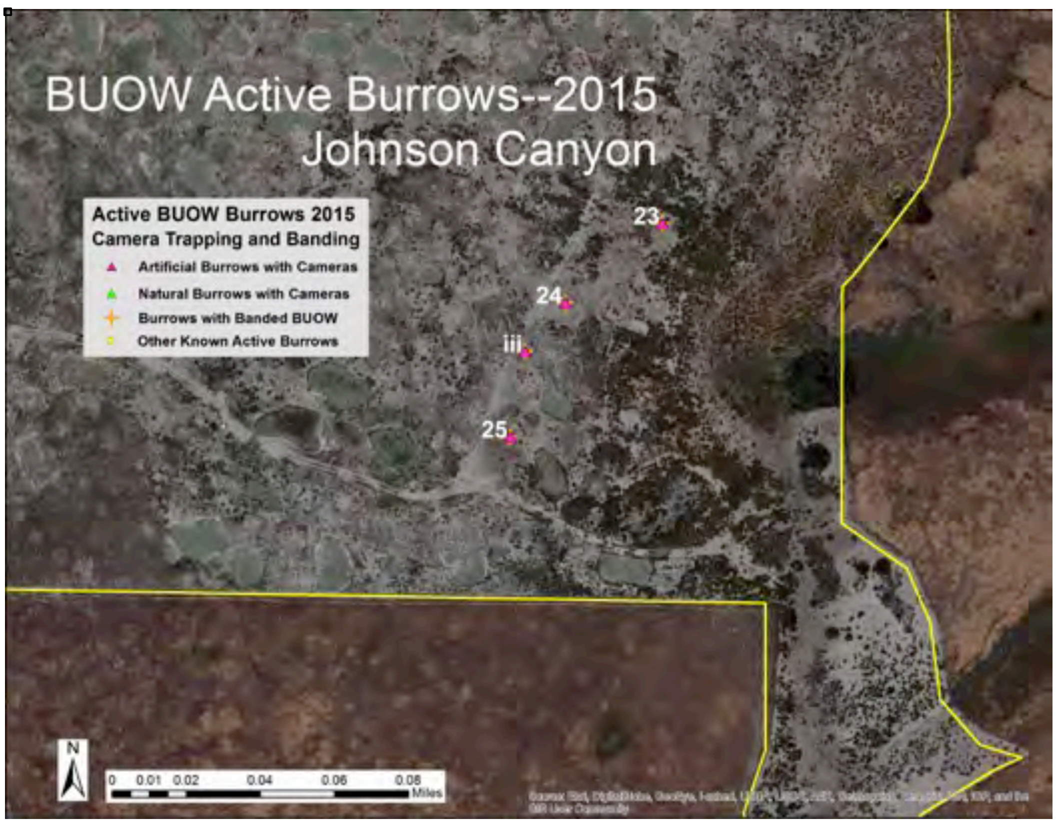
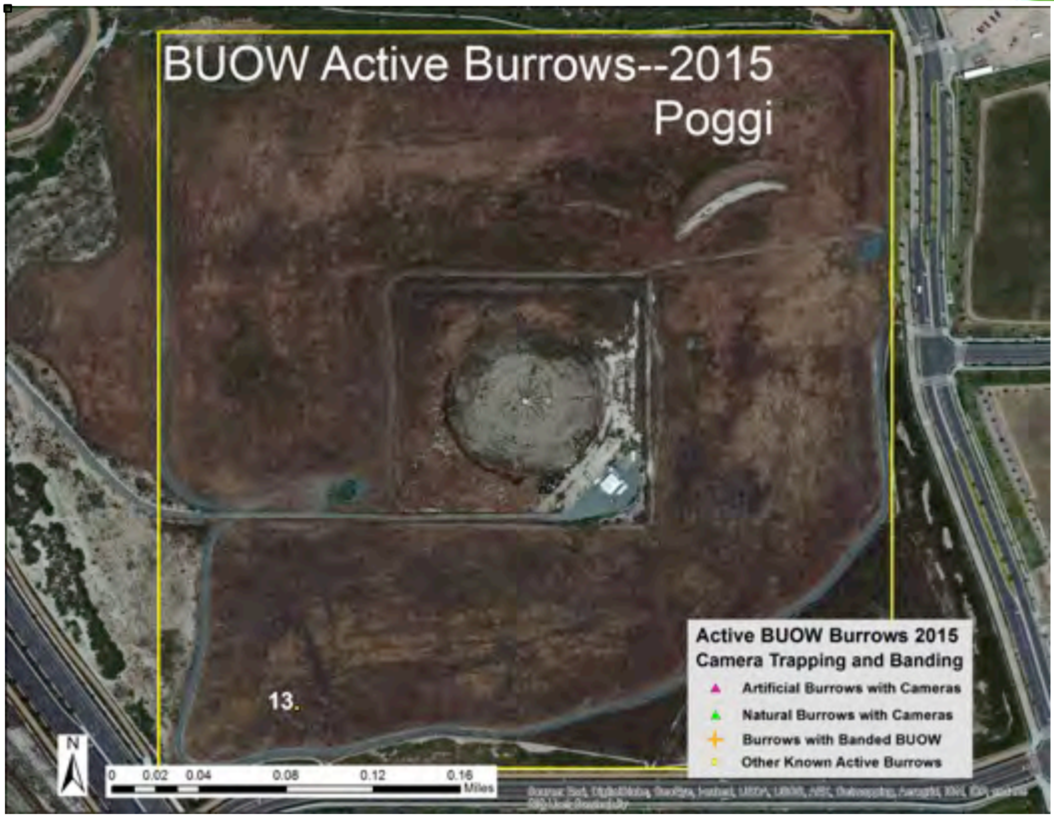




**Figure 3-2c. Map of active BUOW burrows found in 2015.** Numbers refer to Table 3-1.



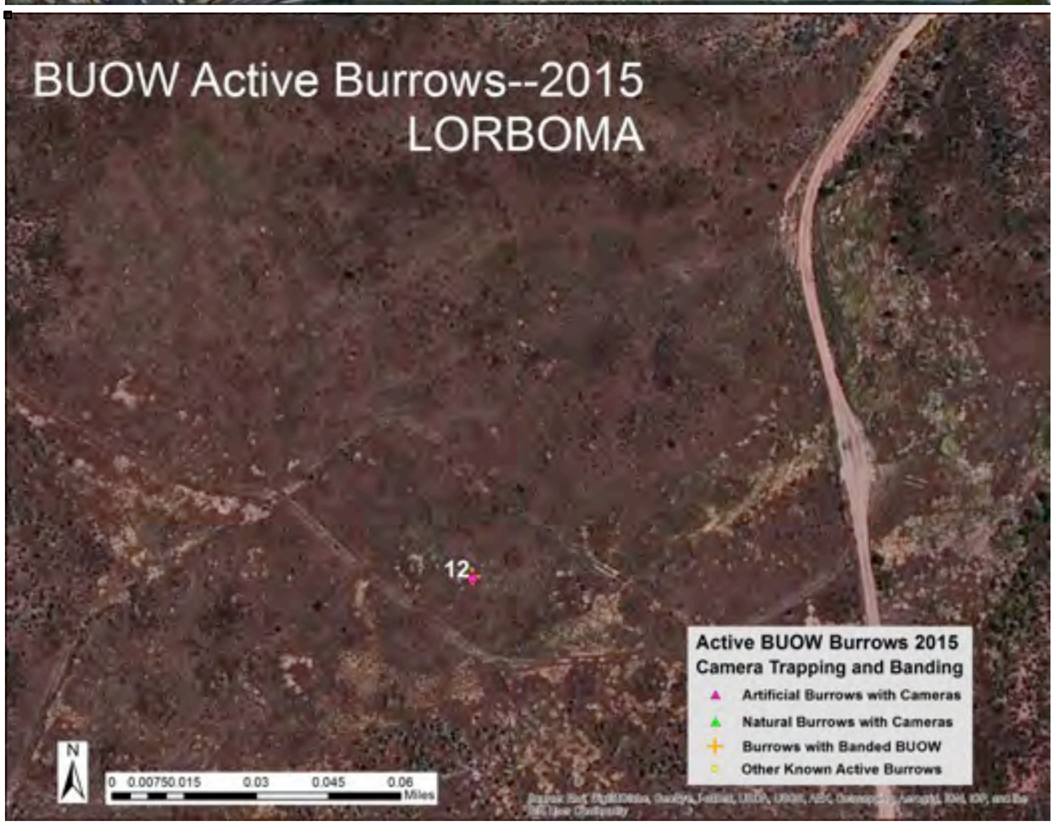




**Figure 3-2d. Map of active BUOW burrows found in 2015.** Numbers refer to Table 3-1.

**Table 3-2. Summary of BUOW banded in 2015.** Asterisk indicates a bird banded in a previous year that was recaptured in 2015. Parentheses indicate a bird banded in a previous year that was resighted but not recaptured in 2015. Italics indicate the individual was accounted for at more than one breeding burrow.

| | | Adults | | | Family Total | | Genetic Samples | * Previously Banded (Year) | |
|---|---|---|---|---|---|---|---|---|---|
| | Burrow | Female | Male | Juvs | New | All | 2015 | Female | Male |
| **Initial Nesting Attempts** | | | | | | | | | |
| 1 | LS: Euc 17 Fence | 1* | 1* | 1 | 1 | 3 | 3 | 12/Y (2014) | 72/X (2014) |
| 2 | LS: LS 159 (A) | 34/Y | 29/Y | 2 | 4 | 4 | 4 | | |
| 3 | LS: LS 146 (A) | DC[1] | (1) | | 0 | 1 | 0 | | 46/X (2014) |
| 4 | LS: LS 133 (A) | 33/Y | 1* | 1 | 2 | 3 | 3 | | 70/X (2014) |
| 5 | LS: LS 114 (A) | (1) | *(1)* | | 0 | 2 | 0 | 80/X (2014) | 00/Y (2014) |
| 6 | LS: LS 201 (A) | DC | (1) | | 0 | 0 | 0 | | 73/X (2014) |
| 7 | LS: LS 185 (A) | 28/Y | (1) | 6 | 7 | 8 | 7 | | 34/X (2013) |
| 8 | LS: LS 13 (A) | 1* | 1* | 2 | 2 | 4 | 4 | 35/Y (was WHITE X5) (2013, J. Kidd) | WHITE AA (2013, J. Kidd) |
| 9 | LS: LS 47 (A) | *(1)* | *(1)* | | 0 | 2 | 0 | 06/Y (2014) | 63/X (2014) |
| 10 | LS: LS 44 (A) | *1** | 32/Y[2] | | 1 | 2 | 2 | 99/X (2014) | |
| 11 | LS: LS 52/53 (A) | 57/Y | 1* | 2 | 3 | 4 | 4 | | 04/Y (2014) |
| 12 | LO: LO 49 (A) | DC | (1) | | 0 | 1 | 0 | Unknown[3] | 69/X (2014) |
| 13 | Poggi | DC | DC | | 0 | 0 | 0 | | |
| 14 | BF: Gravel Lot | 1* | 1* | 4 | 4 | 6 | 6 | 07/X (2013) | 32/X (2013) |
| 15 | BF: FBO Lot | possibly 30/Y[4] | 27/Y | 1 | 2 | 2 | 2 | | |
| 16 | BF: Tripad North | *1** | 1* | | 0 | 2 | 2 | 92/X (2014) | 88/X (2014) |
| 17 | BF: Tripad South | 1* | 1* | 1 | 1 | 3 | 1 | 94/X (2014) | 89/X (2014) |
| 18 | BF: India | 1* | 1* | 6 | 6 | 8 | 8 | 83/X (2014) | 79/X (2014) |
| 19 | BF: Old Schoolhouse | (1) | *(1)* | | 0 | 0 | 0 | 97/X (2014) | 78/X (2014) |
| 20 | BF: La Media Stop Sign | 1* & 39/Y[5] | 1* | 3 | 4 | 6 | 6 | B/E (2011) | 68/X (2014) |
| 21 | BF: Gorilla | 1* | 31/Y | 3 | 4 | 5 | 5 | 77/X (2014) | |
| 22 | BF: Runway | *1** | *(1)* | | 0 | 0 | 0 | 03/Y (2014) | 20/Y (2014) |
| 23 | JC: JC 6 (A) | 37/Y | 26/Y | 2 | 4 | 4 | 4 | | |

***Table 3-2 continued.***

| | Burrow | Adults: Female | Adults: Male | Juvs | Family Total: New | Family Total: All | Genetic Samples 2015 | * Previously Banded (Year): Female | * Previously Banded (Year): Male |
|---|---|---|---|---|---|---|---|---|---|
| 24 | JC: JC 15 (A) | 1* | (1) | | 0 | 0 | 0 | C/C (2011) | 86/X (2014) |
| 25 | JC: JC 18 (A) | 1* | 36/Y | 3 | 4 | 5 | 7[6] | 52/X (2013) | |
| 26 | Satellite Array East (A)[7] | (1) | (1) | | 0 | 0 | 0 | 87/X (2014) | 71/X (2014) |
| **Renests/Late nests** | | | | | | | | | |
| a | BF: Old Schoolhouse | DC | (1) | | 0 | 1 | 0 | | 78/X (2014) |
| b | LS: LS 102 (A) | (1) | (1) | | 0 | 0 | 0 | 06/Y (2014) | 00/Y (2014) |
| c | LS: LS 47 (A) | 1* | (1) | 1 | 1 | 3 | 2 | 03/Y (2014) | 63/X (2014) |
| d | LS: LS 23 (A) | 1* | 32/Y[2] | | see LS 44 | | | 99/X (2014) | |
| e | LS: LS 3 (A) | (1) | (1) | | 0 | 0 | 0 | 87/X (2014) | 71/X (2014) |
| f | LS: Lonestar Mound | 1* | 1* | 2 | 2 | 4 | 3 | C/C (2011) | 25/Y (2015)[8] |
| g | BF: Cul du Sac Hydrant | 30/Y | (1) | | 1 | 2 | 1 | | 15/Y (2014) |
| h | BF: BCS | 1* | (1) | | 0 | 2 | 0 | 92/X (2014) | 20/Y (2014) |
| **Non-breeding?** | | | | | | | | | |
| i | BF: Cul du Sac Hydrant | n/a | (1) | | 0 | 0 | 0 | | 15/Y (2014) |
| ii | BF: Heritage and Datsun | n/a | (1) | | 0 | 0 | 0 | | 31/X (2013) |
| iii | JC: JC 16 (A) | n/a | 90/Y | | 1 | 1 | 1 | | |
| **Others** | | | | | | | | | |
| | 125 Exit (Translocation) | | 24/Y & 25/Y | | 2 | 2 | 2 | | |
| | Dispersing juveniles | | | 4 | | | 4 | | |
| **Totals** | | 7 new/23 total | 9 new/28 total | 44 | | | 81 | | |

[1]DC = did not capture.
[2]Male 32/Y was captured at a non-breeding burrow late in season, but is suspected of being the male from both LS 44 and LS 23.
[3]Female never seen, unknown if previously banded.
[4]Possibly same female as Cul du Sac, not counted in genetic samples for FBO Lot.
[5]39/Y banded at nearby burrow but often observed interacting with male from La Media Stop Sign (including copulations).
[6] Two genetic samples were taken from chicks too small to band at subsequent visits; the two samples may represent the same individual caught twice.
[7]Adults only partially confirmed, but very likely. They were mates in 2014 and presumably last seen at the Satellite Array burrows on 1 December 2014.
[8]25/Y was banded in winter 2015 so was already banded at time of breeding.

**Camera trapping**

We monitored 34 nesting attempts (17 at natural burrows and 17 at artificial burrows) during the breeding season using camera traps, but some had limited data due to nest failures or finding the nesting attempt late in the cycle. Camera traps ran from 27 March to 25 September for a total of 4767 camera days (including secondary cameras at satellite burrows) and collected approximately 2.4 million photos. Volunteers were recruited and trained, and completed the first tier of photo processing. Quality control was completed by staff. Changes in prey identification were related to whether a prey item was categorized as "unknown prey" (meaning volunteers were unable to assign the prey item to a taxon group). Most changes resulted in a prey item being recategorized from the "unknown" or "prey unseen" categories to the "invertebrate" category.

As in 2014, we set the cameras up perpendicular to the burrow entrances to facilitate better identification of prey items. We still had situations in which a prey item could not be positively identified to taxon ("prey seen unknown") or the prey item was too small to be seen (e.g., earwigs), but we could clearly see a beak-to-beak exchange ("prey unseen"). These photos were combined into the "unknown prey" category for analysis.

**Prey**

We recorded a total of 19,711 prey deliveries at 22 nesting attempts (Table 3-3). We could not include data from all monitored nesting attempts because of bad timing or sub-optimal camera set-up (e.g. the Tripad burrows). We recorded an additional 3,148 exchanges that were likely prey deliveries but could have been preening events or other interactions between the owls. These "possible" prey deliveries were not included in data analysis. At all of the burrows, invertebrates made up the highest proportion of prey deliveries. At some of the burrows, the proportion of unknown prey deliveries was relatively high; this was probably a result of not having the cameras set at an optimal angle due to burrow configuration.

Productivity in 2015 (both in terms of the maximum number of chicks and the number fledged) was positively related to the number of prey deliveries per day (max chicks: $R^2 = 0.46$, $F_{(1, 20)} = 16.71$, $p = 0.0006$; number fledged: $R^2 = 0.40$, $F_{(1, 20)} = 13.39$, $p = 0.0016$). This analysis is based on the total number of prey items delivered during the focal period described above and does not take into account the size or quality of the prey item. We reexamined the prey data from 2013 and 2014 with this more restricted focal period (see Appendix 2), and found significant positive relationships between the number of prey deliveries per day and 1) the numbers fledged in both years, and 2) the maximum number of chicks in 2013.

We also found significant *negative* relationships between both metrics for productivity and the proportion of invertebrates delivered (max chicks: $R^2 = 0.25$, $F_{(1, 20)} = 6.69$, $p = 0.018$; number fledged: $R^2 = 0.38$, $F_{(1, 20)} = 12.39$, $p = 0.0022$). This result could suggest that invertebrate prey is suboptimal. Again, we reexamined the data from 2013 and 2014 with the new focal period. We found that this relationship was negative in both previous years but was significant only in 2014 (max chicks: $R^2 = 0.28$, $F_{(1, 20)} = 7.89$, $p = 0.011$; number fledged: $R^2 = 0.17$, $F_{(1, 20)} = 4.08$, $p = 0.057$). We did find that the mean proportion of mammal prey decreased in each year and was significantly lower in 2015 than in 2013 (p=0.031), suggesting that the on-going drought conditions are affecting prey quality and may be affecting reproduction. We did not find any significant relationships from the 3-week post-emergence analysis, but will continue to explore these data.

As in past years, we found a significant negative correlation between the proportion of invertebrates and proportion of unknown prey (r(22) = -0.97, p = <.0001); this is not surprising as most prey items that are categorized as unknown can not be identified because they are too small, which suggests that they are invertebrates. We also found a significant negative correlation between the proportion of invertebrates and the number of photo days in the focal period (r(22)=-0.55, p=0.0081). This is likely a result of productivity having a negative relationship with invertebrate prey and successful nests having a longer focal period. We found an interesting correlation for the burrows that experienced infanticide between the number of BUOW prey (i.e. the number of infanticides) and the maximum number of chicks (r(7)=0.81, p=0.026). We did not observe this correlation in past years (likely due to small sample sizes), but this suggests that food limitation and resulting brood reduction may be the driving force behind infanticides.

**Table 3-3. Summary of all prey deliveries seen in camera trap photos during the 2015 breeding season.** Data were taken only from the focal period starting with the camera set-up date and ending with the fledging or failure date for each respective burrow.

| Site | Burrow | Prey Deliveries/ Photo Day | Birds (%) | Inverts (%) | Herps (%) | Mammals (%) | Unknown (%) | BUOW Prey (#) |
|---|---|---|---|---|---|---|---|---|
| **Initial Nesting Attempts** | | | | | | | | |
| Lonestar | Euc 17 Fence | 23.24 | <1 | 59 | 2 | 2 | 36 | 0 |
| | LS 159 (A) | 19.07 | <1 | 86 | 1 | 6 | 8 | 0 |
| | LS 146 (A) | 1.11 | 0 | 90 | 2 | 8 | 0 | 0 |
| | LS 133 (A) | 29.92 | <1 | 81 | 1 | 2 | 17 | 1 |
| | LS 114 (A) | 5.00 | <1 | 86 | 4 | 4 | 5 | 0 |
| | LS 201 (A) | 4.26 | <1 | 89 | 1 | 2 | 7 | 0 |
| | LS 185 (A) | 17.30 | <1 | 48 | 1 | 4 | 47 | 0 |
| | LS 13 (A) | 14.37 | <1 | 67 | 1 | 6 | 26 | 0 |
| | LS 47 (A) | 12.28 | <1 | 92 | <1 | 3 | 3 | 0 |
| Brown Field | Gravel Lot | 23.99 | <1 | 86 | <1 | 3 | 10 | 0 |
| | FBO Lot | 18.10 | <1 | 82 | <1 | 4 | 13 | 0 |
| | India | 24.32 | <1 | 81 | 1 | 8 | 11 | 1 |
| | Old Schoolhouse | 12.20 | 0 | 91 | 0 | 6 | 3 | 0 |
| | La Media Stop Sign | 33.34 | 0 | 59 | <1 | 2 | 39 | 1 |
| | Gorilla | 25.52 | <1 | 61 | 1 | 2 | 36 | 0 |
| | Runway | 1.93 | 0 | 96 | 0 | 0 | 4 | 0 |
| Johnson Canyon | JC 6 (A) | 37.15 | <1 | 82 | 1 | 4 | 13 | 3 |
| | JC 15 (A) | 8.16 | 0 | 90 | 3 | 3 | 3 | 0 |
| | JC 18 (A) | 9.59 | <1 | 79 | <1 | 15 | 5 | 1 |
| **Renests/Late nests** | | | | | | | | |
| Lonestar | LS 47 (A) | 5.57 | <1 | 86 | 1 | 4 | 7 | 2 |
| | LS 23 (A) | 2.93 | <1 | 91 | 1 | 1 | 5 | 0 |
| | LS 3 (A) | 7.29 | 0 | 94 | 1 | 0 | 5 | 0 |

**Juvenile mortality**

We documented 16 confirmed or likely juvenile mortality events during the 2015 breeding season, which represents 25% of the maximum number of chicks recorded (Tables 3-4 and 3-5). Of these events, 7 were depredations by non-BUOW predators and 6 were depredations by BUOW with 3 additional potential infanticides. As in 2014, infanticide did not seem to be driven by mate loss. Instead, there was a relationship between the maximum number of chicks and the number of infanticides lending support to the hypothesis that infanticide is driven by food limitation. In contrast to both 2013 and 2014, there was no clear leading cause of observed mortality, but if all likely or possible infanticides could have been confirmed, infanticide would have been the leading cause. Once again, at the artificial burrows where we could check the nest chambers (directly or with a peeper camera), there continued to be a discrepancy between the number of eggs laid and the number of chicks that emerged (Table 3-5) suggesting that we are still missing a significant cause of juvenile mortality before emergence.

We recorded three mortality events that resulted in the complete loss of the nest, two of which also seemed to result in the loss of the nesting female. At LS 114, a striped skunk was seen (on camera) entering the burrow on 6 May (before emergence of any juveniles); after this visit, the adult female ("80 over X") was never seen on camera again and the male ("00 over Y") moved to a different burrow approximately one week later. During burrow modifications on 15 October, we found the leg and USGS band of 80 over X, which confirmed her depredation. There was also an unconfirmed skunk depredation at LS 201 on 10 May. Again, a skunk is seen on camera entering the burrow and after this visit, neither the adult female (unbanded) or the remaining chick (also unbanded) was seen on camera again. The adult male ("73 over X") left the burrow immediately and was seen visiting other burrows but never renested. The third nest depredation took place at LS 23 (a renesting attempt) on 7 May where an opossum destroyed the entire clutch of eggs. The banded female ("99 over X") was seen later in the season, but she apparently did not try to nest a third time. These events are the first evidence we have of mesopredators entering the burrows since we began monitoring nesting in 2013. All three events took place at artificial burrows (2 plastic, 1 wooden) and may illustrate another drawback of artificial burrows—the size and simplicity of the tunnels may not discourage some nest predators as effectively as natural burrows. Interestingly, the double entrance design was intended to provide more escape routes for the owls (both into and out of the burrow), but this may be ineffective if the female's response is to fight off a nest predator. We will be testing different burrow designs in 2016 and will address burrow tunnel complexity in terms of the effect on microclimate. Increasing the complexity of artificial burrow tunnels may also help to protect them from mesopredators. Predation can be anticipated to have increasing impacts in the human-altered landscapes of the anthropocence through expanding, subsidized, and invasive predator populations and mesopredator release (Crooks and Soule 1999; Gompper and Vanak 2008). Our results continue to suggest that more attention should be devoted to understanding predation effects on BUOW populations in San Diego County, where fragmentation and subsidization has led to large increases in some predators, and the synergistic effects of drought, artificial burrows, and subsidized predators are impacting population growth.

**Table 3-4. All juvenile mortality events recorded in 2015.**

| Site | Burrow | Mortality event | Date | Additional Info |
|---|---|---|---|---|
| Lonestar | Euc 17 Fence | Likely Raven | 17-May | Predation unconfirmed but likely; max count data corroborate |
| | LS 133 (A) | Unknown--possible infanticide or starvation | 24-May | Half-eaten chick seen on camera |
| | LS 114 (A) | Striped Skunk | 6-May | Likely depredation of adult female (80 over X), 2 chicks, and 3 eggs. Adult female leg with USGS band found in burrow during burrow modifications on 15 Oct. |
| | LS 201 (A) | Likely Raven | 6-May | Predation unconfirmed but likely; max count data corroborate |
| | | Striped Skunk | 10-May | Likely chick and possible female depredation. Adult female (unbanded) and chick not seen on camera again after skunk visits. |
| | LS 47 (A) | Raven | 11-May | |
| Brown Field | Tripad South | Likely Infanticide | 8-May | Adult male seen on camera eating chick |
| | | Possible Infanticide | 15-May | Photos not clear, but max count data corroborate |
| | | Possible Infanticide | 15-May | Photos not clear, but max count data corroborate |
| | La Media Stop Sign | Likely Infanticide | 27-Apr | Adult seen on camera eating chick (emerged 1 day before) |
| Johnson Canyon | JC 6 (A) | Unknown--possible infanticide or starvation | 21-Apr | Adults and other juveniles seen eating chick |
| | JC 18 (A) | Infanticide | 14-Jun | |
| **Late nests/renests** | | | | |
| Lonestar | LS 47 (A) | Infanticide | 7-Jul | Adult female (03 over Y) seen killing unbanded chick (emerged 4 days prior) |
| | | Unknown--possible infanticide or starvation | 13-Jul | Adults and other juveniles seen eating chick |
| | LS 23 (A) | Opossum | 7-May | all eggs (8) destroyed, nest abandoned |
| Brown Field | Cul du Sac Hydrant | Cooper's Hawk | 31-Aug | |
| **Eggs (events seen on camera traps)** | | | | |
| Brown Field | Old Schoolhouse | Egg scavenging | 26-Apr | Different adult female (03 over Y) seen eating egg |
| | Runway | Egg scavenging | 17-May | Ground squirrel with egg |
| | | Egg scavenging | 20-May | Ground squirrel with egg |
| | | Egg scavenging | 31-May | Ground squirrel with egg |
| Poggi | Poggi | Possible depredation | 14-Apr | Unbanded adult eating BUOW egg, both adults gone by 23 April |

**Table 3-5. Nesting stage dates and productivity for 2015 at burrows monitored with camera traps or direct observation.**

| Burrow | Cam Dates | Complete clutch and date (if peeped)[1] | Estimated First Egg Date[2] | Estimated Hatch Date[3] | First Chick Emergence Date[4] | Max # chicks (Date) | Estimated Fledging Date | # Juveniles Fledged[5] |
|---|---|---|---|---|---|---|---|---|
| LS: Euc 17 Fence | Mar 30-Sep 25 | n/a | 19-Mar | 18-Apr | 2-May | 4 (May 5-May 17) | 2-Jun | 1 |
| LS: LS 159 (A) | Apr 30-Jul 1 | 7 (4/10) | 28-Mar | 27-Apr | 11-May | 2[6] (May 14-June 22) | 11-Jun | 2 |
| LS: LS 146 (A) | Apr 3-Jun 5 | 7 (4/30) | 18-Apr[7] | none hatched | n/a | 0 | n/a | 0 |
| LS: LS 133 (A) | Apr 3-May 19; Jul 1-Sep 25 | 7 (4/10) | 26-Mar | 25-Apr | 9-May | 4 (May 9-May 11) | 9-Jun | 1 |
| LS: LS 114 (A) | Apr 3-May 19 | 8 (4/17) | 28-Mar[7] | 2-May[7] | none[8] | 0 | n/a | 0 |
| LS: LS 201 (A) | Mar 30-May 19 | 8 (4/3) | 22-Mar | 21-Apr | 5-May | 2 (May 5-May 6) | 5-Jun | 0 |
| LS: LS 185 (A) | Apr 3-Sep 25 | none seen with peeper | 19-Mar | 18-Apr | 2-May | 6 (May 2-May 13) | 2-Jun | 5 |
| LS: LS 13 (A) | Apr 3-Jun 18 | at least 5 (4/3) | 22-Mar | 21-Apr | 5-May | 3 (May 8-May 12) | 5-Jun | 2 |
| LS: LS 47 (A) | Apr 3-Sep 3 | 7 (4/3) | 27-Mar | 26-Apr | 10-May | 1 (May 10-May 11) | 10-Jun | 0 |
| LS: LS 44 (A) | Apr 3-Apr 10 | 2 (4/3) | 30-Mar[7] | none hatched[9] | n/a | 0 | | 0 |
| LS: LS 52/53 (A) | Jun 5-Sep 25 | n/a | 29-Mar | 28-Apr | unknown | 2[10] (June 5-Sept 25) | 12-Jun | 2 |
| LO: LO 49 (A) | Apr 2-11 | 1 (4/2)[11] | unknown | none hatched | n/a | 0 | n/a | 0 |
| Poggi | Apr 2-May 27 | n/a | n/a | Egg on cam[12] | n/a | 0 | n/a | 0 |
| BF: Gravel Lot | Mar 27-Aug 21 | n/a | 19-Mar | 18-Apr | 2-May | 6 (May 4-May 6) | 2-Jun | 3 |
| BF: FBO Lot | Mar 27-Jul 7 | n/a | 21-Mar | 20-Apr | 4-May | 2 (May 5-May 15) | 4-Jun | 1 |
| BF: Tripad North | Apr 10-Jul 17 | n/a | n/a | BU[13] | n/a | n/a | n/a | n/a |
| BF: Tripad South | Apr 10-Jul 17 | n/a | 27-Mar | 26-Apr | 10-May | 4 (May 12-May 15) | 10-Jun | 1 |
| BF: India | Mar 27-Aug 14 | n/a | 19-Mar | 18-Apr | 2-May | 6 (May 10-June 16) | 2-Jun | 6 |
| BF: Old Schoolhouse | Mar 27-May 7 | n/a | n/a | Egg on cam[12] | none | 0 | n/a | 0 |
| BF: La Media Stop Sign | Mar 27-Sep 25 | n/a | 13-Mar | 12-Apr | 26-Apr | 3 (April 28-June 26) | 27-May | 3 |
| BF: Gorilla | Mar 27-Jul 7 | n/a | 23-Mar | 22-Apr | 6-May | 3 (May 7-June 21) | 6-Jun | 3 |
| BF: Runway | May 7-Jun 2 | n/a | n/a | Egg on cam[12] | none | 0 | n/a | 0 |
| JC: JC 6 (A) | Mar 27-Jul 2 | n/a | 5-Mar | 4-Apr | 18-Apr | 8 (April 19) | 19-May | 3 |
| JC: JC 15 (A) | Mar 27-Apr 28 | n/a | unknown | none hatched[14] | n/a | 0 | n/a | 0 |
| JC: JC 18 (A) | Apr 6-Sep 25 | n/a | 20-Apr | 20-May | 3-Jun | 4 (June 6-June 14) | 4-Jul | 3 |
| Satellite Array East (A) | n/a | n/a | n/a | BU | n/a | n/a | n/a | n/a |

*Table 3-5 continued.*

| Burrow | Cam Dates | Complete clutch and date (if peeped)[1] | Estimated First Egg Date[2] | Estimated Hatch Date[3] | First Chick Emergence Date[4] | Max # chicks (Date) | Estimated Fledging Date | # Juveniles Fledged[5] |
|---|---|---|---|---|---|---|---|---|
| **Renests/ Late nests** | | | | | | | | |
| BF: Old Schoolhouse | May 19-Jul 17 | n/a | n/a | BU | n/a | n/a | n/a | n/a |
| LS: LS 102 (A) | Jun 4-Jul 1 | 4 (6/9-6/16)[15] | 2-Jun[7] | none hatched | n/a | 0 | n/a | 0 |
| LS: LS 47 (A) | Apr 3-Sep 3 | 6 (6/9) | 18-May | 17-Jun | 1-Jul | 5 (July 2-July 3) | 1-Aug | 0 |
| LS: LS 23 (A) | Apr 10-May 19 | 8 (5/5) | 22-Apr[7] | none hatched[16] | n/a | 0 | n/a | 0 |
| LS: LS 3 (A) | Jun 16-Jul 28 | 4 (7/1-7/7)[17] | unknown | none hatched | n/a | 0 | n/a | 0 |
| LS: Lonestar Mound | Apr 17-Jun 26; Aug 7-Sep 11 | n/a | 4-Jun | 4-Jul | unknown | 2[10] (Aug 7-Aug 22) | 18-Aug | 2 |
| BF: Cul du Sac Hydrant | Aug 21-Sep 11 | n/a | n/a | unknown | unknown | 1[18] (Aug 21-31) | unknown | 0[19] |
| BF: BCS | Jun 9-Jul 17 | n/a | n/a | BU | n/a | n/a | n/a | n/a |

[1] The complete clutch size is a minimum estimate. The complete clutch date is the earliest date we observed the full clutch, but is likely not the actual date of clutch completion.
[2] First egg date was determined by back-dating 30 days from estimated hatch date.
[3] Hatch date was determined by back-dating 14 days from first chick emergence date.
[4] First date chicks were seen on camera trap.
[5] Juveniles were considered fledged if they reached 45 days of age.
[6] Possible max of three chicks on 14 May.
[7] These first egg dates (and hatch date for LS 114) were estimated using peeper scope data.
[8] Two chicks seen with peeper on 5 May, but no chicks emerged. Nest (including adult female) depredated by skunk on 6 May.
[9] Nest abandoned by 10 April.
[10] Chick age at capture was estimated using the wing chord measurement; hatch date was estimated by back-dating. Chicks had already emerged at the time camera was deployed.
[11] One egg found on 2 April, female never seen at site. Actual first egg date unknown.
[12] Breeding confirmed because egg(s) were seen on camera (scavenging or depredation), see Table 3-4 for details.
[13] BU = breeding unconfirmed.
[14] Nesting attempt abandoned by 17 April (adult male disappeared). Eggs found still intact in burrow chamber on 8 October.
[15] Nesting attempt abandoned by 16 June.
[16] Nest depredated (all eggs destroyed) by opossum on 7 May.
[17] Eggs hard to see in chamber, possibly laid much earlier. Nesting attempt abandoned by 7 July with total of 4 eggs.
[18] Nest discovered late, max could have been higher. Max chick dates are camera set-up to nest failure date.
[19] Juvenile depredated by Cooper's hawk on 31 August at or near fledging age.

**Reproductive success**

There was a wide range of estimated dates of first egg-laying (5 March—4 June, Table 3-5) and hatching (4 April—4 July); these dates include renesting attempts. There were four confirmed and 2 suspected (but unconfirmed) second nesting attempts, and two late nesting attempts that were likely renests. The Lonestar Mound and Cul du Sac Hydrant burrows were not found until after the juveniles had emerged. For all nesting attempts combined, the overall average maximum number of chicks per burrow was 2.4 (SE = 0.42, n=29) and the overall average maximum number of fledglings per burrow was 1.3 (SE = 0.31, n=29).

Reproductive success (in terms of numbers fledged) was again lower in 2015 compared to 2013, but the differences between all three years were not significant. The maximum number of chicks produced in 2013 was significantly higher than either 2014 or 2015 (the the latter two years were not different from each other). This potential continuing downward trend in population performance needs to be monitored, particularly in light of the continuing drought conditions. Our indicators of reproductive success derived from camera traps provide critical information for analyzing the effects of other factors, such as habitat, foraging patterns, and burrow characteristics. By continuing to monitor reproductive success along with other ecological variables, we will be better able to determine the important drivers of reproductive success. With El Niño conditions forecast for 2016, it will be important to document reproductive output in a potentially better prey year to see how the population may respond.

**GPS data and home range estimates**

Of the 17 males we captured during the breeding season, most were too light to satisfy the 5% of body weight rule. We were able to attach GPS dataloggers to four adult males during the nestling period for their respective broods (Table 3-6). The La Media Stop Sign male ("68 over X") received one of the newer units (that can log more data points) and we were able to obtain ~3 weeks of movement data. This male was GPS-tagged in both 2014 and 2015 (see below). The Tripad North male ("88 over X") carried one of the older units for the entire two-week period. The FBO Lot male ("27 over Y") received one of the newer units which would have been able to log ~3 weeks worth of location data; however, the duration of his GPS deployment was shortened because the harness material began to unravel (observed on camera trap). This was fortuitous because he left the breeding burrow 5-6 days later and we may not have been able to recapture him to download the data. We also outfitted a male we captured at JC 16 ("90 over Y") thinking he was the father of the JC 18 juveniles but we removed the GPS unit only 5 days later when we discovered he was actually a different, unpaired male. Again, this was fortuitous as this bird left the area approximately 1 week after GPS removal. Unfortunately, there was only one male at Lonestar that was large enough to carry a GPS unit (LS 13 male "AA" who had a GPS in 2014), but we weren't able to recapture him early enough in the breeding cycle to place a unit on him.

Our 2015 results were similar to those of 2014. The maximum distance traveled from the breeding burrow was 1012.55 m (compared to 1199.94 m) and the average maximum distance across all individuals was 782.86±181.85 m (compared to 847.25±361.73 m). We used a 95% MCP and a 95% kernel utilization distribution (KUD) with the smoothing factor (h) set to 40m for all individuals to estimate the home range sizes. The two different methods gave similar results with average home range size estimates of 0.27 $km^2$ and 0.24 $km^2$, respectively. This is likely an underestimate of their actual home range size given the short 2- to 3-week time interval. However, this estimate does accurately reflect the area used for foraging while provisioning chicks, and thus the foraging area that likely determines the reproductive outcome. Due to the low number of males that weighed enough to outfit with GPS dataloggers, we did not have a sufficient sample size to tie prey deliveries (type or frequency) or productivity to our estimates of home range. Interestingly, the home range estimate for the unpaired Johnson Canyon male was similar to the estimates for the other males, although the GPS deployment was very short.

Although large individual variation in home range size can occur (Haug and Oliphant 1990; Gervais et al. 2003), we found that 90% of all locations were within 660 m of the respective burrow. Similarly, Haug and Oliphant (1990) and Gervais et al. (2003) found that the majority of foraging locations (95% and 80%, respectively) were within a 600 m radius around a nest site. Moreover, Gervais et al. (2003) found that distance to nest site was a key factor explaining adult male owl foraging site selection. One male ("68 over X") outfitted during the same time period in both 2014 and 2015 used the same breeding burrow in both years. Although we were able to use over eleven times more locations to estimate his home range in 2015 (286 locations vs. 25), there was considerable spatial overlap in his home range between years, and the home range sizes and maximum distances were similar between years (Table 3-6, Figure 3-4). These data, along with band resights, demonstrate the high degree of philopatry exhibited by BUOW and highlight the importance of understanding BUOW spatial ecology and the habitat immediately surrounding the breeding burrow both in terms of its foraging quality and the potential hazards to the birds. For example, three of the owls had home ranges that overlap major roadways in Otay Mesa (Figure 3-3). Consequently, the siting of artificial burrows, habitat restoration, and other management activities (such as passive relocation) should take into account the habitat, food availability, and risks of disturbance or other negative impacts to BUOW within a small (500-600 m radius) spatial scale.

**Table 3-6. Summary of GPS data and home range estimates for four BUOW.**

| Burrow & Bird ID[1] | Total # Locations | Proportion Locations Discarded[2] | # Locs for HR Analysis | 95% MCP (km$^2$) | 95% KUD (km$^2$)[3] | Maximum Distance from Burrow (m) | Start Date/Time (PDT) | End Date/Time (PDT) |
|---|---|---|---|---|---|---|---|---|
| LMSS: 68 over X | 377 | 0.241 | 286 | 0.312 | 0.289 | 1012.55 | 5/9/15 21:30 | 5/27/15 20:00 |
| Tripad North: 88 over X | 105 | 0.152 | 89 | 0.205 | 0.174 | 616.45 | 5/12/15 0:45 | 5/26/15 23:15 |
| FBO Lot: 27 over Y | 220 | 0.168 | 183 | 0.299 | 0.269 | 842.76 | 5/23/15 1:31 | 6/2/15 5:30 |
| JC 16: 90 over Y | 84 | 0.214 | 66 | 0.274 | 0.211 | 659.68 | 6/9/15 2:00 | 6/13/15 0:30 |
| Mean | 196.5 | 0.194 | 156 | 0.273 | 0.236 | 782.86 | | |
| SD | 134.4 | 0.041 | 100.4 | 0.048 | 0.053 | 181.85 | | |

[1]Locations that had DOP > 3 and Satellites ≤ 3 were omitted from analysis.
[2]The smoothing factor (h) was set to 40m for all individuals.

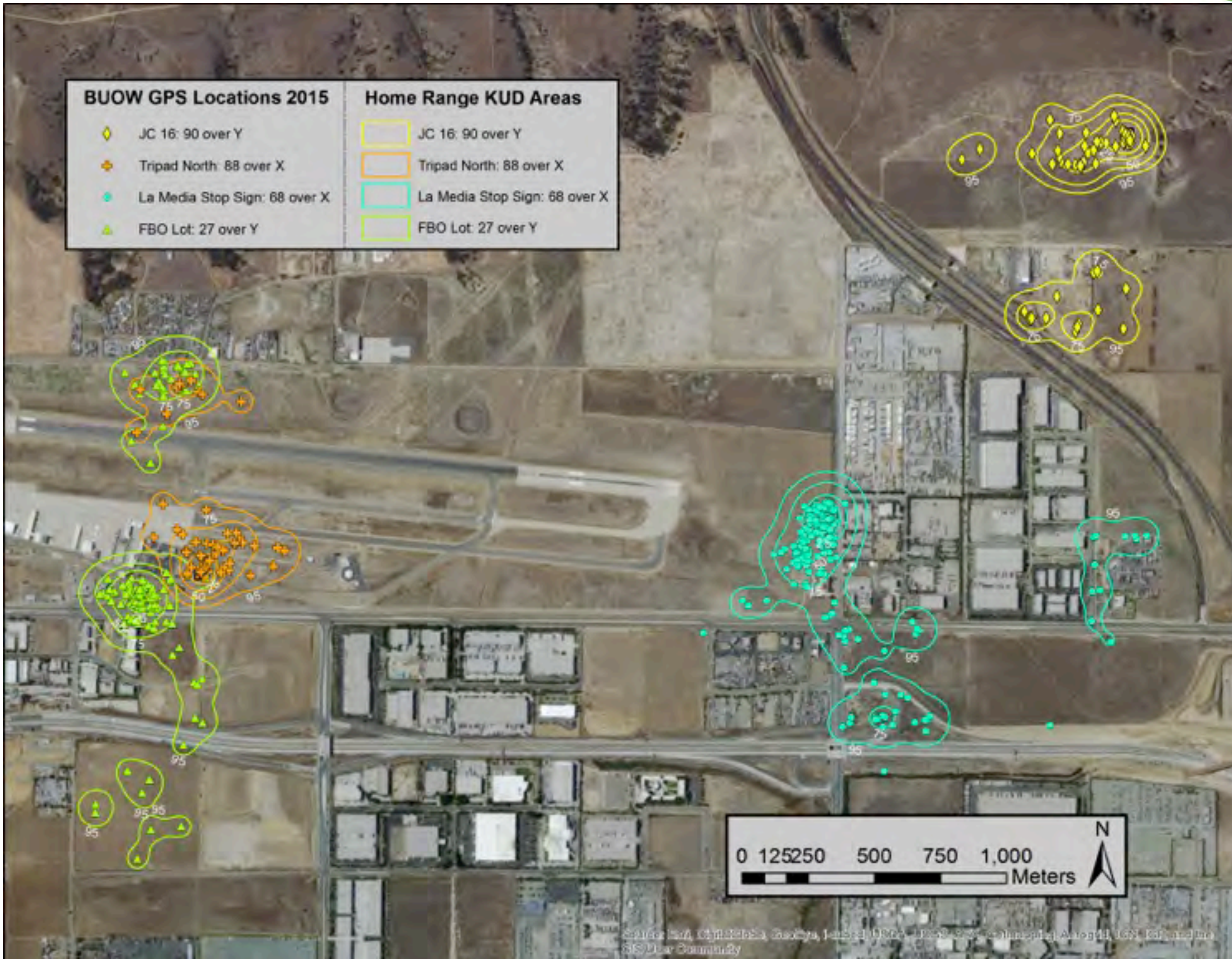



**Figure 3-3. Map of kernel home ranges for four BUOW.** Contour lines indicate 25%, 50%, 75%, and 95% KUD, respectively.

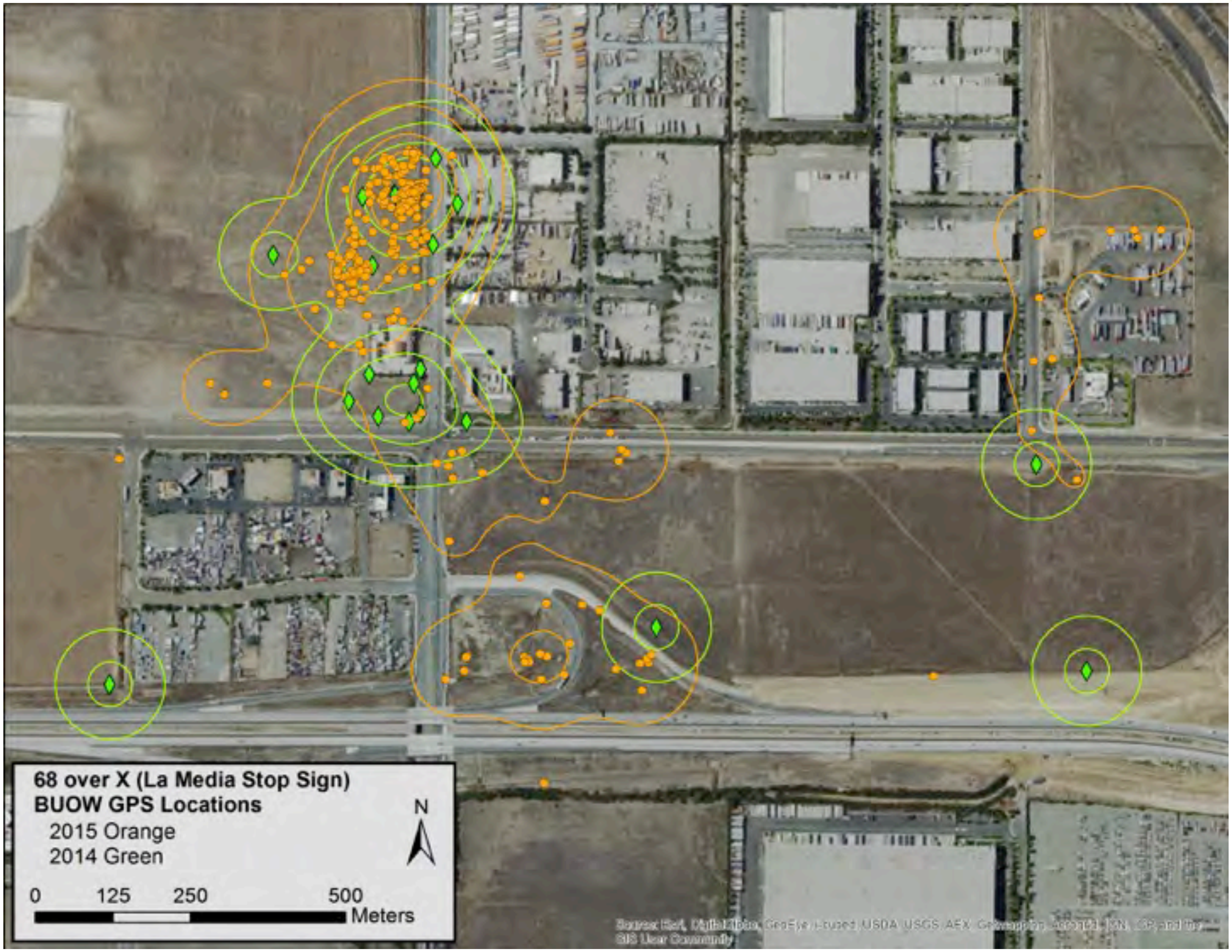



**Figure 3-4. Map of kernel home ranges for male BUOW 68 over X for the 2014 (green) and 2015 (orange) breeding seasons.** Contour lines indicate 25%, 50%, 75%, and 95% KUD, respectively.

**Artificial vs. natural burrows**

The average maximum number of chicks was 2.2 (SE=0.57, n=18) at artificial burrows and 2.8 (SE=0.63, n=11) at natural burrows. The average maximum number of fledglings was 1.0 (SE=0.35, n=18) at artificial burrows and 1.8 (SE=0.55, n=11) at natural burrows. We did not find a statistically significant difference between natural and artificial burrows in the maximum number of chicks (t(27)=0.74, p=0.46) or in the number of fledglings (t(27)=1.31, p=0.20). However, the small sample sizes create low power to detect statistically significant differences.

When we examined the data in all three years of systematic monitoring (2013, 2014, 2015), we found that there were no significant differences between years for the number of fledglings, so we combined the data from all three years. Using the combined dataset, we found that the fledging rate at natural burrows was significantly higher than that at artificial burrows (t(81)=2.68, p=0.0088). The maximum number of chicks in 2013 differed significantly from 2014 and 2015; the maximum number of chicks was significantly lower at artificial burrows in 2013, but there were no significant differences between natural and artificial burrows in 2014 or 2015.

We again found that burrow microclimate was affected by burrow type. The mean daily inside humidity differed significantly by burrow type ($F_{2, 13}$=4.058, p=0.043), as did the mean daily inside temperature ($F_{2, 13}$=12.204, p=0.0010; Table 3-7). We also found that the mean daily differences between inside and outside were significant for humidity ($F_{2, 13}$=10.254, p=0.0021) and temperature ($F_{2, 13}$=28.933, p=<0.0001; Table 3-7). As we found in 2014, these effects were driven by large differences in performance between the natural burrows versus artificial burrows made of either wood or plastic, which did not differ from each other. Unlike in 2014, the mean daily coefficient of variation for humidity was not significantly different in the different burrow types, but the humidity inside natural burrows remained higher than inside artificial burrows. Natural burrows were also better at buffering against outside conditions, as indicated by the finding that inside temperature and humidity were more divergent from outside conditions in natural than artificial burrows. Thus natural burrows were warmer than artificial burrows during the nighttime and were cooler during the hottest part of the day. Temperature and humidity are known to have major effects on hatchability of eggs and chick survival. Maintaining constant conditions is a critical factor, so the less variable microclimate afforded by the natural burrows may account for the differences in fledging rates and may also have undetected impacts on egg outcomes.

Based on our 2014 results, we hypothesized that architectural differences between natural and artificial burrows may account for the differences in microclimate. Nadeau et al. (2015) found that artificial burrow depth affected both temperature and occupancy, with burrows of moderate depth (28-40 cm from the soil surface to the top of the burrow chamber) having the highest probability of occupancy. Furthermore, natural burrows are known to have twists and turns that may influence airflow. The natural burrows we examined seemed to have only one entrance, whereas all of the artificial burrows we examined had two entrances that created a pass-through for airflow that may explain the drier and more variable conditions in artificial burrows, as well as the tendency for artificial burrows to change more readily with outside conditions. We attempted to examine this using door flaps but we did not find statistically significant differences between burrows that had door flaps and those that did not. This is likely attributable to some problems we had with deploying the door flaps. We found that if owls occupied the burrows, the door flaps remained intact (this was the case at LS 23 and LS 133), whereas if the burrows were occupied by ground squirrels, the squirrels removed the door flaps. To answer the question of whether burrow configuration impacts microclimate, we need to conduct a field experiment testing different burrow designs and comparing the conditions to natural burrows. We will undertake this experiment in 2016, including evaluating the effects of burrow depth.

We do not have sufficient data to support any clear causal relationships between burrow type, microclimate, and reproductive success. Clearly, factors such as prey availability, predation, and parental quality must also influence reproductive outcomes. There is no reason to suspect that parental quality varies systematically with burrow type and so should not introduce bias or explain differences in fledging rates. The prey availability hypothesis is also not supported by our camera trap data on prey delivery: the number of prey deliveries per day did not differ significantly between natural and artificial burrows (S=117, Z=1.67, p=0. 095), nor did any of the prey types. From the camera trap data, we documented predation at 4 out of 16 artificial burrows (25%) and 2 out of 12 natural burrows (17%); however, this difference was nonsignificant (Fisher's Exact p=0.67).

These findings lead us to conclude that differences in microclimate and their effects on egg and/or chick survival may be contributing to differences in reproductive output. There are clear management implications, but these findings are encouraging because modification of artificial burrows to make them more like natural burrows may have positive impacts on population performance. In 2016, we will test different burrow designs in an experimental framework to evaluate how design changes impact the microclimate of the burrows. The differences in predation, although nonsignificant with our small sample size, suggest that perhaps the placement of artificial burrows in unsuitable habitat could be creating an ecological trap. However, we were unable to detect differences in prey availability between natural and artificial burrows, so this statement remains more speculative at this time.

**Table 3-7. Microclimate at natural burrows and two types of artificial burrows (plastic and wood).** Humidity measurement is relative and cannot be compared to 2014 values.

| | Burrow Material Type | | | | | |
|---|---|---|---|---|---|---|
| | Natural (n=4) | | Plastic (n=6) | | Wood (n=6) | |
| | Mean | (SE) | Mean | (SE) | Mean | (SE) |
| Daily Inside Humidity | 95.369 | (4.466) | 79.591 | (3.646) | 82.256 | (3.646) |
| Daily Difference in Inside/Outside Humidity | 22.799 | (1.440) | 14.613 | (1.176) | 16.305 | (1.176) |
| Daily Inside Temperature | 79.063 | (0.741) | 74.851 | (0.605) | 74.819 | (0.605) |
| Daily Difference in Inside/Outside Temperature | 10.783 | (0.280) | 8.436 | (0.228) | 8.262 | (0.228) |

**Genetic sexing**

Genetic sexing with molecular techniques was performed on samples from 131 owls. Using enzyme digest and gel electrophoresis, 8 of the 131 (6%) samples were inconclusive. With fluorescent PCR, 38 of the 131 (29%) samples were inconclusive. This method was not as successful, likely due to the use of P2 and P8 primers in a multiplex system with other primers that had higher annealing temperatures. This could be improved by redesigning the P2 and P8 primers to allow for higher annealing temperatures. Seven of the 131 (5%) individuals had no data from both sexing methods and were not used in the analysis. For the remaining 124 individuals, 90 individuals had results from both tests and these were always in agreement. From samples collected in 2013 and 2014, 85 juveniles and 39 adults were genetically sexed. Of these, 25 confirmed birds identified as male in the field, 23 confirmed birds identified as female in the field, and 76 were owls of previously unknown sex.

***Sex ratios by year***

To determine if there was any effect of year on offspring sex ratio, the ratio of male to female offspring was compared to the expected 1:1 ratio using a chi-square test for 2013 and 2014, respectively. In 2013, 23/49 (47%) of chicks were male while 26/49 (53%) were female. In 2014, 17/36 (43%) were male and 19/36 (53%) were female (Table 3-8). These ratios did not differ significantly (p=0.59) and we concluded no effect of year on sex distribution in chicks.

***Sex ratios by burrow type***

To elucidate any effects of burrow type, we pooled data for 2013 and 2014 and compared sex ratios of chicks from artificial and natural burrows using a chi-square test. At artificial burrows, 11/25 (44%) of chicks were male while 14/25 (56%) were female; at natural burrows, 27/58 (47%) of chicks were male and 31/58 (53%) were female (Table 3-8). We did not find a significant difference in sex ratio with respect to the type of burrow (p=0.43).

**Table 3-8. Sex ratio by year and burrow type.**

| Year | Male | Female | p-value |
|---|---|---|---|
| 2013 | 23 (47%) | 26 (53%) | 0.98 |
| 2014 | 17 (47%) | 19 (53%) | |
| **Burrow Type** | **Male** | **Female** | **p-value** |
| Artificial | 11 (44%) | 14 (56%) | 0.72 |
| Natural | 29 (48%) | 31 (52%) | |

**Genotyping and population genetics**

***Parentage***

Parentage analysis using COLONY allowed us to confirm the family groups identified in the field as well as elucidate information about unbanded parents and multi-year breeding pairs. All family groups identified in the field were confirmed as the correct parents and

96% of multi-chick families were confirmed as full siblings. The only group that did not match was a pair of fledglings banded at Johnson Canyon. In 2013, we trapped two fledglings ("54 over X" and "55 over X") of unknown origin with no information about parentage and natal burrows. Genetic testing confirmed the fledglings were not related, but that "54 over X" was fathered by "00 over Y," an owl banded in 2014 at LS 105.

Our genetic analysis provided multiple cases of consistent pairing across multiple breeding seasons and allowed us to determine parentage from 2013 by owls banded in 2014 and/or not yet banded. "69 over X" was banded at LORBOMA in 2014 and his mate was not captured. Genetic data from "69 over X" and all chicks captured at LORBOMA in 2013 and 2014 show that "69 over X" also fathered the 2013 LORBOMA family and that in both years, the same unknown female mothered the chicks. Similarly, female "97 over X" was banded at Old Schoolhouse in 2014 and her unbanded mate was not caught, but genetic analysis from her and the chicks from 2013 and 2014 show that she paired with the same male in both 2013 and 2014 at Old Schoolhouse. Another mated pair banded in 2014 (F: "94 over X", M: "89 over X") at Tripad South was found to be the parents of the chicks at Tripad Fence in 2013. "51 over X", a male banded in 2013, turned out to be the father of the 2014 Squirrel Plot family. Field observations determined "C over C" was the mother, and "51 over X" (her mate in 2013) was suspected of being the father, but we had not been able to determine this in the field. These family dynamics were previously unknown due to limitations of field observations.

Not only did genetic analysis allow us to determine parentage we could not resolve in the field, it also demonstrated that the BUOW in San Diego are generally seasonally monogamous, as we found no evidence of extra-pair copulations.

***Population Genetics***

In order to determine the genetic health of the San Diego BUOW population, we examined the heterozygosity and inbreeding coefficient, and compared these values to published results of populations in other locations (Table 3-9). These values help demonstrate gene flow and immigration within the population. These data show that the BUOW population in San Diego County is genetically healthy and has a comparable amount of heterozygosity to other populations. The inbreeding coefficient is lower than the overall value found for the entire United States (Korfanta et al. 2005), indicating that inbreeding is not occurring at a high rate and there is a healthy amount of immigration and emigration to prevent genetic catastrophe.

**Table 3-9. Population genetic statistics of the San Diego BUOW population and other published populations.**

| Location | N[1] | A[1] | $H_O$[1] | $H_e$[1] | $F_{IS}$[1] |
|---|---|---|---|---|---|
| San Diego (this study) | 50 | 9 | 0.73 | 0.77 | 0.051 |
| Lemoore, CA (Macias-Duarte 2011) | 40 | 12 | 0.79 | 0.81 | --- |
| Sinoloa, Mexico (Macias-Duarte 2011) | 40 | 12 | 0.79 | 0.82 | --- |
| Idaho (Faircloth et al. 2010) | 23 | 5.1 | 0.49 | 0.58 | --- |
| Overall US (Korfanta et al. 2005) | 201 | 4.9 | 0.54 | 0.54 | 0.061 |

[1]N = Number of unrelated individuals, A = Number of Alleles, $H_o$ = Observed Heterozygosity, $H_e$ = Expected Heterozygosity, $F_{IS}$ = Inbreeding Coefficient

### Over-winter BUOW presence at Rancho Jamul Ecological Reserve

During the 2015-2016 winter (3 March 2016), ICR staff observed a BUOW using the JC squirrel plot at Rancho Jamul Ecological Reserve. We will monitor this area in 2016 to determine whether the owl is banded and if it remains during the breeding season.

### Other wildlife at/near burrows

We documented a number of other species at or using the owl burrows including other bird species, mammals, herpetofauna, and invertebrates. Other species seen on camera at owl burrows included:

- American crow
- American kestrel
- cactus wren
- California towhee
- common raven
- Cooper's hawk
- European starling
- great blue heron
- great horned owl
- greater road runner
- horned lark
- killdeer
- kingbird spp.
- loggerhead shrike
- mourning dove
- northern harrier
- northern mockingbird
- passerine spp.
- red-tailed hawk
- rock pigeon
- rock wren
- sparrow spp
- western meadowlark
- white-crowned sparrow
- black-tailed jackrabbit
- California ground squirrel
- coyote
- desert cottontail
- domestic dog
- kangaroo rat spp.
- striped skunk
- Virginia opossum
- various mouse and vole spp.
- woodrat spp.
- California king snake
- red coachwhip snake
- other various snake spp.
- western fence lizard
- alligator lizard

### *General Discussion & Conclusions*

The combination of research efforts has provided a comprehensive understanding of the ecological factors driving population performance, which help guide strategic management for the recovery of BUOW in San Diego County. In fact, the data gathered was used to help inform population models and forms the basis for the BUOW Implementation Plan (ICR 2016). From this combined effort, the following discoveries have been revealed:

Reproductive success appears related to the frequency of prey deliveries and possibly type of prey. Importantly, there is substantial variation among burrows in the proportion of invertebrate vs. vertebrate prey, indicating that some home ranges may be of higher quality than others. However, owls living at these burrows do not appear to increase their foraging range to access higher quality prey, and this appears to have impacts on reproductive success. This is an important consideration: BUOW may not show adaptive behavior to poor foraging conditions by expanding home range, thus managers will need to take special consideration when siting artificial burrows or encouraging BUOW colonization. If burrows are sited in poor foraging habitat, they may become an ecological trap, drawing in owls to areas of low productivity.

Our data also reveal that post-emergence chick mortality (and perhaps egg and pre-emergence chick mortality, which are more difficult to document) is a significant issue potentially limiting population recruitment. Sources of mortality vary in time and space, but two primary sources appear to be predators and infanticide. Infanticide is likely driven by other ecological conditions that make rearing of chicks more difficult, again pointing to possible habitat influences on productivity. Predation is not well understood in BUOW but it is clear that anthropogenically-subsidized predators such as ravens, coyotes, and mesopredators have the potential to negatively impact these small vulnerable populations. Establishing new recovery sites for BUOW that are more removed from areas where these opportunistic predators are subsidized by human activities may help minimize this problem.

Lastly, we continued research to determine the efficacy of artificial burrows as a strategy for recovering BUOW populations. Artificial burrows are an important management tool, but it is important to understand their limitations, and whether they can be improved. Our data suggest that reproductive success is lower in artificial than natural burrows, leading us to evaluate factors that may potentially explain this difference. Of course, natural and artificial burrows may differ with regard to all of the ecological variables discussed above, including the surrounding habitat, predation pressure, and foraging opportunities. Thus placement of artificial burrows needs to be closely scrutinized to ensure that we are not creating ecological traps, drawing in owls to areas of high mortality or low reproductive success. While we did not find a difference in prey deliveries, we did observe microclimatic differences between artificial and natural burrows. Artificial burrows performed more poorly in providing a stable microclimate buffering the nests from the changes in temperature and humidity outside. It is plausible that the microclimate inside burrows led to egg or chick loss, explaining the lower reproductive success found in artificial burrows. Design changes for artificial burrows may bring about improvements which can be readily incorporated into management plans; this will be an area of focus in 2016.

## Burrowing Owl Habitat Suitability Modeling

### *Introduction*

#### Objectives and overview for habitat suitability model

Habitat suitability models are a powerful tool for communicating management needs and for supporting management decisions about species conservation. The purpose of this habitat suitability model was to enable the creation of a prioritized, ranked list of the best sites in San Diego for current and future BUOW management and conservation. The intent was to develop a quantitatively defensible model, based on the best species and environmental data available, to support the development and implementation of a coordinated management plan for BUOW. For the area of interest (western San Diego County from northern to southern boundaries), the suitability model was intended to validate or challenge the existing best guesses about the suitability of various known potential sites, such as Jamul and Ramona Grasslands. The model was also expected to identify areas of suitable habitat that might not have previously received consideration for species management.

In addition to providing quantitative answers to questions about the relative likelihood of habitat suitability of different parcels of land, suitability maps also provide powerful visuals. For example, pairs of maps with and without developed areas masked communicate just how much potential habitat in San Diego County has been developed. The model also provides insights about the applicability of current conservation plans to BUOW management through maps that show how well various conservation easements are aligned with high quality habitat areas.

The methodological details for the selected modeling approach and an overview of model results and validation are presented here. A brief description of other modeling approaches that were considered and trialed is included. Although this report provides some detailed maps of habitat suitability for southern San Diego County, more site-specific details about model quality will be found in the Burrowing Owl Implementation Plan (ICR 2016). BUOW and California ground squirrel habitat suitability models were developed with data products and methodological guidance from the San Diego Management and Monitoring Program (SDMMP). The development of a county-wide model would not have been possible without their support.

### *Methods*

#### Mahalanobis partition models

The Mahalanobis partition model has been utilized to create habitat suitability models for several species in southern California (Barr et al. 2015, Preston et al. 2008, Rotenberry et al. 2006). The model requires two inputs of data. The first is a set of spatially precise species occurrence records. Each record in the dataset must be checked for temporal and spatial precision, with spatially redundant records removed.

The species occurrences for BUOW were compiled from the California Natural Diversity Database (CNDDB), SANBIOS, U.S. Fish and Wildlife Service, and species occurrence data (2005-2014) shared by Western Riverside County Regional Conservation Authority. Owl occupancy records since 1998 with a GPS location with a precision of 180 m or less were selected. The model includes recent occurrences from western Riverside County, as well as Orange and Los Angeles Counties. They extend as far east as Western Riverside, but exclude Coachella Valley, Imperial Valley, and desert occurrences (Figure 4-1). The rationale behind this regional approach is to utilize occurrence records from interior grasslands in other counties in order to improve the ability of the model to identify interior grasslands in San Diego County with good potential suitability for BUOW. In order to control the influence of clustered data points, BUOW occurrences were categorized by region and random sampling (1000 iterations) was conducted on these subsets in order to ensure the model represented the characteristics of each region evenly, rather than allowing the sites with the most occurrences to dominate model results. This approach leverages the habitat information from a wide range of sites and produces a model with good generalizability to San Diego County.

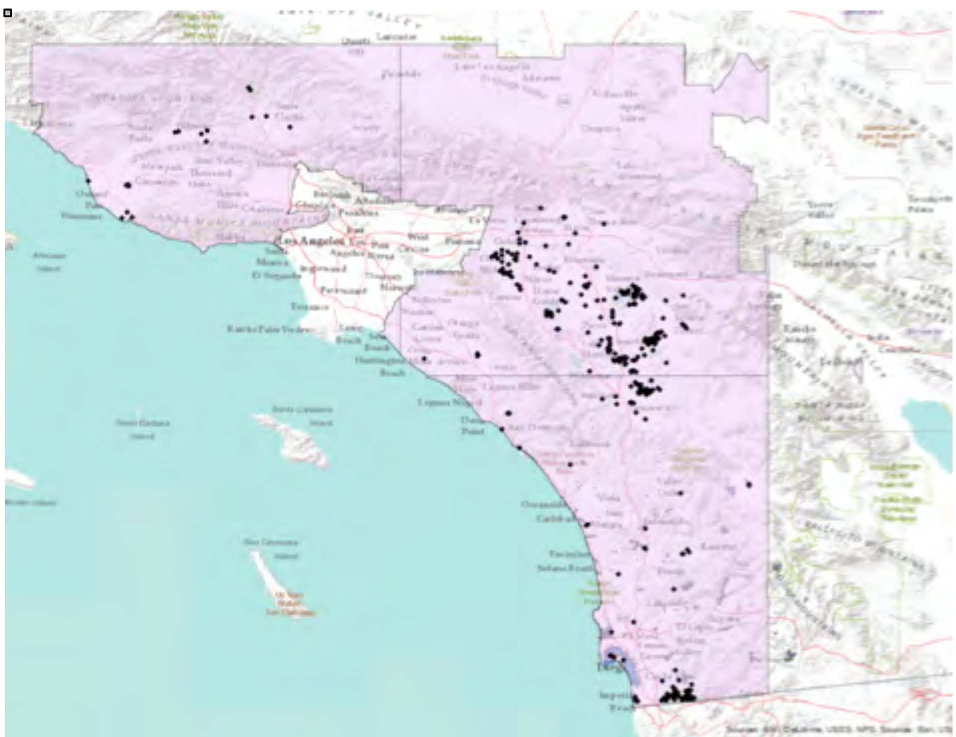


**Figure 4-1. Extent of regional dataset for BUOW habitat suitability.** BUOW occurrence records (n=417) are marked as black points. The eastern extent was delineated to limit the extent of desert habitats included in the analysis.

The second data input required for the Mahalanobis model is a landscape-level data layer. The layer was produced and shared by SDMMP for this modeling effort. The data layer consists of a spatially explicit grid of points with values for a suite of climate, topography, and land use variables assigned to each individual point (Table 4-1). Land use variables are defined as the percent cover of each land use type within a 150 m or 1 km diameter of the point. The set of species occurrence records and the grid of environmental variables must be temporally matched so that habitat suitability is a function of the environmental conditions that existed at the same time as species occupancy. There are two versions of the layer- a San Diego County extent with points spaced 180 m apart, and a southern California extent with points spaced 150 m apart (Figure 4-2). The data for each point was compiled by SDMMP from publicly available data sources including USDA soil maps, regional vegetation maps, and USGS digital elevation maps (Table 4-2). These data inputs were collected at varying scales, and several layers are polygon-based, so it is important to note that the minimum mapping unit of the underlying data source was not constrained to be at the same scale as the environmental grid. However, utilizing the SDMMP data layer enabled us to increase both the spatial extent of the model and the number of potential predictor variables.

**Table 4-1. Set of climate, topography, and land use variables assigned to each individual point in the spatially explicit grid of points.**

| *Climatic* | *Topographic* | *Soil texture* | *Percent land use (150 m & 1km)* |
|---|---|---|---|
| Min temp Feb | Elevation at Point | Percent Clay | Urban |
| Min temp March | Slope at Point | Percent Sand | Coastal sage scrub |
| Min temp April | | | Chaparral |
| Max temp Feb | | | Grassland |
| Max temp March | | | Riparian |
| Max temp April | | | Agriculture |
| Max temp July | | | Oak woodland |
| Max temp August | | | |
| Annual Precipitation | | | |
| Spring Precipitation (Feb-May) | | | |
| Winter Precipitation (Oct-Jan) | | | |

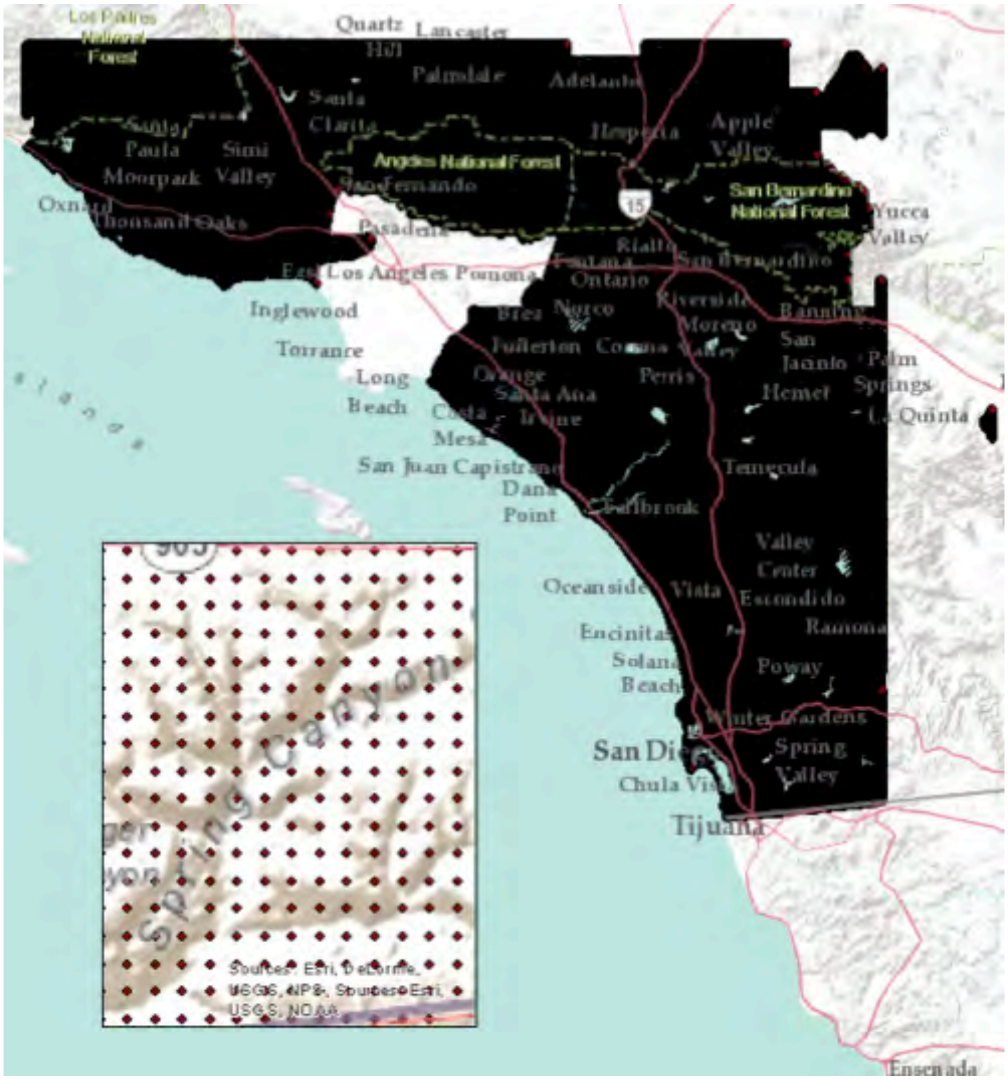



**Figure 4-2. Extent of regional environmental grid, consisting of 1,352,749 points spaced 150 m apart (inset).** Metropolitan Los Angeles was excluded from the grid, as were eastern desert areas.

**Table 4-2. Data sources for BUOW regional environmental data grid**

| Data | Source | Dates |
|---|---|---|
| *Climatic* | PRISM averages | 1981-2010 |
| *Topographic* | USGS DEM 10 m | 2013 |
| *Soil texture* | USDA Soil Viewer ArcMap extension | NA |
| *Percent land use - 150 m and 1 km* | Western San Diego | 2012 |
| | Southern OC | 2013 |
| | Northern OC | 2013 |
| | Western Riverside | 2014 |
| | Miramar | 2012-2014 |
| | Fallbrook | 2010 |
| | Camp Pendleton | 2003 |
| | Fire Resource Assessment Program (all gaps) | 2006 |

The model methodology is based on Mahalanobis distance, a multivariate distance measure calculated from a defined set of environmental variables, based on a set of species presence occurrences. A multivariate mean is calculated from the environmental variables for all presence records. The mean represents ideal habitat values for predicting species occurrence. The relative distance from the mean is calculated for every location in a large spatial grid of environmental measures, rescaled to range from 0 to 1, known as the habitat suitability index (HSI). On this scale, one represents habitat that perfectly matches the environmental characteristics of known occupied habitat, and zero represents poor habitat. After rescaling, a principal components analysis (PCA) is applied to the HSI values. One partition is selected to represent the model, chosen for its ability to predict high HSI values for occurrence locations, and for strong concurrence between sets of calibration and validation occurrence records. The orthogonal nature of the partitioning controls the collinearity that is common in multivariate grids of temperature, precipitation, and topographic variables.

A comparative model selection approach was used to identify the most predictive set of environmental variables, with validation based on a random sample of 25% (104 occurrences) of the BUOW occurrence records. We tested 25 owl models with and without inclusion of abiotic, soils, and land use variables. One predictor variable for the owl model is a habitat suitability index score for California ground squirrels developed from a parallel Mahalanobis partition model and the same grid of environmental variables. Full model development was conducted for squirrels.

### *Results*

The best model was identified by maximized median HSI (0.77) for the set of BUOW occurrence points, which indicates that the model predicts high suitability for known BUOW occurrences, and good validation with median HSI=0.75 (Figure 4-3). This model includes abiotic factors and land use variables. The abiotic variables included are minimum temperature in April, maximum temperature in August, annual precipitation, elevation, slope, percent of clay to a depth of 150 cm, and percent sand to 150 cm. The inclusion of land use factors (urban, coastal sage scrub, chaparral, grassland, riparian, and agricultural) at 1km scale improved the model.


**Figure 4-3. Selected habitat suitability model.** A habitat suitability index value has been calculated for every point in the gridded extent (150 m) based on the eigenvector of the one component selected from principal components analysis. On this scale, one represents habitat that perfectly matches the environmental characteristics of known occupied habitat, and zero represents poor habitat.

The abiotic variables most strongly correlated with the resulting modeled BUOW habitat suitability index are elevation (-0.45), and maximum February temperature (0.46). The negative relationship between BUOW presence and elevation is consistent with their preference for lowlands in this region, and the positive correlation with February temperature likely results from habitat selection for warmer sites at the beginning of the breeding season. In terms of land use factors, urban land use at 1 km (0.57) was the most strongly related factor. One consideration is that we included occurrence records dating back to 1998 in order to maximize the sample size. Since the San Diego land use dataset dates to 2012, some occurrence records may be in locations that have since been developed. As a result, these correlation values may overemphasize any potential positive influence of urbanization on BUOW, as well as underemphasizing the negative influences of urbanization.

Squirrel habitat suitability is also correlated (0.50). The habitat suitability index for ground squirrels only had a marginal effect on BUOW model results, and was therefore omitted from the final model. It may seem counterintuitive that squirrel suitability doesn't improve the model, but is correlated with model output. However, the sample size for squirrels was limited to only 89 spatially distinct occurrence records across the region. In addition, squirrels are a habitat generalist influenced by soil type. Therefore, the existing sample captures some, but not all of the environmental conditions found in habitat types with squirrels present. If additional squirrel occurrences were collected across the full range of habitat types, then using squirrel habitat suitability as an input variable for BUOW suitability could create an even better model than the abiotic inputs we used. However, that would require the collection of much more data.

Another way to identify the variables that are most important to BUOW habitat suitability is to compare the descriptive statistics for the occurrence points to the statistics for the entire landscape (Table 4-3). At occurrence points, minimum spring temperatures are higher, precipitation (winter, spring, and total) is lower, elevation is generally lower, and slope is generally lower. Owls are recorded more frequently in lower elevation sites with warmer and drier spring conditions. In terms of land use variables, presence points had higher median values for urban, coastal sage scrub, grassland and agricultural land uses at 1 km. While the association with urban may be an artifact, the positive association of owls with open shrublands, grasslands, and agricultural land makes qualitative sense in terms of the known habitat utilization patterns of BUOW.

**Table 4-3. Descriptive statistics for BUOW presence points only compared to all points contained in the landscape extent.** Median values are reported because the distributions for land use variables are all heavily skewed towards zero. Note the difference in sample size between the sets of presence only and all points.

| | Presence only (n=417) | | | All points (n=1,352,749) | | |
|---|---|---|---|---|---|---|
| | **Median** | **Mean** | ***SD*** | **Median** | **Mean** | ***SD*** |
| ***Abiotic*** | | | | | | |
| minimum temperature (April, ˚C) | | 8.6 | *1.2* | | 7 | *2.8* |
| maximum temperature (August, ˚C) | | 33.3 | *4.3* | | 32 | *3.5* |
| annual precipitation (cm) | | 3064.0 | *533.7* | | 4429.0 | *1969.8* |
| spring precipitation (Feb-May, cm) | | 1572.9 | *280.6* | | 2212.3 | *1019.5* |
| winter precipitation (Oct-Jan, cm) | | 1381.9 | *256.9* | | 2028.7 | *912.7* |
| ***Topography*** | | | | | | |
| Elevation (m) | | 344.5 | *161.2* | | 750.7 | *554.5* |
| Slope (percent) | | 3.6 | *5.4* | | 13.8 | *12.8* |
| ***Soils*** | | | | | | |
| Clay (percent) | | 24.5 | *14.8* | | 15.1 | *10.3* |
| Sand (percent) | | 44.9 | *22.2* | | 54.6 | *24* |
| ***Percent land use within 1 km*** | | | | | | |
| urban | *0.16* | 0.29 | *0.32* | 0 | 0.23 | *0.35* |
| coastal sage scrub | *0.03* | 0.13 | *0.2* | 0 | 0.12 | *0.22* |
| chaparral | *0* | 0.02 | *0.09* | 0.03 | 0.27 | *0.35* |
| grassland | *0.16* | 0.27 | *0.27* | 0 | 0.06 | *0.14* |
| riparian | *0* | 0.01 | *0.03* | 0 | 0.01 | *0.04* |
| agricultural (excl. grazed pasture) | *0.107* | 0.24 | *0.29* | 0 | 0.06 | *0.18* |
| oak forest | *0* | 0.0004 | *0.005* | 0 | 0.02 | *0.07* |
| ***Squirrel habitat suitability*** | | | | | | |
| HSI- Model R1P1 | | 0.39 | *0.33* | | 0.2 | *0.29* |

### San Diego County habitat suitability

The selected model identifies many areas of suitable habitat in San Diego County (Figures 4-4 and 4-5). However, the mask overlay for developed (unavailable) habitat confirms that the most suitable habitat for BUOW has already been developed. Map details for other areas of the county are provided and discussed in the BUOW Implementation Plan (ICR 2016).

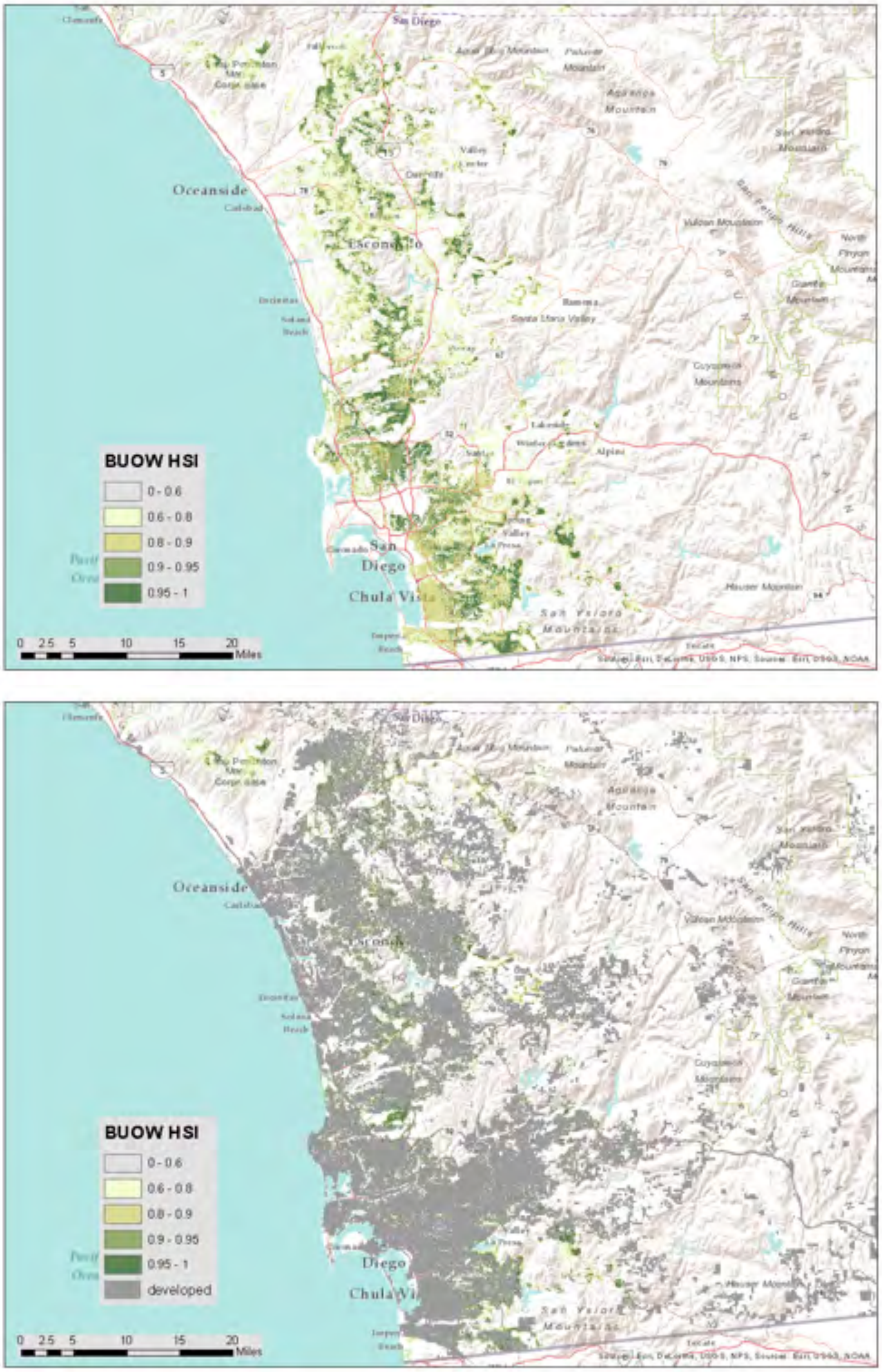



**Figure 4-4. A habitat suitability index value has been calculated for every point in the gridded extent (150 m, upper).** A mask of developed areas shows that most suitable habitat is unavailable (lower).

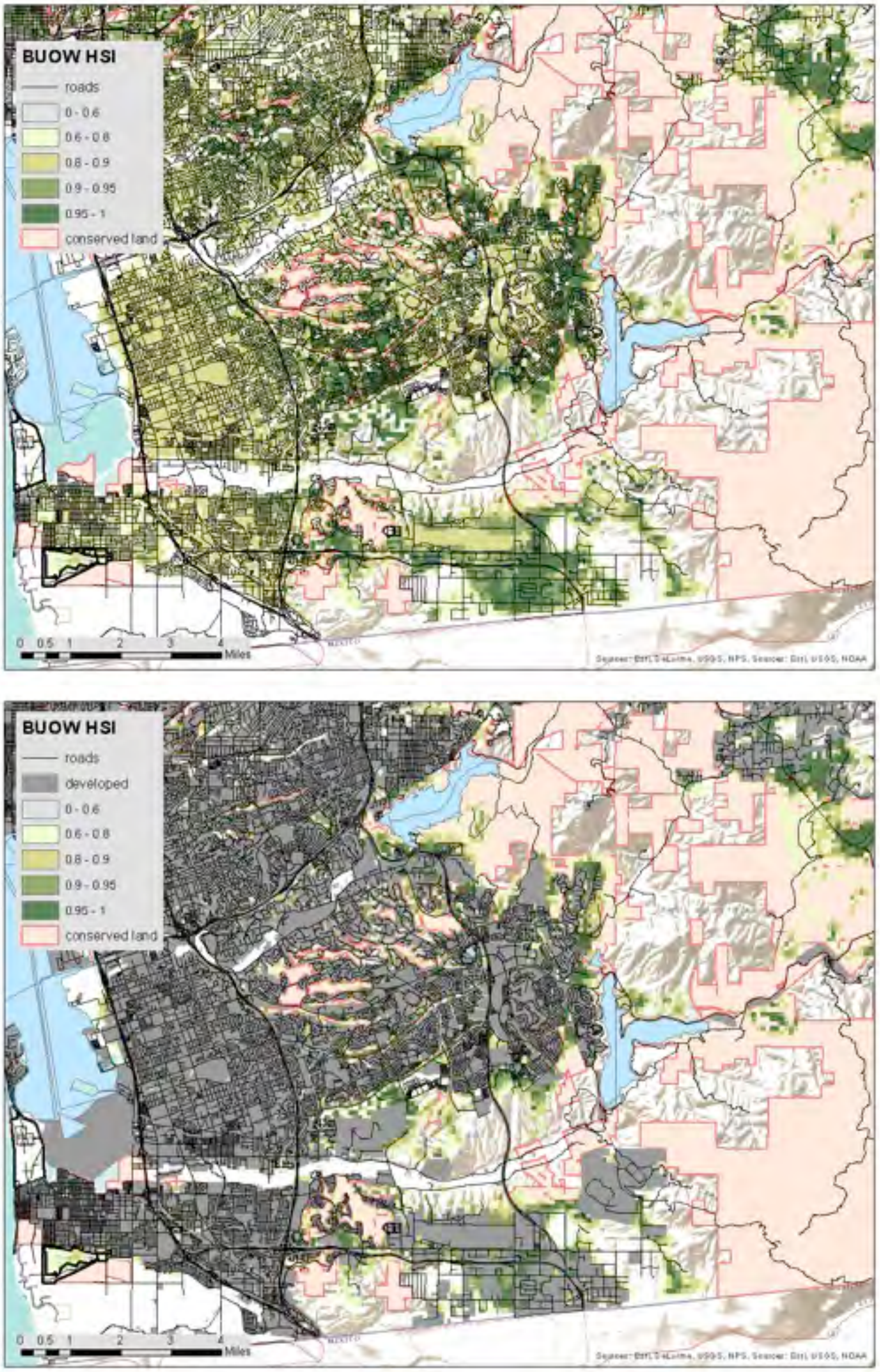



**Figure 4-5. Detail for south San Diego County.**

**California ground squirrels**

The best squirrel model was identified by maximized median HSI (0.66) for the set of CAGS occurrence points. The model was validated (HSI 0.64) but the relatively low HSI value for occurrence points indicates the model is not distinguishing between high and low suitability areas well. This model includes climatic and topographic factors (April minimum temperature, spring precipitation, elevation, slope) and soil factors (percentage clay and sand to 150 cm). The inclusion of land use factors (urban, coastal sage scrub, chaparral, grassland, riparian, and agricultural) at both available scales (150 cm and 1 km) was evaluated but did not improve model prediction.

## *Discussion*

**Squirrel model development**

The best squirrel suitability model indicated highest suitability inland at intermediate elevations. However, the low median HSI for points with known squirrel occurrence indicated that the model is not distinguishing accurately between high and low suitability areas for squirrels. The pattern of habitat suitability across the landscape was unstable among model runs. In addition, the squirrel model did not improve the BUOW model, either qualitatively or quantitatively. Owl models that included the squirrel suitability as an input did not have increased HSI scores, and indicated limited overlap between squirrel and owl suitability areas. These problems are likely due to small sample size, because some combinations of conditions that are suitable for squirrels are not included in the current set of squirrel occurrence records. The current set of squirrel occurrence points may also be strongly affected by historical artifacts. For example, squirrels may not be recorded in high suitability areas if they were removed in the course of human use of the same areas. In addition ground squirrels occurring on private lands may not be well represented in this dataset. As a result, the ground squirrel model was not pursued further, and full results are not reported here. Additional data points that accurately capture the range of habitat sites where squirrels may be found will be needed before a reliable landscape-scale habitat suitability model for squirrels can be developed. Nevertheless, our findings from presence-absence surveys for ground squirrels identified microhabitat features such as soils and vegetation that can be used to predict ground squirrel presence and guide management decisions for reestablishing sustainable habitats for BUOW at the site level.

**Owl model development**

We initially developed a Mahalanobis model for San Diego County only. However, a regional approach to BUOW habitat suitability was required due to the current absence of BUOW in many of the interior grassland sites in San Diego County that would otherwise be considered suitable habitat. In San Diego, most BUOW occurrence records come from the Otay Mesa area. Unfortunately, the Otay site is unlike most suitable habitat locations in the county due to unique clay soils and proximity to the coast. Consideration of coastal sites for BUOW habitat is an issue since almost all of these areas are already heavily developed, and are unavailable for future BUOW management actions. Therefore it was necessary to expand the focal area in order to capture BUOW occurrence records from interior grassland sites in western Riverside County. Clusters of BUOW occurrences were subsampled in order to leverage the habitat information from a wide range of sites and produce a model with good generalizability to San Diego County.

Further exploratory modeling included historic BUOW occurrences back to 1990 instead of to 1998, to increase the sample size of owl occurrences. However, this approach was of limited utility because it only added presence points in North County coastal areas. Local extinctions occurred at these sites between 1990 and 1998 likely due to development pressure. The models based on historic BUOW occurrences also reflected strong influence by coastal occurrences, and showed highest suitability in coastal sites. The inclusion of historic points also changed the variables that could be used as inputs to the model, primarily by excluding land use data variables. The land use variables were derived from the 2012 San Diego vegetation classification map. Model inputs about vegetation type must come from the same time period as the owl occurrence data in order to make accurate predictions of owl land use. A time lag between the 2012 land use data and owl occurrence points dating back to 1990 meant that correlations between owl occurrence and land use might not be accurate due to widespread and recent development and other changes in land use.

We evaluated other methodologies in addition to the Mahalanobis partition model. We trialed the application of logistic models derived from field sampling to county-wide prediction, but found they were limited by differences in scale between the sampling and the data layers used for landscape-scale prediction. Data layers that provided the same variables sampled at the same scale over the extent of San Diego County were unavailable. We also tested the use of Maxent, a popular modeling application. The inputs for the Maxent model consisted of a set of raster layers, each depicting a single variable from the SDMMP dataset at 180 m scale. The Maxent application is frequently utilized in part due a very accessible user interface. The drawbacks of Maxent are that model specification is difficult to control and model interpretation can be limited by the "black box" nature of the algorithm. We do not present Maxent results here since the Mahalanobis method is more interpretable.

**Owl model reliability**

The BUOW model shows several indications of quality and reliability for a range of uses going forward. The sample size of occurrence records was high enough to support a calibration median HSI value that met the minimum acceptable threshold of 0.70. Validation with a subset of owl occurrence records withheld from model calibration (n=104) indicated the model accurately predicts high suitability for sites where owls have actually been recorded. The BUOW model showed stable patterns in suitability across the landscape across different sets of input variables (Figure 4-6). This habitat suitability model can be used to help guide site selection for BUOW recovery nodes and identify areas important for the conservation of the species.

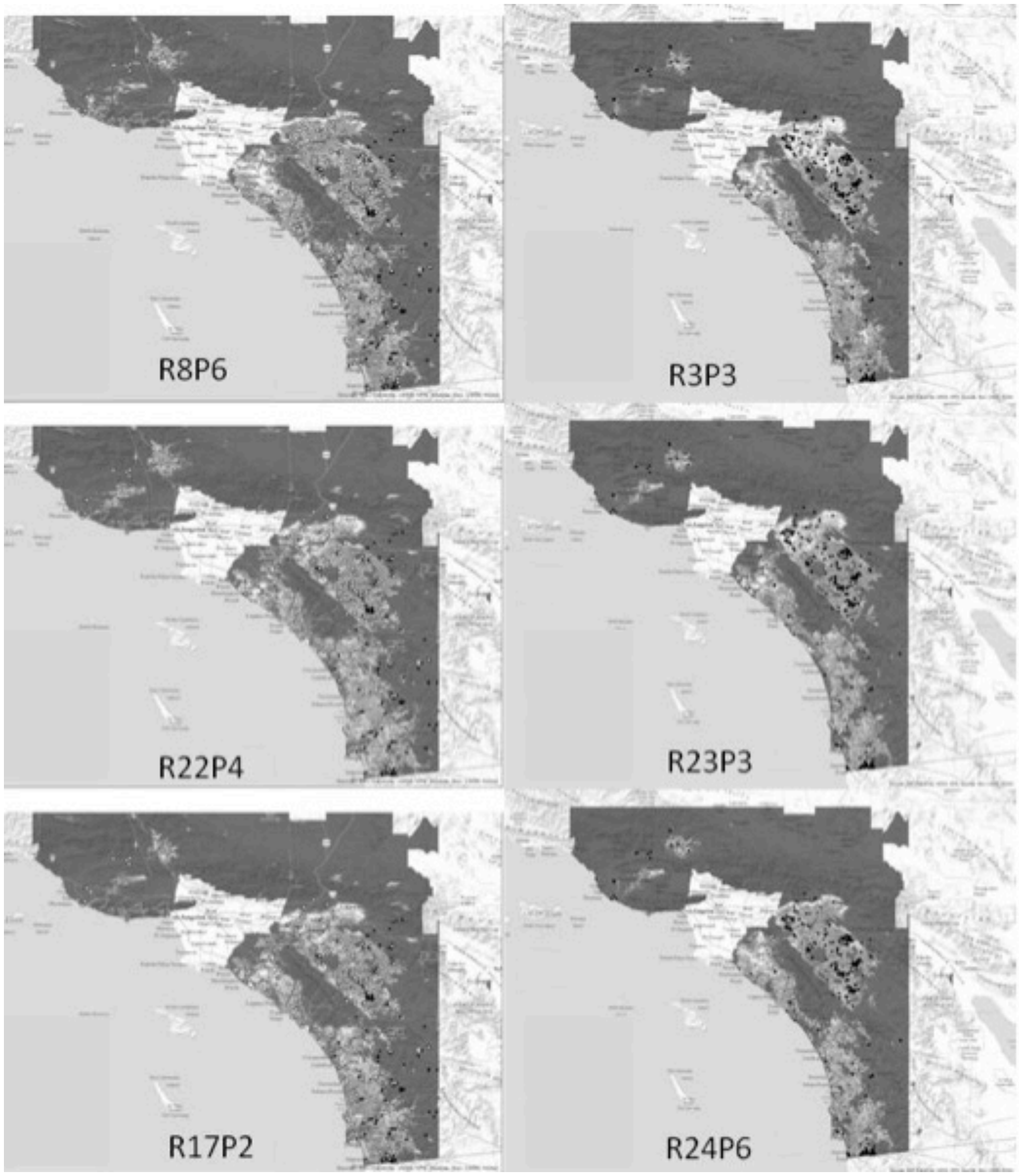



**Figure 4-6. Landscape patterns in owl habitat suitability indexes for six model iterations.** Each iteration represents a slightly different set of input variables. The similarity among panels indicates that model output is stable and is being driven by a strong pattern between owl occurrence points and the environmental conditions at occurrence points.

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## Appendix 1. Camera Trap Photo Processing Protocol

We have collected a large number of photographs from Burrowing Owl (BUOW) nest burrows. In order to make use of the information contained in the photos, we need to classify what is in each picture. The photos are saved on a high capacity external hard drive. They are organized by site, burrow, camera, and week of collection.

Photo processing will be done with the program Adobe Bridge, which allows us to tag each photo with relevant keywords. We are interested in recording: 1) the frequency of prey deliveries and the type of prey, 2) the frequency of predation events and type of predators, 3) human disturbances, 4) other species present in the photos, 5) copulation, 6) other interesting events and photos, and 7) the maximum number (and band codes, if present) of adult and juvenile burrowing owls present at each burrow per day.

We use Reconyx Hyperfire camera traps. Photos are taken in series of 3 and are labeled as such (1/3, 2/3, 3/3).

Independent Events

It is important that we only record independent events, which means that you should only mark the first occurrence of each prey delivery or other event—DO NOT tag more than one photo in each series or each event. For example, if a rabbit is delivered and appears in several series of photos, only mark the first photo in which it appears (you can also mark the most illustrative photo instead of the first one, but only mark ONE).

In order to save time, do not tag every photo that contains a burrowing owl, only mark those that contain the types of events listed above (and see the following list of keywords).

In order to estimate the productivity and survival of the owls at each burrow, we need to keep track of how many and which owls appear in the photos each day. We do this by counting the maximum number of adults and the maximum number of juveniles seen each day. If the birds are banded, we also want to keep track of the band codes seen each day. The photo at right shows an example of the bands with alphanumberic code.


The Binder

There is a large binder called "BUOW 2015 Cam Trap Processing" which contains the datasheets needed for photo processing. It is divided by burrow and within each burrow section further divided by camera. Each camera has three types of datasheet associated with it (see below).

Datasheets

- Check sheet—Each camera has a check sheet that lists all of the file folders that contain photos from that camera. Each folder should be checked off as it is processed (enter the date it was processed in the "DONE" column and your initials in the "initials" column).

- Maximum BUOW Counts Sheet—We keep track of the adults and juveniles separately by keeping a tally for each day photos were taken. "Date" refers to the photo date, "Max Adults/Chicks Seen" should be filled in with tally marks, "Bands" should be filled in with all band codes seen on a given day that apply to the appropriate age class. The band codes used at a burrow are listed at the bottom of the Max Count datasheet (if there are no band codes on the sheet, no owls were banded at that burrow). The band in the picture above would appear as "02 over X" and should be written on the datasheet as it appears on the band. Again, fill in the date processed and your initials.

- Good Pictures & Interesting Events Sheet—This data sheet is used to describe photos that are marked as "Good Picture" or "Other interesting event" (see keyword list below for further explanation). On the data sheet, note the photo file name and date and give a brief description of the photo. Initial and date each line.

<u>Logging on to computer/server</u>
To sign in to the computer, click the Novell Logon icon. Then click the "Computer Only Logon" option. Enter username: buow and password: buow1. At ZENworks prompt, click cancel.

To log in to the server where the photos are stored (folder: buow (Aae-storage P:), enter the username: buow and password: buow2013.

<u>Using Adobe Bridge</u>
We will use Adobe Bridge to record prey deliveries/types, predation events/types, human disturbances, other species, copulation, and other interesting events. Bridge is set up to easily navigate to the appropriate folder, view photos, and tag each photo with keywords using a pre-designed checklist. You can also select multiple photos at a time and simultaneously tag them.

To open Bridge, click on the Start Menu and Bridge is at the top of the pane.

<u>Navigating to folders</u>
All folders are stored on the "Aae-storage" drive under "buow". The pathway is Computer→buow(Aae-storage P:)→Cam Trap Originals→Cam Traps—BUOW→2015→[Site]→[Burrow]→[Camera]

<u>Keyword list</u>
- Good/Bad Picture
    - Bad Picture –Picture quality is too poor to see what is in it. This might be a result of the photo being washed out or the camera having condensation on it. You can mark a picture as a bad picture even if you tag something in it (this will indicate a low level of confidence in the identification). Mark all

photos that are “bad”—you can do this quickly by selecting all photos that apply in the middle bottom pane of the Bridge, then clicking the “Bad Picture” box in the keyword pane.
    - Good Picture –Mark this for photos that are exemplary of the owls or their behavior—in short, photos that would be good in a presentation, on a poster, or in a report. “Good Picture” can be marked for any photo (not just ones that are tagged for other reasons). Note the photo file name and a short description on the datasheet.
- Human Disturbance
    - Human –Mark if a person/people is/are in the frame and within ~50m of the burrow.
    - Misc. human disturbance –Mark for any human-related disturbance that doesn’t fit into the other categories.
    - Vehicle –Mark if a vehicle(s) is in the frame and within ~50m of the burrow.
    - Watering –This category is primarily for Lonestar; mark if there are workers watering or if the spray from a hose is seen in the frame.
- Interesting Events
    - Adult predation event –Mark in the event that an adult burrowing owl is killed by another animal (including another burrowing owl).
    - Copulation –Mark when two owls are seen copulating on camera.
    - Interesting prey –Mark if an interesting prey item is delivered to the burrow.
    - Juvenile Predation event –Mark in the event that a juvenile burrowing owl is killed by another animal (including another burrowing owl).
    - Other interesting events –Mark interesting events that don’t fit into the above categories or prey deliveries. Note the photo file name and a short description on the datasheet.
- Prey: This refers to the type of prey that the BURROWING OWLS bring to the burrow.
    - Bird prey - Mark if a bird is brought as prey.
    - Burrowing Owl prey - Mark if a burrowing owl is the prey item. Should be marked in conjunction with “Adult/Juvenile Predation event” (in most cases it will be a juvenile).
    - Invertebrate prey - Mark if prey is insect/arachnid
    - Mammal prey - Mark if a mammal is brought as prey.
    - Possible feeding - Mark if a prey delivery occurs, but you can’t see beak-to-beak contact.
    - Prey Seen Unknown - Mark if you are able to see a prey item but are not able to narrow it down further.
    - Prey Unseen - Mark if you are able to see beak-to-beak contact (indicating prey was exchanged), but you are not able to see a prey item. You must be able to see the beak-to-beak contact.
    - Reptile prey - Mark if prey is reptile.
- Visitor/Predator Species: This refers to other species that may appear on camera (but not as a prey item). It will refer to a predator in the case of a predation event.
    - bird other –Mark if a bird other than a burrowing owl, cactus wren, raptor,

raven/crow, or roadrunner is present in the photo.
  - burrowing owl –Mark if a burrowing owl is the predator or if a burrowing owl is seen in a photo with another species.
  - cactus wren –Mark if a cactus wren is present in the photo.
  - CAGS –Mark if a California ground squirrel is present in the photo.
  - coyote –Mark if a coyote is present in the photo.
  - domestic cat –Mark if a domestic cat is present in the photo.
  - domestic dog –Mark if a domestic dog is present in the photo.
  - K-rat –Mark if a kangaroo rat is present in the photo.
  - mouse/vole –Mark if a mouse or vole is present in the photo.
  - raccoon – Mark if a raccoon is present in the photo.
  - rabbit –Mark if a rabbit is present in the photo.
  - raptor –Mark if a raptor other than a burrowing owl is present in the photo.
  - raven/crow –Mark if a raven or crow are present in the photo.
  - roadrunner –Mark if a roadrunner is present in the photo.
  - skunk –Mark if a skunk is present in the photo.
  - snake/lizard –Mark if a snake or lizard is present in the photo.
  - weasel –Mark if a weasel is present in the photo.
  - woodrat –Mark if a woodrat is present in the photo.
  - other species –Mark for species other than those in this list.

Miscellaneous guidelines

- Make sure to mark prey items as prey items, not as visitor species (some species are listed in both categories).
- Make sure to note the presence of a burrowing owl if there is something else in the picture (vehicle, visitor species, etc.). However, if it is just a burrowing owl, you do not need to mark it.
- If you accidentally move items in the keyword list around, please re-organize it properly.
- If there is a frequent visitor (squirrel, rabbit, etc.) that is in a large number of the photos, only mark its appearance once per hour unless it is directly impacting an owl's behavior (in which case ALWAYS mark the respective visitor species as well as the presence of the burrowing owl).
- Only mark Human Disturbances that involve individuals or vehicles not associated with the San Diego Zoo Institute for Conservation Research team.

## Appendix 2. Recalculated Prey Delivery Data for 2013 and 2014

**Table A2-1. Summary of all prey deliveries seen in camera trap photos during the 2013 breeding season.** Data taken only from the focal period starting with the camera set-up date and ending with the fledging or failure date for each respective burrow.

| Site | Burrow | Prey Deliveries/ Photo Day | Birds (%) | Inverts (%) | Herps (%) | Mammals (%) | Unknown (%) | BUOW Prey (#) |
|---|---|---|---|---|---|---|---|---|
| **Initial Nesting Attempts** | | | | | | | | |
| Lonestar | Gate 1 | 13.89 | 0 | 86 | 2 | 6 | 6 | 2 |
| | Euc 7 Fence | 9.25 | 0 | 71 | 1 | 2 | 26 | 4 |
| | LS 160 (A) | 5.35 | 0 | 78 | 3 | 11 | 8 | 0 |
| | LS 166 (A) | | | | | | | |
| | LS 176 (A) | 2.07 | 0 | 64 | 2 | 5 | 30 | 0 |
| | LS 201 (A) | 7.18 | 0 | 95 | 0 | 5 | <1 | 0 |
| | LS 132 (A) | 0.99 | 0 | 89 | 2 | 4 | 4 | 0 |
| | LS 146 (A) | 3.16 | 12 | 75 | 3 | 10 | 1 | 0 |
| Brown Field | Heritage and Datsun | 11.29 | 0 | 60 | 1 | 32 | 6 | 0 |
| | Gravel Lot | 21.63 | 0 | 66 | 0 | 4 | 29 | 0 |
| | Power Pole | 29.03 | <1 | 70 | 1 | 1 | 28 | 0 |
| | Gailes | 20.11 | <1 | 62 | <1 | 11 | 26 | 1 |
| | La Media Stop Sign | | | | | | | |
| | Berm Abeam Napa | 9.53 | <1 | 73 | 3 | 7 | 17 | 0 |
| Johnson Canyon | JC 6 (A) | 13.21 | <1 | 88 | 0 | 2 | 10 | 0 |
| | JC 19 (A) | 31.91 | <1 | 81 | <1 | 5 | 13 | 0 |
| Poggi | Poggi | 9.76 | <1 | 66 | 2 | 16 | 16 | 2 |
| LORBOMA | LORBOMA | 7.26 | 0 | 70 | 1 | 18 | 11 | 2 |

**Table A2-2. Summary of all prey deliveries seen in camera trap photos during the 2014 breeding season.** Data taken only from the focal period starting with the camera set-up date and ending with the fledging or failure date for each respective burrow.

| Site | Burrow | Prey Deliveries/ Photo Day | Birds (%) | Inverts (%) | Herps (%) | Mammals (%) | Unknown (%) | BUOW Prey (#) |
|---|---|---|---|---|---|---|---|---|
| **Initial Nesting Attempts** | | | | | | | | |
| Lonestar | LS 3 (A) | 22.69 | <1 | 82 | 1 | 2 | 16 | 0 |
| | LS 23 (A) | 20.63 | <1 | 90 | <1 | 4 | 6 | 2 |
| | LS 42 (A) | 20.06 | <1 | 81 | 1 | <1 | 18 | 0 |
| | LS 97 (A) | 4.70 | <1 | 73 | 0 | 4 | 23 | 0 |
| | LS 105 (A) | 21.00 | 0 | 65 | 3 | 0 | 32 | 0 |
| | LS 107 (A) | 6.04 | 0 | 93 | 1 | 4 | 2 | 0 |
| | LS 112 (A) | 21.72 | 0 | 93 | 0 | <1 | 7 | 0 |
| | LS 129 (A) | 7.28 | 0 | 79 | 1 | 17 | 3 | 1 |
| | LS 133 (A) | 11.42 | 0 | 84 | 2 | 8 | 6 | 0 |
| | LS 160 (A) | 5.43 | 0 | 72 | 3 | 19 | 6 | 1 |
| | LS 193 (A) | 5.27 | <1 | 77 | <1 | 3 | 19 | 0 |
| | LS Squirrel Plot (A) | 7.94 | <1 | 80 | 1 | 4 | 15 | 0 |
| | Euc 17 fence | 4.19 | <1 | 85 | 2 | 7 | 4 | 0 |
| | LS 185 Berm | | | | | | | |
| Brown Field | Cul du Sac | | | | | | | |
| | La Media Stop Sign | 26.45 | 0 | 55 | <1 | 4 | 41 | 0 |
| | Gravel Lot | 11.00 | 0 | 94 | 1 | 3 | 3 | 0 |
| | India | 8.18 | <1 | 67 | <1 | 9 | 23 | 0 |
| | Old Schoolhouse | 16.26 | 0 | 71 | <1 | 3 | 26 | 0 |
| Johnson Canyon | JC 17 (A) | | | | | | | |
| LORBOMA | LO 33 (A) | 4.36 | 2 | 69 | 14 | 8 | 7 | 0 |
| Poggi | Poggi | | | | | | | |
| **Renests/Late nests** | | | | | | | | |
| Lonestar | LS 105 (A) | 1.00 | 0 | 87 | 0 | 13 | 0 | 0 |
| | LS 160 (A) | 5.40 | 1 | 76 | 3 | 15 | 4 | 0 |
| Brown Field | Gravel Lot | 4.49 | 0 | 89 | 1 | 3 | 7 | 0 |
| Johnson Canyon | JC 12 (A) | 12.17 | <1 | 77 | <1 | 13 | 8 | 3 |

## Appendix 3. 2015 BUOW Banding Data

**Table A3-1. All burrowing owls captured in 2015 (auxiliary bands were green unless specified).** Asterisk denotes capture burrow, not breeding/natal burrow. GPS denotes an owl outfitted with a GPS datalogger.

| Burrow | Date | Age | Sex | USGS band ID | Aux band ID | DNA Sample | Banding Year |
|---|---|---|---|---|---|---|---|
| LS Euc 17 Fence | 18-May-15 | Adult | Male | 0804-19772 | 72 over X | Blood | 2014 |
| LS Euc 17 Fence | 18-May-15 | Adult | Female | 0804-43288 | 12 over Y | Blood | 2014 |
| LS Euc 17 Fence | 26-May-15 | Chick | Unknown | 1004-15545 | 60 over Y | Blood | 2015 |
| LS 159 | 12-May-15 | Adult | Female | 1004-15520 | 34 over Y | Blood | 2015 |
| LS 159 | 18-May-15 | Adult | Male | 1004-15528 | 29 over Y | Blood | 2015 |
| LS 159 | 2-Jun-15 | Chick | Unknown | 1004-15549 | 96 over Y | Blood | 2015 |
| LS 159 | 4-Jun-15 | Chick | Unknown | 1004-15552 | 85 over Y | Blood | 2015 |
| LS 133 | 12-May-15 | Adult | Male | 0804-19770 | 70 over X | Blood | 2014 |
| LS 133 | 12-May-15 | Adult | Female | 1004-15519 | 33 over Y | Blood | 2015 |
| LS 133 | 26-May-15 | Chick | Unknown | 1004-15543 | 94 over Y | Blood | 2015 |
| LS 185 | 12-May-15 | Adult | Female | 1004-15518 | 28 over Y | Blood | 2015 |
| LS 185 | 12-May-15 | Chick | Unknown | 1004-15521 | Tarsus Too Small | Blood | 2015 |
| LS 185 | 12-May-15 | Chick | Unknown | 1004-15522 | 40 over Y | Blood | 2015 |
| LS 185 | 18-May-15 | Chick | Unknown | 1004-15526 | Tarsus Too Small | Blood | 2015 |
| LS 185 | 18-May-15 | Chick | Unknown | 1004-15527 | 51 over Y | Blood | 2015 |
| LS 185 | 26-May-15 | Chick | Unknown | 1004-15544 | 98 over Y | Blood | 2015 |
| LS 185 | 4-Jun-15 | Chick | Unknown | 1004-15550 | 62 over Y | Blood | 2015 |
| LS 13 | 18-May-15 | Adult | Male | 1204-61171 | White AA | Blood | 2013 |
| LS 13 | 30-May-15 | Adult | Female | 1204-61185 | 35 over Y (White X5) | Blood | 2013 |
| LS 13 | 30-May-15 | Chick | Unknown | 1004-15548 | 61 over Y | Blood, Feather | 2015 |
| BF Gailes Windsock* | 28-Aug-15 | Adult | Female | 0804-19800 | 99 over X | Blood | 2014 |
| BF Gailes Windsock* | 28-Aug-15 | Adult | Male | 1004-15567 | 32 over Y | Blood | 2015 |
| LS 52/53 | 10-Jun-15 | Adult | Male | 0804-43283 | 04 over Y | Blood | 2014 |
| LS 52/53 | 10-Jun-15 | Adult | Female | 1004-15557 | 57 over Y | Blood | 2015 |
| LS 52/53 | 10-Jun-15 | Chick | Unknown | 1004-15556 | 68 over Y | Blood | 2015 |
| LS 52/53 | 10-Jun-15 | Chick | Unknown | 1004-15558 | 79 over Y | Blood | 2015 |

| Burrow | Date | Age | Sex | USGS band ID | Aux band ID | DNA Samples | Banding Year | |
|---|---|---|---|---|---|---|---|---|
| BF Gravel Lot | 11-May-15 | Adult | Female | 0804-19707 | 07 over X | Blood | 2013 | |
| BF Gravel Lot | 11-May-15 | Adult | Male | 0804-19732 | 32 over X | Blood | 2013 | |
| BF Gravel Lot | 11-May-15 | Chick | Unknown | 1004-15516 | 91 over Y | Blood | 2015 | |
| BF Gravel Lot | 11-May-15 | Chick | Unknown | 1004-15517 | Tarsus Too Small | Blood | 2015 | |
| BF Gravel Lot | 25-May-15 | Chick | Unknown | 1004-15540 | 48 over Y | Blood | 2015 | |
| BF Gravel Lot | 25-May-15 | Chick | Unknown | 1004-15541 | 59 over Y | Blood | 2015 | |
| BF FBO Lot | 11-May-15 | Adult | Male | 1004-15514 | 27 over Y | Blood | 2015 | GPS |
| BF FBO Lot | 10-Jun-15 | Fledgling | Unknown | 1004-15559 | 56 over Y | Blood, Feather | 2015 | |
| BF Tripad North | 27-May-15 | Adult | Male | 0804-19788 | 88 over X | Blood | 2014 | GPS |
| BF Tripad North | 11-May-15 | Adult | Female | 0804-19792 | 92 over X | Blood | 2014 | |
| BF Tripad South | 25-May-15 | Adult | Male | 0804-19789 | 89 over X | Blood | 2014 | |
| BF Tripad South | 11-May-15 | Adult | Female | 0804-19794 | 94 over X | Blood | 2014 | |
| BF Tripad South | 25-May-15 | Chick | Unknown | 1004-15539 | 65 over Y | Blood | 2015 | |
| BF India | 9-May-15 | Adult | Male | 0804-19779 | 79 over X | Blood | 2014 | |
| BF India | 9-May-15 | Adult | Female | 0804-19783 | 83 over X | Blood | 2014 | |
| BF India | 20-May-15 | Chick | Unknown | 1004-15531 | 44 over Y | Blood | 2015 | |
| BF India | 20-May-15 | Chick | Unknown | 1004-15532 | 55 over Y | Blood | 2015 | |
| BF India | 20-May-15 | Chick | Unknown | 1004-15533 | 66 over Y | Blood, Feather | 2015 | |
| BF India | 20-May-15 | Chick | Unknown | 1004-15534 | 77 over Y | Blood | 2015 | |
| BF India | 20-May-15 | Chick | Unknown | 1004-15535 | 99 over Y | Blood | 2015 | |
| BF India | 21-May-15 | Chick | Unknown | 1004-15536 | 88 over Y | Blood | 2015 | |
| BF La Media Stop Sign | 9-May-15 | Adult | Female | 1084-05304 | B over E | Blood | 2011 | |
| BF La Media Stop Sign | 5-Jun-15 | Adult | Male | 0804-19768 | 68 over X | Blood | 2014 | GPS |
| BF No Outlet* | 9-May-15 | Adult | Unknown | 1004-15513 | 39 over Y | Blood | 2015 | |
| BF La Media Stop Sign | 20-May-15 | Chick | Unknown | 1004-15530 | 42 over Y | Blood | 2015 | |
| BF La Media Stop Sign | 29-May-15 | Fledgling | Unknown | 1004-15546 | 53 over Y | Blood | 2015 | |
| BF La Media Stop Sign | 29-May-15 | Fledgling | Unknown | 1004-15547 | 64 over Y | Blood | 2015 | |
| BF Gorilla | 9-May-15 | Adult | Female | 0804-19777 | 77 over X | Blood | 2014 | |
| BF Gorilla | 25-May-15 | Adult | Male | 1004-15542 | 31 over Y | Blood | 2015 | |
| BF Gorilla | 9-May-15 | Chick | Unknown | 1004-15512 | 89 over Y | Blood | 2015 | |

| Burrow | Date | Age | Sex | USGS band ID | Aux band ID | DNA Samples | Banding Year | |
|---|---|---|---|---|---|---|---|---|
| BF Gorilla | 21-May-15 | Chick | Unknown | 1004-15537 | 46 over Y | Blood | 2015 | |
| BF Gorilla | 25-May-15 | Chick | Unknown | 1004-15538 | 50 over Y | Blood | 2015 | |
| JC 6 | 13-May-15 | Adult | Female | 1004-15523 | 37 over Y | Blood | 2015 | |
| JC 6 | 14-May-15 | Adult | Male | 1004-15525 | 26 over Y | Blood | 2015 | |
| JC 6 | 13-May-15 | Chick | Unknown | 1004-15524 | 84 over Y | Blood | 2015 | |
| JC 6 | 20-May-15 | Chick | Unknown | 1004-15529 | 95 over Y | Blood | 2015 | |
| JC 18 | 9-Jun-15 | Adult | Female | 0804-19752 | 52 over X | Blood | 2013 | |
| JC 18 | 12-Jun-15 | Adult | Male | 1004-15561 | 36 over Y | Blood | 2015 | |
| JC 18 | 22-Jun-15 | Chick | Unknown | 1004-15554 | 54 over Y | Blood | 2015 | |
| JC 18 | 9-Jun-15 | Chick | Unknown | 1004-15555 | 43 over Y | Feather | 2015 | |
| JC 18 | 12-Jun-15 | Chick | Unknown | 1004-15560 | 97 over Y | Blood | 2015 | |
| JC 18 | 9-Jun-15 | Chick | Unknown | Tarsus Too Small | Tarsus Too Small | Feather | n/a | |
| JC 18 | 12-Jun-15 | Chick | Unknown | Tarsus Too Small | Tarsus Too Small | Feather | n/a | |
| BF Cul du Sac | 28-Aug-15 | Adult | Female | 1004-15568 | 30 over Y | Blood | 2015 | |
| JC 16 | 13-Jun-15 | Adult | Male | 1004-15553 | 90 over Y | Blood | 2015 | **GPS** |
| LS 47 | 8-Jul-15 | Adult | Female | 0804-43281 | 03 over Y | Blood | 2014 | |
| LS 47 | 17-Jul-15 | Chick | Unknown | 1004-15562 | 45 over Y | Blood | 2015 | |
| Lonestar Mound | 10-Aug-15 | Adult | Female | 1084-05314 | C over C | Blood | 2011 | |
| Lonestar Mound | 10-Aug-15 | Chick | Unknown | 1004-15565 | 63 over Y | Blood | 2015 | |
| Lonestar Mound | 10-Aug-15 | Chick | Unknown | 1004-15566 | 74 over Y | Blood | 2015 | |
| 125 offramp* | 26-Feb-15 | Adult | Male | 0804-43300 | 24 over Y | Blood | 2015 | |
| 125 offramp* | 26-Feb-15 | Adult | Male | 1004-15511 | 25 over Y | Blood | 2015 | |
| LS 28* | 4-Jun-15 | Fledgling | Unknown | 1004-15551 | 72 over Y | Blood | 2015 | |
| LS 112* | 23-Jul-15 | Fledgling | Unknown | 1004-15563 | 67 over Y | Blood | 2015 | |
| LS 27* | 23-Jul-15 | Fledgling | Unknown | 1004-15564 | 78 over Y | Blood | 2015 | |
| LS 146* | 3-Sep-15 | Fledgling | Unknown | 1004-15569 | 73 over Y | Blood | 2015 | |

## Appendix 4. Modification of artificial burrows

In an effort to make pre-existing artificial burrows more useful for both management and research, we modified the artificial burrows at the Lonestar Ridge West and Lonestar Ridge East (Johnson Canyon) Mitigation sites. The goal of the modification was to allow access to the burrow chambers which enables the following: (1) monitoring the condition of artificial burrows for management; (2) cleaning of burrow chambers for BUOW accessibility; (3) collection of productivity data; (4) installation of iButtons; and (5) monitoring of nests to facilitate conservation research. We designed a "chimney" modification that included attaching a bucket with the bottom removed to the top of the existing chamber box (Johnson et al. 2010). The following is a summary of burrow conditions prior to and following the excavations. For each burrow, we assigned a classification of the amount of debris that was in the chamber, the amount of effort required to clear the chamber and tunnels to usable conditions, any field notes, and a description of the type of modification added. Below is a key to the classifications and modifications used.

***Key***

Debris

- **Minimal:** 25% or less of chamber volume removed.
- **Moderate:** 25%-50% or chamber volume removed.
- **Severe:** greater than 50% of chamber volume removed.

Cleaning

- **Easy:** Took approximately ten minutes or less to clear the chamber.
- **Moderate:** required more time (10-30 minutes) and physical effort to remove debris and clean chamber.
- **Severe:** took at least 30 minutes to clear and/or required significant physical effort.

Burrow modifications

- **Single bucket with lid**: 5-gallon bucket closed with lid.
- **Single collared bucket with lid:** Single 5-gallon bucket with top removed, placed around bottom of bucket, and secured as a collar. Bucket closed with lid.
- **Tall bucket with lid:** Single tall 6-gallon bucket closed with a lid.
- **Two buckets:** Two 5 gallon buckets stacked. One has access to the chamber through the bottom, the other placed inside the first and filled with dirt and rocks to secure and seal it.
- **Two buckets with collar:** Same as two buckets above, but with the top of a third bucket secured around the outside bucket to increase the height of the chimney.

*Information on modifications*

**Lonestar**

- **LS 3**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** 3 eggs and fragments of a fourth found in burrow; only one could be removed whole.
  - **Modification:** two buckets
- **LS 7**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Little cleaning required.
  - **Modification:** two buckets
- **LS 13**
  - **Debris:** minimal
  - **Cleaning:** moderate
  - **Notes:** Chamber bottom is uneven. North entrance open, but opening is small. South entrance unobstructed. Removed rodent nest from chamber.
  - **Modification:** two buckets with collar
  - Photograph shows the entrance of the tube into the burrow chamber. Note that the entrance is open, but the opening is smaller than originally designed due to debris (dirt).

- **LS 14**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Chamber had moderate amount of loose dirt and rocks.
  - **Modification:** two buckets with collar
- **LS 21**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** Chamber was full to the top with soft dirt and mud.
  - **Modification:** two buckets with short collar
- **LS 23**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Both entrances clear but not a lot of clearance in the chamber prior to excavation.
  - **Modification:** two buckets
- **LS 27**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Removed rabbit bones and nesting material in chamber.
  - **Modification:** two buckets with collar
- **LS 28**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:**
  - **Modification:** two buckets
- **LS 36**
  - **Debris:** minimal
  - **Cleaning:** moderate
  - **Notes:** Soil was hard packed clay in both tube entrances. Both tubes clear after excavation. Natural CAGS burrows on mound.
  - **Modification:** two buckets
- **LS 40**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** East tunnel was blocked before excavation.
  - **Modification:** two buckets with short collar
- **LS 42**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** West entrance partially open at chamber but seems to be blocked. East entrance fully blocked at chamber but seems to be open.
  - **Modification:** two buckets

- **LS 44**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Removed rodent nest.
  - **Modification:** single collared bucket with lid
- **LS 47**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Removed rodent nest.
  - **Modification:** two buckets
- **LS 52**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** South tunnel was completely buried. Chamber fairly full of soft, wet clay. Removed rodent nest from chamber.
  - **Modification:** two buckets with collar
- **LS 53**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Owl leg found on mound. Chamber close to ground surface.
  - **Modification:** single (short) collared bucket with lid
- **LS 60**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** Chamber was ¾ full of soft dirt. CAGS nest, skull, and bones removed from chamber
  - **Modification:** two buckets
- **LS 67**
  - **Debris:** minimal
  - **Cleaning:** moderate
  - **Notes:** Broke up large clay chunks. Removed whole dead rabbit and nesting material.
  - **Modification:** two buckets
- **LS 70**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Cement-like clay in chamber. Both tunnels had hard-packed clay at the bottom, but clay was removed and both are accessible.
  - **Modification:** two buckets
- **LS 97**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Chamber placed very shallow. Burrow had recently been repaired following coyote damage.
  - **Modification:** Did not install bucket, covered with heavy rocks.

- **LS 100**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** East tunnel was 75% filled in and west tunnel was completely blocked in chamber. Chamber was full within 5 inches of the top with hard-packed clay.
  - **Modification:** two buckets with lid
- **LS 102**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Both entrances are clear. Small amount of CAGS nesting material (removed).
  - **Modification:** One tall bucket with lid
- **LS 105**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Chamber was filled with clay. Dug out at least six vertical inches. North tunnel likely clear, but south tunnel likely not.
  - **Modification:** two buckets
- **LS 107**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Two full eggs in chamber. One tunnel was completely blocked and the other mostly blocked. Chamber was filled in with moist clay.
  - **Modification:** two buckets
- **LS 109**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** Both tunnels were 75% buried and chamber fairly full of soft, wet clay. Removed CAGS nest from chamber.
  - **Modification:** two buckets
- **LS 112**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Both entrances clear but not a lot of clearance in the chamber prior to excavation. Dead small mammal (mouse?).
  - **Modification:** two buckets
- **LS 114**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Chamber cleaning was easy but entire burrow modification was difficult. Found leg with USGS band 804-19780. Both tunnels are accessible. Chicken wire and quick-crete bags around the chamber had to be broken. Chamber is very close to surface.
  - **Modification:** single collared bucket with lid

- **LS 121**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Both tunnels were buried and chamber was approximately 75% full. Cleaning took approximately 1 hour. Rodent bones also found on mound.
  - **Modification:** two buckets (one tall)
  - **Before (B):** Photographs demonstrate the amount of debris filling the chamber prior to modification. **B1** shows the entire chamber, note the level of the dirt is close to the top of the tunnel entrance and fills close to 75% of the chamber. **B2** shows a close-up of a tunnel entrance. Note the debris fills the entire entrance, making this an unusable burrow entrance.


**B1.**


**B2.**

- **After (A):** Photographs display the condition of the chamber after cleaning. **A1** shows the entire chamber. Notice the residue on the chamber wall demonstrating the amount of debris removed. **A2** shows the state of the tunnel entrance after debris removal. The tunnel now allows access to the burrow chamber.

**A1.**

**A2.**

- **LS 128**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Chamber was fairly clear.
  - **Modification:** two buckets (one tall)
- **LS 129**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** CAGS nest in chamber.
  - **Modification:** two buckets
- **LS 132**
  - **Did not modify**
- **LS 133**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** Filled with dirt prior to excavation.
  - **Modification:** two buckets

- **LS 142**
    - **Debris:** moderate
    - **Cleaning:** moderate
    - **Notes:** Clay was thick, but both entrances seem clear.
    - **Modification:** two buckets
- **LS 144**
    - **Debris:** moderate
    - **Cleaning:** easy
    - **Notes:** Nesting material and a dead rabbit found in chamber. Both entrances now clear.
    - **Modification:** two buckets
- **LS 146**
    - **Debris:** minimal
    - **Cleaning:** easy
    - **Notes:** Clean. Piled rocks around buckets.
    - **Modification:** two buckets
- **LS 148**
    - **Debris:** moderate
    - **Cleaning:** moderate
    - **Notes:** Both tunnels were completely filled in, but soil was loose. Tunnel from west side now has a clear opening, but tunnel is likely still plugged, while the east tunnel is partially filled in but likely usable. CAGS digging on mound and nesting material in chamber. *Peromyscus maniculatus* ran out of dirt above chamber while digging was occurring.
    - **Modification:** two buckets
- **LS 150**
    - **Debris:** minimal
    - **Cleaning:** moderate
    - **Notes:** Small amounts of ground squirrel nesting material (removed). Soil in chamber was wet clay. Tunnel from east side of chamber likely obstructed.
    - **Modification:** two buckets
- **LS 159**
    - **Debris:** minimal
    - **Cleaning:** easy
    - **Notes:** Chamber was fairly open.
    - **Modification:** two buckets
- **LS 160**
    - **Debris:** minimal
    - **Cleaning:** easy
    - **Notes:** CAGS nest in chamber (removed).
    - **Modification:** two buckets
- **LS 166**
    - **Debris:** minimal
    - **Cleaning:** easy

- **Notes:** West tube entrance was half open but the east entrance was completely covered. Both were cleared. Soil inside chamber was loose.
- **Modification:** two buckets

- **LS 168**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Baby bunny found in tube (removed for cleaning and placed back in tube. Now a one entrance burrow, as the north entrance is completely blocked by solidified clay. South entrance now clear. Broke up and leveled clay, but chamber is not level.
  - **Modification:** two buckets (one tall)
  - North entrance: The wooden frame of the tunnel entrance is barely visible at the top right corner of the photo and is covered by hardened clay.

South entrance: Prior to excavation, entrance partially filled with debris and nesting material, but was not buried to the same degree as the north entrance.

- **LS 170**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Chamber clear, just removed a few chunks of clay.
  - **Modification:** two buckets (one tall) with collar
- **LS 175**
  - **Debris:** minimal
  - **Cleaning:** easy

- **Notes:** Chamber clear.
- **Modification:** two buckets (one tall)

- **LS 176**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Both entrances were 2/3 covered.
  - **Modification:** two buckets (one tall)
- **LS 180**
  - **Debris:** minimal
  - **Cleaning:** moderate
  - **Notes:** Chamber bottom was hard clay.  Not much debris was removed, but the bottom was broken up and softened.
  - **Modification:** two buckets
  - Before: Note the large chunks of clay limiting the size of the tunnel entrance.

  - After: Note the increase in size of the tunnel entrance and absence of thick clay chunks in burrow chamber.

- **LS 185**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Chamber was at least 75% full with wet, friable clay.  Cleaning took over 1 hour.  South tunnel remains blocked in the tube, but opened in chamber.  North tunnel is accessible but the opening is small.  Found skeletal remains including a sternum with prominent keel that could be BUOW.

- **Modification:** two buckets with collar
- Photographs show condition of chamber prior to modification. Note the degree of debris filling in the chamber (left) and the partial obstruction of tunnel entrances (right).

- **LS 190**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Chamber full to the top of wet, mud-like clay and took over an hour to clean. Once cleared, tubes appeared clear.
  - **Modification:** two buckets with collar
- **LS 193**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Both entrances clear but not a lot of clearance in the chamber prior to excavation.
  - **Modification:** two buckets
- **LS 194**
  - **Debris:** minimal
  - **Cleaning:** moderate
  - **Notes:** Bees in west entrance. Chamber bottom was hard clay. Not much debris was removed, but the bottom was broken up and softened.
  - **Modification:** two buckets with collar

- **LS 200**
    - **Debris:** minimal
    - **Cleaning:** moderate
    - **Notes:** Chamber bottom was hard clay. Not much debris was removed, but the bottom was broken up and softened.
    - **Modification:** two buckets
- **LS 201**
    - **Debris:** minimal
    - **Cleaning:** easy
    - **Notes:** Not much cleanup required.
    - **Modification:** two buckets

***Lonestar Summary***

In total, 50 artificial burrows in the Lonestar site were evaluated. One burrow (LS 132) was not modified. Of the remaining 49, 26 (53%) required the removal of minimal debris, 13 (27%) were moderately filled, and 10 (20%) were classified as removing a severe amount of debris. During the modifications, 21 (43%) of the burrows were easy to excavate while 23 (47%) and 5 (10%) were considered moderate or difficult, respectively. Based on our observations, prior to cleaning and modification, 32 (65%) were considered usable, while 12 (24%) were usable, but accessible through only one entrance, and 5 (10%) were entirely unusable. After the modifications, the number of usable burrows increased to 40 (82%), the number with only one working entrance decreased to 9 (18%) and no burrows were considered unusable.

**Johnson Canyon**

- **JC 1**
    - **Debris:** severe
    - **Cleaning:** moderate
    - **Notes:** Chamber almost completely full of dirt and cholla. Also removed approximately half a chamber's worth of dirt and cholla from tubes.
    - **Modification:** two buckets
    - Photograph shows the burrow chamber of JC 1 with no space between the dirt and the chamber top.

- **JC 2**
    - **Debris:** severe
    - **Cleaning:** moderate
    - **Notes:** Completely filled with dirt and top layer was entirely cholla. East opening was fairly clear and just required minimal cholla and dirt removal. North entrance had much more dirt but was cleared.
    - **Modification:** single collared bucket with lid
    - Photographs highlight the amount of space left between the debris and the top of the chamber (the amount of debris filling the chamber; top) and the north entrance obstructed by dirt (bottom).

- **JC 3**
    - **Debris:** moderate
    - **Cleaning:** severe
    - **Notes:** Southern Pacific Rattlesnake in south tube. Bees and wasps in south tube. South entrance obstructed. Chamber box is larger. Chamber box close to ground surface.
    - **Modification:** single collared bucket with lid

- **JC 4**
    - **Debris:** severe
    - **Cleaning:** moderate
    - **Notes:** Cholla and dirt for at least 3 feet into south tube. Removed large amount of cholla and dirt from chamber.
    - **Modification:** two buckets

- Photograph shows the complete obstruction of JC4 tunnel entrances (left and right-black tubes) as well as the amount of cholla present in the chamber (see top section of the photo).

- **JC 5**
  - **Debris:** severe
  - **Cleaning:** severe
  - **Notes:** Chamber was full of debris and cholla. Tubes were cleaned out using burrow camera. Cleaning took 30 to 45 minutes.
  - **Modification:** two buckets

- **JC 6**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Bird leg and cholla in chamber.
  - **Modification:** two buckets

- **JC 7**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Both tubes were packed with dirt and cholla- cleaned as far as trowel would allow. Found mammal skull and bone in chamber.
  - **Modification:** single collared bucket with lid

- **JC 8**
  - **Debris:** moderate
  - **Cleaning:** moderate
  - **Notes:** Tubes packed- cleared as much as possible. Chamber had rodent rest and a lot of cholla as well as 4 skulls and other bones.
  - **Modification:** two buckets

- Photograph shows the complete obstruction of the tube entrances (left side-black tube), as well as the rodent nest (bottom, middle portion of photo) and amount of cholla distributed throughout the chamber.

- **JC 9**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Beehive in east entrance, 3 carcasses (woodrat and rabbit) found in chamber. Chamber had very little cholla.
  - **Modification:** two buckets

- **JC 10**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Owl pellets in burrow. Removed a woodrat nest, cholla, and debris.
  - **Modification:** two buckets

- **JC 11**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Tubes were approximately half open from inside chamber. Cleared dirt and cholla. Half a carcass (likely woodrat) and rabbit skull found in chamber.
  - **Modification:** two buckets
  - Photographs showing the burrow chamber of JC 11. Note presence of more space between the debris and chamber top (left photo) in this burrow than the previously shown “severe” burrows, but that the bottom still covers half of the tunnel entrance, which is also loosely filled with cholla (right photo).

- **JC 12**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** South tube fairly plugged from chamber side. Removed dirt and cholla from chamber. Chamber fairly close to ground surface (put rocks around bucket to supplement the dirt).
  - **Modification:** single bucket with lid

- **JC 13**
  - **Debris:** severe
  - **Cleaning:** easy
  - **Notes:** Chamber was difficult to locate and required a large digging investment. Two woodrat carcasses and other skulls in chamber. Removed a large amount of cholla.
  - **Modification:** single bucket with lid

- **JC 14**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Chamber was difficult to locate and required a large digging investment. Dead rabbit found in chamber. Removed nesting material, dirt, and cholla.
  - **Modification:** two buckets

- **JC 15**
  - **Debris:** moderate
  - **Cleaning:** easy

- **Notes:** Five BUOW eggs found in chamber (see photo below) along with a lizard skin. Chamber close to ground surface.
- **Modification:** single collared bucket with lid

- **JC 16**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Live woodrat in chamber. Removed dirt, cholla, and nesting material. Chamber very close to ground surface.
  - **Modification:** single collared bucket with lid

- **JC 17**
  - **Did not modify**

- **JC 18**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Fairly clean- mostly loose dirt and cholla
  - **Modification:** single bucket with lid

- **JC 19**
  - **Debris:** moderate
  - **Cleaning:** easy
  - **Notes:** Found 2 skulls and a bird leg in chamber. Removed dirt and cholla from chamber.
  - **Modification:** two buckets

- **JC 20**
  - **Debris:** minimal
  - **Cleaning:** easy
  - **Notes:** Bees in northeast entrance.
  - **Modification:** single bucket with lid

- **JC 21**
  - **Debris:** severe
  - **Cleaning:** moderate
  - **Notes:** full of dirt, nesting material, and cholla. Chamber box shallow (approximately 4 inches below ground).
  - **Modification:** single collared bucket with lid

***Johnson Canyon Summary***

In total, 21 artificial burrows in the Johnson Canyon site were evaluated. One burrow (JC 17) was not modified. Of the remaining 20, 5 (25%) required the removal of minimal debris, 9 (45%) were moderately filled, and 6 (30%) were classified as removing a severe amount of debris. During the modifications, 12 (60%) of the burrows were easy to excavate while 6 (30%) and 2 (10%) were considered moderate or difficult, respectively. Based on our observations, prior to cleaning and modification, 9 (45%) were considered usable, while 4 (20%) were usable, but accessible through only one entrance, and 7 (35%) were entirely unusable. After the modifications, the number of usable burrows increased to 15 (75%), the number with only one working entrance decreased to 3 (15%) and no burrows were considered unusable, but 2 (10%) were classified as unknown because we could not confidently determine the status.

**General Summary**

We modified pre-existing artificial burrows in order to make burrow management easier, as well as increase our monitoring potential for research purposes. In total, we modified 69 burrows. These burrows now have a convenient way to view the chambers for routine maintenance and clearing, as well as studying productivity by identifying nesting burrows, counting eggs and chicks, and determining egg laying and hatching dates. Along with the modification process, we cleared out the burrows, discovering that many of the artificial burrows were in conditions unusable by burrowing owls. We classified 41 (59%) of the burrows as usable, 16 (23%) as usable with only one working entrance, and 12 (17%) as unusable. Following maintenance, we increased usable to 55 (80%), decreased the single entrance to 12 (17%) and the unusable to zero, with two newly classified as unknown (3%). However, these conclusions are subjective, as all status were assigned based on field observations and we were unable at the time to determine the condition of the tunnel beyond what could be visualized and touched from the tunnel openings inside the chamber and at the entrances.