SEASONAL HABITAT REQUIREMENTS AND USE BY THE WESTERN BURROWING OWL (*ATHENE CUNICULARIA HYPUGAEA*) IN THE NORTHERN SACRAMENTO VALLEY, CALIFORNIA

A Thesis

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to the Faculty of

California State University, Chico

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Biological Sciences

by

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DEDICATION

This is dedicated to my wonderful partner in life, Avanti, who provided great distraction, inspiration, help, patience, support, and encouragement in this endeavor. Thank you for being who you are and accompanying me on this journey. We'll be hiking soon, I promise!

To my mother and late father for helping me become the person I am today and always being there for me, believing in me and helping me believe in myself.

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Thank you to the private land owners that allowed me access to their properties. I hope this research helps you to improve your land for generations to come.

Thank you to my family and friends who have supported me along the way. You were always there to give advice, or encouragement and share your varied talents and knowledge when it was needed most.

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TABLE OF CONTENTS

PAGE

Publication Rights iii

Dedication iv

Acknowledgements v

List of Tables vii

List of Figures viii

Abstract ix

CHAPTER

I. Introduction 11

Species Status 13
Natural History and Ecology 13
Conservation Concerns 15
Study Area 15

II. Methods 19

Internal Burrow Data 20
Data Processing 20
Presence-Absence Surveys 21
External Burrow Data 23

III. Results 25

Natural Burrows 26
Artificial Burrows 29
Rock Piles 30
Culverts 31

IV. Discussion 35

Management Implications 39

Literature Cited 41

LIST OF TABLES

TABLE PAGE

1. Greatest Humidity and Temperature Mean Differentials between Internal and Ambient Conditions 27

2. Physical Attributes and Seasonal Usage of Fall-Winter Burrowing Owl Burrows 28

LIST OF FIGURES

FIGURES		PAGE
1.	Location of Study Area	17
2.	One $meter^2$ Quadrat	24
3.	Vegetation Survey Plot Map	24
4.	Burrow Entrance Orientations on	25
5.	Mean Percentage Ground Cover for Natural Burrows	27
6.	Mean Percentage Ground Cover for Artificial Burrows	30
7.	Mean Percentage Ground Cover for Rock Piles	31
8.	Mean Percentage Ground Cover for Culverts	32
9.	Mean Humidity Differentials by Season and Burrow Type	33
10.	Mean Temperature Differentials by Season and Burrow Type	34

ABSTRACT

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The western burrowing owl (*Athene cunicularia hypugaea*) is a small fossorial owl found in the western United States, Canada and northern Mexico (Shuford and Gardali 2008). Populations in northern California have suffered recent declines, and a better understanding of their habitat requirements is needed in order to make better management decisions (Wellicome and Holroyd 2001). For this study I described internal and external characteristics found in owl burrow sites in the northern Sacramento Valley, California in the fall and winter months. I measured and recorded a variety of characteristics at 17 locations confirmed to be utilized by burrowing owls. I used iButton® data loggers to record internal humidity and temperature throughout the day for multiple years. I calculated means by season and semidiurnal period and compared them to ambient means. The physical attributes I recorded included burrow entrance direction, burrow type, distance to water, type of water source, whether the area was grazed, and whether burrowing mammals were present. Using a 1-m^2 quadrat, I recorded vegetation height and density three meters in front of, behind and to each side of each burrow entrance and calculated the means for each site. I also utilized student research assistants to conduct visual

occupancy surveys to determine the season(s) of usage for each burrow. Observations were summarized for burrow types.

All sites were on or near land grazed by cattle in the winter. Natural burrows were all located in cut-banks of seasonal drainages. Seventy-one percent of all burrows were located within 6.55 m of water in the winter. Natural burrow internal temperature means were consistently higher in the mornings and lower in the evenings than ambient conditions for every season, except for winter, which was slightly higher. Artificial burrows and rock piles displayed a similar pattern but were consistent across seasons. Culvert temperature means were higher than ambient means in all seasons and semidiurnal periods except for spring which showed lower internal means than the ambient means. The greatest difference between internal and ambient temperature means was 10.35° C (SD=2.83) for artificial burrows (n=676).

Internal relative humidity [rH] means tended to be higher than ambient means for all natural and culvert sites. For artificial burrows, internal rH means were lower in the A.M. and higher in the P.M. than ambient means for every season. Internal humidity means for rock pile burrows were higher than ambient means in the P.M. The greatest difference between internal and ambient relative humidity means was 55.17% (SD=26.15) for natural burrows (n=763).

CHAPTER I

INTRODUCTION

The burrowing owl (*Athene cunicularia*) is a small, long legged fossorial owl that occupies burrows often created by mammals, such as ground squirrels, badgers, coyotes and prairie dogs (Coulombe 1971, Zarn 1974, Haug et al. 1993). Breeding habitat in California is typically open grassland with short, sparse vegetation, gentle slopes, and well-drained soils (Haug et al. 1993). This owl is widely distributed throughout western North America, Florida, the Bahamas, and Central and South America (Shuford and Gardali 2008). There are two subspecies found in North America: the Florida burrowing owl (*Athene cunicularia floridana*), found in Florida and the Bahamas, and the western burrowing owl (*Athene cunicularia hypugaea*), found throughout the remainder of their range, and the focus of this study.

Somveille et al. (2015) found that avian distribution during the non-breeding season was linked to avoidance of harsh winter conditions and connectivity to breeding grounds. The costs of migration increase with distance from breeding grounds (Somveille et al. 2015). The burrowing owl is semi-migratory, with *A. c. floridana* and the southerly populations of *A. c. hypugaea* maintaining mostly resident status (Haug et al. 1993). According to James and Ethier (1989) and Klute et al. (2003), California is considered an important wintering ground for migrants which breed in North America. Most studies on habitat requirements for this owl focus on the breeding season; there are few published studies on winter habitat, with the exception of two studies conducted in Texas (Williford et al. 2009, Holroyd et al. 2010) and one in southern Nevada (Greger and Hall 2009). While breeding habitat is intrinsically important to the survival of the species, winter habitat may play just as important a role. If conditions are not favorable on wintering grounds, or if other factors negatively impact migration, an owl may not reach its breeding grounds or be able to reproduce once it arrives (Wellicome et al. 2014). There are currently no data published on winter habitat requirements for burrowing owls in the northern Sacramento Valley [NSV]. The species has been experiencing declines over much of its range for the last several years (Wellicome and Holroyd 2001). The Institute of Bird Populations attempted to quantify the breeding population of burrowing owls in California from 1991-93 and again from 2006-2007 using citizen science volunteers. These studies showed a nearly 11% decline in burrowing owls throughout their summer breeding range, with the most precipitous declines in the San Francisco Bay Area and also near Bakersfield (Wilkerson and Siegel 2011). In northern California, the decline is largely due to anthropogenic habitat loss and fragmentation (Restani et al. 2008). Human caused habitat fragmentation has been linked to practices such as conversion of grasslands to cropland or urban areas, and burrowing mammal control (Moulton et al. 2006). Other factors that likely contribute to declines include wind turbine strikes and agricultural pesticide use (Gervais and Anthony 2003, Poulin et al. 2005, Smallwood et al. 2007, Engleman et al. 2012).

Although breeding habitat characteristics are fairly well understood, winter requirements have not been studied in the NSV. For this reason, I studied, and describe here, winter habitat of the western burrowing owl in the NSV. With a better understanding of those requirements, conservation minded land managers may be able to make wise management decisions when they relate to burrowing owl habitat.

Species Status

In 1994 the western burrowing owl was designated by the U. S. Fish and Wildlife Service [FWS] as a Category 2 species for consideration as Threatened or Endangered under the Endangered Species Act [ESA] of 1972 (Klute et al. 2003). In 1996, that designation was rescinded. In 2002, the FWS then designated the owl as a National Bird of Conservation Concern, which remains its current national status (Klute et al. 2003). The California Department of Fish and Wildlife [CDFW] designated this species as a California Bird Species of Special Concern in 1992 (Shuford and Gardali 2008). While neither of these designations confer any special legal protections, the western burrowing owl is protected under the Migratory Bird Treaty Act of 1918. It is listed as Endangered throughout its range in Canada and Threatened in Mexico (Klute et al. 2003). Florida listed the Florida burrowing owl as Threatened in 2016 (Florida Fish and Wildlife Conservation Commission 2017). The western burrowing owl is state listed as Endangered in Minnesota and Threatened in Colorado. It is also considered a Species of Special Concern in Montana, Oklahoma, Oregon, Utah, Washington, and Wyoming (Klute et al. 2003).

Natural History and Ecology

Burrowing owls are considered a grassland specialist (Klute et al. 2003). They seldom excavate their own burrow, relying on mammals such as ground squirrels, prairie dogs, badgers, foxes, and coyotes, which provide burrows for breeding and winter refuge (Klute et al. 2003, Poulin et al. 2005). They will also utilize artificial burrows in the absence of natural burrows. Smith and Belthoff (2001) found that burrowing owls prefer artificial burrows with large nest chambers and small entrance tunnels. Good burrowing owl habitat is generally described as being open with short vegetation and available burrows (Coulombe 1971, Zarn 1974, Haug et al. 1993, Klute et al. 2003).

In North America, the western burrowing owl ranges from Texas to California and from Canada to northern Mexico (Korfanta et al. 2005). Its overall range in California has not changed dramatically since 1945, but Gervais et al. (2008) reported that locally, distributions within the state have undergone significant changes. They reported that regions experiencing rapid urbanization have experienced declines and local extirpations of the owls, whereas areas in southeastern California, have experienced sizable population increases. This is likely due to the extensive land conversion that has taken place in the Imperial Valley over the last 100 years, to agricultural croplands that provide both habitat in the form of ground squirrel burrows and a stable prey base, such as small rodents, which are often associated with the crops (Moulton et al. 2006, Manning and Kaler 2011). Most owls throughout the state occur on privately held pasture land, which makes them difficult to monitor (DeSante et al. 1997, Shuford and Gardali 2008). Populations in northern California are likely both migratory and resident, while populations in southern California are largely resident (Martin 1973, Korfanta et al. 2005, Chromczak et al. 2016). This species is also quite philopatric, exhibiting strong nest site fidelity (Ronan 2002). Site fidelity decreases in winter, as owls are reported to "roam" (Zarn 1974). Resident owls banded in the San Francisco Bay Area were found to occasionally move relatively short distances (0.26—3.88 km) from breeding sites to wintering sites (Chromczak et al. 2016).

Studies have shown that large scale abiotic factors such as soil characteristics and climate provide the greatest predictive accuracy of home-range selection by burrowing owls (Stevens et al. 2011). The reason for this may be that these factors also influence agricultural practices and grassland distribution, which could affect resource availability (Stevens et al. 2011).

Burrowing owl diet consists primarily of insects (e.g., beetles, crickets, and grasshoppers), small rodents, reptiles, amphibians, and even birds (Silva et al. 1995, Gervais et al. 2000). Poulin et al. (2001) found that burrowing owls had a numerical and functional response to increases in vole (*Microtus spp.*) populations, suggesting that voles may play an important role in their survival and reproductive success (Gervais and Anthony 2003).

Conservation Concerns

In addition to the threats discussed earlier, burrowing owls face continued threats from anthropogenic manipulation of the environment. For example, the Altamont Pass Wind Resource Area claims the lives of approximately 600 burrowing owls annually due to wind turbine strikes (Smallwood et al. 2013). McCullough-Hennessy et al. (2016) reported that changes in grassland composition to non-native annual species and reductions in the distribution and abundance of ecosystem engineers like the California ground squirrel (*Otospermophilus beecheyi*) are primary factors for burrowing owl declines in California. Ground squirrels physically change their environment through burrow excavation and herbivory, which creates a favorable habitat for burrowing owls (Machiote et al. 2004). Other anthropogenic effects, such as exposure to rodenticides and insecticides, have been shown to negatively impact owl populations (Engleman et al. 2012, Justice-Allen and Lloyd 2017). The Central Valley (of which the Sacramento Valley is part), is projected to reach a human population of over 10 million by 2040, which could result in the loss of large tracts of open space, eliminating additional habitat for this species (Shuford and Gardali 2008).

Study Area

My study area consisted of 17 locations known to be used by burrowing owl in the winter months, in Butte and Tehama Counties, California, and covered 1600 km^2 (Fig. 1). Butte and Tehama Counties occupy the northeast portion of the Northern Sacramento Valley [NSV]. Much of this area consists of open grassland habitat primarily used for cattle grazing. It is bordered on the east by the Sierra Nevada and Cascade ranges, to the north by the Cascades, and to the west by the Coast Ranges. Floristically, it is primarily a Valley Grassland, which, pre-European settlement, was largely comprised of perennial bunch grasses, such as purple needle grass (*Stipa pulchra*), bluegrass (*Poa spp.*), and three-awn (*Aristida sp.*) (Ornduff et al. 2003). Today, most of the native bunch grasses have been replaced by exotic annual grasses and cultivated crops, such as a variety of orchard and row crops, as well as rice (Ornduff et al. 2003). The terrain in the valley is mostly flat with a gently sloping topography. Drainages in this habitat often create cut-banks, into which burrows are often constructed.

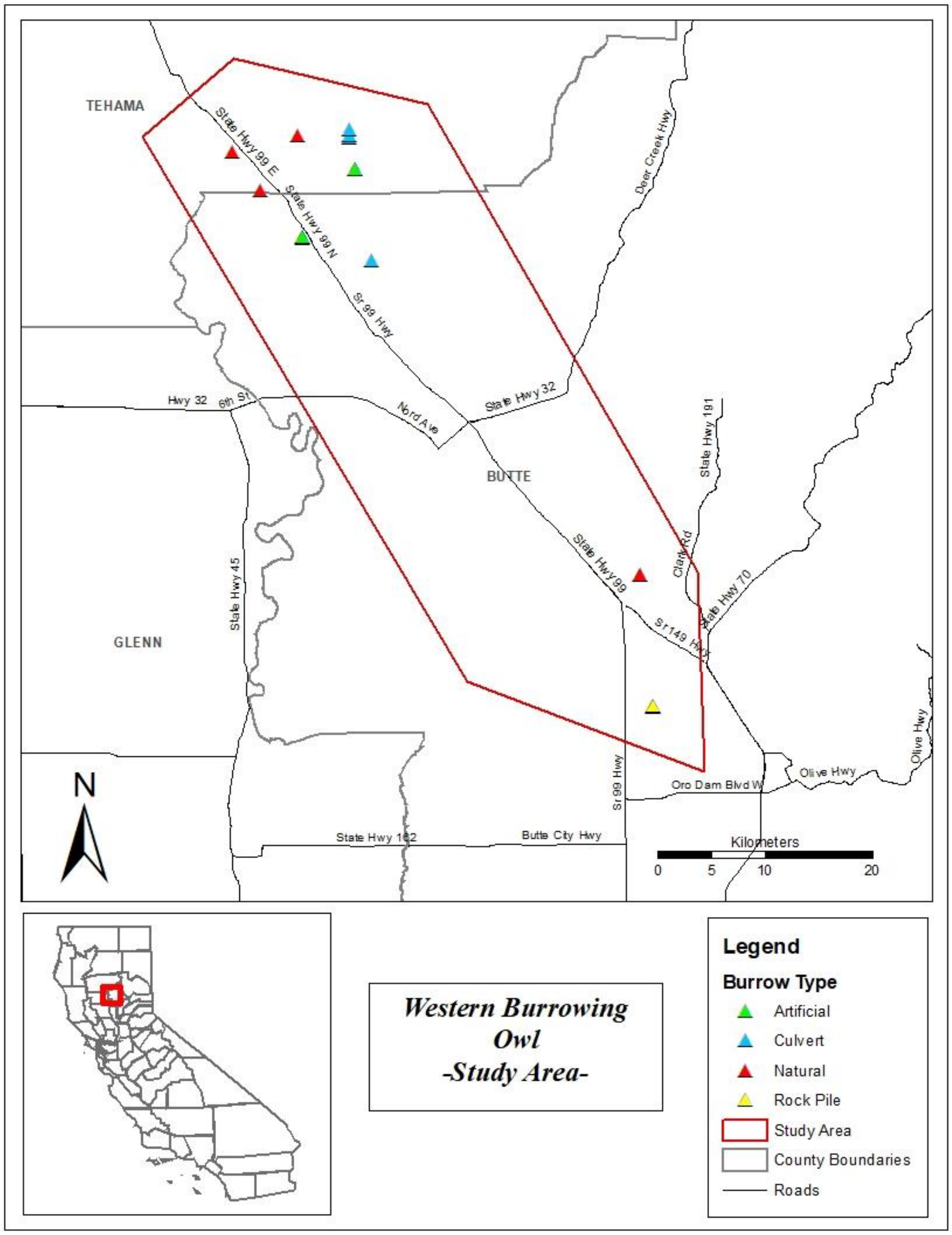

Figure 1. The location of the study sites represented in this study in the northern Sacramento Valley, California.

Land management varied across sites and included conservation management, private-agricultural, and county maintained water conveyances. The Nature Conservancy [TNC], the largest non-governmental conservation organization in the world, manages 29.4% of the sites in this study at the 1,862 km^2 Vina Plains Preserve, 21 kilometers north of Chico. The site is managed for the conservation of vernal pool grasslands (Kareiva et al. 2014). There were natural [NB] and artificial burrows [AB] at Vina Plains (sites NB1, NB2, NB6, AB1, and AB2). Private, agricultural lands comprised 47.1% of the sites. They consisted of mostly cattle pasture (sites NB 3, NB4, NB5, AB3, and AB4) and rock-pile [RP] habitat at the edge of an olive orchard (sites RP1, RP2, and RP3).

Williford et al. (2009) reported the use of culverts by burrowing owls in winter in southern Texas. The culverts used in my study were all located under county maintained roads, and were managed by their appropriate counties. Culverts [CU] represented 23.5% of the study sites. Culvert diameter ranged from 61 cm to 122 cm. The 61-cm culvert was located on a moderately traveled gravel road in Butte County. The 122-cm culverts typically had 1-2 similar culverts immediately adjacent to them, and were placed under minimally traveled paved roads in Tehama County. The sites associated with this category are CU1, CU2, CU3 and CU4. Cattle grazing occurred within 10 m of each culvert.

CHAPTER II

METHODS

I conducted surveys year-round at pre-determined sites of known burrowing owl occupancy or use in Butte and Tehama Counties, from July 2012 to March 2015. To identify locations of reported burrowing owl activity, I contacted local Audubon Society chapters, birding clubs, and citizen science databases, such as eBird and the California Natural Diversity Database [CNDDB]. I also relied on personal observations to identify burrowing owl locations. Twenty-eight sites were originally chosen for this study, ranging throughout five counties (Butte, Colusa, Glenn, Tehama, and Yuba). Six of those sites were discarded because permission to access was not granted.

I confirmed usage at each site through personal observation before the start of the investigation. Once I confirmed site utilization, I requested permission from local landowners and managers for access to each site. Presence-absence surveys began as soon as access was granted.

I categorized and named each location based on the following physical characteristic types:

- Natural Burrow [NB]: non-anthropogenic burrow located in cut-bank of seasonal drainage
- Artificial Burrow [AB]: burrow created and installed for the purpose of burrowing owl use
- Rock-pile [RP]: burrow located within an anthropogenic pile of boulders
- Culvert [CU]: road culvert used by burrowing owl for cover or protection

Internal Burrow Data

To record the relative internal environment of each burrow, an iButton® DS1923 data logger from Maxim Incorporated was used to record relative humidity [rH] and temperature [T]. A housing was created using 1.9-cm PVC couplings and end caps to hold the iButtons. The couplers were double female (Dura D2466) with six 5 mm holes drilled along the circumference on the centerline to allow for air flow. The coupler was capped with a 1.9-cm male screw-on end piece (Dura D2464). A 15-mm hole was drilled through the end of each cap for air flow. The housing was then painted dark brown to camouflage it better within its surroundings.

I programmed the iButton in the field to record rH and T (°C) at 4-hr intervals. Recording times were 2400, 0400, 0800, 1200, 1600, and 2000. I chose these times in an attempt to capture the natural progression of highs and lows for each day, while maintaining consistency in timing throughout the year. Once a data logger was programmed, I placed it in the prepared housing. I secured a 180 cm length of 16 gauge wire to the housing at one end. The other end of the wire was secured to a 15-cm metal spike. I secured the spike to the ground just outside the opening of the burrow and placed the data logger (in its housing) as far back into the entrance of the burrow as it would reach (approximately 180 cm). I secured the wire as close to the edge of the burrow wall as possible so that it did not present an obstacle for owls.

Data Processing

Using the Trifacta Wrangler software tool, I transformed the data retrieved from the data loggers. I extracted all measurements for 0400 (A.M.) and 1600 (P.M.) for further analysis. I chose these times to best represent likely extremes in both relative humidity and temperature (high-low). Diurnal fluctuations of rH and T did not follow the same pattern, so for simplicity, these data are identified as A.M. and P.M. instead of high and low. I calculated means for morning and afternoon readings by season. Seasons were defined as follows: December – February = winter, March – May = spring, June – August = summer, and September – November = autumn. I obtained ambient humidity and temperature measurements from the nearest airports for comparison with internal burrow readings. Airports record weather data hourly, and so they proved to be the most reliable sources for this kind of data. I used data from the Chico Municipal Airport for the northernmost sites and Oroville Municipal Airport for the southern sites. Both airports are located in open grassland areas similar to my study sites. Distances ranged from 7-24 km from the study sites for the northern area and 10-22 km for the southern area.

The means for rH and T were calculated for each season and for A.M. and P.M. within each burrow type. Ambient means were also calculated for the above parameters and subtracted from the corresponding internal means. These differences represent the differential between internal and ambient conditions for each burrow type.

Presence-Absence Surveys

To determine seasonal occupancy I utilized a team of student research assistants to conduct presence-absence surveys. Team size fluctuated throughout the study period, and was adjusted to ensure sufficient coverage of all sites throughout the seasons.

Timing

We conducted surveys once a week during migration (typically August-September and February-March) and twice monthly outside of migration. Surveys were conducted in either the morning or the evening. Morning surveys were conducted within 4 hours after sunrise. Timing of evening surveys differed between winter and summer. Winter evening surveys were conducted within 4 hours before sunset and summer surveys were conducted within 3 hours before sunset due to afternoon heat concerns. I chose this timing to increase detection probability, and to coincide with periods when owls were more likely to be active outside of their burrows (in daylight hours) and more easily detected (Conway et al. 2008). Detection probability decreases significantly during periods of rain or heavy wind (≥16 km/h); we did not conduct surveys during these conditions (Conway et al. 2008). Very light precipitation did not preclude surveys.

Duration

Each survey was conducted for 20-min at each site. We recorded weather data and disturbance level and type upon arrival at each site. Most sites were viewable from a road and so, wherever possible, we conducted the first 5 minutes of observation from within a vehicle to minimize disturbance. After 5 minutes, we exited the vehicle, if necessary, and moved around the burrow to gain a better view. If an owl was detected, we retreated back to the vehicle to limit disturbance. At the end of 20 minutes, we finalized and recorded all observations.

Data recorded

Weather data recorded during each visit included temperature (°C), wind (using the Beaufort scale), percent cloud cover, and precipitation (light, moderate, or heavy). Disturbance levels were determined based upon the activity level and disturbance type in the area around the burrow, and were recorded as low, moderate, or heavy. Typical activities included traffic on nearby roads, cattle grazing, or the presence of the observer. If we reported a disturbance, we provided further explanation on the field data sheet. Due to the subjective nature of these data, I did not use them in my final analysis. When we detected an owl, we recorded the location at first sighting (e.g., at burrow entrance, on top of burrow) and any behavioral observations. The same data were recorded for each additional owl observed at the site.

Safety Precautions

In order to minimize impacts, we took special precautions to ensure an owl's safety. For instance, if a predator was detected in the vicinity at the time of the survey, we terminated the survey immediately, and conducted a make-up survey within 4-days of the aborted attempt, regardless of whether or not an owl was observed prior to the detection of the predator. If, in searching for an owl, one was flushed from a hidden location, we immediately left the area to allow the owl to relocate cover. Additionally, if an owl displayed signs of alarm (crouching in cover while looking at the observer, rapidly scanning the area, bobbing its head, etc.), we retreated from the area, sometimes returning to the vehicle.

External Burrow Data

External burrow data were also collected at each site. I characterized burrow type as Natural, Artificial, Rock Pile, or Culvert (see definitions at the beginning of this chapter). I classified land use for each site into three management categories: conservation management, private agriculture-pasture, and county road maintenance. Using a standard compass, I determined the orientation of each burrow entrance. The presence or absence of burrowing mammals, and whether the area was grazed were also recorded. Distance to the nearest water source and type (permanent or seasonal) were also recorded.

Vegetation Surveys

To determine the dominant vegetation type, average vegetation height, and density of cover, the following protocol was used: A 1-m^2 quadrat, made out of PVC pipe, was used to describe vegetation data in front of, behind and to the sides of each burrow. The quadrat was divided at the 0.5-m mark on each side as shown in Figure 2 to facilitate density estimations.

To begin, I placed the quadrat at the mouth of the burrow entrance, in the #1 position (Figure 3). I used three categories for ground cover: bare ground, defined as an area devoid of vegetation, grass, and forb. For each category, I recorded the estimated average height (cm) and percent cover. I then moved the quadrat one meter forward (Fig. 3), to the #2 position, and recorded the above data again. This was done one more time, to the #3 position, for a total of three square meters of vegetation data in the area directly in front of the burrow entrance. I then turned clockwise 90°, positions #4-6, and recorded the vegetation for 3 m. I repeated this at 90° to record the vegetation behind the burrow entrance, positions #7-9, and at 90° again, positions #10-12, to record vegetation to the left of the burrow entrance (Fig. 3). I then calculated the overall means for percent cover of each type as well as vegetation heights.

Figure 2. One-meter^2 quadrat used to measure vegetation type and density.

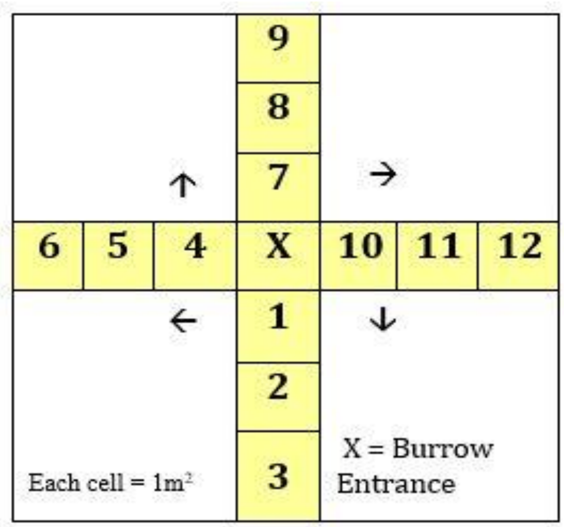

Figure 3. Plot map illustrating direction and order of vegetation measurements in relation to burrow entrance. Numbers and arrows indicate order of progression.

CHAPTER III

RESULTS

Wintering burrowing owls in the NSV were found to use 4 different habitats: natural burrows, artificial burrows, rock piles, and culverts. Data were collected at 17 sites throughout Butte and Tehama Counties. Mean values were calculated for each site and sample numbers (n) represent the number of measurements (rH or T) for each burrow type within the relevant categories (e.g., season and semidiurnal period, or vegetation height). Negative results represent lower rH or T and positive results represent higher rH or T within burrows, compared to ambient conditions.

Most burrow entrances (71%) were oriented to the west, northwest and northeast, between 256 and 360 degrees and 0 and 30 degrees (Fig. 4).

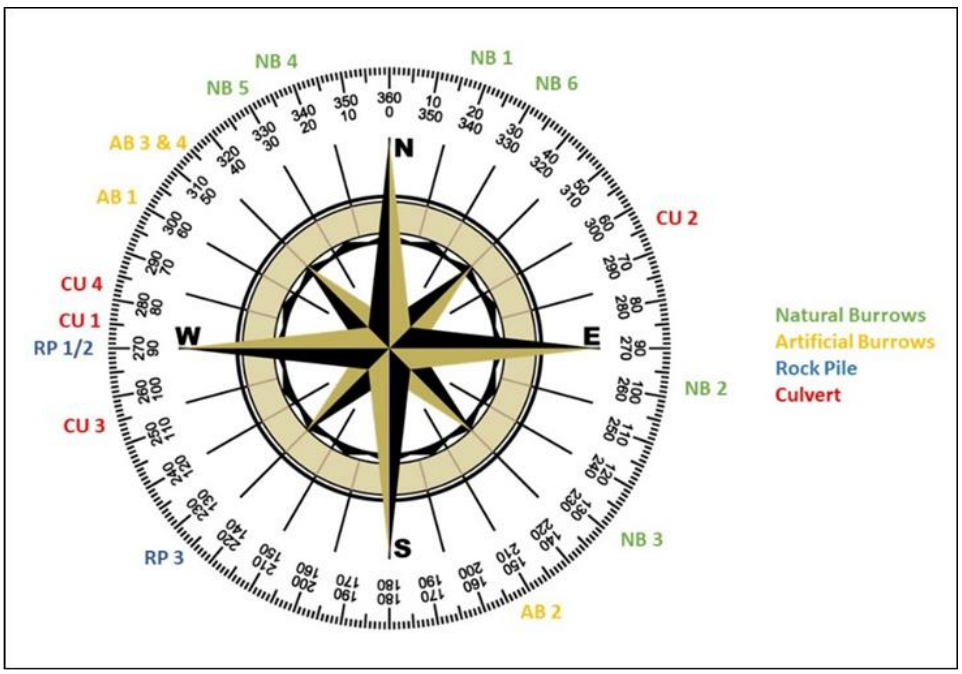

Figure 4. Burrow entrance aspect in degrees, overlaid onto a compass to illustrate the various orientations of burrow entrances on the landscape.

Natural Burrows

All natural burrows were located in cut-banks of seasonal drainages with no apparent burrowing mammals at or near the burrows. Fifty percent of the burrows were on private cattle ranches, and 50% were on land managed by TNC; all were grazed by cattle in the winter. Most natural burrow entrances were oriented to the northwest or northeast (Figure 4). All but one burrow were within 3 m of water during the wet season. All burrow entrance openings were round to laterally oblong in shape, and varied in height from 16-63 cm (Table 2).

Burrowing owl occupancy was observed in the fall and winter for all sites, and year-round at 75% of these sites. No breeding was observed during the study. However, breeding was confirmed at one natural burrow the year prior to the start of this study (2011), and at another natural burrow the year following the study, in Spring 2015. The maximum number of owls we observed at any natural burrow was two.

In all natural burrow sites relative humidity [rH] means were consistently higher than ambient humidity means across all seasons and semidiurnal periods (A.M. or P.M.) (Fig. 9). The greatest difference between internal and ambient rH means occurred in the spring P. M. ($\bar{x}$ = 55.17%, SD = 26.15%, n = 763) (Table 2).

Mean temperatures within natural burrows were warmer than ambient conditions across all seasons in the A. M., whereas, in the P.M., internal temperature means tended to be cooler than ambient means for all seasons except winter (Fig. 10). Winter temperature mean differential (n=891) was 0.71 °C (SD=4.41 °C), which was also the lowest differential for all means. The greatest difference between internal and ambient temperature means occurred in the summer P.M. (n=868) with $\bar{x}$= -6.85 °C (SD=2.67 °C) (Table 1).

Mean vegetation heights surrounding natural burrows ranged from 22.9 cm (SD = 16.1 cm) to 23.8 cm (SD = 15.9 cm) for forbs (n = 62) and grasses (n = 56), respectively. I found that bare ground was the dominant mean ground cover at 67%, followed by grass at 23% and forbs at 10% for this burrow type (Fig. 5).

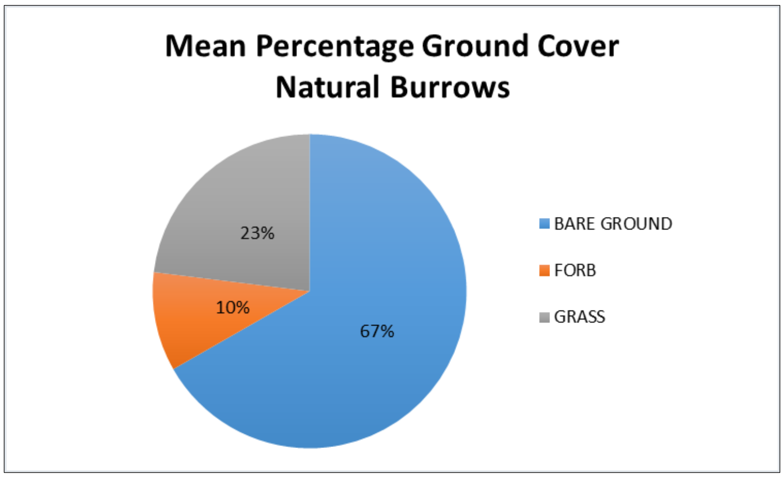

Figure 5: Mean percentage of ground cover surrounding natural burrows for 3 m^2 in front, behind, and to each side.

Table 1: Greatest differences between internal and ambient means for relative humidity and temperature and in which season and time they occurred.

Burrow type	Greatest mean T differential (°C)	Season and Time	Greatest mean rH differential (%)	Season and Time
Natural	-6.85	Summer P. M.	55.17	Spring P. M.
Artificial	10.36	Summer A. M.	42.01	Spring P. M
Rock pile	6.80	Summer A. M.	43.34	Spring P. M
Culvert	3.37	Autumn A. M.	21.32	Spring P. M

Table 2. Physical attributes and seasonal usage of fall-winter burrowing owl burrows, by type, in 2012-2015. F = autumn, W = winter, SP = spring and SU = summer.

Site	Burrow entrance orientation in compass degrees	Dist. to water (m)	Type of water source	Burrow entrance height (cm)	Burrow entrance shape	Max # owls observed	*Seasons occupied
Natural Burrows							
NB 1	18	2.81	Seasonal	34	laterally oblong	2	F, W, SP, SU
NB 2	98	2.34	Seasonal	19	round	2	F, W, SP, SU
NB 3	128	23.23	Seasonal	16	round	1	F, W, SP, SU
NB 4	342	0.81	Seasonal	63	laterally oblong	2	F, W, SP, SU
NB 5	331	1.14	Seasonal	23	laterally oblong	2	F, W, SP
NB 6	30	2.86	Seasonal	27	laterally oblong	1	F, W, SP
Artificial Burrows							
AB 1	300	59.08	Seasonal	15	round	3	F, W, SU
AB 2	152	24.79	Seasonal	15	round	3	F, W, SP, SU
AB 3	316	48.23	Seasonal	15	round	1	F, W
AB 4	315	44.75	Seasonal	15	round	1	F, W
Rock Pile							
RP 1	268	4.27	Seasonal	18	irregular	3	F, W
RP 2	270	6.55	Seasonal	25	irregular	3	F, W
RP 3	226	1.38	Seasonal	20	irregular	3	F, W
Culvert							
CU 1	273	0	Seasonal	122	round	1	F, W, SU
CU 2	248	0	Seasonal	122	round	1	F, W
CU 3	256	0	Seasonal	122	round	1	F, W
CU 4	281	0	Seasonal	61	round	1	F, W, SP

Artificial Burrows

Artificial burrow sites were on land that allowed winter cattle grazing. Two of these sites were on private land and two were managed by TNC. Seventy-five percent of the artificial burrow entrances faced northwest (Fig. 4). All artificial burrow entrance openings were round and 15 cm in diameter (Table 2).

We observed owls at all artificial burrow sites during the fall and winter, and 50% of the sites year-round. No burrowing mammals were observed at any of these sites, and no breeding was documented during the study. The maximum number of owls observed at any artificial burrow was 3. On this occasion, the owls were observed moving between adjacent burrows.

The differential for mean rH in artificial burrows indicated that internal humidity was lower than ambient humidity in the A.M., regardless of season (Fig. 9). An opposite trend was shown in the P.M., with higher internal humidity than ambient conditions across all seasons. (Fig. 9). The greatest difference between internal rH and ambient occurred in the spring P.M. (n = 502) $\bar{x}$ = 42.0%, SD = 12.08% (Table 1).

Temperature differences showed an opposite trend. Internal temperature means were warmer (higher) than ambient means in the A. M. and cooler (lower) in the P. M. for all seasons (Fig. 10). The greatest difference between internal and ambient temperature occurred in the autumn A. M. (n=764), $\bar{x}$= -24.47 °C (SD=12.63 °C) (Table 1).

Mean grass height (n = 48) was 28.3 cm (SD = 6.3 cm), and the mean forb height (n = 48) was 21.8 cm (SD = 8.6 cm). Ground cover consisted of 39% bare ground, 34% grass and 27 % forbs (Fig. 6).

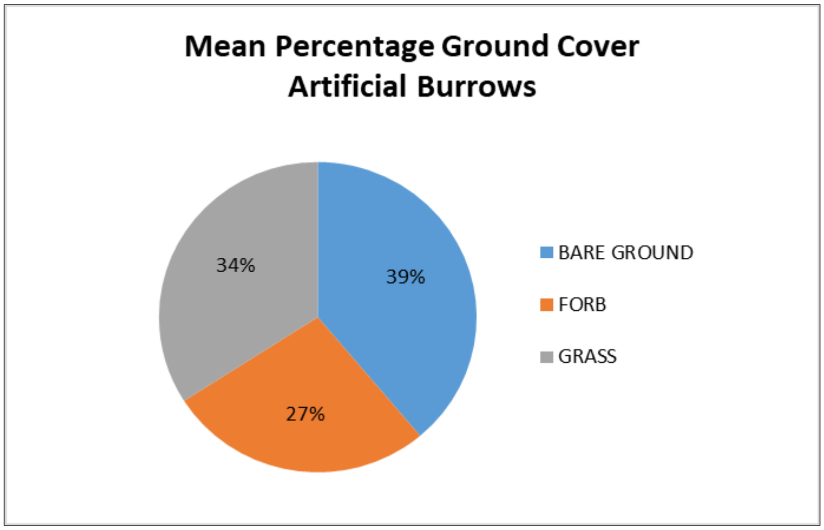

Figure 6: Mean percentage of ground cover surrounding artificial burrows for 3 m^2 in front, behind, and to each side.

Rock Piles

These burrows were located in the same series of rock piles, which was approximately 96 m long. Burrow entrances were not well defined (gaps between boulders), and were of irregular shape and size, ranging from 18-25 cm. The rock pile was oriented north-south near a gravel road adjacent to an olive orchard. Cattle were not present within the area but were observed grazing within 10 m of the rock pile. I recorded at least two species of burrowing mammals, including California ground squirrel and desert cottontail (*Sylvilagus audubonii*). We did not observe any evidence of breeding at these sites, and the maximum number of owls observed during any survey was three. The owls were observed moving from one burrow to another and only during the fall and winter.

For rock piles, internal rH means tended to be greater than ambient means with the exception of autumn A. M. and summer A. M. (Fig. 9). The mean differential for rH in autumn A. M. (n=546) was -7.84% (SD=14.37%), and summer A. M. (n=522) mean was -9.66%, (SD=17.95%), indicating lower internal humidity means for these time categories. The greatest difference between internal and ambient humidity occurred in spring P.M. (n=312), $\bar{x}$=43.34%, (SD=14.88%) (Table 1).

Temperatures tended to follow the same trend as the previous burrow types with higher internal temperatures in the A.M. and lower temperatures in the P.M., relative to ambient measurements (Fig. 10). The largest difference between internal and ambient temperatures for rock piles occurred in the summer A. M. (n = 522) $\bar{x}$ = 6.80 °C (SD = 6.23 °C).

The dominant ground cover type at these sites was bare ground at 94%, followed by 5% grass and 1% forb (Fig. 7). I calculated mean grass height (n = 14) to be 48.5 cm, (SD = 9.6 cm) and forb height (n = 5) was determined to be 32.4 cm (SD = 15.9 cm).

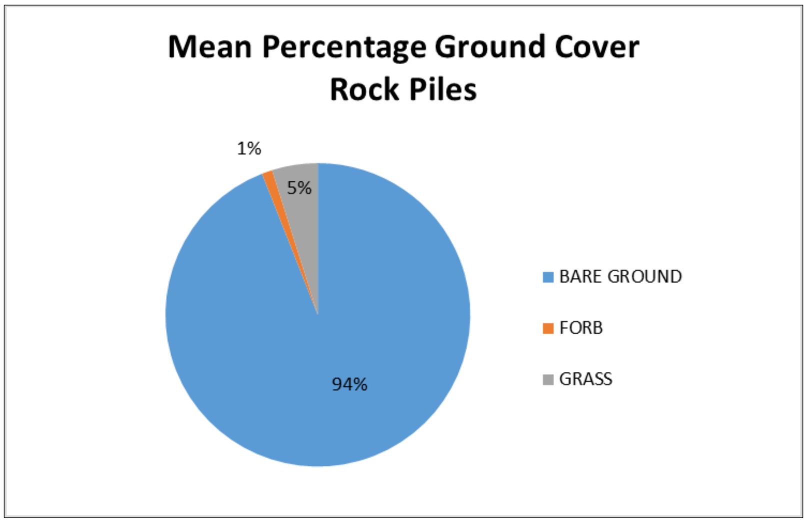

Figure 7: Mean percentage of ground cover surrounding rock piles for 3 m^2 in front, behind, and to each side.

Culverts

Culverts used by burrowing owls in this study do not represent the typical burrow structure used by this species. They are open-ended and do not provide an enclosed chamber as do other types already documented here. These “burrows” are large, cylindrical, culverts ranging in diameter from 61 cm to 122 cm. Culverts are made of corrugated steel pipes and act as water conduits for seasonal drainages under roadways. These sites were located near grazed cattle pastures, but cattle were excluded from the immediate area of these sites. No burrowing mammals were observed at any of these sites. Burrowing owl observations occurred primarily during the fall and winter, and breeding activity was not documented by my team at culverts (Table 2).

In most cases, culverts showed higher internal means for humidity and internal temperature means inside of culverts were also higher when compared to ambient means for all seasons except for spring (Fig. 9 and 10).

Bare ground comprised 60% of the ground cover near culverts, followed by 27% grass and 13% forbs (Fig. 8). Mean grass height (n=30) was 56.2 cm (SD = 11.5 cm), and mean forb height (n = 31) was 34.6 cm (SD = 13.5 cm).

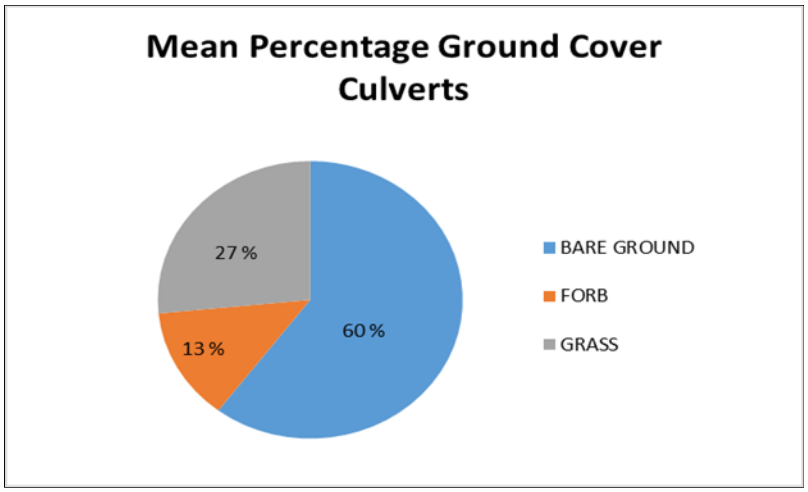

Figure 8: Mean percentage of ground cover surrounding culverts for 3 m^2 in front of, behind, and to each side.

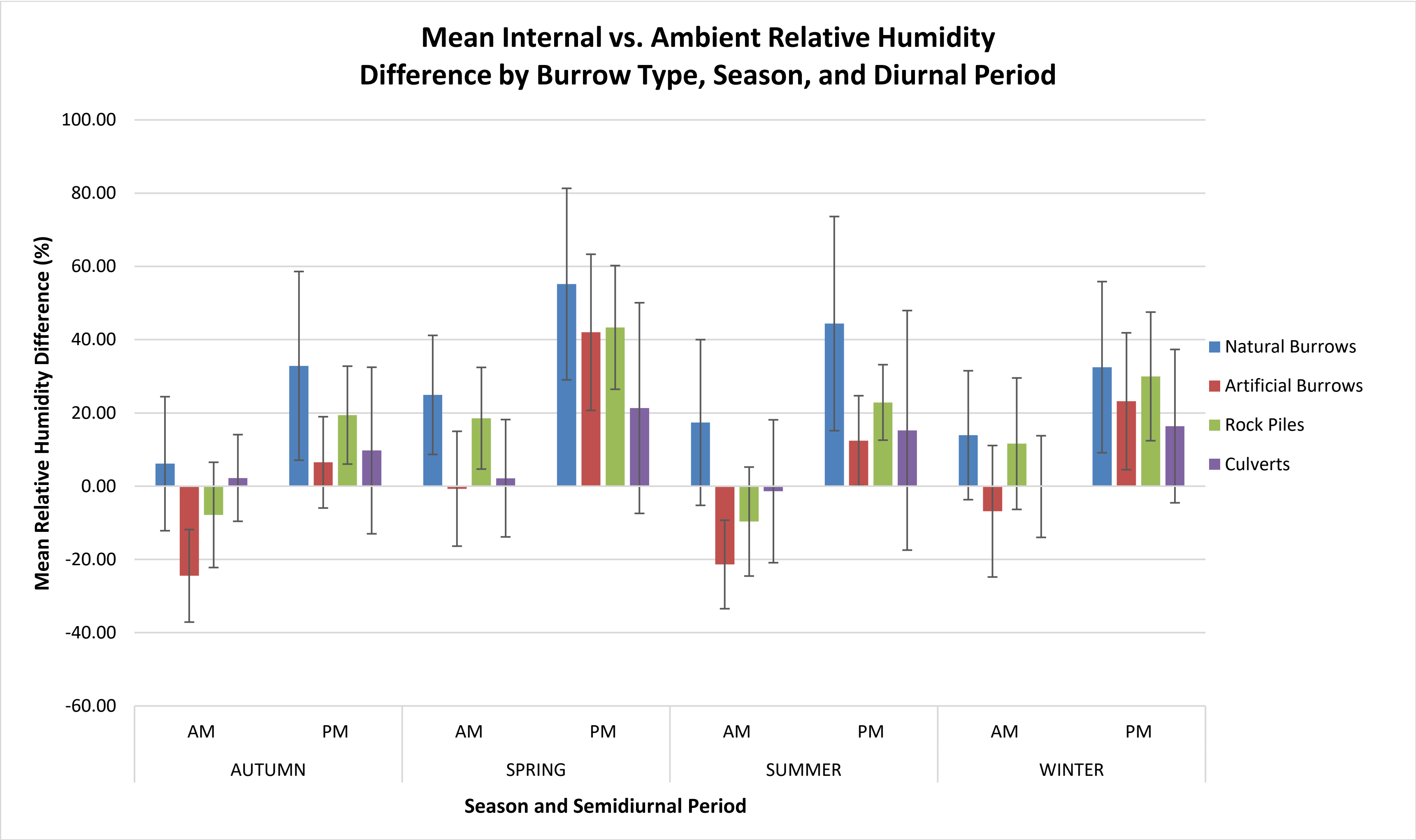

Figure 9. Internal rH mean – ambient rH mean for each burrow type. Positive results indicate higher internal humidity, while negative results indicate lower internal humidity when compared to the ambient mean. Error bars are 1 standard deviation.

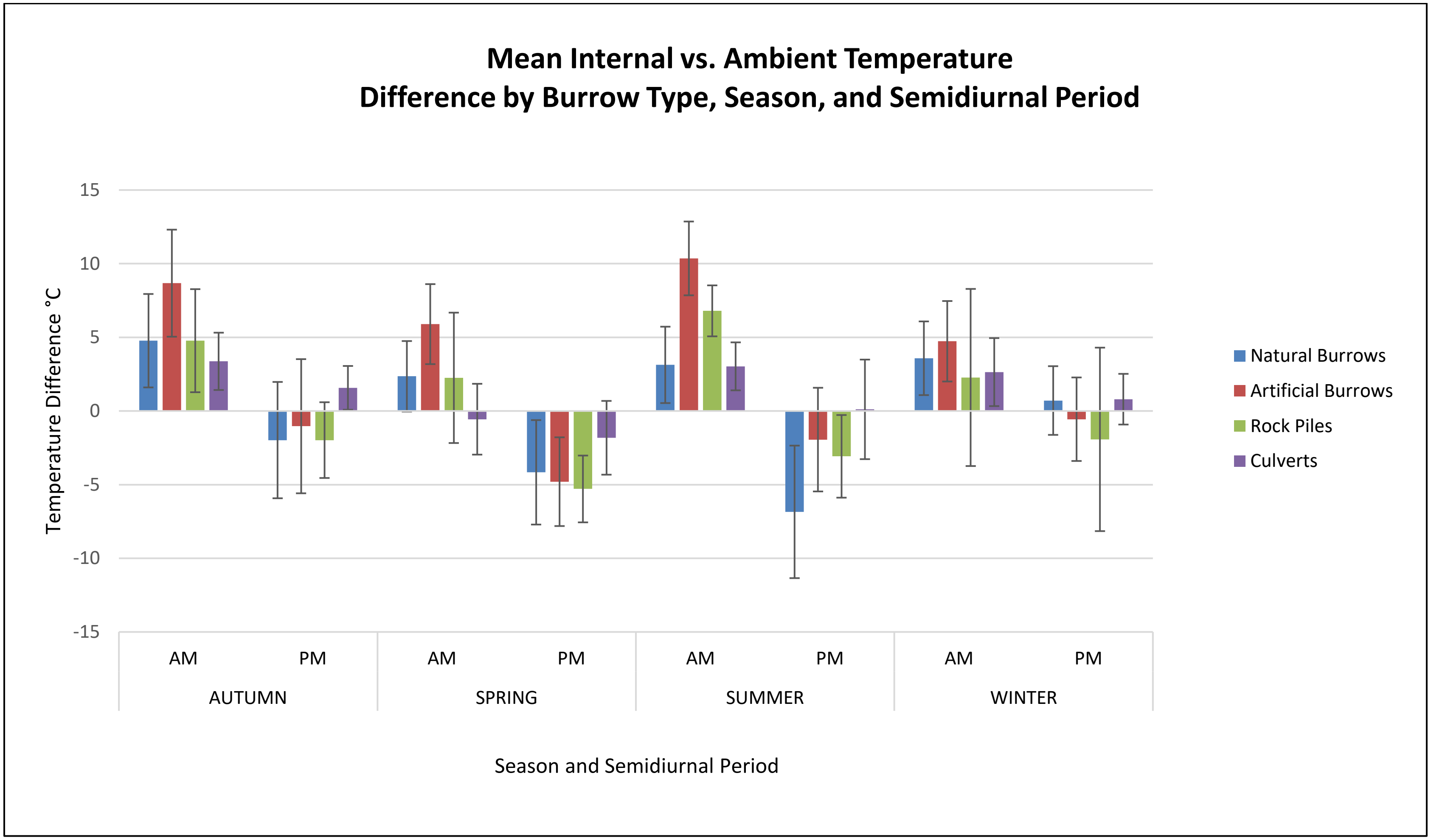

Figure 10. Internal temperature mean – ambient temperature mean for each burrow type. Positive results indicate higher internal temperature compared to ambient temperature, while negative results indicate lower internal temp., when compared to the ambient mean. Error bars are 1 standard deviation.

CHAPTER IV

DISCUSSION

All natural burrows were located in cut-banks along seasonal drainages. All but one of the burrows in this category (83%) occurred within 2.86 m of water during winter; 71% of all burrows, across types, were located within 6.55 m of a water source. This association with water is an interesting characteristic of natural burrows in this region and its importance is yet to be determined. Birds of prey, such as owls, often rely on the body fluids of their prey to satisfy most of their water intake needs (Gill 1990). However, Coulombe (1971) reported that burrowing owls were observed, on several occasions, drinking water from free water sources. This occurred regardless of ambient temperatures, but most frequently when ambient temperature was 30 °C or higher (Coulombe 1971). He suggested that the owls drink water for thermoregulation in hot temperatures. It is suggestive that close proximity to water may enhance the attractiveness of burrows to potential owl users. Beebe et al. (2014) stated that "owl occupancy was positively associated with soil type and canal water presence" in Phoenix, Arizona. All water sources recorded in this study were seasonal and were dry by late summer when temperatures peaked. Small mammal abundance may be greater within 50 m of a water source (Switalski and Bateman 2017). Could close proximity to water enhance the availability of prey or add protection from predators in the fall and winter? Further study is needed to determine which characteristics of these cut-banks are of greatest importance to owls.

Internally, natural burrows showed higher humidity than ambient conditions across all seasons and semidiurnal periods. The greatest differences occurred in the P.M. (Fig. 10). This could be important, especially in the summer months, when nesting. Although no breeding activity was observed during this study, the only sites that were confirmed to support breeding outside of the study period were in natural burrows. Burrow temperatures tended to be higher than ambient readings in the mornings, but lower than ambient readings in the late afternoons for these burrows. This is what you would expect for burrows that are insulated by earth and would therefore have a moderating effect on internal conditions. Many organisms manipulate their surroundings, creating microhabitats that provide environmental buffers as well as protection from predators (Coulombe 1971, Bronner 1992, Miller et al. 2009). Temperature and humidity modulation in burrow microclimates has been documented for several burrowing species, including the Mojave desert tortoise (*Gopherus agassizii*), house mouse (*Mus musculus*), and gall-forming arthropods such as the California gall wasp (*Andricus quercuscalifornicus*), to name a few (Bulova 2002, Avenant and Smith 2003, and Miller et al. 2009). Desert tortoise burrows provided lower temperatures and considerably higher humidity than ambient conditions. This likely resulted in lower evaporative water loss in the tortoise (Bulova 2002). California gall wasp larvae were able to modify their surroundings significantly by the induction of the gall, which increased internal humidity by around 40% in immature galls (Miller et al. 2009). The increased humidity relative to ambient conditions provided a microenvironment favorable to developing larvae (Miller et al. 2009). Avenant and Smith (2003) found that temperatures in house mouse burrows on Marion Island, South Africa, fluctuated less inside the burrows compared to ambient conditions. This was also true for most burrow sites in this study. In general, all burrow types showed warmer temperature means internally (A.M.) compared to ambient means, and conversely, showed cooler temperature means (P.M.) than ambient high temperature means. Artificial burrows showed the greatest differences from ambient means while culverts showed the lowest difference.

It is unclear if burrow entrance orientation is an important factor in burrow choice. Slightly more than half (59%) of burrow site entrances faced between 268° and 360° (west, northwest and northeast). Orientation could provide protection from cold winter winds. Avenant and Smith (2003) found that house mouse burrow entrances generally faced away from prevailing winds. The prevailing winds within the NSV between October and December were reported by the National Oceanic and Atmospheric Administration [NOAA] (1998) to primarily come from the north-northwest for the southern portion of the NSV and northwest for the northern portion of the study area. This suggests that burrow orientation may not be an important factor in protection from winter winds.

Artificial burrows could be an important management tool in attempts to provide additional habitat for the western burrowing owl. This study shows usage of habitat by burrowing owls primarily in winter, with moderate use in the spring and summer months. Artificial burrow sites associated with spring and summer use are also associated with the presence of natural burrows.

In general, artificial burrows tended to have an insulating effect on ambient temperatures similar to that seen in natural burrows. Burrow temperature means were higher in the morning and lower in the afternoon compared to ambient means. Overall, internal relative humidity means were lower in the morning and higher in the afternoon relative to ambient means.

Artificial burrows are designed to mimic natural burrows although they may fall short of the needs of their target species. For instance, they may be installed too deep or too shallow, the aspect may be in the wrong orientation, or it may be prone to flooding. Nevertheless, this study showed that burrowing owls selected these sites frequently. All sites were occupied in the fall and winter, which suggests that these burrows may provide important winter habitat.

Rock-piles represent a small portion of both available and utilized habitat, and were only occupied in the fall and winter. It is possible that the cavities present in such piles create refugia for owls with convenient perches nearby from which to be vigilant. The presence of burrowing mammals at this site could suggest that burrows are more extensive than they appear to be.

The temperature and relative humidity differentials for rock piles followed similar patterns as the previous two burrow types. Rock piles contain many gaps that are formed between rocks that may allow ambient weather conditions to assert a greater influence internally. However, internal relative humidity means in the afternoon were consistently higher than external means for all seasons. Like the previous two burrow types, internal temperature means were higher in the morning and lower in the afternoon than ambient means.

These sites are also located extremely close to a seasonal water source which occurs in a depression to one side of the rock pile (west side) which accumulates rain and does not flow. This could explain the high rH differential which occurs during the winter and spring. The proximity of the pools is such that is likely that the soil beneath the rock piles remain saturated for most of the winter and spring, even when the surrounding soil appears dry. Once the pools dry up, the soil under the piles would also dry up, allowing the humidity to decrease.

Culverts had little effect on moderating internal humidity and temperature from ambient conditions. While there was some evidence of moderation, the differences were likely tempered by the size and open nature of the culverts which allows for more air to pass through than the other burrow types.

The primary reason for use by owls during the fall and winter months may have little to do with a culvert’s ability to protect the owl from extreme weather. In fact, culverts would often flood and owls were not observed during these periods. Once the site had drained sufficiently, an owl would often be seen back at the culvert. It is unknown where owls would temporarily relocate to or why they would choose to use a location that floods regularly. Perhaps there are other features of this landscape, not revealed by this study, which would better explain culvert utilization. A simple explanation is that there are not enough suitable burrows available during the fall and winter to accommodate the winter population. Future studies may help to better understand this behavior.

Management Implications

This study was designed to provide a baseline understanding of landscape types and features known to be used by burrowing owls in the fall and winter. This is the only such study within the NSV. Understanding where and when one might find burrowing owls in the NSV is the first step to developing valuable management plans and making sound management recommendations. There are several actions suggested by this study that could be employed by land managers interested in creating or maintaining habitat for burrowing owls.

Land managers should consider protecting large tracts of grasslands and grazing cattle for sound vegetation management. Managers might also consider limiting burrowing mammal control measures. This could help to minimize secondary poisoning or accidental shooting, and may lead to more potential burrow habitat. Bylo et al. (2014) found that increased grazing intensity increased ground squirrel burrow counts. If adequate burrow habitat is not present, artificial burrows may serve to mitigate for this deficiency.

Care should be taken in considering the design and placement of artificial burrows. Artificial burrows need regular maintenance to ensure accessibility, such as mowing or grazing. This study suggests that proximity to water sources during the fall and winter may be an important factor in habitat selection.

Land managers are encouraged to maintain rock and debris piles on their land. If a pile needs to be removed, it is suggested that it first be surveyed for the presence of owls, especially in the fall and winter. To mitigate for the loss of this habitat, artificial burrows may be placed nearby.

Workers and land managers should be aware that owls may be present at road culverts and should take steps to minimize disturbance. Providing artificial burrows near culverts with known owl use may provide a better alternative in the fall and winter. Care should also be taken to minimize disturbance when conducting maintenance.

LITERATURE CITED

LITERATURE CITED

Avenant, N., and V. Smith. 2003. The microenvironment of house mice on Marion Island (sub-Antarctic). Polar Biology 26:129-141.

Beebe, S.R.H., A. B. Switalski, H. L. Bateman, and K. D. Hristovski. 2014. Burrowing owl (*Athene cunicularia*) habitat associations in agriculture fields and along canal trails in Phoenix, Arizona. Journal of the Arizona-Nevada Academy of Science 45:52-58.

Bronner, G. 1992. Burrow system characteristics of seven small mammal species (Mammalia: Insectivora; Rodentia; Carnivora). Koedoe 35, Sep. 1992.

Bulova, S. 2002. How temperature, humidity, and burrow selection affect evaporative water loss in desert tortoises. Journal of Thermal Biology. 27:175-189.

Bylo L., N. Koper, and K. A. Molloy. 2014. Grazing intensity influences ground squirrel and American badger habitat use in mixed-grass prairies. Rangeland Ecology & Management 67(3):247-254.

Chromczak, D., L. Trulio, and P. Higgins. 2016. Winter Burrowing Owl Banding Project-Final Report. Natrual Community Conservation Planning Local Assistance Grant. Grant Agreement P13821111. <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=119730>. Accessed 25 November 2017.

Conway, C., V. Garcia, M. Smith, and K. Hughes. 2008. Factors affecting detection of burrowing owl nests during standardized surveys. Journal of Wildlife Management, 72(3):688-696.

Coulombe, H. N. 1971. Behavior and population ecology of the burrowing owl, *Speotyto cunicularia*, in the Imperial Valley of California. Condor 73:162-176.

DeSante, D. F., E. D. Ruhlen, S. L. Adamany, K. M. Burton, and S. Amin. 1997. A census of burrowing owls in central California in 1991. Raptor Research Report. 9:38-48.

Engleman, W. E. Grant, M. A. Mora, and M. Woodin. 2012. Modelling effects of chemical exposure on birds wintering in agricultural landscapes: The western burrowing owl (*Athene cunicularia hypugaea*) as a case study. Ecological Modelling. 90-102.

Florida Fish and Wildlife Conservation Commission [FWC]. 2017. FWC listed birds: Burrowing Owl. < http://myfwc.com/wildlifehabitats/imperiled/profiles/birds/burrowing-owl/>. Accessed 15 September 2017.

Gervais, J., D. Rosenberg, D. Fry, L. Trulio, and K. Sturm, K. 2000. Burrowing owls and agricultural pesticides: Evaluation of residues and risks for three populations in California, USA. Environmental Toxicology and Chemistry 19(2):337-343.

Gervais, J., and R. Anthony. 2003. Chronic organochlorine contaminants, environmental variability, and the demographics of a burrowing owl population. Ecological Applications 13(5):1250-1262.

Gervais, J. A., D. K. Rosenberg, D. M. Fry, L. Trulio, and K. K. Sturm. 2000. Burrowing owls and agricultural pesticides: Evaluation of residues and risks for three populations in California, USA. Environmental Toxicology and Chemistry 19:337-343.

Gill, Frank B. 1990. Ornithology. W. H. Freeman and Company. New York, New York. USA.

Greger, P. D. and D. B. Hall. 2009. Burrow occupancy patterns of the western burrowing owl in southern Nevada. Western North American Naturalist 69(3):285-294.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing owl (*Athene cunicularia*). The Birds of North America (A. Poole and F. Gill, eds.) no. 61. Academy of Natural Sciences. Philadelphia, and American Ornithologists' Union, Washington D.C. USA.

Holroyd, G., H. Trefry, and J. Duxbury. 2010. Winter destinations and habitats of Canadian burrowing owls. Journal of Raptor Research 44(4):294-299.

James, P. C., and T. J. Ethier. 1989. Trends in the winter distribution and abundance of burrowing owls in North America. American Birds 43:1224-1225.

Justice-Allen, A. and K. A. Loyd. 2017. Mortality of western burrowing owls (*Athene cunicularia hypugaea*) associated with brodifacoum exposure. Journal of Wildlife Diseases 53(1):165-169.

Kareiva, P., C. Groves, and M. Marvier. 2014. The evolving linkage between conservation science and practice at The Nature Conservancy. Journal of Applied Ecology 51:1137-1147.

Klute, D. S., L. W. Ayers, M. T. Green, W. H. Howe, S. L. Jones, J. A. Shaffer, S. R. Sheffield, and T. S. Zimmerman. 2003. Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R6001-2003, Washington, D.C. USA.

Korfanta, N. M., D. B. McDonald, and T. C. Glenn. 2005. Burrowing owl (*Athene cunicularia*) population genetics: A comparison of North American forms and migratory habits. The Auk 122 (2):464-478.

Machicote, M., L. C. Branch, L.C. and D. Villarreal. 2004. Burrowing owls and burrowing mammals: are ecosystem engineers interchangeable as facilitators? Oikos 106(3):527-535.

Manning, J. A. and R. S. A. Kaler. 2011. Effects of survey methods on burrowing owl behaviors. The Journal of Wildlife Management 75:525-530.

Martin, D. 1973. Selected Aspects of Burrowing Owl Ecology and Behavior. The Condor *75*(4):446-456.

McCullough-Hennessy, S., D. Deutschman, D. Shier, L. Nordstrom, C. Lenihan, J. Montagne, and R. Swaisgood. 2016. Experimental habitat restoration for conserved species using ecosystem engineers and vegetation management. Animal Conservation 19(6):506-514.

Miller, D., C. Ivey, and J. Shedd. 2009. Support for the microenvironment hypothesis for adaptive value of gall induction in the California gall wasp, *Andricus* quercuscalifornicus. Entomologia Experimentalis Et Applicata 132(2):126-133.

Moulton, C., R. Brady, and J. Belthoff, 2006. Association between wildlife and agriculture: Underlying mechanisms and implications in burrowing owls. Journal of Wildlife Management 70(3):708-716.

National Oceanic and Atmospheric Administration [NOAA]. 1998. Climatic wind data for the United States. Monthly wind data for Marysville, California and Red Bluff, California. <https://www.ncdc.noaa.gov/sites/default/files/attachments/wind1996.pdf> Accessed on 19 November 2017.

Ornduff, R., P. M. Faber, and T. Keeler-Wolf. 2003. Introduction to California plant life-revised edition. California Natural History Guides No. 69. University of California Press Ltd. Berkeley, California. USA.

Poulin, R. G., T. I. Wellicome, and L. D. Todd. 2001. Synchronous and delayed numerical responses of a predatory bird community to a vole outbreak on the Canadian prairies. Journal of Raptor Research 35(4):288-295.

Poulin, R.G., L. D. Todd, K. M. Dohms, R. M. Brigham, and T. I. Wellicome. 2005. Factors associated with nest- and roost-burrow selection by burrowing owls (*Athene cunicularia*) on the Canadian prairies. Canadian Journal of Zoology 83:1373-1380

Restani, M., J. M. Davies, and W. E. Newton. 2008. Importance of agricultural landscapes to nesting burrowing owls in the northern Great Plains, USA. Landscape Ecology (23):977-988.

Ronan, N. A. 2002. Habitat selection, reproductive success, and site fidelity of burrowing owls in a grassland ecosystem. Thesis, Oregon State University, Corvallis, USA.

Shuford, W. D., and T. Gardali, editors. 2008. California bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento. USA.

Silva, S. I., I. Lazo, E. Silva-Aranguiz, F. M. Jaksic, P. L. Meserve, and J. R. Gutierrez. 1995. Numerical and functional response of burrowing owls to long-term mammal fluctuations in Chile. Journal of Raptor Research 29(4):250-255.

Smallwood, K. S., C. G. Thelander, M. L. Morrison, and L. M. Rugge. 2007. Burrowing owl mortality in the Altamont Pass Wind Resource Area. The Journal of Wildlife Management 71: 1513-1524.

Smallwood, K. S., L. Neher, J. Mount, and R. C. E. Culver. 2013, Nesting burrowing owl density and abundance in the Altamont Pass Wind Resource Area, California. Wildlife Society. Bulletin 37:787-795.

Smith, B., and J. Belthoff. 2001. Effects of nest dimensions on use of artificial burrow systems by burrowing owls. The Journal of Wildlife Management 65(2):318-326.

Somveille, M., A. S. L. Rodrigues, and A. Manica. 2015. Why do birds migrate? A macroecological perspective. Global Ecology and Biogeography 24:664-674.

Stevens, A. F. J., E. M. Bayne, and T. I. Wellicome. 2011. Soil and climate are better than biotic land cover for predicting home-range habitat selection by endangered burrowing owls across the Canadian prairies. Biological Conservation 144(5):1526-1536.

Switalski, A.B. and H. L. Bateman. 2017. Anthropogenic water sources and the effects on Sonoran Desert small mammal communities. PeerJ 5:1-18.

Wellicome, T.I., and G. L. Holroyd. 2001. The second international burrowing owl symposium: Background and context. Journal of Raptor Research 35:269-273.

Wellicome, T I, R. J. Fisher, R. G. Poulin, L. D. Todd, E. M. Bayne, D. T. Flockhart, J. K. Schmutz, K. D. Smet, and P. C. James. 2014. Apparent survival of adult burrowing owls that breed in Canada is influenced by weather during migration and on their wintering grounds. The Condor Vol 116(3):446-458.

Wilkerson, R., and R. Siegel. 2011. Distribution and abundance of western burrowing owls (*Athene cunicularia hypugaea*) in southeastern California. The Southwestern Naturalist 56(3): 378-384.

Williford, D., M. Woodin, M. Skoruppa, and G. Hickman. 2009. Rodents new to the diet of the western burrowing owl (*Athene cunicularia hypugaea*). The Southwestern Naturalist 54(1): 87-90.

Zarn, M. 1974. Burrowing owl, *Speotyto cunicularia hypugaea.* Technical note: United States Bureau of Land Management: 250. Denver, Colorado, USA.