SPECIES DIVERSITY CHANGES AND HABITAT ASSOCIATIONS OF SMALL MAMMALS AT ASH MEADOWS NATIONAL WILDLIFE REFUGE, NYE COUNTY, NEVADA

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ABSTRACT

SPECIES DIVERSITY CHANGES AND HABITAT ASSOCIATIONS OF SMALL MAMMALS AT ASH MEADOWS NATIONAL WILDLIFE REFUGE, NYE COUNTY, NEVADA

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Ash Meadows National Wildlife Refuge (Ash Meadows NWR), a spring-fed wetlands and alkaline desert system located in the Mojave Desert in Nye County, Nevada, supports 25 species of endemic plants and animals (5 currently listed as federally endangered). Human activities have caused scale habitat alterations to the land and biotic communities of Ash Meadows NWR through peat-mining and spring diversions for irrigation purposes. Restoration projects are currently being developed because of the endangered endemic species. My objectives were to determine changes in small mammal diversity over time and identify habitat types and vegetative characteristics inhabited by small mammals. Information on small mammal specimens collected for two surveys in 1891 and 1933 was used to assess species diversity changes over time. Small mammal trap lines were set in 18 qualitatively different habitat types during 6 sampling seasons (2 each in spring, summer, and fall) in 2008–2009. Habitat characteristics were quantified for each habitat type then joined to individual small mammal traps in ArcMap 9.3. A two-factor MANOVA (multivariate analysis of variance) was conducted to test for differences in habitat variables between habitat types and a single-factor MANOVA for differences between capture and non-capture sites. A CCA (canonical correspondence analysis) was conducted to assess small mammal habitat associations. Species diversity in 1891 was similar to the results of my study; however, diversity in 1933 was not similar. Habitats differed in structural components seasonally as well as between capture and non-capture trap sites mostly because of the unique seeps and springs system present. Small mammals were primarily associated with shrub dominated and graminoid dominated habitat associations. Overall, shrub and graminoid dominated habitats are important for small mammal communities; however, other habitat types are equally important in sustaining biodiversity at Ash Meadows NWR.

CHAPTER I

INTRODUCTION

Desert ecosystems are global occurring in North America, South America, Australia, Africa, and Asia (Kelt et al. 1996). These arid ecosystems have similar biotic conditions and structure with low, highly variable annual precipitation and temperature extremes influencing plant composition and animal activities (Noy-Meir 1973). Desert ecosystem conditions change infrequently due to minimal disturbance, making deserts popular areas for studying community ecology and vertebrate life history (Kelt et al. 1996).

Desert small mammals are model organisms for research in vertebrate community ecology (Jorgensen 2004). The common question regarding small mammals living in deserts revolves around survival mechanisms. Small mammals have adapted to desert environments by hibernation or estivation, types of mobility, nocturnal activity patterns, flexible diets to accommodate food resource availability, and modified bodily functions to minimize water loss and maximize water intake (Brown 1986, Pavlik 2008).

The functional role of small mammals in desert ecosystems also is ecologically important. Kangaroo rats (genus Dipodomys: Heteromyidae) function as a keystone guild in North American desert grasslands, affecting the density and composition of the grass community, particularly tall tussock-forming grasses (Brown and Heske 1990, Heske et al. 1993, Kerley et al. 1997). Small mammals function to create biotic disturbance, primarily soil disturbance, through foraging activities, excavating burrows and runways, and creating/recovering seed caches (Brown and Heske 1990). These disturbances mix nutrients and materials from top soil layers with deeper soil layers (Abaturov 1972). This mixing of nutrients in soil layers also contributes and enhances components of the nitrogen cycle by accelerating the flow of organic material from plants to detritus and decomposers through feeding activities, creating short-circuits (directly or enhancing the rate materials enter the soil for decomposition and/or recycling), for plant or animal material to enter the soil (Gist and Sferra 1978, West and Skujins 1978). Small mammals also function as prey supporting higher levels of the trophic system. The importance of small mammals to desert ecosystems has intrigued scientists for hundreds of years resulting in expeditions, surveys, and on-going research on desert ecosystems and desert biota (Pavlik 2008).

Desert oases are found globally. These oases typically occur where vegetation depends on groundwater for a water source. Access to groundwater usually occurs in springs flowing through the landscape (Bornkamm and Kehl 1990). This in turn creates more habitat types because multiple plants occupy these more mesic habitats along these water sources. The Feiran Oasis in western Egypt is a desert oasis consisting of numerous species of vascular taxa, many of which have only recently been discovered (Abd El-Ghani and Fahmy 1998). However, disappearance of many species was documented in the current inventory of Feiran Oasis. This is due to drilling wells and excessive pumping of groundwater for tourism and military needs, which in turn affects the vegetation (Abd El-Ghani and Fahmy 1998). Groundwater depletion and alteration is a common issue for the biota of desert oases. These areas are typically subjected to environmental management to ensure protection of organisms inhabiting the ecosystem

(Jorgensen et al. 1998, Baskaran et al. 2006). Therefore, it is important for biologists to understand key processes and interactions within a desert ecosystem to maintain wildlife populations and diversity (Edwards et al. 1996, Jorgensen et al. 1998).

These environmental issues also have impacted a desert oasis in the Mojave Desert, Ash Meadows National Wildlife Refuge (Ash Meadows NWR). I assessed responses of small mammals to this habitat alteration overtime. My objectives were to compare the current small mammal assemblages in different habitat types at Ash Meadows NWR to small mammal species collected during the 1891 U.S. Biological Survey-Death Valley Expedition (Fisher 1893) and a 1933 Ash Meadows trip (Russell 1933) to assess time-related changes in the small mammal community. An understanding of how the small mammal assemblage changed over time leads into the main focus of my study. My primary objective was to identify habitat associations of current small mammals at Ash Meadows NWR. It is important to understand how these small mammal communities respond to habitat alterations, primarily changes in vegetation over time. To support my primary objective, I looked at habitat structural differences among current habitat types and compared structural characteristics between capture and non-capture trap locations. From this, appropriate restoration and management plans can be developed to restore historical natural conditions to Ash Meadows NWR.

CHAPTER II

STUDY AREA

Ash Meadows NWR (36˚25.24 N; 116˚18.78W) is located approximately 145 km northwest of Las Vegas, Nevada in Nye County and 8 km from the California/Nevada state line in the Mojave Desert, east of Death Valley National Park (Fig. 1). The 9,500-ha refuge, established on 18 June 1984, consists of alkaline desert and spring-fed wetlands. Ash Meadows NWR is an important discharge area for a regional carbonate aquifer, resulting in spring flow from over 30 seeps and springs of over 17,000 acre feet of water per year (USFWS 2005, Otis Bay and Stevens Ecological Consulting 2006). These seeps and springs, soil characteristics, and topography form many habitat communities (USFWS 1998). The unique hydrogeology of Ash Meadows NWR has produced habitat for 25 species of endemic plants and animals; five are currently listed as federally endangered (Deacon 2003, Otis Bay and Stevens Ecological Consulting 2006, USFWS 2008).

Human agricultural activities ranging from domestic ungulate herbivory, fire, and diversion of springs, seeps, and pools for irrigation and agricultural purposes altered the environment of Ash Meadows NWR for nearly 4,000 years (Otis Bay and Stevens Ecological Consulting 2006, USFWS 2008). The presence of a water source in this desert environment attracted settlers. Shoshone Native Americans were earlier occupants of Ash Meadows NWR (USFW 1990).

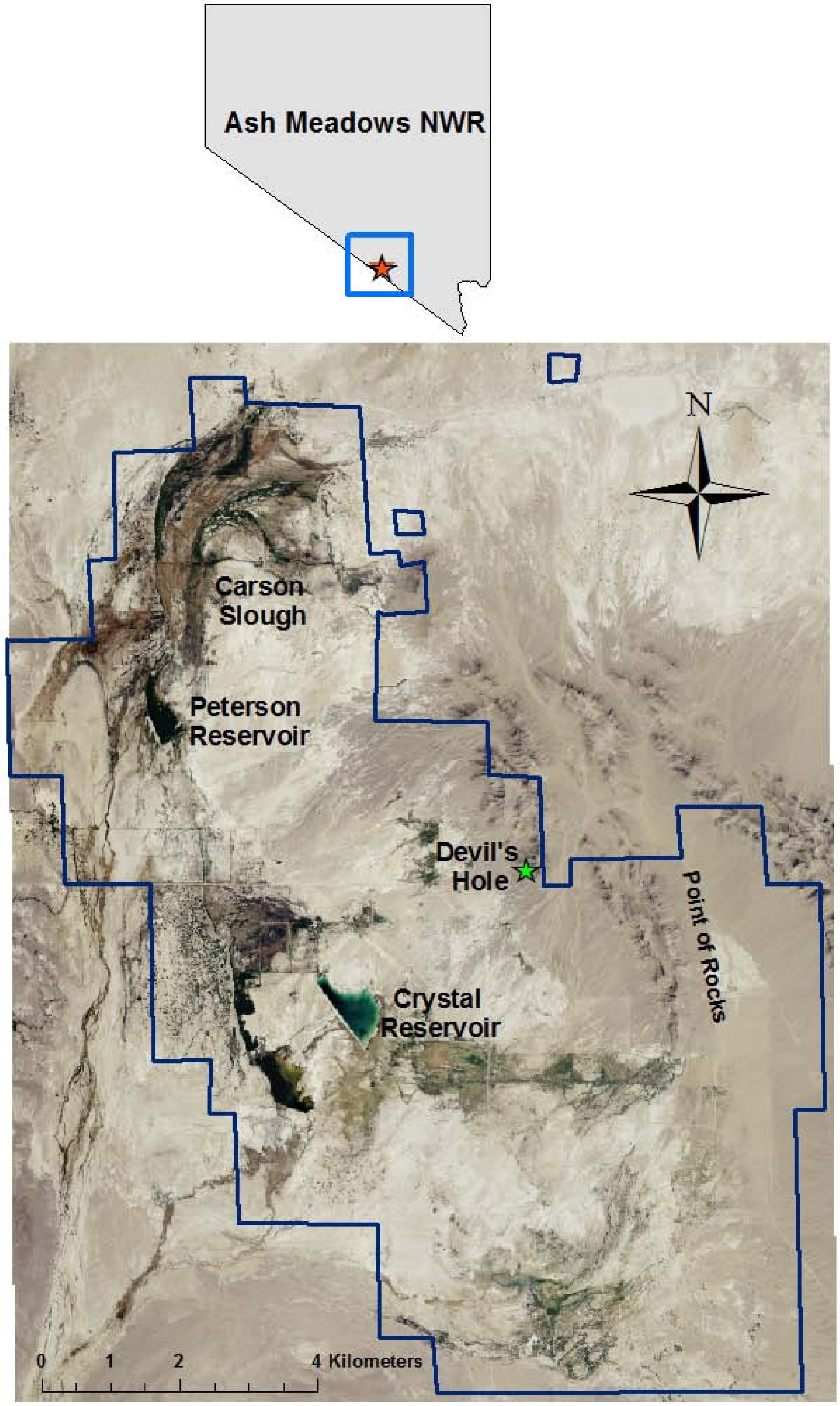


Figure 1. Location of Ash Meadows National Wildlife Refuge in Nye County, Nevada. The green star represents the location of Devil's Hole which is part of Death Valley National Park. Major topographic formations also are represented.

Ash Meadows NWR was included in the 1891 U.S. Biological Survey-The Death Valley Expedition. The survey covered approximately 260,000 km^2 within boundaries from the Pacific Coast, to southern California and Nevada, southwestern Utah, and northwestern corner of Arizona. The survey included the highest and lowest areas in the United States (Merriam 1895). During this time, scientists studied influences of temperature and humidity on animal and plant distributions at different altitudes. Records and collections of terrestrial animals and plants were used to depict geographic distributions and assign species to life zones (Merriam 1895). The first biological inventory of Ash Meadows NWR (Merriam 1895, USFWS 1990) was conducted by this expedition.

The greatest number of habitat alterations to Ash Meadows NWR occurred in the 1960s by a peat-mining operation in marshlands (~ 809 ha) associated with Carson Slough, the primary drainage in Ash Meadows NWR (Sanchez 1981, USFWS 1990, USFWS 2008). Larger-scale alterations followed when the Spring Meadows Ranch, Inc. began cattle and agriculture production (Sanchez 1981, USFWS 1990, USFWS 2008). Spring discharge reduction, water diversions and habitat depletions caused the decline of many plant and animal species and advanced several species closer to listing as endangered, including the Ash Meadows montane vole (*Microtus montanus nevadensis*), which has not been documented in Ash Meadows since a 1933 trip to Ash Meadows NWR led by W. C. Russell (University of California-Berkeley) and accompanied by W. B. Davis (Russell 1933, USFWS 1990). Preferred Equities Corporation bought Ash Meadows NWR from Spring Meadows Ranch in the 1970s and began developing land for a future residential community (Deacon 2003, USFWS 2008). During this time, the discovery of the large number of endemic plant and animal species stopped development and Ash Meadows National Wildlife Refuge was formed in 1984 (Otis Bay and Stevens Ecological Consulting 2006). Restoration projects have been developed for Ash Meadows NWR because of previous large-scale habitat alterations and decline of endemic species.

CHAPTER III

MATERIALS AND METHODS

Museum Specimen Collection.---I obtained information on small mammal specimens collected during the 1891 Death Valley Expedition in Nevada from the Smithsonian National Museum of Natural History (245 total) and information on small mammal specimens from the Museum of Vertebrate Zoology, University of California-Berkeley collected during the 1933 Ash Meadows, Nye County, Nevada trip (58 total, Table1). I recorded collection date, scientific identification, location, sex, collector name, type of preparation, additional collecting location information, and the date of the last modification to the specimen for all specimens obtained from Ash Meadows, Nye County. I also obtained field notes written by W. C. Russell and W. B. Davis from the 1933 Ash Meadows trip for additional information on the collection scheme, landscape, and vegetation at Ash Meadows at this time.

Site Selection and Small Mammal Trapping.---Small mammal trapping occurred 11–15 March, 12–16 May and 1–5 September 2008 and 16–19 March, 11–14 May and 16–19 September 2009 for a total of 6 sampling seasons (2 each in spring, summer, and fall). Teams consisting of Bio-West, Inc. personnel and I, trapped small mammals on 244 different trap lines in 18 qualitatively different habitat types (Appendix A). Number of trap lines in each habitat type as proportional to the size of the habitat type in most cases to account for possible variation within the habitat type (Bio-West 2010). We used

Sherman® live traps (Sherman traps) to capture small mammals. Traps were paired (facing opposite directions) and spaced approximately 10 m between pairs with 30–40 traps per line in each habitat type (Jones et al. 1996, Bio-West 2010). We used sterilized oats for bait. We set traps for 1 night and picked them up the following morning with re-location at a different habitat type the next night with a total trapping effort of 10,910 trap-nights (7,059 traps set). A trap-night is defined as 1 trap set for 1 night (Bio-West 2010).

Table 1. Small mammal species collected on the 1891 Death Valley Expedition and the 1933 Ash Meadows, Nye County, Nevada trip.

Species	**1891**	**1933**
Ammospermophilus leucurus	16	0
Chaetodipus formosus	4	0
Dipodomys deserti	42	0
Dipodomys merriami	36	3
Dipodomys microps	3	0
Microtus montanus	17	13
Mus musculus	0	2
Neotoma lepida	5	0
Onychomys torridus	3	3
Perognathus longimembris	1	0
Peromyscus crinitus	3	1
Peromyscus eremicus	17	2
Peromyscus maniculatus	10	1
Reithrodontomys megalotis	31	2
Spermophilus tereticaudus	4	0
Sylvilagus audubonii	5	2
Thomomys bottae	48	29
TOTAL	**245**	**58**

During this study, pitfall drift fence arrays (PDFA) were set up for a herpetofauna study in 16 of 18 habitat types sampled. Where a PDFA was present, starting points for small mammal trap lines began at the end of an arm of the PDFA (terminal bucket) and rotated clockwise between arms for each sampling season, otherwise random trap lines were set (Bio-West 2010) (Fig. 2). Live captures were identified to species and sex and then released. All small mammal trapping was conducted under a Nevada Department of Wildlife's scientific collection permit (permit # S-29822), United States Department of the Interior, Fish and Wildlife Service's Special Use Permit, and Texas State IACUC code 0909_0218_08.

Habitat Sampling.---Plant sampling was conducted between March and October 2008. A National Agricultural Image Program (NAIP) aerial image of Ash Meadows NWR was divided into 285 laminated map sheets with each including 61.51-ha sections put into a grid system (Bio-West 2009). These maps had a UTM, NAD 83, Zone 11 coordinate scale. Random transects were placed through each section and walked to identify vegetative communities within different habitats. Vegetative community boundaries were drawn using an Archer Global Positioning System (GPS) (Garmin, Olathe, Kansas), a polygon of the vegetative community was drawn on the aerial image labeled with a unique identifier, and minimum mapping unit size was 0.1 ha (Bio-West 2009). Random line transects were walked within each vegetative polygon and variables were quantified. Parameters recorded included physiognomy based on dominant vegetation, canopy height (m) based on highest canopy layer composing at least 5% total aerial coverage, emergent height (m) based on vegetation emerging from open water (i.e., springs), dominant plant species within a community, aerial percent cover of dominant plant species, percent totals of vascular vegetative cover, non-vascular vegetative cover, rocky outcrop cover, lichen cover, and open water. Additional parameters recorded, but not used in statistical analysis included rare plants within a community and percentage of occurrence, moisture (based on vegetation, soil conditions, and hydrology), hydrology (based on vegetation, erosion evidence, water movement and moisture), and whether foraging or disturbances occurred in the community. These data were compiled with the vegetative community locations (polygons) and overlaid on the Ash Meadows NWR aerial image (Bio-West 2009). I used ArcGIS 9: ArcView® 9.3 and Extensions (ESRI, Redlands, CA) to spatially join all individual Sherman traps to the vegetative polygons, which resulted in having vegetative data collected for a specific trap location in a habitat type (Fig. 3). I then exported the joined attribute table to a Microsoft Office 2007 Excel spreadsheet (Microsoft Inc., Bellevue, WA), and classified dominant plant species and the corresponding aerial percent cover within a community into categories of percent graminoid, herbaceous, shrub, tree, and vine vegetation.

Statistical Analysis.---I compared small mammal species captured during the 2008–2009 study to small mammal species captured during the 1891 Death Valley Expedition and 1933 Russell and Davis trip. I assessed species richness and heterogeneity among these three collections. Krebs (1999) defines species richness as the number of species in a community. Heterogeneity is a measure of how individual species are distributed within a community, whether there is a dominant species or somewhat uniform numbers of species (Krebs 1999). When measuring species richness and heterogeneity during the different time periods, I bootstrapped the three collections 5,000 times (DIVERSITY-BOOTSTRAP, Version 7.1; Krebs 1999) because sample sizes were not equivalent between sampling periods. I measured species heterogeneity using Simpson's Index of Diversity (1-D) and Brillouin's Diversity Index (Krebs 1999) to ascertain changes in the small mammal community composition during this chronological time scale (1891, 1933, 2008–2009). I excluded *Thomomys bottae* from the analyses due to bias capture methods in the 1933 collection period.

I conducted a two-factor multivariate analysis of variance (MANOVA) with response variables of canopy and emergent vegetation height, percent covers of vascular plants, nonvascular plants, open water, rocky outcrops, graminoids, herbaceous plants, shrubs, trees, and vines to test for differences in habitat variables among overall habitat types and followed up by a two-factor analysis of variance (ANOVA) of each response variable to detect insignificance ($P \geq 0.05$). A single-factor MANOVA with response variables the same as previously stated for differences in habitat variables between capture and non-capture sites and followed up by a univariate ANOVA of each response variable to detect insignificance ($P \geq 0.05$). Percent lichen cover was not included in analysis because of all zero values, as well as alkali playa habitat type where no small mammal species were captured. Single-factor MANOVAs were not conducted on alkali seep and riparian shrubland habitats due to small sample size of captures ($n < 5$) as well as for non-native weeds habitat type for small sample size of non-zero values for response variables. For ash habitat types due to multicollinearity issues, vascular vegetation cover and tree and shrub cover were not included in analysis. For tamarisk habitat types due to multicollinearity issues and greater number of zero values for response variables, vascular and nonvascular plant cover, emergent vegetation height, herbaceous, shrub, and tree covers were not included in analysis to meet response variable sample size criteria for multivariate analysis. Vascular plant cover was not included in analysis due to multicollinearity in creosote shrubland habitat types. Mesquite bosque habitats did not include nonvascular plant cover due to multicollinearity. Vine cover was not included in analysis for transitioning agriculture trap sites due to multicollinearity.

I conducted a canonical correspondence analysis (CCA) to determine small mammal species selection for habitat variables and assess habitat variation between small mammal species. I used R version 2.9.2 software (The R Foundation for Statistical Computing, Vienna, Austria) to conduct the MANOVAs and, CANOCO version 4.55 software (1988–2006 Biometris – quantitative methods in the life and earth sciences Plant Research International, Wageningen University and Research Centre, Wageningen, the Netherlands) to conduct the CCA. *Spermophilus tereticaudus*, (n = 1) *Thomomys bottae*, (n = 1) and *Peromyscus maniculatus* (n = 4) were not included in the CCA due to small sample size.

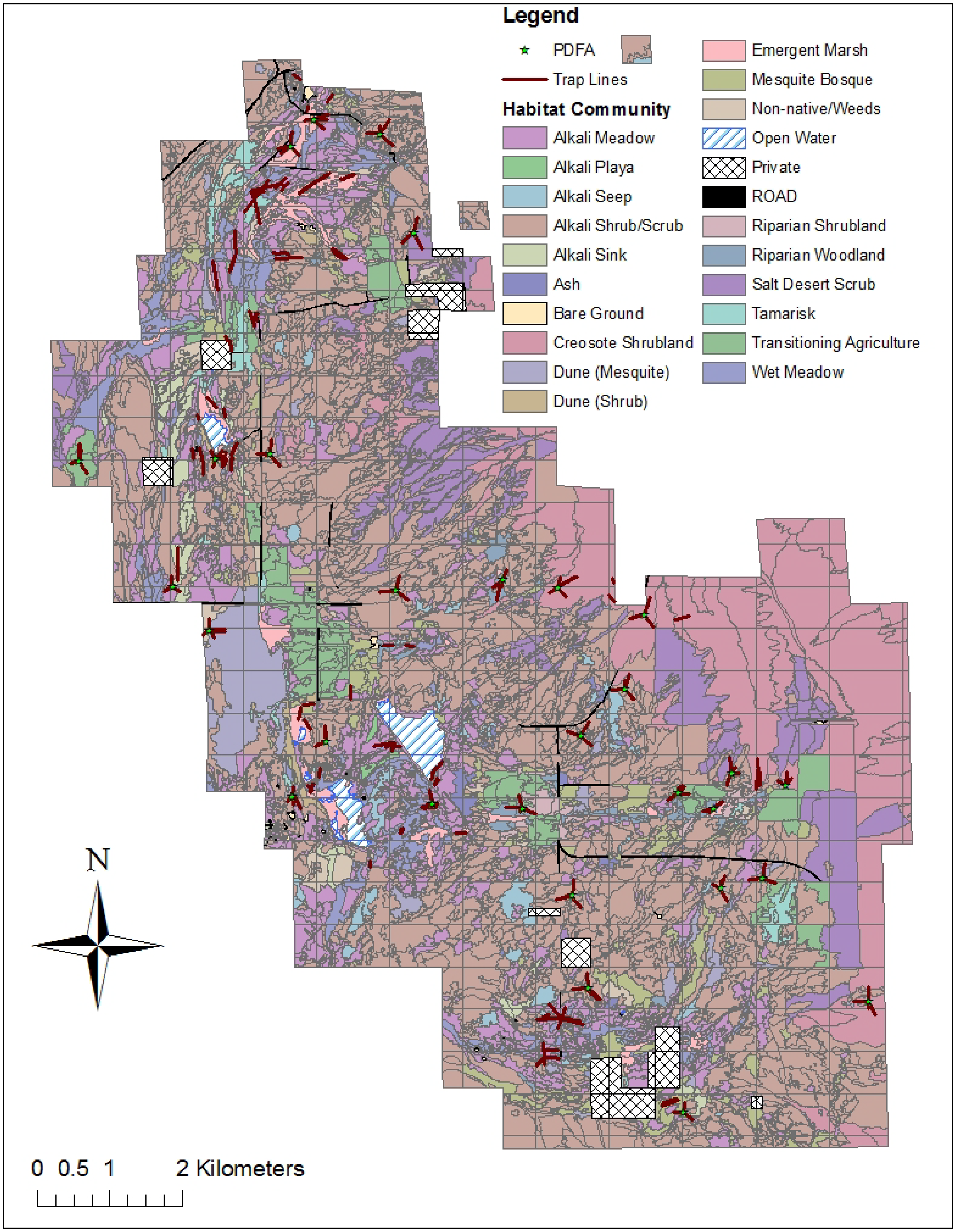


Figure 2. Small mammal trap line locations. Trapping effort was proportional to the extent of habitat.

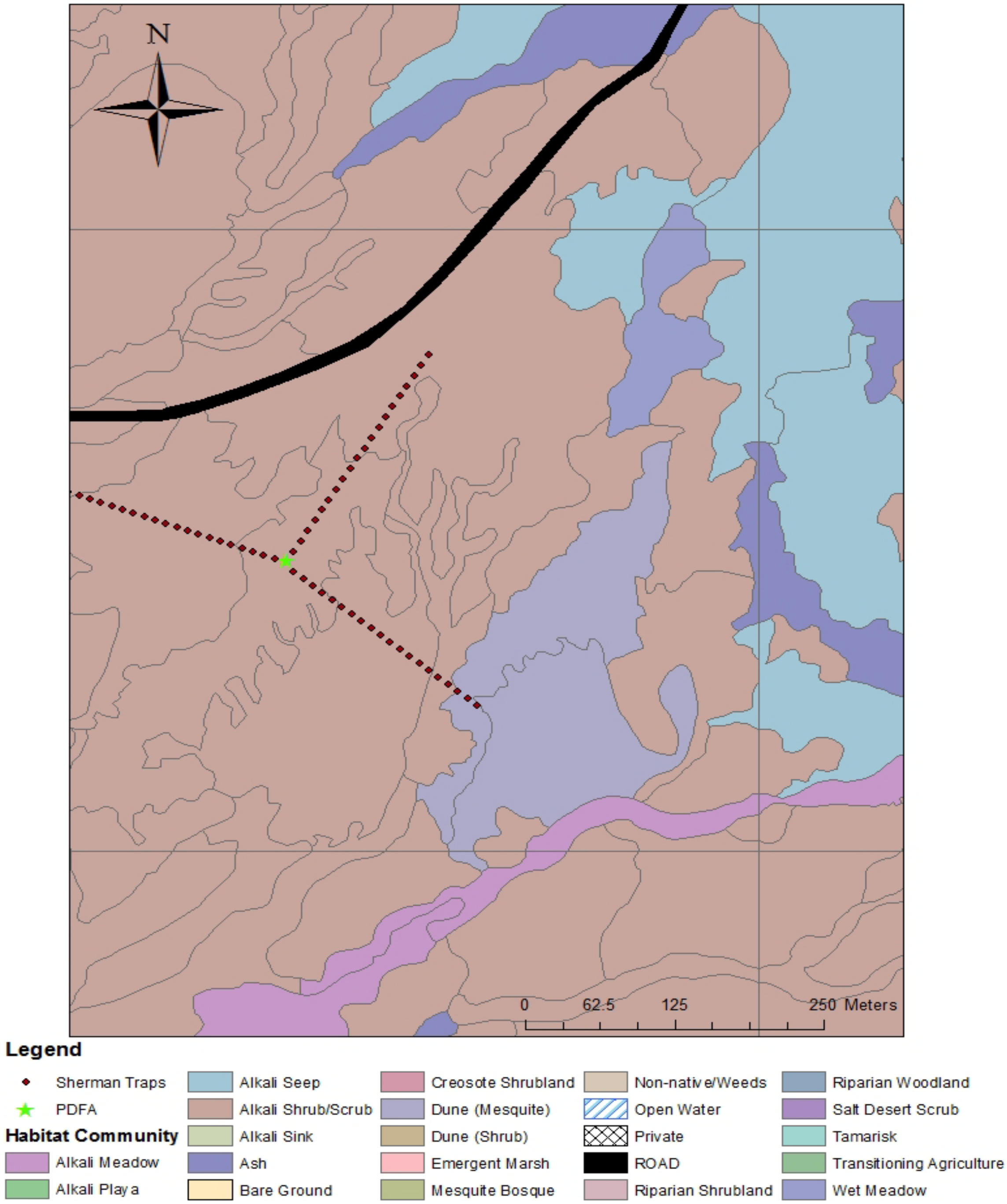


Figure 3. Small mammal trap line setup in an alkali shrub/scrub habitat type. Each trap line rotates clockwise between PDFA arms for each sampling season. Individual traps were joined to corresponding vegetation polygons for each habitat type.

CHAPTER IV

RESULTS

We captured a total of 1,133 individuals of 15 different species from four different mammalian families (Table 2). *Dipodomys merriami*, *Reithrodontomys megalotis*, *Peromyscus eremicus*, and *Mus musculus* were captured the most (24.4%, 24.3%, 23.6%, and 11.5%, respectively). *Spermophilus tereticaudus* and *Thomomys bottae* were captured the least in Sherman traps (0.09% each).

Species Diversity Comparisons.---In a comparison of species richness (Fig. 4) of small mammals collected at Ash Meadows NWR in 1891, 1933, and 2008-2009 the species richness for the three collection periods were different. The Biological Survey and Bio-West survey had the same species richness (16 total species). However, Simpson's Index of Diversity was different due to the difference in proportion of individuals of each species (Fig. 4). Simpson's Index of Diversity was highest for the Biological Survey and lowest in 1933 (Fig. 5). Brillouin's Diversity Index produced this same pattern. Shifts in the proportion of individuals of each species, primarily the Ash Meadows montane vole (*Microtus montanus nevadensis*) disappearance after 1933, and the invasive *Mus musculus* absent in 1891 was present in 1933 and 2008—2009 surveys, indicating introduction probably occurred during habitat alteration.

Habitat Type Comparisons.---Among the five habitat physiognomy types, woodland, shrubland, and herbaceous indicated significant differences for most habitat variables within each habitat type and among seasons, while dwarf shrubland/scrub showed some differences in structural components within each habitat type and among seasons (Table 3). There were no differences for forest because only the riparian woodland habitat type was represented.

Results of a two-factor MANOVA for woodlands with factors of season and habitat type with interaction between season and habitat type to determine if there is a seasonal change among habitat types and response variables of canopy height, emergent vegetation height, percent cover of vascular vegetation, nonvascular vegetation, open water, graminoids, herbaceous plants, shrubs, trees, and vines indicated a significant interaction (season:habitat-Pillai's Trace TS = 0.27, $P < 0.0001$). Two-factor ANOVAs were conducted on each response variable. Results of the two-factor ANOVAs detected significance of the interaction term (df = 6 on 1,525) for canopy height ($F = 5.59$, $P < 0.0001$), emergent vegetation height ($F = 39.0$, $P < 0.0001$), percent covers of nonvascular vegetation ($F = 2.76$, $P = 0.011$), open water ($F = 2.38$, $P = 0.027$), shrub ($F = 20.8$, $P < 0.0001$), tree ($F = 13.2$, $P < 0.0001$), and vine ($F = 10.8$, $P < 0.0001$). Interaction terms for the ANOVAs were not significant for percent vascular plant cover ($F = 0.50$, $P = 0.812$), graminoid cover ($F = 0.75$, $P = 0.608$), and herbaceous cover ($F = 0.07$, $P = 0.998$), but season and habitat were significant individually.

Results of a two-factor MANOVA for shrubland with factors of season and habitat type with interaction between season and habitat type to determine if there is a seasonal change among habitat types and response variables of canopy height, percent covers of vascular vegetation, nonvascular vegetation, rocky outcrops, graminoids, herbaceous plants, shrubs, trees, and vines indicated a significant interaction (season:habitat-Pillai's Trace TS = 0.63, $P < 0.0001$). Two-factor ANOVAs were conducted on each response variable.

Results of the two-factor ANOVAs interaction term (df = 7 on 835) were significant for canopy height ($F = 6.10$, $P < 0.0001$), percent covers of vascular vegetation ($F = 7.42$, $P < 0.0001$), nonvascular vegetation ($F = 13.5$, $P < 0.0001$), rocky outcrops ($F = 8.22$, $P < 0.0001$), graminoid ($F = 10.7$, $P < 0.0001$), herbaceous vegetation ($F = 27.3$, $P < 0.0001$), shrub ($F = 5.923$, $P < 0.0001$). Interaction terms were not significant for percent tree cover ($F = 0.201$, $P = 0.201$), and percent vine cover ($F = 0.13$, $P = 0.996$), but season and habitat were significant individually.

Results of a two-factor MANOVA for herbaceous with factors of season and habitat type with interaction between season and habitat type to determine if there is a seasonal change among habitat types and response variables of canopy height, emergent vegetation height, percent covers of vascular vegetation, nonvascular vegetation, open water, graminoids, herbaceous plants, shrubs, trees, and vines indicated a significant interaction (season:habitat-Pillai's Trace TS = 0.55, $P < 0.0001$). Two-factor ANOVAs were conducted on each response variable. Results of the two-factor ANOVAs interaction term (df = 5 on 3,080) were significant for canopy height (F= 4.45, $P = 0.0005$), emergent vegetation height ($F = 263.3$, $P < 0.0001$), percent covers of vascular vegetation ($F = 5.69$, $P < 0.0001$), nonvascular vegetation ($F = 4.13$, $P = 0.0009$), open water ($F = 2.66$, $P < 0.0208$), graminoid (F= 8.78, $P < 0.0001$), herbaceous vegetation ($F = 75.21$, $P < 0.0001$), shrub ($F = 45.1$, $P < 0.0001$), and tree ($F = 30.5$, $P < 0.0001$).

Interaction terms for the ANOVAs were not significant for percent vine cover ($F = 0.77$, $P = 0.574$), and season and habitat were not significant individually.

Results of a two-factor MANOVA for dwarf shrubland/scrub with factors of season and habitat type with interaction between season and habitat type to determine if there is a seasonal change among habitat types and response variables of canopy height, percent covers of vascular vegetation, nonvascular vegetation, graminoids, herbaceous vegetation, shrubs, and trees detected a significant interaction (season:habitat-Pillai's Trace TS = 0.145, $P < 0.0001$). Two-factor ANOVAs were conducted on each response variable. Results of the two-factor ANOVAs were significant for the interaction term (df = 8 on 1,540) for percent covers of nonvascular vegetation ($F = 2.86$, $P < 0.004$), and graminoid ($F = 13.1$, $P < 0.0001$). Interaction terms were not significant for canopy height ($F = 1.39$, $P = 0.194$), percent covers of vascular vegetation ($F = 1.41$, $P = 0.189$), herbaceous vegetation ($F = 0.67$, $P = 0.715$), and shrub ($F = 0.51$, $P = 0.851$), but season and habitat were significant individually.

Table 2. Number of individuals captured per season in 18 different habitat types at Ash Meadows National Wildlife Refuge in 2008-2009.

	Alkali Meadow			Alkali Playa			Alkali Seep		
Season	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Ammospermophilus leucurus	0	0	0	0	0	0	0	0	0
Chaetodipus formosus	1	0	0	0	0	0	0	0	0
Dipodomys deserti	1	0	0	0	0	0	0	0	0
Dipodomys merriami	1	1	4	0	0	0	0	0	1
Dipodomys microps	0	0	0	0	0	0	0	0	0
Mus musculus	2	44	0	0	0	0	0	0	0
Neotoma lepida	0	1	0	0	0	0	0	0	0
Onychomys torridus	0	0	0	0	0	0	0	0	0
Perognathus longimembris	0	0	0	0	0	0	0	0	0
Peromyscus crinitus	0	0	0	0	0	0	0	0	0
Peromyscus eremicus	6	1	1	0	0	0	0	0	0
Peromyscus maniculatus	0	0	0	0	0	0	0	0	0
Reithrodontomys megalotis	27	79	2	0	0	0	0	0	0
Spermophilus tereticaudus	0	0	0	0	0	0	0	0	0
Thomomys bottae	0	0	1	0	0	0	0	0	0
TOTAL	38	126	8	0	0	0	0	0	1

Table 2. (Continued)

Season	Alkali Shrub/Scrub			Alkali Sink			Ash		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Ammospermophilus leucurus	0	4	7	0	0	0	0	0	0
Chaetodipus formosus	2	1	0	0	0	0	0	0	0
Dipodomys deserti	1	1	1	0	1	3	0	0	0
Dipodomys merriami	19	32	33	7	7	7	0	0	0
Dipodomys microps	1	2	6	0	0	0	0	0	0
Mus musculus	2	0	0	0	0	0	0	0	0
Neotoma lepida	1	2	4	0	0	0	0	0	0
Onychomys torridus	0	0	0	0	0	0	0	0	0
Perognathus longimembris	1	0	3	0	0	0	0	0	0
Peromyscus crinitus	0	0	0	0	0	0	0	0	0
Peromyscus eremicus	9	5	4	0	0	0	3	3	1
Peromyscus maniculatus	0	0	0	0	0	1	0	0	0
Reithrodontomys megalotis	9	4	0	0	0	0	0	0	1
Spermophilus tereticaudus	0	0	0	0	0	1	0	0	0
Thomomys bottae	0	0	0	0	0	0	0	0	0
TOTAL	45	51	58	7	8	12	3	3	2

Table 2. (Continued)

	Creosote Shrubland			Dune (Mesquite)			Dune (Shrub)		
Season	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Ammospermophilus leucurus	1	2	0	0	0	0	0	0	0
Chaetodipus formosus	13	18	14	0	0	0	0	0	0
Dipodomys deserti	0	0	0	5	2	4	5	11	12
Dipodomys merriami	24	23	16	21	21	21	4	1	2
Dipodomys microps	0	1	0	0	0	0	0	0	0
Mus musculus	0	0	0	0	0	1	0	0	0
Neotoma lepida	2	5	5	0	2	0	0	0	0
Onychomys torridus	0	0	0	1	0	2	1	2	1
Perognathus longimembris	0	0	0	0	1	0	0	0	0
Peromyscus crinitus	3	2	0	0	0	0	0	0	0
Peromyscus eremicus	5	8	9	6	4	9	4	0	0
Peromyscus maniculatus	0	2	0	0	0	0	0	0	0
Reithrodontomys megalotis	0	0	0	0	1	0	0	0	0
Spermophilus tereticaudus	0	0	0	0	0	0	0	0	0
Thomomys bottae	0	0	0	0	0	0	0	0	0
TOTAL	48	61	44	33	31	37	14	14	15

Table 2. (Continued)

Season	Emergent Marsh			Mesquite Bosque			Non-native/Weeds		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Ammospermophilus leucurus	0	0	0	0	0	0	0	0	0
Chaetodipus formosus	0	0	0	0	0	0	0	0	0
Dipodomys deserti	0	0	0	0	0	0	0	0	0
Dipodomys merriami	0	0	3	4	4	5	0	0	0
Dipodomys microps	0	0	0	0	0	0	0	0	0
Mus musculus	1	12	2	0	0	0	0	11	0
Neotoma lepida	2	3	0	0	1	0	0	0	0
Onychomys torridus	0	0	0	0	0	0	0	0	0
Perognathus longimembris	0	0	0	0	0	0	0	0	0
Peromyscus crinitus	0	0	0	0	0	0	0	0	0
Peromyscus eremicus	17	20	20	3	1	1	1	0	1
Peromyscus maniculatus	0	0	0	0	0	0	0	0	0
Reithrodontomys megalotis	22	16	6	3	0	1	0	20	0
Spermophilus tereticaudus	0	0	0	0	0	0	0	0	0
Thomomys bottae	0	0	0	0	0	0	0	0	0
TOTAL	42	51	31	10	6	7	1	31	1

Table 2. (Continued)

Season	Riparian Shrubland			Riparian Woodland			Salt Desert Scrub		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Ammospermophilus leucurus	0	0	0	0	0	0	0	0	0
Chaetodipus formosus	0	0	0	0	0	0	0	0	0
Dipodomys deserti	0	0	0	0	0	0	0	0	0
Dipodomys merriami	0	0	1	1	1	1	1	1	1
Dipodomys microps	0	0	0	0	0	0	1	2	0
Mus musculus	0	0	0	0	0	5	0	0	0
Neotoma lepida	0	0	0	1	1	0	0	0	0
Onychomys torridus	0	0	0	0	0	0	0	0	0
Perognathus longimembris	0	0	0	0	0	0	0	0	1
Peromyscus crinitus	0	0	0	0	0	0	0	0	0
Peromyscus eremicus	0	1	0	16	34	52	0	0	0
Peromyscus maniculatus	0	0	0	0	0	0	0	0	0
Reithrodontomys megalotis	0	0	0	1	4	0	0	0	0
Spermophilus tereticaudus	0	0	0	0	0	0	0	0	0
Thomomys bottae	0	0	0	0	0	0	0	0	0
TOTAL	0	1	1	19	40	58	2	3	2

Table 2. (Continued)

Season	Tamarisk			Transitioning Agriculture			Wet Meadow			TOTAL
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	
Ammospermophilus leucurus	0	0	0	0	0	0	0	0	0	14
Chaetodipus formosus	0	0	0	0	0	0	0	0	0	49
Dipodomys deserti	0	0	0	0	0	0	0	0	0	47
Dipodomys merriami	0	0	0	0	1	7	0	0	0	276
Dipodomys microps	0	0	0	0	0	0	0	0	0	13
Mus musculus	0	16	0	0	0	0	1	33	0	130
Neotoma lepida	0	0	0	2	1	0	0	0	0	33
Onychomys torridus	0	0	0	0	0	0	0	0	0	7
Perognathus longimembris	0	0	0	0	2	0	0	0	0	8
Peromyscus crinitus	0	0	0	0	0	0	0	0	0	5
Peromyscus eremicus	1	0	0	3	5	10	2	2	2	270
Peromyscus maniculatus	0	0	0	0	1	0	0	0	0	4
Reithrodontomys megalotis	0	26	0	6	5	0	8	34	0	275
Spermophilus tereticaudus	0	0	0	0	0	0	0	0	0	1
Thomomys bottae	0	0	0	0	0	0	0	0	0	1
TOTAL	1	42	0	11	15	17	11	69	2	1133

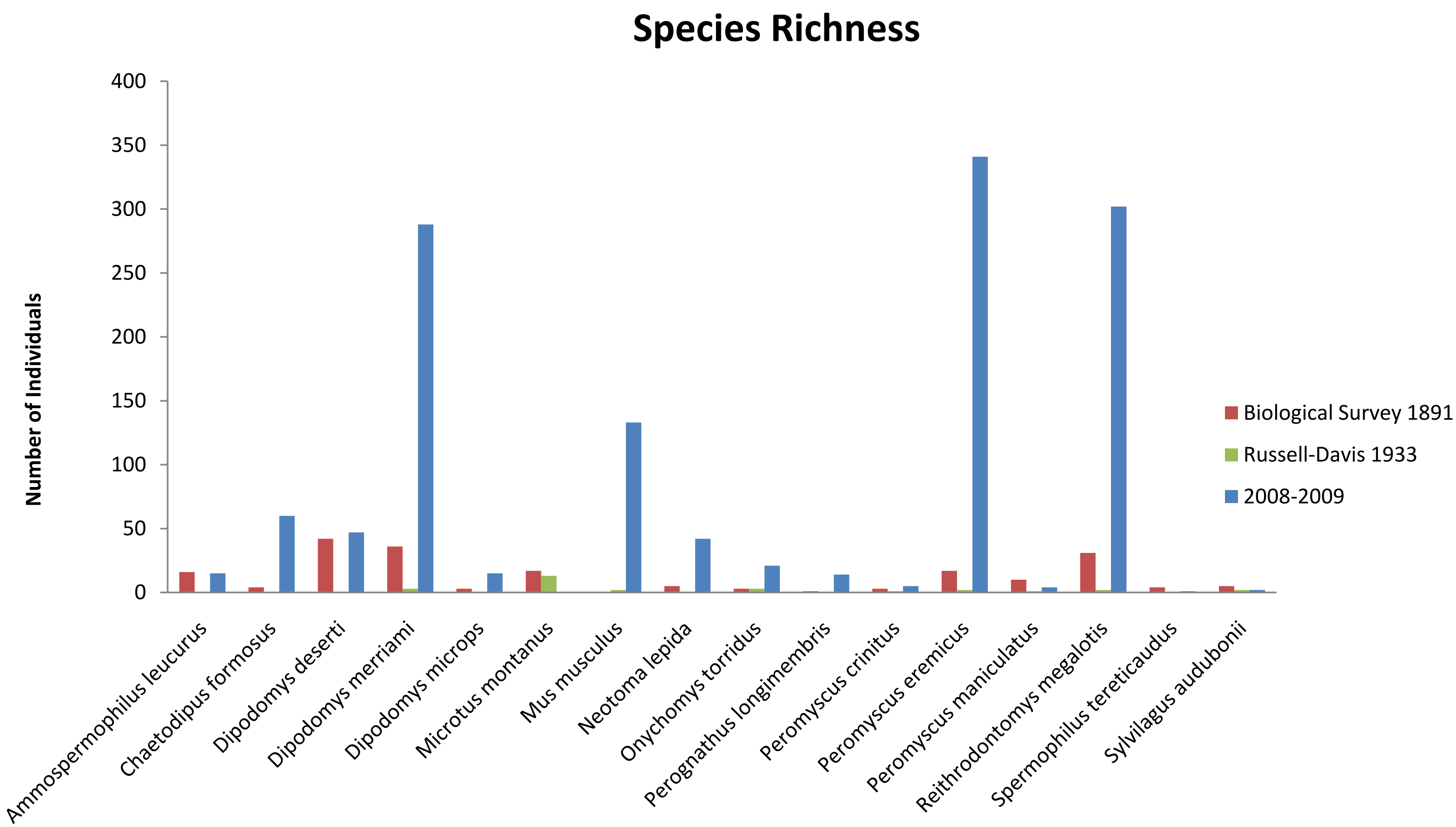
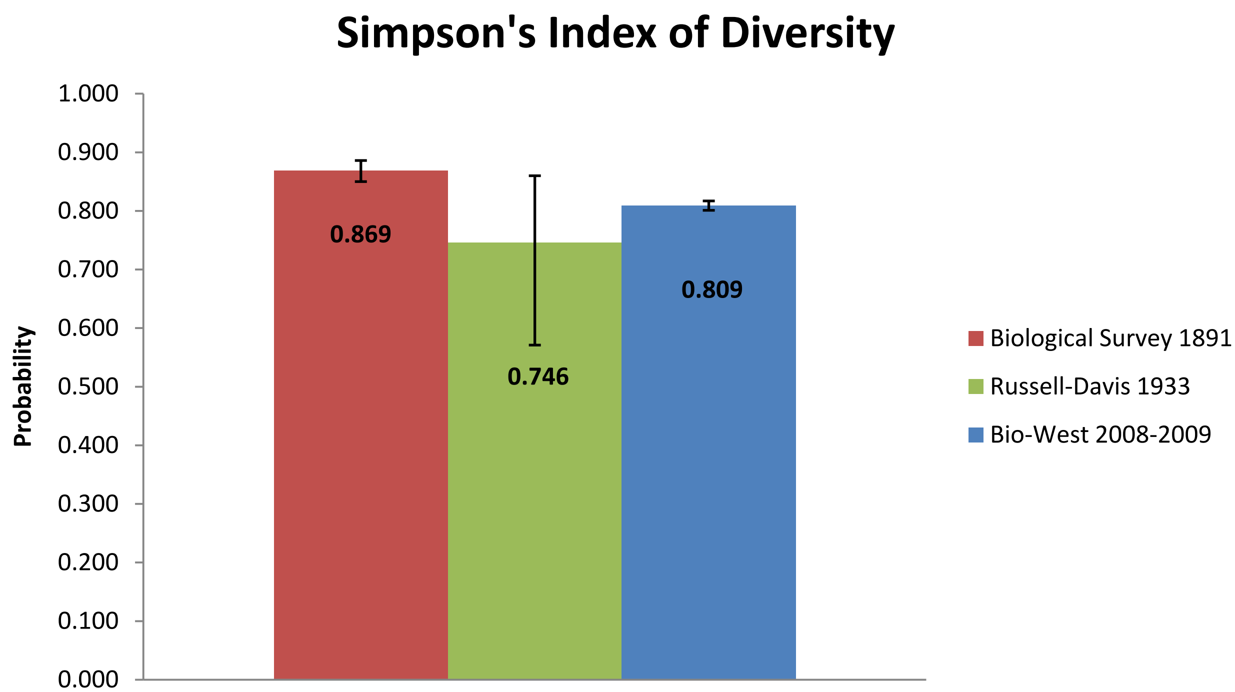
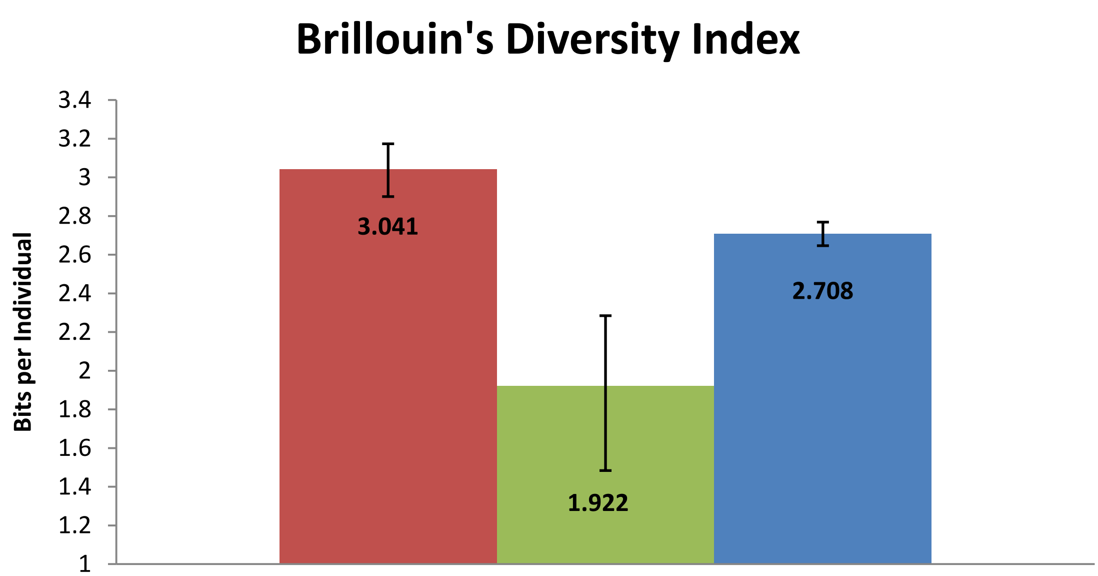


Figure 4. Number of small mammals captured at Ash Meadows National Wildlife Refuge for 1891, 1933, and 2008—2009 collection periods.



(a)



(b)

Figure 5. Heterogeneity comparisons of small mammals occurring at Ash Meadows National Wildlife Refuge using Simpson's Index of Diversity (a) and Brillouin's Diversity Index (b) with 90% confidence limit for 1891, 1933, and 2008—2009 collection periods.

Capture versus Non-capture Trap Locations.---Habitat variables differed for capture and non-capture trap sites for most habitat types (Table 4). For ash habitat types, results for a single-factor MANOVA response variables of canopy height, nonvascular plant cover and graminoid cover was not significant for differences between capture and non-capture trap sites (Pillai's Trace TS = 0.021, $P = 0.693$). Alkali sink habitat analysis did not include vascular vegetation cover due multicollinearity issues; therefore, response variables of canopy height, nonvascular plants, graminoid, and shrub did not detect a difference between trap sites (Pillai's Trace TS = 0.023, $P = 0.512$). Likewise, salt desert scrub did not include canopy height, vascular plant cover and nonvascular plant cover in a single-factor MANOVA. Response variables included and detected insignificant were herbaceous and shrub cover (Pillai's Trace TS = 0.074, $P = 0.186$). Results of a single-factor MANOVA for alkali meadow habitat types with response variables of canopy height, emergent vegetation height, percent covers of vascular vegetation, nonvascular vegetation, open water, graminoids, herbaceous, shrubs, and tree was significant (Pillai's Trace TS = 0.051, $P < 0.0001$).

Results of the univariate ANOVAs for each response variable were insignificant (df = 1 on 1,481) for percent open water (F =0.75, $P = 0.386$) and emergent vegetation height ($F = 0.66$, $P = 0.417$). Results for alkali shrub/scrub habitats with response variables of canopy height, percent cover of vascular vegetation, nonvascular vegetation, graminoids, herbaceous plants, shrubs, and trees for the single-factor MANOVA was significant (Pillai's Trace TS = 0.06, $P < 0.0001$). Insignificant response variables for the univariate ANOVA (df = 1 on 1,082) were percent graminoid cover ($F = 0.13$, $P = 0.716$) and percent shrub cover ($F = 0.44$, P = 0.506). Results for the dune (shrub) MANOVA with response variables of canopy height and nonvascular plant cover was significant (Pillai's Trace TS = 0.0889, *P* = 0.001), however nonvascular plant cover (df = 1 on 136) was insignificant (*F* = 3.45, *P* = 0.065) in the ANOVA.

Results of the emergent marsh MANOVA with response variables of canopy height, percent covers of vascular vegetation, nonvascular vegetation, open water, graminoids, herbaceous plants, shrubs, trees, and vines was significant (Pillai's Trace TS = 0.2001, *P* < 0.0001). ANOVA insignificant response variables (df = 1 on 640) were vascular plant cover (*F* = 3.17, *P* = 0.075), nonvascular plant cover (*F* = 1.25, *P* = 0.26), open water (*F* = 0.49, *P* = 0.485), and vine cover (*F* = 0.49, *P* = 0.485). Results of the dune (mesquite) MANOVA with response variables of canopy height, emergent vegetation height, percent covers of vascular and nonvascular plants, graminoids, shrubs, and trees was significant (Pillai's Trace TS = 0.096, *P* < 0.0001). Insignificant variables detected in the single-factor ANOVAs (df = 1 on 378) were vascular plant cover (*F* = 0.41, *P* = 0.524), nonvascular plant cover (*F* = 0.33, *P* = 0.569), emergent vegetation height (*F* = 0.06, *P* = 0.804), and tree cover (*F* = 0.20, *P* = 0.657). Results for the riparian woodland single-factor MANOVA response variables of canopy height, vascular plant cover, open water cover, graminoid cover, herbaceous cover, shrub cover, tree cover, and vine cover was significant (Pillai's Trace TS = 0.13, *P* < 0.0001). Response variables for the ANOVAs that were insignificant (df = 1 on 359) included canopy height (*F* = 1.64, *P* =0.202), open water (*F* = 1.96, *P* = 0.162), herbaceous vegetation (*F* = 2.66, *P* = 0.104), and shrub cover (*F* = 0.32, *P* = 0.573).

Single-factor MANOVA results for tamarisk habitat types with response variables of canopy height, open water, and graminoids was significant (Pillai's Trace TS = 0.033, P = 0.0005). However, percent covers of open water and graminoids were not significant (df = 1 on 521) in the ANOVAs (F = 0.57, P = 0.45; F = 0.02, P = 0.878, respectively). Wet meadow MANOVA results with response variables of canopy height, percent covers of vascular plants, nonvascular plants, open water, graminoids, herbaceous vegetation, shrubs, and trees was significant (Pillai's Trace TS = 0.0234, P = 0.005). Insignificant variables detected in the single-factor ANOVAs (df = 1 on 909) were vascular plant cover (F = 0.16, P = 0.692), nonvascular plant cover (F = 0.65, P = 0.42), open water (F = 0.30, P = 0.586), and herbaceous vegetation (F = 0.06, P = 0.807).

Results for the single-factor MANOVA for creosote shrubland habitat types with response variables of canopy height, rocky outcrop cover, herbaceous vegetation, shrubs, trees, and vines was not significant (Pillai's Trace TS = 0.017, P = 0.226), however canopy height was significant (F = 5.00, P = 0.026) in the single-factor ANOVAs (df = 1 on 489). Mesquite bosque habitats with response variables of canopy and emergent vegetation height, vascular plant cover, graminoid cover, shrub cover, and tree cover in the MANOVA results was insignificant (Pillai's Trace TS = 0.042, P = 0.170). Canopy height was significant (F = 5.03, P = 0.0256), as well as emergent vegetation height (F = 7.19, P = 0.008), and vine cover (F = 4.15, P = 0.043) for the results of the ANOVAs (df = 1 on 213). Results for transitioning agriculture with MANOVA response variables of canopy and emergent height, vascular and nonvascular plant cover, open water, graminoids, herbaceous vegetation, shrubs, and trees was not significant (Pillai's Trace TS = 0.0256, P = 0.395), however, vascular plant cover and herbaceous vegetation are significant (df = 1 on 366) for the single-factor ANOVAs results (F = 3.82, P = 0.051; F = 4.35, P = 0.038, respectively).

Small Mammal Species Habitat Associations.---Overall, of the 14 habitat variables and 12 small mammal species (n > 5 individuals) quantified, habitat association was divided into two distinct small mammal species groups: shrub associated species and graminoid associated species (Fig. 6). Canonical axis 1 of the CCA explained 5.6% of the variation, while canonical axis 2 explained 3.6%, with a total variation explained by 12.9% (Table 5). Strongest positive loadings for axis 1 were percent graminoid cover (0.637), and percent vascular plant cover (0.429), and strongest negative loading was percent shrub cover (-0.627) displaying a high percent of shrub cover, lower graminoid and vascular plant cover to high percent graminoid cover, high percent vascular cover, and low shrub cover gradient (Table 6). Summer and fall seasons had a positive loading (0.371) and negative loading (-0.329), respectively, for canonical axis 1; however, these loadings were generally weak. Axis 2 only had high positive loadings for percent tree cover (0.413), percent vine cover (0.431), and canopy height (0.356) displaying a high percent tree and vine cover, and high canopy height gradient (Table 6). Axis 1 is more indicative of a shrubland and herbaceous habitat type, while axis 2 is more indicative of woodland. The first canonical axis was significant (F = 65.4, P = 0.001), as well as the remaining axes (F = 11.8, P = 0.001).

Peromyscus eremicus (n = 267) was associated with high percent covers of trees and vines Fig. 6). *Perognathus longimembris* (n = 7) was associated with higher canopy height and herbaceous vegetation cover. Small mammal species associated with high shrub cover were *Chaetodipus formosus* (n = 49), *Peromyscus crinitus* (n = 5), *Dipodomys microps* (*n* = 13), *Ammospermophilus leucurus* (*n* = 14), *Dipodomys merriami* (*n* = 276), *Onychomys torridus* (*n* = 7), and *Dipodomys deserti* (*n* = 47). Small species associated with high percentage of graminoid cover were *Reithrodontomys megalotis* (*n* = 275) and *Mus musculus* (*n* = 130). *Neotoma lepida* (*n* = 37) was associated more with percentage of rock outcrops and intermediate to low shrub cover.

Table 3. Differences of habitat variables between five habitat physiognomy variables and three seasons.

		Dwarf Shrubland/Scrub Habitat Types									
Source of	Degrees of	Canopy Height		Vascular		Nonvascular		Graminoid		Herbaceous	
Variation	Freedom	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	1	2.77	0.10	19.3	<0.01	4.53	0.03	30.5	<0.01	0.04	0.83
Habitat	8	48.2	<0.01	57.2	<0.01	198.	<0.01	205.	<0.01	78.5	<0.01
Season:Habitat	8	1.39	0.19	1.41	0.19	2.86	<0.01	13.1	<0.01	0.67	0.72
Residuals	1,540										
		Herbaceous Habitat Types									
Source of	Degrees of	Canopy Height		Vascular		Nonvascular		Open Water		Emergent Height	
Variation	Freedom	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	1	45.5	<0.01	24.4	<0.01	20.7	<0.01	1.76	0.18	8.49	<0.01
Habitat	7	148.	<0.01	69.0	<0.01	2.36	0.02	4.52	<0.01	26.2	<0.01
Season:Habitat	5	6.6	<0.01	5.68	<0.01	4.13	<0.01	2.66	0.02	263.	<0.01
Residuals	3,080										
		Shrubland Habitat Types									
Source of	Degrees of	Canopy Height		Vascular		Nonvascular		Rock Outcrops		Graminoid	
Variation	Freedom	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	1	48.6	<0.01	0.13	0.72	4.26	0.04	27.5	<0.01	0.15	0.70
Habitat	10	1090	<0.01	81.4	<0.01	50.6	<0.01	4.94	<0.01	202.	<0.01
Season:Habitat	7	6.10	<0.01	7.42	<0.01	13.5	<0.01	8.22	<0.01	10.7	<0.01
Residuals	835										
		Woodland Habitat Types									
Source of	Degrees of	Canopy Height		Vascular		Nonvascular		Open Water		Emergent Height	
Variation	Freedom	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	1	16.9	<0.01	24.0	<0.01	17.6	<0.01	7.84	0.01	3.10	0.08
Habitat	7	928.	<0.01	792.	<0.01	2.12	0.04	1.86	0.07	222.	<0.01
Season:Habitat	6	5.59	<0.01	0.50	0.81	2.76	0.01	2.38	0.03	39.0	<0.01
Residuals	1,525										

Table 3. (Continued)

Dwarf Shrubland/Scrub Habitat Types				
Source of	Shrub		Tree	
Variation	*F*	*P*	*F*	*P*
Season	0.23	0.63	0.01	0.93
Habitat	17.4	<0.01	675.	<0.01
Season:Habitat	0.51	0.85	0.69	0.70

Herbaceous Habitat Types										
Source of	Graminoid		Herbaceous		Shrub		Tree		Vine	
Variation	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	364.	<0.01	131.	<0.01	379.	<0.01	19.1	<0.01	2.89	0.09
Habitat	810.	<0.01	802.	<0.01	115.	<0.01	40.4	<0.01	0.94	0.47
Season:Habitat	8.78	<0.01	75.2	<0.01	45.1	<0.01	30.5	<0.01	0.77	0.57

Shrubland Habitat Types								
Source of	Herbaceous		Shrub		Tree		Vine	
Variation	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	20.0	<0.01	0.63	0.43	20.7	<0.01	1.94	0.16
Habitat	1680	<0.01	101.	<0.01	1970	<0.01	75.7	<0.01
Season:Habitat	27.3	<0.01	5.92	<0.01	1.40	0.20	0.13	0.99

Woodland Habitat Types										
Source of	Graminoid		Herbaceous		Shrub		Tree		Vine	
Variation	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season	0.15	0.71	8.60	<0.01	111.0	<0.01	0.07	0.79	24.4	<0.01
Habitat	163.	<0.01	305.	<0.01	1420	<0.01	1090	<0.01	305.	<0.01
Season:Habitat	0.75	0.61	0.07	0.99	20.8	<0.01	13.2	<0.01	10.8	<0.01

*Forest habitat types only represented 1 habitat community

Table 4. Differences in habitat variables between capture and non-capture trap sites for each habitat type.

Alkali Meadow

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Vascular *F*	Vascular *P*	Nonvascular *F*	Nonvascular *P*	Open Water *F*	Open Water *P*	Emergent Height *F*	Emergent Height *P*
Capture	1	44.4	<0.01	5.95	0.01	9.94	<0.01	0.75	0.39	0.66	0.42
Residuals	1,481										

Graminoid *F*	Graminoid *P*	Herbaceous *F*	Herbaceous *P*	Shrub *F*	Shrub *P*	Tree *F*	Tree *P*
16.2	<0.01	16.5	<0.01	17.7	<0.01	11.7	<0.01

Alkali Shrub/Scrub

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Vascular *F*	Vascular *P*	Nonvascular *F*	Nonvascular *P*	Graminoid *F*	Graminoid *P*	Herbaceous *F*	Herbaceous *P*
Capture	1	43.4	<0.01	4.52	0.03	6.39	0.01	0.13	0.72	41.9	<0.01
Residuals	1,082										

Shrub *F*	Shrub *P*	Tree *F*	Tree *P*
0.44	0.51	21.8	<0.01

Alkali Sink

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Nonvascular *F*	Nonvascular *P*	Graminoid *F*	Graminoid *P*	Shrub *F*	Shrub *P*
Capture	1	1.86	0.17	0.18	0.67	1.01	0.32	2.03	0.16
Residuals	141								

Ash

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Nonvascular *F*	Nonvascular *P*	Graminoid *F*	Graminoid *P*
Capture	1	0.25	0.62	0.65	0.42	0.63	0.43
Residuals	71						

Table 4. (Continued)

		Creosote Shrubland									
Source of Variation	Degrees of Freedom	Canopy Height		Rock Outcrops		Herbaceous		Shrub		Tree	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Capture	1	5.00	0.03	0.14	0.71	1.61	0.21	0.85	0.36	0.34	0.56
Residuals	489										
		Vine									
		F	*P*								
		1.75	0.19								

		Dune (Mesquite)									
Source of Variation	Degrees of Freedom	Canopy Height		Vascular		Nonvascular		Emergent Height		Graminoid	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Capture	1	5.67	0.02	0.41	0.52	0.32	0.57	0.06	0.80	12.5	<0.01
Residuals	378										
		Shrub		Tree							
		F	*P*	*F*	*P*						
		5.44	0.02	0.20	0.66						

		Dune (Shrub)			
Source of Variation	Degrees of Freedom	Canopy Height		Nonvascular	
		F	*P*	*F*	*P*
Capture	1	4.07	0.05	3.45	0.07
Residuals	136				

		Salt Desert Scrub			
Source of Variation	Degrees of Freedom	Shrub		Herbaceous	
		F	*P*	*F*	*P*
Capture	1	2.01	0.16	0.64	0.43
Residuals	45				

Table 4. (Continued)

		Emergent Marsh									
Source of Variation	Degrees of Freedom	Canopy Height		Vascular		Nonvascular		Open Water		Graminoid	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Capture	1	17.8	<0.01	3.17	0.08	1.25	0.26	0.49	0.48	19.0	<0.01
Residuals	640										
		Herbaceous		Shrub		Tree		Vine			
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*		
		109	<0.01	38.7	<0.01	8.88	<0.01	0.49	0.48		

		Mesquite Bosque									
Source of Variation	Degrees of Freedom	Canopy Height		Vascular		Emergent Height		Graminoid		Shrub	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Capture	1	5.03	0.03	1.89	0.17	7.19	0.01	0.26	0.61	0.78	0.38
Residuals	213										
		Tree									
		F	*P*								
		4.15	0.04								

		Riparian Woodland									
Source of Variation	Degrees of Freedom	Canopy Height		Vascular		Open Water		Graminoid		Herbaceous	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Capture	1	1.64	0.20	6.70	0.01	1.96	0.16	14.3	<0.01	2.66	0.10
Residuals	359										
		Shrub		Tree		Vine					
		F	*P*	*F*	*P*	*F*	*P*				
		0.32	0.57	27.8	<0.01	39.0	<0.01				

Table 4. (Continued)

Tamarisk

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Open Water *F*	Open Water *P*	Graminoid *F*	Graminoid *P*
Capture	1	15.0	<0.01	0.57	0.45	0.02	0.88
Residuals	521						

Transitioning Agriculture

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Vascular *F*	Vascular *P*	Nonvascular *F*	Nonvascular *P*	Open Water *F*	Open Water *P*	Emergent Height *F*	Emergent Height *P*
Capture	1	1.48	0.23	3.83	0.05	1.98	0.16	0.21	0.65	2.97	0.09
Residuals	366										

Graminoid *F*	Graminoid *P*	Herbaceous *F*	Herbaceous *P*	Shrub *F*	Shrub *P*	Tree *F*	Tree *P*
0.27	0.60	4.35	0.04	0.77	0.38	1.15	0.28

Wet Meadow

Source of Variation	Degrees of Freedom	Canopy Height *F*	Canopy Height *P*	Vascular *F*	Vascular *P*	Nonvascular *F*	Nonvascular *P*	Open Water *F*	Open Water *P*	Graminoid *F*	Graminoid *P*
Capture	1	3.83	0.05	0.16	0.69	0.65	0.42	0.30	0.59	12.6	<0.01
Residuals	909										

Herbaceous *F*	Herbaceous *P*	Shrub *F*	Shrub *P*	Tree *F*	Tree *P*
0.06	0.81	6.44	0.01	11.4	<0.01

*Alkali Seep, Non-native Weeds, and Riparian Shrubland habitat communities not included in analysis due to small sample size

Table 5. Canonical correspondence analysis variation explained by 4 canonical axes.

Axes	1	2	3	4	Total Inertia
Eigenvalues	0.611	0.378	0.271	0.077	11.0
Species-environment correlations	0.782	0.615	0.521	0.277	
Cumulative percentage variance					
species data	5.60	9.00	11.5	12.2	
species-environment relation	43.0	69.7	88.8	94.2	

Sum of all eigenvalues	11.0
Sum of all canonical eigenvalues	1.42

Table 6. Habitat variable loadings for canonical axes 1 and 2.

Variable	Axis 1	Axis 2
Canopy Height (m)	0.2776	0.3558
% Vascular Plant Cover	0.4291	0.1253
% Nonvascular Plant Cover	-0.0730	-0.0501
% Open Water Cover	0.0843	-0.0274
% Rock Outcrop Cover	-0.1123	0.0164
Emergent Vegetation Height (m)	-0.0987	-0.0312
% Graminoid Cover	0.6367	-0.2256
% Herbaceous Cover	0.2252	0.2077
% Shrub Cover	-0.6274	-0.0686
% Tree Cover	-0.048	0.4135
% Vine Cover	-0.111	0.4305
Spring	-0.0966	0.0451
Summer	0.3706	-0.1839
Fall	-0.3288	0.1666

	F	*P*
First Canonical Axis	65.4	0.001
All Canonical Axes	11.8	0.001

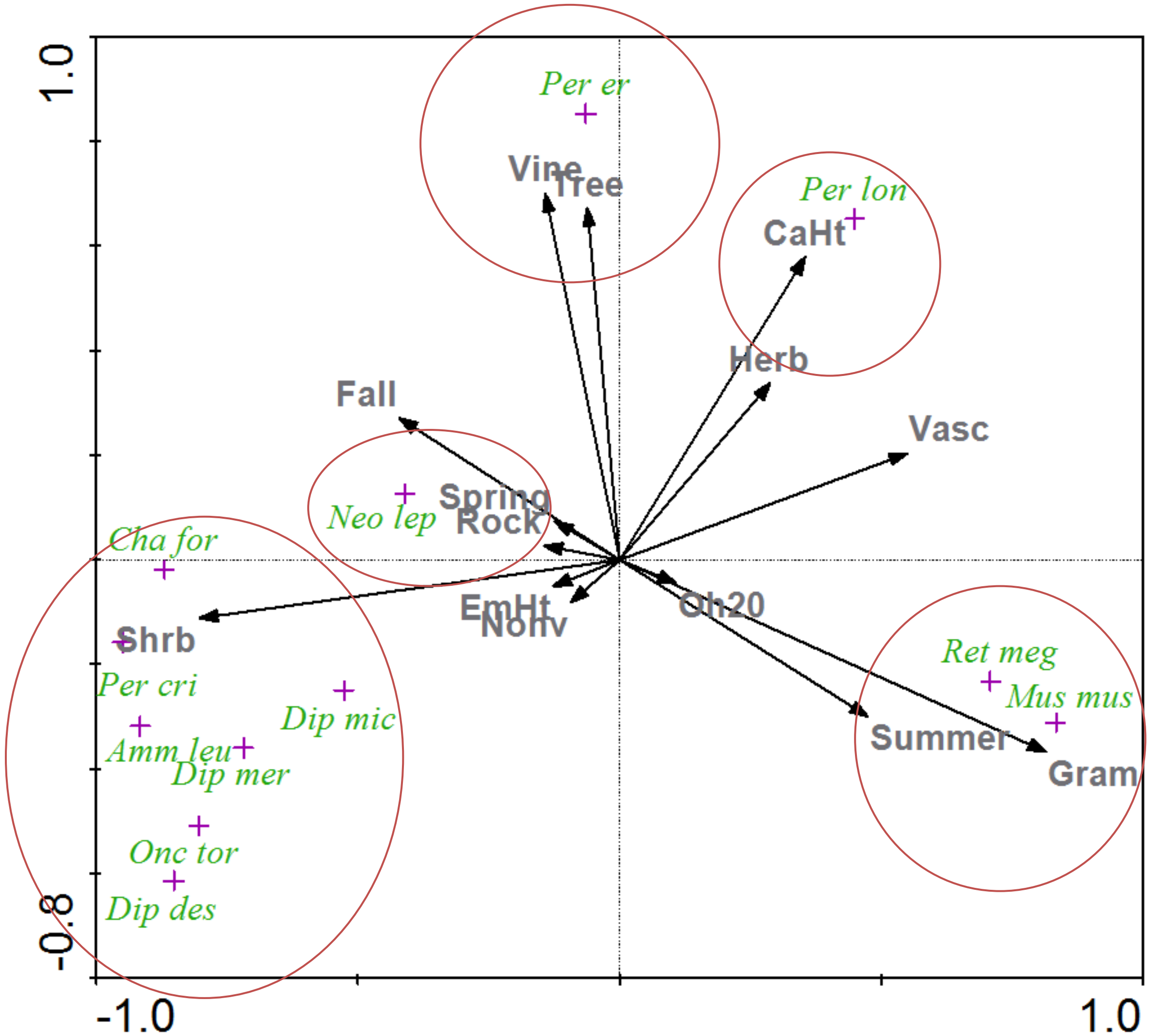


Figure 6. Canonical correspondence analysis ordination plot of small mammal species and habitat variables for Ash Meadows NWR.

CHAPTER V

DISCUSSION

We verified the presence of 15 species of small mammals at Ash Meadows National Wildlife Refuge. The most common species were three murids (*Reithrodontomys megalotis*, *Peromyscus eremicus*, and *Mus musculus*) and one heteromyid (*Dipodomys merriami*). Small mammals were primarily associated with shrub dominated areas and graminoid dominated areas. Habitats differed in structural components seasonally as well as between capture and non-capture trap sites mostly because of the unique seeps and springs systems present. Species diversity was similar to 1891; however, species diversity was lowest in 1933 perhaps due to habitat alterations.

Species Diversity Comparisons.---During the 1891Biological Survey, habitat alterations were minimal; however, between the 1891 and the 2008-2009 survey, intensive land use by various human activities occurred including spring diversions for agricultural use. In the 1960s and 1970s, a peat-mining operation altered marshland in Carson Slough and Preferred Equities Corporation bought Ash Meadows Ranch to develop land for a future community (Sanchez 1981, Deacon 2003, USFWS 2008). These habitat alterations caused shifts in the abundance of individuals of species especially the disappearance of the Ash Meadows montane vole (*Microtus montanus nevadensis*) after 1933, and the presence of invasive *Mus musculus*, absent in 1891, in 1933 and 2008-2009 surveys, indicating possible introduction during habitat alteration.

Montane voles inhabited arid grasslands, while *Mus musculus* inhabits human habitations or cultivated fields. *Mus musculus* natural habitat includes forests, savannahs, grasslands, and rocky areas. This commensalism would have increased the probability of appearing at Ash Meadows as humans associated with habitat alterations, primarily cultivation of grasslands and settlement of the area became more numerous. Cultivation of grasslands would have significantly impacted habitat for the montane vole.

The primary reason for Russell's trip to Ash Meadows in 1933 was collection of and verification of *Microtus montanus nevadensis* or other species of *Microtus* sp. (Russell 1933); therefore, this bias in trapping for meadow voles could have contributed to a lower diversity indices compared to 1891 and 2008-2009 surveys. Russell used primarily gopher traps and mouse traps (Russell 1933), which captured a greater number of *Thomomys bottae* than in the 1891 survey or my study where we primarily used mouse traps and Sherman traps.

Small Mammal Species Habitat Associations.---The primary objective of this study was to determine the habitat variables with which small mammal species were associated at Ash Meadows NWR. Small mammals inhabited two distinct associations: shrub cover association and graminoid cover association. Habitat associations were consistent with the natural history of small mammal species captured in my study. Shrub cover associated species consisted of *Chaetodipus formosus*, *Peromyscus crinitus*, *Dipodomys microps*, *Ammospermophilus leucurus*, *Dipodomys merriami*, *Onychomys torridus*, and *Dipodomys deserti*. Graminoid cover associated species consisted of *Reithrodontomys megalotis* and *Mus musculus*. *Peromyscus eremicus* was more associated with tree and vine cover habitat and *Perognathus longimembris* was more associated with herbaceous vegetation cover and canopy height.

Peromyscus eremicus was one of the most common small mammals captured in the emergent marsh and riparian woodland habitat types. Although in this study *P. eremicus* was mostly associated with higher tree and vine cover, it also was found in shrubland and meadow habitats, which it is associated with in southern Nevada (Bradley and Mauer 1973). Davis (1966) reported *P. eremicus* foraged in mesquite and hackberry trees, which concurred with the species presence in more wooded areas in this study.

Perognathus longimembris was associated with canopy height and herbaceous vegetation cover. However, capture sites were primarily shrub dominated sites; therefore, canopy height association may not be a good designation for the association. Since different shrub species attain different heights when mature, *P. longimembris* should have been assigned to the shrub cover association. *Perognathus longimembris* inhabits sandy areas with creosote bush (*Larrea tridentata*) and sagebrush (*Artemisia* spp.) (Mantooth and Riddle 2005). Occasional association of lower elevation grasslands has been documented for *P. longimembris brevinasus*, which would support the association of herbaceous cover at Ash Meadows NWR (Brylski 1998).

Neotoma lepida was associated with intermediate shrub cover and rock outcrops. *Neotoma lepida* was captured mostly in alkali shrub/scrub, creosote shrubland and emergent marsh habitats. The natural history of *N. lepida* supports its presence in these habitat types. This species is found in a variety of habitats with succulent vegetation, excluding cultivated areas. Vegetation includes sagebrush, creosote bush, shadscale

(*Atriplex* sp.) (Verts and Carraway 2002). Rocky outcrops afford protection against predators. Commonly inhabited shrub vegetation is used to construct middens as well as food sources (Brown et al. 1972, Verts and Carraway 2002).

Reithrodontomys megalotis and *Mus musculus* were both associated with high graminoid cover and tended to inhabit this habitat during summer. The natural history of *R. megalotis* supports my finding. Webster and Jones (1982) indicated this species typically inhabits grassy and weedy habitats such as meadows, agricultural and riparian areas. Catlett and Shellhammer (1962) found *R. megalotis* and *M. musculus* can be associated together. Similar to *R. megalotis*, *M. musculus* also inhabits meadows, savannahs, cultivated fields, and forested areas (Nowak and Paradiso 1983). The majority of *R. megalotis* were captured in alkali meadow, alkali shrub/scrub, emergent marsh, non-native weeds, tamarisk, and wet meadow habitat types with the majority of captures in summer.

Small mammal species associated with shrub dominated areas were *Ammospermophilus leucurus*, *Dipodomys deserti*, *D. merriami*, *D. microps*, *Onychomys torridus*, *Peromyscus crinitus*, and *Chaetodipus formosus*. *Ammospermophilus leucurus* is typically found in shrub areas primarily dominated by sagebrush and shadscale, as well as some herbaceous vegetation, but is known to be a generalist in regard to vegetation species (Belk and Smith 1991). This small mammal will utilize burrows of other *Dipodomys* sp. and actively forages in open areas present in shrub dominated habitats. Only 14 individuals were captured which is quite low relative to the sampling effort; however, *A. leucurus* typically have lower densities than other small mammals found in an area, but are an important biomass source for predators in desert communities (Bradley and Mauer 1973, Belk and Smith 1991).

Three species of *Dipodomys* were captured at Ash Meadows NWR during this study and all were associated with high shrub cover. *Dipodomys deserti*, the largest of the three species, was most common in the mesquite dune and shrub dune habitats. Grinnell (1937) typically found *D. deserti* in areas where wind-driven sand had accumulated and less abundant where shrubs were spaced closer together (primarily creosote bushes). This small mammals usually occurs in areas with less precipitation, therefore Munger et al. (1983) concluded *D. deserti* utilizes dune habitats for higher food resources provided from surface wind action. *Dipodomys deserti* co-exists with *D. merriami* and *D. microps*; however, *D. deserti* tends to consume larger seeds (Brown 1975, Best et al. 1989). *Dipodomys microps* will consume more vegetation than seeds unlike *D. deserti* and *D. merriami*. Shrub species associated with *D. microps* include blackbush (*Coleogyne* spp.) and *Grayia/Lycium*, and *D. microps* is least abundant in creosote bush dominated areas (Allred and Beck 1963). *Dipodomys microps* is more active during spring and early summer; however, the species was also captured during fall. *Dipodomys microps* and *D. merriami* exhibit niche partitioning because *D. microps* usually requires more of a mesic habitat and higher shrub cover, while *D. merriami* inhabits areas with less shrub cover. In some areas of southern Nevada, *D. merriami* has begun to replace *D. microps* (Beatley 1976a). *Dipodomys merriami* associates with more open habitats for ease of its fast locomotion and view of the surrounding area (Nowak and Paradiso).

Onychomys torridus inhabits scrub habitats and are less abundant in desert communities (McCarty 1975). All but a single individual of *O. torridus* was captured in mesquite dune or shrub dune habitat types. The openness of these habitats is ideal in aiding the nocturnal vocalization communication between territorial males (Chew and Chew 1970).

Peromyscus crinitus inhabits rocky areas (Johnson and Armstrong 1987). Eisenberg (1963) found *Peromyscus eremicus* and *P. crinitus* were sympatric with *P. eremicus* occupying vegetated areas and *P. crinitus* in rocky areas. *Peromyscus crinitus* inhabited rock outcrop association in this study; however, all individuals were captured in a rocky ridge in creosote shrubland habitat on the eastern side of Ash Meadows NWR.

Chaetodipus formosus was associated with shrublands with the majority of individuals captured in alkali shrub/scrub and creosote shrubland habitat types. However, according to Nowak and Paradiso (1983), it usually occurs in grassy areas, but Geluso (1999) found an association with creosote, shadscale, and sagebrush communities. *Chaetodipus formosus* replaces *Perognathus longimembris* in stonier soils (Beatley 1976b) and distributions are typically in lowlands and valleys (Mantooth and Riddle 2005).

I did not include *Peromyscus maniculatus*, *Spermophilus tereticaudus*, and *Thomomys bottae* in the habitat association analysis because of small sample sizes. However, *P. maniculatus* occurred in a variety of habitat types including woodlands, grasslands, and brushlands. *Spermophilus tereticaudus* was found in low, flat desert shrub areas of creosote, mesquite (*Prosopis* spp.), and shadscale. Sand dunes are also inhabited as well as sand accumulated around shrubs for burrows (Ernest and Mares 1987, Mantooth and Riddle 2005). *Thomomys bottae* occupies agricultural areas, desert ranges, and valleys and any other soils that are suitable for burrow excavation while feeding on underground parts of plants (Jones and Baxter 2004).

Habitat Type Comparisons.---Among the four habitat physiognomies present at Ash Meadows NWR, differences among habitat structure between habitat types was expected due to the presence of seeps and springs throughout the refuge. Dwarf shrubland/scrub physiognomies did not experience seasonal differences between habitat structure except for the percentages of nonvascular and graminoids which were higher in representative habitats during spring and summer (Appendix D). Most precipitation occurs during winter and spring into early summer (Pavlik 2008). Dwarf shrubland/scrub areas are moderately uniform in structure and are similar to shrubland areas. Shrubland differed in structure during seasons except for percentage of trees and vines which occur infrequently in this type of physiognomy. The same seasonal pattern is observed in shrublands with greater coverage of vegetation during spring and summer. Creosote shrubland habitat types had highest shrub cover during the summer, which is important for small mammals, especially kangaroo rats and pocket mice which utilize these seeds for food and water reserves stored in underground burrows when temperatures become extreme (Pavlik 2008).

Herbaceous physiognomies experienced seasonal differences in habitat structure except for the percentage of vines present. Graminoids were more common in summer and fall. Herbaceous cover was more common in spring. Emergent marsh, non-native/weeds, transitioning agriculture, and wet meadow habitat types fell into this category. This provided habitat for *Reithrodontomys megalotis* and *Mus musculus* which usually are found in grassland areas. *Mus musculus* was found in non-native/weeds habitat which indicates past introduction when Ash Meadows was being cultivated for agriculture, and altering habitats for urban development. This activity probably induced invasive species into the area. Woodland areas experienced seasonal changes in habitat structure except for percent of vascular plants, graminoids, and herbaceous plants. This would represent ground cover in woodlands; however, most of these areas were along seeps and springs, and did not extend outward from the water source. Greatest cover was during the fall. *Peromyscus eremicus* was commonly found in these areas.

Capture versus Non-capture Trap Locations.---In addition to the primary objective of my study, I also assessed whether there was a difference in habitat structure between capture and non-capture trap sites. Overall, difference between capture and non-capture sites primarily occurred with the amount of vegetation present. However, differences were not as common as I predicted among most habitats. Ash, alkali sink, and salt desert scrub habitats did not have differences between capture and non-capture sites. These habitats tended to be represented less frequently at Ash Meadows NWR than dominant communities; therefore dissimilarities between different areas were less likely. Small mammals captured included *D. merriami* and *P. eremicus*, which were commonly captured.

Alkali shrub/scrub, creosote shrubland, dune (mesquite), dune (shrub) are considered to have a shrubland physiognomy with moderately open areas that are uniformly similar throughout. In alkali shrub/scrub, dune (mesquite), and dune (shrub) habitats differences occurred, but were minimal. Capture sites tended to have more habitat structure which would provide food resources and protection for small mammals. Creosote shrublands did not differ in structure between capture and non-capture sites except for canopy height, which was greater in capture sites. Open areas between shrubs allow for ease in mobility which is important for *Dipodomys* sp. commonly found in these habitats as well as enhancing view of the surrounding area for predators.

Alkali meadow, emergent marsh, transitioning agriculture, and wet meadow habitat types also have more ground cover and structure overall at capture sites. These communities represent herbaceous areas supporting small mammals that utilize herbaceous vegetation in diets, nest building, and cover for protection. These areas also are susceptible for becoming inundated during certain times of the year due to the carbonate aquifer. This likely prevents shrubs from dominating the area.

Mesquite bosque, riparian woodland, and tamarisk habitats were characteristic of a woodland physiognomy. Woody vegetation tended to be higher in capture sites and a less dense understory also was characteristic of capture sites. These areas provided unique habitat along seeps and springs that are typically not present in desert environments. Riparian woodlands had greater small mammal diversity relative to mesquite bosque and tamarisk habitats. This is due to being adjacent to seeps and springs, which also will have other vegetation species and different strata that will support more small mammals.

Management Implications.---This study reveals small mammals inhabit several different habitat types at Ash Meadows NWR. Shrub associated and graminoid associated groups of small mammals were revealed; however, other vegetation groups are important for small mammals at Ash Meadows NWR. These habitat associations are important for biologists at Ash Meadows NWR because as seen in the species diversity analysis conducted, diversity seemed to recover overtime, but proportions of small mammal species has shifted with an introduction of a non-native species and possible extirpation of another. This is important to note when restoration projects will be conducted to restore natural hydrology of Ash Meadows NWR, which will consequently alter vegetation. Ash Meadows NWR is a unique desert ecosystem in the Mojave Desert and maintaining biodiversity is a crucial objective of the refuge as well as conservation and protection of the endemic and endangered species inhabiting it.

Appendix A. Habitat community classifications derived from the California Wildlife Habitat Relationships System (Bio-West 2009), total trap lines set for each habitat community, size, and dominant (> 20% cover) vegetative species at Ash Meadows.

Habitat Community	No. of Traplines	Acreage (ha)	Physiognom (s)
Alkali Meadow	28	1088.07	Dwarf Shrubland/Scrub, Herbaceous, Shrubland, Woodland

Description: Grassland areas that predominately consist of saltgrass (*Distchlis spicata)* ; Seasonally flooded at Ash Meadows; Shrubs are present sporadically throught this habitat.
Graminoids: *Distichlis spicata, Sporobolus airoides, Juncus arcticus, Eleocharis rostellata, Carex praegracilis* Shrubs: *Atriplex confertifolia, Chrysothamnus albidus, Suaeda moquinii, Phragmites australis, Atriplex canescens, Atriplex lentiformis, Isocoma acradenia, Baccharis emoryi, Atriplex parryi*
Herbaceous: *Nitrophila occidentalis, Bassia californica, Typha sp., Scirpus americanus, Bassia hyssopifolia, Centaurium namophilum, Helianthus annuus*
Trees: *Prosopis pubescens* , *Tamarix* sp.

Habitat Community	No. of Traplines	Acreage (ha)	Physiognom (s)
Alkali Seep	3	129.13	Dwarf Shrubland/Scrub, Shrubland

Description: Habitats that are moist throughout most of the year due to presence of seeps; often associated with alkali meadows
Shrubs: *Chrysothamnus albidus, Sporobolus airoides*

Appendix A. (Continued)

Alkali Shrub/Scrub	42	4153.45	Dwarf Shrubland/Scrub, Shrubland, Woodland

Description: Typically divided into 2 phases: xerophytic and halophytic; xerophytic phases are low to moderatly high shrubs, occur on relatively dry soils, widely spaced; halophytic phases are suffrutescent species varying in succulence, more widely spaced than xerophytic, tolerate periodic flooding; fairly heterogenous assemblage along moisture, microtopography, and salinity gradiants; occur at low to middle elevations Graminoids: *Distichlis spicata, Eleocharis rostellata, Carex praegracilis, Scirpus americanus* Shrubs: *Atriplex contertifolia, Isocoma acradenia, Suaeda moquinii, Atriplex polycarpa, Atriplex canescens, Chrysothamnus albidus, Ericameria nauseosa, Atriplex lentiformis, Phragmites australis* Herbaceous: *Typha* sp. Trees: *Prosopis glandulosa, Tamarix* sp., *Fraxinus velutina, Prosopis pubescens*

Alkali Playa	6	8.14	Herbaceous

Description: Unique community in seasonally wet areas due to poorly drained soils and high salinity; supports large populations of rare and endimic plants at Ash Meadows Graminoids: *Distichlis spicata, Sporobolus airoides* Shrub: *Atriplex confertifolia*

Alkali Sink	6	96.7	Dwarf Shrubland/Scrub, Shrubland

Description: Shrubland community dominated primarily by succulant shrubs; occur adjacent to seasonally flooded wetlands and among desert washes
Graminoid: *Distichlis spicata* Shrub: *Suaeda moquinii* Herbaceous: *Typha* sp.

Ash	6	50.08	Herbaceous, Woodland

Description: Woodland areas dominated by velvet ash (*Fraxinus velutina*)
Graminoids: *Juncus arcticus, Sporobolus airoides, Distichlis spicata* Shrubs: *Scirpus americanus, Eleocharis rostellata* Herbaceous: *Typha* sp. Tree: *Fraxinus velutina*

Appendix A. (Continued)

Creosote Shrubland	33	1070.53	Dwarf Shrubland/Scrub, Shrubland

Description: Found in alluvial flats and dominated by creosote bush (*Larrea tridentata*); also found in areas of old field agricultural disturbances; shrubs typically 0.5—3 meters tall and widely spaced
Graminoids: *Eleocharis rostellata, Juncus arcticus, Carex praegracilis, Distichlis spicata* Shrubs: *Ambrosia dumosa, Larrea tridentata, Atriplex confertifolia, Isocoma acradenia, Atriplex hymenelytra, Baccharis emoryi*

Dune (Mesquite)	13	273.05	Dwarf Shrubland/Scrub, Shrubland, Woodland

Description: Typically open, scattered assemblages of woody species especially mesquite (*Prosopis* sp.); canopy cover less than 50 percent with bare ground visible among vegetation; proceeds slowly through succession after disturbance; plant growth depends on moisture levels; coarse and well-drained soils; occur at low elevations
Shrubs: *Chrysothamnus albidus, Sporobolus airoides, Larrea tridentata, Atriplex confertifolia, Atriplex polycarpa, Atriplex canescens, Isocoma acradenia, Atriplex lentiformis* Herbaceous: *Bassia hyssopifolia* Trees: *Prosopis glandulosa, Prosopis pubescens*

Dune (Shrub)	6	50	Shrubland

Description: Typically open, scattered assemblages of broadleaved evergreen or deciduous shrubs between 0.5 and 2.0 m in height rarely exceeding 3.0 m; canopy cover less than 50 percent with bare ground visible among vegetation; proceeds slowly through succession after disturbance; plant growth depends on moisture levels; coarse and well-drained soils; occur at low elevations
Graminoids: *Sporobolus airoides, Distichlis spicata* Shrubs: *Atriplex confertifolia, Chrysothamnus albidus, Atriplex canescens* Herbaceous: *Typha* sp. Tree: *Prosopis glandulosa*

Appendix A. (Continued)

Emergent Marsh	19	196.03	Herbaceous, Shrubland

Description: Characterized by erect, rooted herbaceous hydrophytes; occur on most exposures and slopes and need periodically flooding; silty clay soils
Graminoids: *Schoenoplectus americanus, Eleocharis rostellata, Juncus arcticus, Distichlis spicata, Sporobolus airoides, Scirpus americanus, Cynodon dactylon*
Shrubs: *Baccharis emoryi, Phragmites australis, Atriplex confertifolia, Chrysothamnus albidus, Atriplex canescens, Isocoma acradenia* Herbaceous: *Typha* sp., *Bassia hyssopifolia, Helianthus annuus* Trees: *Fraxinus velutina, Prosopis pubescens, Tamarix* sp.

Mesquite Bosque	6	355.65	Woodland

Description: Often occur on high alluvial terraces; open to fairly dense thorn forest; near-surface groundwater supply is substantial
Graminoids: *Distichlis spicata, Juncus arcticus* Shrubs: *Isocoma acradenia, Baccharis emoryi, Atriplex confertifolia, Atriplex lentiformis, Suaeda moquinii, Phragmites australis* Herbaceous: *Typha* sp., *Helianthus annuus, Bassia hyssopifolia* Trees: *Prosopsis pubescens, Tamarix* sp.

Non-native/Weeds	12	74.86	Herbaceous

Description: Habitats that are dominated primarily by populations of non-native species; usually a water source is nearby
Graminoids: *Eleocharis rostellata, Juncus arcticus, Scirpus americanus, Distichlis spicata* Shrubs: *Atriplex lentiformis, Atriplex confertifolia, Baccharis emoryi*
Herbaceous: *Typha* sp., *Bassia hyssopifolia* Trees: *Prosopis pubescens, Prosopis glandulosa*

Appendix A. (Continued)

Riparian Shrubland	6	62.33	Shrubland

Description: Characterized by low shrublike trees or tall shrubs; usually adjacent to a permanent water source; tend to be an abrupt change in vegetation from desert habitat to riparian habitat, moist soils (dry on top, wet below); silky alluvial to rocky, sandy well-drained soils
Graminoids: *Distichlis spicata, Cynodon dactylon* Shrubs: *Atriplex lentiformis, Baccharis emoryi, Phragmites australis* Herbaceous: *Salsola paulsenii, Bassia hyssopifolia* Trees: *Prosopis glandulosa, Prosopis pubescens*

Riparian Woodland	6	78.88	Forest, Woodland

Description: Same characteristics as riparian shrubland except woodland is characterized by small to medium-sized trees usually adjacent to a permanent water source
Graminoids: *Juncus arcticus, Distichlis spicata, Sporobolus airoides, Cynodon dactylon* Shrubs: *Atriplex lentiformis, Isocoma acradenia, Baccharis emoryi, Phragmites australis* Herbaceous: *Thelypodium integrifolium, Typha* sp., *Bassia hyssopifolia* Trees: *Fraxinus velutina, Prosopis pubescens*

Salt Desert Scrub	6	640.06	Dwarf Shrubland/Scrub, Shrubland

Description: Open habitats with scattered shrubs 0.5 to 2 meters tall; canopy cover less than 50 percent; occur at low elevations
Shrubs: *Atriplex hymenelytra, Suaeda moquinii* Herbaceous: *Bassia californica*

Tamarisk	4	104.74	Woodland

Description: Typically woodlands found along riparian areas; can provide important wildlife habitat
Graminoids: *Sporobolus airoides, Distichlis spicata, Juncus arcticus, Scirpus americanus,Eleocharis rostellata, Polypogon monspeliensis* Shrubs: *Atriplex canescens, Atriplex confertifolia, Phragmites australis* Herbaceous: *Bassia hyssopifolia, Typha* sp., *Helianthus annuus* Trees: *Tamarix* sp., *Prosopis pubescens*

Appendix A. (Continued)

Transitioning Agriculture	8	436.81	Dwarf Shrubland/Scrub, Herbaceous, Woodland

Description: Occur in association with pastures; mixture of perennial grasses and legumes; vegetation usually provides entire canopy cover
Graminoids: *Distichlis spicata, Juncus arcticus* Shrubs: *Atriplex confertifolia, Isocoma acradenia, Atriplex polycarpa, Baccharis emoryi* Herbaceous: *Typha* sp., *Helianthus annuus, Bassia hyssopifolia* Trees: *Tamarix* sp., *Prosopis pubescens*

Wet Meadow	34	357.23	Dwarf Shrubland/Scrub, Herbaceous, Shrubland

Description: Consists of a layer of herbaceous plants, rarely shrubs or trees except on edges; consists of many plant species; succeed bog communities; hydrology (seasonal inflows and outflows) determine vegetation stability; ecotones of fresh emergent wetlands and perennial grasslands
Graminoids: *Juncus arcticus, Sporobolus airoides, Distichlis spicata, Carex praegracilis, Eleocharis rostellata, Juncus nodosus, Scirpus americanus, Poa secunda* Shrubs: *Atriplex canescens, Atriplex confertifolia, Phragmites australis, Atriplex lentiformis, Isocoma acradenia* Herbaceous: *Grindelia fraxinopratensis, Typha* sp., *Bassia hyssopifolia, Helianthus annuus* Trees: *Prosopis pubescens, Fraxinus velutina*

Bare Ground[a]	—	9.72	—

Description: Absence of vegetation; less than 2 percent vegetation cover of herbaceous, desert, or wildland species; less than 10 percent cover of trees and shrubs

Open Water[a]	—	85.24	—

Description: Varying from small ponds less than 1 hectare to large areas covering several square kilometers of standing water from a few centimeters to hundreds of meters deep;

Private[a]	—	184.8	—
Road[a]	—	23.23	—
TOTAL	244	9528.73	

[a] Traplines not included in these areas

Appendix B. Mean (SE) for habitat variables in habitat types for capture and non-capture sites at Ash Meadows NWR.

	Alkali Meadow			Alkali Seep		
Season	Spring	Summer	Fall	Spring[a]	Summer[a]	Fall[b]
NONCAPTURE SITES						
Canopy Height (m)	2.23 (0.06)	2.90 (0.05)	1.33 (0.10)	0.90 (0.10)	1.00 (0)	1.12 (0.03)
% Vascular	90.1 (0.76)	91.2 (0.64)	71.1 (2.40)	46.0 (6.0)	40.0 (0)	28.0 (3.27)
% Nonvascular	3.39 (0.52)	2.64 (0.32)	7.41 (1.07)	48.0 (12.0)	60.0 (0)	24.0 (9.80)
% Open Water	0.95 (0.28)	1.48 (0.35)	1.67 (0.37)	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0.02 (0.01)	0	0	0	0
% Graminoid	69.1 (0.99)	71.8 (0.92)	57.2 (2.31)	9.00 (4.00)	5.00 (0)	5.60 (0.16)
% Herbaceous	14.3 (0.68)	7.38 (0.43)	7.31 (0.60)	8.00 (2.00)	10.0 (0)	4.00 (1.63)
% Shrub	7.40 (0.59)	3.37 (0.35)	8.67 (1.02)	29.0 (4.00)	25.0 (0)	19.0 (1.63)
% Tree	5.08 (0.27)	9.23 (0.27)	3.77 (0.64)	0	0	0
% Vine	0	0	0	0	0	0
CAPTURE SITES						
Canopy Height (m)	2.34 (0.23)	3.57 (0.08)	1.33 (0.52)			1.20 (–)
% Vascular	84.6 (3.73)	95.3 (1.46)	80.0 (11.2)			20.0 (–)
% Nonvascular	1.41 (0.90)	0.60 (0.14)	5.00 (5.0)			0 (–)
% Open Water	1.15 (0.65)	0.60 (0.26)	2.14 (2.14)			0 (–)
% Rock Outcrops	0	0	0			0 (–)
Emergent Height (m)	0	0	0			0 (–)
% Graminoid	61.4 (3.80)	82.6 (1.56)	57.1 (16.8)			6.0 (–)
% Herbaceous	16.2 (2.49)	2.66 (0.72)	8.00 (2.43)			0 (–)
% Shrub	6.03 (2.29)	0.24 (0.10)	6.43 (5.64)			15.0 (–)
% Tree	5.26 (0.84)	10.2 (0.42)	2.14 (1.49)			0 (–)
% Vine	0	0	0			0 (–)

[a] No captures during season   [b] 1 individual captured during season

Appendix B. (Continued)

Season	Alkali Shrub/Scrub Spring	Alkali Shrub/Scrub Summer	Alkali Shrub/Scrub Fall	Alkali Sink Spring	Alkali Sink Summer	Alkali Sink Fall
NONCAPTURE SITES						
Canopy Height (m)	1.26 (0.06)	1.22 (0.13)	1.17 (0.08)	0.83 (0.04)	0.9 (0.03)	0.86 (0.04)
% Vascular	60.8 (1.36)	53.9 (1.69)	57.9 (1.57)	62.2 (3.57)	68.6 (3.26)	64.7 (3.9)
% Nonvascular	3.9 (0.73)	1.83 (0.5)	0.97 (0.42)	11.2 (2.77)	15.0 (3.1)	13.3 (3.33)
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	7.03 (0.55)	7.54 (0.6)	5.4 (0.42)	0.35 (0.35)	2.13 (1.26)	0.45 (0.45)
% Herbaceous	0.29 (0.08)	0.9 (0.15)	0.31 (0.08)	0	0	0
% Shrub	47.1 (1.46)	44.4 (1.68)	47.4 (1.77)	62.2 (3.49)	66.7 (3.13)	64.5 (3.81)
% Tree	2.94 (0.27)	1.7 (0.23)	2.53 (0.32)	0	0	0
% Vine	0	0	0	0	0	0
CAPTURE SITES						
Canopy Height (m)	2.7 (0.53)	2.41 (0.45)	1.75 (0.25)	1.0 (0)	0.81 (0.09)	0.96 (0.04)
% Vascular	69.4 (3.74)	62.8 (3.85)	58.2 (3.68)	72.9 (6.06)	65.6 (9.66)	72.9 (5.52)
% Nonvascular	0	0.59 (0.59)	0	22.9 (8.08)	5.0 (5.0)	16.8 (5.95)
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	9.78 (1.75)	6.76 (1.04)	5.09 (1.01)	0	0	0
% Herbaceous	2.58 (0.65)	1.57 (0.49)	1.03 (0.31)	0	0	0
% Shrub	45.9 (4.21)	48.9 (4.38)	48.9 (3.13)	72.9 (6.06)	66.0 (9.49)	73.0 (5.47)
% Tree	4.31 (0.86)	4.41 (0.95)	4.97 (0.91)	0	0	0
% Vine	0	0	0	0	0	0

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Ash Spring	Ash Summer	Ash Fall	Creosote Shrubland Spring	Creosote Shrubland Summer	Creosote Shrubland Fall
NONCAPTURE SITES						
Canopy Height (m)	4.91 (0.06)	5.0 (0)	5.0 (0)	1.06 (0.01)	1.14 (0.03)	1.24 (0.02)
% Vascular	88.9 (1.4)	85.0 (0)	85.0 (0)	38.7 (1.73)	42.8 (1.74)	40.9 (1.87)
% Nonvascular	0	1.04 (0.42)	1.04 (0.42)	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	8.40 (1.72)	4.76 (1.44)	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	20.0 (6.18)	5.0 (0)	5.0 (0)	0	0	0
% Herbaceous	5.22 (0.22)	5.0 (0)	5.0 (0)	0.16 (0.03)	0.05 (0.05)	0
% Shrub	3.74 (0.45)	5.0 (0)	5.0 (0)	36.9 (1.75)	40.2 (1.77)	39.9 (1.88)
% Tree	74.6 (4.48)	85.0 (0)	85.0 (0)	0.13 (0.03)	0.29 (0.11)	0.04 (0.04)
% Vine	0	0	0	3.7 (0.44)	4.19 (0.48)	2.81 (0.42)
CAPTURE SITES						
Canopy Height (m)	5.0 (0)	5.0 (0)	5.0 (0)	1.12 (0.03)	1.24 (0.04)	1.23 (0.04)
% Vascular	85.0 (0)	85.0 (0)	85.0 (0)	42.3 (3.1)	43.9 (2.78)	39.2 (2.85)
% Nonvascular	0	1.04 (0.42)	1.04 (0.42)	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	7.29 (2.57)	3.28 (1.6)	1.14 (1.14)
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	5.0 (0)	5.0 (0)	5.0 (0)	0	0	0
% Herbaceous	5.0 (0)	5.0 (0)	5.0 (0)	0.1 (0.04)	0	0
% Shrub	5.0 (0)	5.0 (0)	5.0 (0)	40.9 (3.13)	42.7 (2.75)	37.8 (2.9)
% Tree	85.0 (0)	85.0 (0)	85.0 (0)	0.21 (0.11)	0.33 (0.16)	0
% Vine	0	0	0	2.92 (0.66)	2.62 (0.57)	3.41 (0.72)

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Dune (Mesquite) Spring	Dune (Mesquite) Summer	Dune (Mesquite) Fall	Dune (Shrub) Spring	Dune (Shrub) Summer	Dune (Shrub) Fall
NONCAPTURE SITES						
Canopy Height (m)	2.3 (0.06)	2.15 (0.06)	2.22 (0.07)	1.43 (0.01)	1.4 (0.01)	1.43 (0.01)
% Vascular	88.1 (0.85)	84.6 (1.5)	87.1 (0.98)	80.0 (0)	80.0 (0)	80.0 (0)
% Nonvascular	3.49 (0.96)	0	0	9.66 (3.34)	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0.14 (0.06)	0.15 (0.07)	0	0	0	0
% Graminoid	11.6 (1.32)	11.1 (1.41)	13.8 (1.66)	0	0	0
% Herbaceous	0	0	0	0	0	0
% Shrub	43.6 (0.46)	40.5 (0.59)	41.7 (0.33)	80.0 (0)	80.0 (0)	80.0 (0)
% Tree	45.6 (0.81)	46.9 (1.03)	48.8 (0.76)	0	0	0
% Vine	0	0	0	0	0	0
CAPTURE SITES						
Canopy Height (m)	2.0 (0.11)	2.03 (0.11)	2.13 (0.11)	1.44 (0.01)	1.44 (0.01)	1.43 (0.01)
% Vascular	86.8 (1.3)	84.5 (1.28)	86.0 (1.31)	80.0 (0)	80.0 (0)	80.0 (0)
% Nonvascular	4.55 (2.95)	0.97 (0.97)	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0.18 (0.13)	0.1 (0.1)	0	0	0	0
% Graminoid	5.76 (1.56)	6.13 (1.99)	7.86 (1.66)	0	0	0
% Herbaceous	0	0	0	0	0	0
% Shrub	41.2 (0.58)	40.7 (0.38)	40.6 (0.4)	80.0 (0)	80.0 (0)	80.0 (0)
% Tree	45.6 (1.19)	46.3 (1.09)	47.6 (1.11)	0	0	0
% Vine	0	0	0	0	0	0

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Emergent Marsh Spring	Emergent Marsh Summer	Emergent Marsh Fall	Mesquite Bosque Spring	Mesquite Bosque Summer	Mesquite Bosque Fall
NONCAPTURE SITES						
Canopy Height (m)	3.38 (0.04)	3.02 (0.05)	3.16 (0.08)	2.36 (0.12)	2.23 (0.3)	1.05 (0.05)
% Vascular	99.1 (0.47)	99.8 (0.12)	83.2 (5.36)	92.4 (0.63)	95.0 (0)	95.0 (0)
% Nonvascular	0.61 (0.26)	0.63 (0.36)	0.53 (0.25)	2.84 (0.79)	0	0
% Open Water	0	0	4.2 (2.94)	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0.85 (0.14)	2.26 (0.18)	2.45 (0.18)
% Graminoid	8.74 (0.91)	20.9 (2.06)	9.74 (2.25)	28.0 (1.53)	28.7 (0.89)	25.0 (0)
% Herbaceous	50.3 (1.42)	60.1 (1.8)	71.3 (5.61)	0	0	0
% Shrub	34.9 (1.56)	15.2 (2.31)	2.11 (0.67)	37.9 (1.77)	38.9 (1.49)	45.0 (0)
% Tree	10.3 (0.52)	8.2 (0.9)	0	73.3 (3.11)	86.5 (3.28)	100. (0)
% Vine	0.06 (0.04)	0	0	0	0	0
CAPTURE SITES						
Canopy Height (m)	2.98 (0.14)	3.01 (0.06)	2.94 (0.06)	1.5 (0.33)	1.33 (0.33)	1.0 (0)
% Vascular	100 (0)	100 (0)	100 (0)	95.0 (0)	95.0 (0)	95.0 (0)
% Nonvascular	3.1 (1.99)	0.39 (0.19)	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	2.4 (0.4)	2.5 (0.5)	2.57 (0.43)
% Graminoid	5.83 (1.94)	5.0 (1.71)	0.91 (0.91)	28.0 (2.0)	25.0 (0)	25.0 (0)
% Herbaceous	77.5 (4.07)	75.7 (3.84)	95.8 (1.95)	0	0	0
% Shrub	12.9 (2.91)	12.6 (3.23)	1.97 (1.02)	39.0 (4.0)	45.0 (0)	45.0 (0)
% Tree	6.67 (1.52)	7.84 (1.63)	2.27 (1.27)	88.0 (8.0)	100. (0)	100. (0)
% Vine	0	0	0	0	0	0

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Non-Native/ Weeds			Riparian Shrubland		
	Spring[b]	Summer	Fall[b]	Spring[a]	Summer[b]	Fall[b]
NONCAPTURE SITES						
Canopy Height (m)	2.5 (0)	1.5 (0)	2.5 (0)	4.67 (0.17)	4.77 (0.07)	4.5 (0)
% Vascular	100. (0)	100. (0)	100. (0)	71.7 (3.33)	69.7 (1.33)	75.0 (0)
% Nonvascular	0	0	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	3.0 (0)	0	0	0	0	0
% Graminoid	0	110. (0)	0	20.0 (10.0)	14.0 (4.0)	30.0 (0)
% Herbaceous	85.0 (0)	40.0 (0)	0	6.67 (6.67)	10.7 (2.67)	0
% Shrub	0	0	0	41.7 (3.33)	39.7 (1.33)	45.0 (0)
% Tree	15.0 (0)	0	0	19.0 (1.0)	18.4 (0.4)	20.0 (0)
% Vine	0	0	0	0	0	0
CAPTURE SITES						
Canopy Height (m)	1.5 (–)	1.5 (0)	2.5 (–)		4.5 (–)	4.5 (–)
% Vascular	100. (–)	100. (0)	100. (–)		75.0 (–)	75.0 (–)
% Nonvascular	0 (–)	0	0 (–)		0 (–)	0 (–)
% Open Water	0 (–)	0	0 (–)		0 (–)	0 (–)
% Rock Outcrops	0 (–)	0	0 (–)		0 (–)	0 (–)
Emergent Height (m)	0 (–)	0	0 (–)		0 (–)	0 (–)
% Graminoid	110. (–)	110. (0)	0 (–)		30.0 (–)	30.0 (–)
% Herbaceous	40.0 (–)	40.0 (0)	85.0 (–)		0 (–)	0 (–)
% Shrub	0 (–)	0	0 (–)		45.0 (–)	45.0 (–)
% Tree	0 (–)	0	15.0 (–)		20.0 (–)	20.0 (–)
% Vine	0 (–)	0	0 (–)		0 (–)	0 (–)

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Riparian Woodland Spring	Riparian Woodland Summer	Riparian Woodland Fall	Salt Desert Scrub Spring	Salt Desert Scrub Summer	Salt Desert Scrub Fall
NONCAPTURE SITES						
Canopy Height (m)	5.96 (0.15)	5.49 (0.27)	6.61 (0.3)	0.67 (0.05)	1.3 (0)	1.3 (0)
% Vascular	95.9 (1.32)	92.5 (2.17)	96.5 (0.64)	42.1 (1.45)	60.0 (0)	60.0 (0)
% Nonvascular	0	0	0	4.21 (2.89)	37.3 (2.67)	40.0 (0)
% Open Water	2.66 (1.31)	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	16.5 (1.63)	19.3 (2.5)	26.3 (3.12)	0	0	0
% Herbaceous	3.75 (1.57)	2.17 (0.94)	0	1.58 (1.09)	14.0 (1.0)	15.0 (0)
% Shrub	48.9 (1.97)	33.7 (1.67)	35.1 (2.09)	36.1 (0.72)	45.0 (0)	45.0 (0)
% Tree	80.9 (2.3)	84.2 (3.75)	85.1 (3.29)	4.47 (0.36)	0	0
% Vine	3.59 (0.42)	6.23 (0.58)	5.33 (0.72)	0	1.0 (1.0)	0
CAPTURE SITES						
Canopy Height (m)	6.79 (0.48)	5.0 (0.25)	5.21 (0.2)	0.95 (0.35)	1.3 (0)	1.3 (0)
% Vascular	99.5 (0.36)	95.0 (0.35)	98.2 (1.2)	50.0 (10.0)	60.0 (0)	60.0 (0)
% Nonvascular	0	0	0	20.0 (20.0)	40.0 (0)	20.0 (20.0)
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	14.6 (4.68)	41.0 (2.16)	9.92 (1.52)	0	0	0
% Herbaceous	1.58 (1.58)	0	0.51 (0.51)	7.5 (7.5)	15.0 (0)	7.5 (7.5)
% Shrub	39.6 (5.5)	60.0 (2.22)	40.1 (1.38)	40.0 (5.0)	45.0 (0)	45.0 (0)
% Tree	97.6 (3.38)	20.0 (2.67)	97.8 (2.5)	2.5 (2.5)	0	0
% Vine	7.37 (0.96)	0	8.47 (0.47)	0	0	7.5 (7.5)

[a] No captures during season   [b] 1 individual captured during season

Appendix B. (Continued)

Season	Tamarisk			Transitioning Agriculture		
	Spring[b]	Summer	Fall[b]	Spring	Summer	Fall
NONCAPTURE SITES						
Canopy Height (m)		3.9 (0.01)		3.45 (0.29)	3.33 (0.29)	2.91 (0.37)
% Vascular		54.9 (0.66)		79.3 (2.35)	78.4 (2.09)	70.7 (3.0)
% Nonvascular		0.51 (0.16)		14.9 (2.17)	16.9 (2.31)	29.3 (3.0)
% Open Water		0.1 (0.05)		0.5 (0.2)	0.4 (0.18)	0
% Rock Outcrops		0		0	0	0
Emergent Height (m)		0.02 (0.01)		0	0.02 (0.02)	0
% Graminoid		30.4 (0.16)		15.9 (1.58)	10.8 (0.84)	10.3 (0.66)
% Herbaceous		6.6 (0.23)		12.9 (1.67)	14.2 (2.21)	2.88 (0.51)
% Shrub		0.9 (0.01)		44.4 (1.98)	43.3 (2.02)	50.0 (1.78)
% Tree		17.9 (0.39)		14.7 (1.88)	15.7 (1.87)	12.9 (2.29)
% Vine		0		1.57 (0.21)	1.56 (0.21)	1.44 (0.25)
CAPTURE SITES						
Canopy Height (m)	4.0 (–)	3.69 (0.07)		1.77 (0.64)	3.89 (0.86)	5.3 (0.81)
% Vascular	50.0 (–)	64.4 (3.37)		70.5 (6.96)	89.6 (3.21)	90.0 (3.61)
% Nonvascular	0 (–)	0.48 (0.23)		23.2 (8.18)	10.7 (6.75)	9.12 (3.54)
% Open Water	0 (–)	0.24 (0.24)		0	0.71 (0.71)	0.59 (0.59)
% Rock Outcrops	0 (–)	0		0	0	0
Emergent Height (m)	0 (–)	0.05 (0.05)		0	0.14 (0.14)	0
% Graminoid	30.0 (–)	30.4 (0.81)		19.5 (5.09)	14.3 (2.96)	9.41 (2.01)
% Herbaceous	5.0 (–)	10.2 (1.29)		9.09 (5.43)	28.9 (8.8)	14.7 (5.68)
% Shrub	1.0 (–)	0.69 (0.07)		45.5 (6.34)	35.5 (6.73)	45.9 (4.25)
% Tree	15.0 (–)	23.8 (2.06)		4.45 (4.06)	18.2 (5.92)	27.4 (5.34)
% Vine	0 (–)	0		0.45 (0.45)	1.79 (0.66)	2.94 (0.62)

[a] No captures during season [b] 1 individual captured during season

Appendix B. (Continued)

Season	Wet Meadow Spring	Wet Meadow Summer	Wet Meadow Fall
NONCAPTURE SITES			
Canopy Height (m)	1.79 (0.12)	1.56 (0.05)	2.71 (0.26)
% Vascular	97.1 (0.83)	99.1 (0.1)	98.3 (0.63)
% Nonvascular	4.25 (1.11)	0.88 (0.29)	0
% Open Water	1.42 (0.81)	0	0
% Rock Outcrops	0	0	0
Emergent Height (m)	0	0	0
% Graminoid	95.4 (2.09)	110. (1.21)	109. (4.58)
% Herbaceous	10.8 (1.64)	2.79 (0.21)	1.5 (0.57)
% Shrub	4.4 (0.61)	2.29 (0.5)	0
% Tree	1.82 (0.27)	4.37 (0.28)	5.25 (1.72)
% Vine	0	0	0
CAPTURE SITES			
Canopy Height (m)	1.25 (0.38)	2.05 (0.13)	2.5 (1.5)
% Vascular	98.6 (0.97)	98.9 (0.36)	100. (0)
% Nonvascular	4.54 (4.07)	0	2.5 (2.5)
% Open Water	0	0	0
% Rock Outcrops	0	0	0
Emergent Height (m)	0	0	0
% Graminoid	92.7 (6.69)	94.7 (4.31)	121. (30.5)
% Herbaceous	6.55 (3.08)	3.59 (0.81)	3.0 (3.0)
% Shrub	5.45 (2.82)	6.67 (2.96)	0.5 (0.5)
% Tree		6.84 (0.82)	15.0 (15.0)
% Vine	0	0	0

[a] No captures during season [b] 1 individual captured during season

Appendix C. Mean (SE) of habitat variables for small mammals captured at Ash Meadows NWR.

	Ammospermophilus leucurus			*Chaetodipus formosus*		
Season	Spring[b]	Summer	Fall	Spring	Summer	Fall
Canopy Height (m)	1.0 (–)	0.93 (0.16)	1.4 (0.28)	0.94 (0.08)	1.22 (0.06)	1.21 (0.07)
% Vascular	40.0 (–)	44.2 (6.38)	30.0 (2.44)	33.1 (4.1)	31.3 (3.06)	33.6 (3.41)
% Nonvascular	0	0	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	15.6 (5.98)	10.5 (4.8)	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	0	0	0	4.38 (4.38)	0	0
% Herbaceous	0	0.17 (0.17)	0.57 (0.2)	0.19 (0.1)	0	0
% Shrub	32.0 (–)	42.8 (6.69)	30.3 (1.66)	27.5 (3.0)	31.2 (3.09)	32.6 (3.46)
% Tree	0	0.67 (0.21)	4.43 (0.57)	0.38 (0.13)	0.05 (0.05)	0
% Vine	10.0 (–)	1.67 (1.67)	0	3.13 (1.2)	2.63 (1.04)	3.57 (1.33)

[a] Not captured during season   [b] Only 1 individual captured during season

Appendix C. (Continued)

	Dipodomys deserti			*Dipodomys merriami*		
Season	Spring	Summer	Fall	Spring	Summer	Fall
Canopy Height (m)	1.94 (0.25)	1.47 (0.13)	1.63 (0.14)	1.55 (0.17)	1.53 (0.16)	1.78 (0.16)
% Vascular	85.4 (2.71)	77.3 (3.81)	83.5 (1.5)	71.8 (2.38)	69.9 (2.3)	68.7 (2.49)
% Nonvascular	5.0 (3.37)	0	0	3.84 (1.53)	1.52 (0.76)	3.24 (1.04)
% Open Water	0	0	0	0	0	0.15 (0.15)
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0.22 (0.09)	0.16 (0.07)	0.15 (0.06)
% Graminoid	12.5 (5.76)	2.0 (1.45)	4.0 (1.72)	5.62 (1.11)	5.5 (1.24)	8.1 (1.6)
% Herbaceous	0	0.07 (0.07)	0.25 (0.25)	0.99 (0.36)	0.62 (0.28)	3.98 (1.69)
% Shrub	58.8 (6.86)	71.1 (5.43)	73.5 (3.72)	52.5 (2.46)	53.9 (2.57)	46.6 (2.17)
% Tree	18.3 (6.44)	6.67 (4.57)	10.0 (4.67)	18.1 (3.07)	16.8 (2.76)	18.0 (2.73)
% Vine	0	0	0	0.61 (0.27)	0.43 (0.21)	0.69 (0.23)

[a] Not captured during season [b] Only 1 individual captured during season

Appendix C. (Continued)

Season	*Dipodomys microps* Spring		*Dipodomys microps* Summer		*Dipodomys microps* Fall		*Mus musculus* Spring		*Mus musculus* Summer		*Mus musculus* Fall	
Canopy Height (m)	0.6	(0)	2.96	(1.76)	4.38	(1.8)	1.97	(0.64)	2.91	(0.1)	6.13	(0.91)
% Vascular	40.0	(0)	69.0	(10.3)	71.7	(12.6)	88.3	(9.8)	94.8	(1.5)	97.5	(2.5)
% Nonvascular	0		16.0	(9.8)	0		0		0.39	(0.12)	0	
% Open Water	0		0		0		0		0.34	(0.2)	0	
% Rock Outcrops	0		0		0		0		0		0	
Emergent Height (m)	0		0		0		0		0.02	(0.02)	0	
% Graminoid	0		6.0	(4.0)	6.67	(3.33)	40.8	(13.7)	71.7	(3.53)	8.75	(2.27)
% Herbaceous	0		8.0	(3.39)	3.5	(2.06)	14.2	(6.38)	15.1	(2.23)	25.0	(16.4)
% Shrub	37.5	(2.5)	41.4	(10.6)	39.7	(12.1)	30.0	(11.9)	5.1	(1.91)	23.8	(5.32)
% Tree	3.0	(2.0)	4.0	(2.45)	8.5	(1.98)	4.17	(2.01)	10.6	(1.02)	72.5	(17.0)
% Vine	0		2.0	(2.0)	0		0		0		6.25	(1.83)

[a] Not captured during season   [b] Only 1 individual captured during season

Appendix C. (Continued)

	Neotoma lepida			*Onychomys torridus*		
Season	Spring	Summer	Fall	Spring	Summer	Fall
Canopy Height (m)	2.53 (0.82)	2.38 (0.44)	2.35 (0.32)	1.45 (0.05)	1.4 (0)	1.83 (0.33)
% Vascular	70.6 (12.4)	68.1 (8.38)	68.9 (9.59)	82.5 (2.5)	80.0 (0)	88.3 (6.01)
% Nonvascular	15.6 (11.3)	1.88 (1.88)	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	12.5 (8.18)	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	7.5 (2.99)	10.0 (5.72)	1.92 (1.21)	0	0	6.67 (6.67)
% Herbaceous	24.5 (15.9)	19.1 (10.0)	15.8 (10.4)	0	0	0
% Shrub	36.1 (9.91)	28.1 (5.44)	39.1 (7.63)	60.0 (20.0)	80.0 (0)	53.3 (13.3)
% Tree	13.3 (10.0)	19.1 (8.88)	17.3 (8.37)	22.5 (22.5)	0	33.3 (16.9)
% Vine	0	1.88 (1.01)	0.77 (0.77)	0	0	0

[a] Not captured during season [b] Only 1 individual captured during season

Appendix C. (Continued)

Season	*Perognathus longimembris* Spring[b]	*Perognathus longimembris* Summer	*Perognathus longimembris* Fall	*Peromyscus crinitus* Spring	*Peromyscus crinitus* Summer	*Peromyscus crinitus* Fall[a]
Canopy Height (m)	2.5 (–)	4.75 (3.25)	0.69 (0.22)	1.33 (0.17)	1.5 (0)	
% Vascular	95.0 (–)	92.5 (7.5)	36.3 (13.8)	18.3 (1.67)	20.0 (0)	
% Nonvascular	0	0	0	0	0	
% Open Water	0	0	0	0	0	
% Rock Outcrops	0	0	0	0	0	
Emergent Height (m)	0	0	0	0	0	
% Graminoid	20.0 (–)	2.5 (2.5)	0	0	0	
% Herbaceous	0	5.0 (5.0)	1.25 (1.25)	0.33 (0.33)	0	
% Shrub	70.0 (–)	45.0 (5.0)	31.8 (12.4)	20.0 (2.0)	22.0 (0)	
% Tree	5.0 (–)	45.0 (0)	0	0	0	
% Vine	0	2.5 (2.5)	3.75 (3.75)	0	0	

[a] Not captured during season [b] Only 1 individual captured during season

Appendix C. (Continued)

Season	*Peromyscus eremicus* Spring	*Peromyscus eremicus* Summer	*Peromyscus eremicus* Fall	*Peromyscus maniculatus* Spring[a]	*Peromyscus maniculatus* Summer	*Peromyscus maniculatus* Fall[b]
Canopy Height (m)	3.93 (0.35)	4.19 (0.25)	3.9 (0.2)		1.33 (0.17)	1.0 (–)
% Vascular	88.4 (2.32)	89.7 (2.38)	91.0 (2.0)		36.7 (16.7)	60.0 (–)
% Nonvascular	0.86 (0.6)	1.07 (1.07)	0.61 (0.4)		10.0 (10.0)	40.0 (–)
% Open Water	0	0.12 (0.12)	0.09 (0.09)		0	0
% Rock Outcrops	0	0	0.47 (0.47)		0	0
Emergent Height (m)	0.12 (0.07)	0.06 (0.04)	0		0	0
% Graminoid	16.3 (3.44)	10.9 (2.38)	9.4 (1.97)		5.0 (5.0)	0
% Herbaceous	24.0 (4.52)	23.5 (4.35)	20.9 (3.71)		0	0
% Shrub	23.7 (2.82)	29.5 (2.35)	31.9 (1.96)		34.7 (12.7)	60.0 (–)
% Tree	35.1 (5.0)	50.4 (4.97)	56.0 (4.47)		0	0
% Vine	2.3 (0.47)	3.69 (0.52)	4.86 (0.47)		0	0

[a] Not captured during season [b] Only 1 individual captured during season

Appendix C. (Continued)

Season	*Reithrodontomys megalotis*			*Spermophilus tereticaudus*			*Thomomys bottae*		
	Spring	Summer	Fall	Spring[a]	Summer[a]	Fall[b]	Spring[b]	Summer[a]	Fall[a]
Canopy Height (m)	2.29 (0.16)	3.18 (0.12)	2.54 (0.43)			1.0 (–)	3.0 (–)		
% Vascular	86.4 (2.55)	91.3 (1.33)	96.0 (2.33)			90.0 (–)	100 (–)		
% Nonvascular	3.62 (1.38)	0.37 (0.1)	0			0	0		
% Open Water	0.59 (0.34)	0.24 (0.14)	0			0	0		
% Rock Outcrops	0	0	0			0	0		
Emergent Height (m)	0.04 (0.04)	0	0.3 (0.3)			0	0		
% Graminoid	38.3 (3.94)	70.4 (2.82)	14.0 (8.16)			0	60.0 (–)		
% Herbaceous	27.1 (3.51)	13.3 (1.6)	58.5 (14.9)			0	30.0 (–)		
% Shrub	20.1 (2.86)	4.35 (1.02)	5.5 (4.44)			90.0 (–)	0		
% Tree	9.47 (1.96)	12.0 (1.08)	19.0 (12.3)			0	10.0 (–)		
% Vine	0	0.13 (0.08)	0			0	0		

[a] Not captured during season [b] Only 1 individual captured during season

Appendix D. Mean (SE) for habitat variables for each habitat type at Ash Meadows NWR.

Season	Alkali Meadow			Alkali Seep		
	Spring	Summer	Fall	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	2.24 (0.06)	3.02 (0.05)	1.33 (0.1)	0.9 (0.1)	1.0 (0)	1.13 (0.03)
% Vascular	89.8 (0.75)	91.9 (0.59)	71.5 (2.34)	46.0 (6.0)	40.0 (0)	27.3 (3.04)
% Nonvascular	3.25 (0.48)	2.3 (0.27)	7.31 (1.05)	48.0 (12.0)	60.0 (0)	21.8 (9.13)
% Open Water	0.96 (0.27)	1.33 (0.3)	1.69 (0.37)	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0.01 (0.01)	0	0	0	0
% Graminoid	68.5 (0.96)	73.6 (0.82)	57.4 (2.31)	9.0 (4.0)	5.0 (0)	5.64 (0.15)
% Herbaceous	14.4 (0.65)	6.59 (0.38)	7.34 (0.58)	8.0 (2.0)	10.0 (0)	3.64 (1.52)
% Shrub	7.31 (0.57)	2.85 (0.29)	8.58 (1.01)	29.0 (4.0)	25.0 (0)	18.6 (1.52)
% Tree	5.09 (0.26)	9.4 (0.23)	3.7 (0.61)	0	0	0
% Vine	0	0	0	0	0	0

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

Season	Alkali Shrub/Scrub Spring	Alkali Shrub/Scrub Summer	Alkali Shrub/Scrub Fall	Alkali Sink Spring	Alkali Sink Summer	Alkali Sink Fall
Habitat Variable						
Canopy Height (m)	1.41 (0.08)	1.41 (0.13)	1.27 (0.08)	0.85 (0.03)	0.89 (0.03)	0.89 (0.03)
% Vascular	61.7 (1.29)	55.4 (1.55)	57.9 (1.45)	63.7 (3.21)	68.1 (3.11)	66.9 (3.23)
% Nonvascular	3.5 (0.65)	1.64 (0.43)	0.79 (0.35)	12.8 (2.67)	13.3 (2.75)	14.2 (2.89)
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	7.31 (0.52)	7.41 (0.53)	5.34 (0.39)	0.3 (0.3)	1.77 (1.06)	0.33 (0.33)
% Herbaceous	0.52 (0.1)	1.0 (0.15)	0.44 (0.09)	0	0	0
% Shrub	46.9 (1.38)	45.1 (1.57)	47.7 (1.55)	63.7 (3.14)	66.6 (3.01)	66.8 (3.17)
% Tree	3.08 (0.26)	2.13 (0.25)	2.97 (0.31)	0	0	0
% Vine	0	0	0	0	0	0

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

Season	Ash			Creosote Shrubland		
	Spring	Summer	Fall	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	4.92 (0.05)	5.0 (0)	5.0 (0)	1.08 (0.01)	1.18 (0.02)	1.23 (0.02)
% Vascular	88.5 (1.26)	85.0 (0)	85.0 (0)	39.7 (1.52)	43.2 (1.5)	40.47 (1.56)
% Nonvascular	0	0.93 (0.38)	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	8.08 (1.43)	4.22 (1.08)	0.32 (0.32)
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	18.3 (5.54)	5.0 (0)	5.0 (0)	0	0	0
% Herbaceous	5.19 (0.19)	5.0 (0)	5.0 (0)	0.14 (0.03)	0.03 (0.03)	0
% Shrub	3.89 (0.41)	5.0 (0)	5.0 (0)	38.1 (1.54)	41.1 (1.51)	39.4 (1.58)
% Tree	75.8 (4.0)	85.0 (0)	85.0 (0)	0.16 (0.04)	0.3 (0.09)	0.03 (0.03)
% Vine	0	0	0	3.47 (0.37)	3.61 (0.37)	2.97 (0.36)

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

	Dune (Mesquite)			Dune (Shrub)		
Season	Spring	Summer	Fall	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	2.23 (0.05)	2.13 (0.06)	2.19 (0.06)	1.43 (0.01)	1.42 (0.01)	1.43 (0.01)
% Vascular	87.8 (0.72)	84.6 (1.18)	86.7 (0.79)	80.0 (0)	80.0 (0)	80.0 (0)
% Nonvascular	3.74 (1.01)	0.23 (0.23)	0	7.33 (2.59)	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0.15 (0.06)	0.14 (0.06)	0	0	0	0
% Graminoid	10.2 (1.09)	9.88 (1.18)	11.9 (1.28)	0	0	0
% Herbaceous	0	0	0	0	0	0
% Shrub	43.0 (0.38)	40.6 (0.46)	41.4 (0.26)	80.0 (0)	80.0 (0)	80.0 (0)
% Tree	45.6 (0.68)	46.8 (0.82)	48.4 (0.63)	0	0	0
% Vine	0	0	0	0	0	0

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

Season	Emergent Marsh			Mesquite Bosque		
	Spring	Summer	Fall	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	3.33 (0.04)	3.02 (0.04)	3.06 (0.05)	2.28 (0.12)	2.14 (0.27)	1.04 (0.04)
% Vascular	99.2 (0.42)	99.8 (0.09)	90.9 (3.02)	92.6 (0.58)	95.0 (0)	95.0 (0)
% Nonvascular	0.89 (0.32)	0.57 (0.27)	0.28 (0.14)	2.57 (0.72)	0	0
% Open Water	0	0	2.25 (1.58)	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	1.0 (0.14)	2.29 (0.17)	2.47 (0.16)
% Graminoid	8.41 (0.84)	16.7 (1.66)	5.62 (1.37)	28.0 (1.4)	28.3 (0.82)	25.0 (0)
% Herbaceous	53.3 (1.41)	64.3 (1.73)	82.7 (3.44)	0	0	0
% Shrub	32.5 (1.47)	14.5 (1.9)	2.04 (0.59)	38.1 (1.64)	39.5 (1.36)	45.0 (0)
% Tree	9.87 (0.5)	8.11 (0.79)	1.06 (0.6)	74.7 (2.94)	87.9 (2.99)	100 (0)
% Vine	0.05 (0.04)	0	0	0	0	0

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

Season	Non-Native/ Weeds Spring	Non-Native/ Weeds Summer	Non-Native/ Weeds Fall	Riparian Shrubland Spring	Riparian Shrubland Summer	Riparian Shrubland Fall
Habitat Variable						
Canopy Height (m)	2.39 (0.11)	1.5 (0)	2.5 (0)	4.67 (0.17)	4.75 (0.06)	4.5 (0)
% Vascular	100 (0)	100 (0)	100 (0)	71.7 (3.33)	70.0 (1.29)	75.0 (0)
% Nonvascular	0	0	0	0	0	0
% Open Water	0	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	2.67 (0.33)	0	0	0	0	0
% Graminoid	12.2 (12.2)	110 (0)	0	20.0 (10.0)	15.0 (3.87)	30.0 (0)
% Herbaceous	80.0 (5.0)	40.0 (0)	85.0 (0)	6.67 (6.67)	10.0 (2.58)	0
% Shrub	0	0	0	41.7 (3.33)	40.0 (1.29)	45.0 (0)
% Tree	13.3 (1.67)	0	15.0 (0)	19.0 (1.0)	18.5 (0.39)	20.0 (0)
% Vine	0	0	0	0	0	0

[a] Only 1 trap in trap line passed through habitat type   [b] No traps during season

Appendix D. (Continued)

	Riparian Woodland			Salt Desert Scrub		
Season	Spring	Summer	Fall	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	6.07 (0.15)	5.62 (0.19)	5.82 (0.18)	0.7 (0.05)	1.3 (0)	1.3 (0)
% Vascular	96.4 (1.16)	94.9 (1.41)	97.5 (0.73)	42.9 (1.56)	60.0 (0)	60.0 (0)
% Nonvascular	0	0	0	5.71 (3.13)	37.8 (2.22)	35.0 (5.0)
% Open Water	2.31 (1.14)	0	0	0	0	0
% Rock Outcrops	0	0	0	0	0	0
Emergent Height (m)	0	0	0	0	0	0
% Graminoid	16.3 (1.54)	16.7 (1.8)	17.1 (1.79)	0	0	0
% Herbaceous	3.47 (1.38)	1.38 (0.6)	0.29 (0.29)	2.14 (1.17)	14.2 (0.83)	13.1 (1.88)
% Shrub	47.7 (1.87)	36.9 (1.39)	37.9 (1.22)	36.4 (0.78)	45.0 (0)	45.0 (0)
% Tree	83.1 (2.1)	88.4 (2.61)	92.2 (2.09)	4.29 (0.39)	0	0
% Vine	4.08 (0.4)	6.65 (0.45)	7.1 (0.44)	0	0.83 (0.83)	1.88 (1.88)

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

Season	Tamarisk			Transitioning Agriculture		
	Spring[a]	Summer	Fall[b]	Spring	Summer	Fall
Habitat Variable						
Canopy Height (m)	4.0 (–)	3.88 (0.01)		3.31 (0.27)	3.38 (0.27)	3.33 (0.34)
% Vascular	50.0 (–)	55.7 (0.67)		78.6 (2.23)	79.6 (1.93)	74.1 (2.65)
% Nonvascular	0	0.51 (0.14)		15.6 (2.11)	16.3 (2.18)	25.8 (2.66)
% Open Water	0	0.11 (0.05)		0.45 (0.18)	0.43 (0.17)	0.1 (0.1)
% Rock Outcrops	0	0		0	0	0
Emergent Height (m)	0	0.02 (0.01)		0	0.03 (0.02)	0
% Graminoid	30.0 (–)	30.4 (0.16)		16.3 (1.51)	11.2 (0.81)	10.1 (0.64)
% Herbaceous	5.0 (–)	6.9 (0.24)		12.6 (1.59)	15.7 (2.2)	4.95 (1.15)
% Shrub	1.0 (–)	0.88 (0.01)		44.5 (1.88)	42.5 (1.94)	49.3 (1.64)
% Tree	15.0 (–)	18.4 (0.4)		13.8 (1.77)	16.0 (1.77)	15.5 (2.17)
% Vine	0	0		1.48 (0.2)	1.58 (0.2)	1.7 (0.24)

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

Appendix D. (Continued)

	Wet Meadow		
Season	Spring	Summer	Fall
Habitat Variable			
Canopy Height (m)	1.76 (0.11)	1.61 (0.05)	2.70 (0.25)
% Vascular	97.2 (0.78)	99.1 (0.09)	98.3 (0.61)
% Nonvascular	4.26 (1.07)	0.79 (0.26)	0.12 (0.12)
% Open Water	1.32 (0.76)	0	0
% Rock Outcrops	0	0	0
Emergent Height (m)	0	0	0
% Graminoid	95.3 (2.0)	109 (1.17)	109 (4.49)
% Herbaceous	10.5 (1.55)	2.87 (0.21)	1.57 (0.56)
% Shrub	4.47 (0.6)	2.72 (0.54)	0.02 (0.02)
% Tree	1.95 (0.26)	4.62 (0.27)	5.71 (1.74)
% Vine	0	0	0

[a] Only 1 trap in trap line passed through habitat type [b] No traps during season

LITERATURE CITED

Abaturov, B. D. 1972. The role of burrowing animals in the transport of mineral substances in the soil. Pedobiologia 12:261-266.

Abd El-Ghani, M. M. and A. G. Fahmy. 1998. Composition of and changes in the spontaneous flora of Feiran Oasis, S Sinai, Egypt, in the last 60 years. Willdenowia 28:123-134.

Allred, D. M. and D. E. Beck. 1963. Ecological distribution of some rodents at the Nevada Atomic Test Site. Ecology 44:211-214.

Baskaran, L. M., V. H. Dale, R. A. Efroymson, and W. Birkhead. 2006. Habitat modeling within a regional context: an example using gopher tortoise. American Midland Naturalist 155:335-351.

Beatley, J. C. 1976a. Environments of kangaroo rats (*Dipodomys*) and effects of environmental change on populations in southern Nevada. Journal of Mammalogy 57:67-93.

Beatley, J. C. 1976b. Rainfall and fluctuating plant populations in relation to distributions and numbers of desert rodents in southern Nevada. Oecologia 24:21-42.

Belk, M. C. and H. D. Smith. 1991. *Ammospermophilus leucurus*. Mammalian Species 368:1-8.

Best, T. L., N. J. Hildreth, and C. Jones. 1989. *Dipodomys deserti*. Mammalian Species 339:1-8.

BIO-WEST, Inc. 2009. Ash Meadows National Wildlife Refuge: Vegetation mapping and rare plants survey 2008 progress report. Ash Meadows National Wildlife Refuge. Desert National Wildlife Refuge Complex. Las Vegas, Nevada, USA.

BIO-WEST, Inc. 2010. Ash Meadows National Wildlife Refuge: Wildlife baseline inventory final report. Ash Meadows National Wildlife Refuge. Desert National Wildlife Refuge Complex. Las Vegas, Nevada, USA.

Bornkamm, R. and H. Kehl. 1990. The plant communities of the western desert of Egypt. Phytocoenologia 19:149-231.

Bradley, W. G. and R. A. Mauer. 1973. Rodents of a creosote bush community in southern Nevada. Southwestern Naturalist 17:333-344.

Brown, J. H., G. A. Lieberman, and W. F. Dengler. 1972. Woodrats and cholla: dependence of a small mammal population on the density of cacti. Ecology 53:310-314.

Brown, J. H. 1975. Geographical ecology of desert rodents. Pages 315-341 *in* M. L. Cody and J. M. Diamond, editors. Ecology and evolution of communities. Harvard University Belknap Press, Cambridge, Massachusetts.

Brown, J. H. 1986. The roles of vertebrates in desert ecosystems. Pages 51-71 *in* W.G. Whitford, editor. Patterns and process in desert ecosystems. University of New Mexico Press, Albuquerque, USA.

Brown, J. H. and E. J. Heske. 1990. Control of a desert-grassland transition by a keystone rodent guild. Science 250:1705-1707.

Brylski, P. V. 1998. Los Angeles pocket mouse, *Perognathus longimembris brevinasus*. Terrestrial Mammal Species of Special Concern in California 111-113.

Catlett, R. H. and H. S. Shellhammer. 1962. A comparison of behavioral and biological characteristics of house mice and harvest mice. Journal of Mammalogy 42:133-144.

Chew, R. M. and A. E. Chew. 1970. Energy relationships of the mammals of a desert shrub (*Larrea tridentata*) community. Ecological Monographs 40:1-19.

Davis, W. B. 1966. The mammals of Texas. Bulletin Texas Game and Fish Commission 41:5-267.

Deacon, J. E. 2003. National wildlife refuge: Ash Meadows oasis. Pages 8-9 *in* Desert Report. Sierra Club California/Nevada Desert Committee, Los Angeles, California, USA.

Edwards Jr., T. C., E. Deshler, D. Foster, and G. G. Moison. 1996. Adequacy of wildlife habitat relations models for estimating spatial distributions of terrestrial vertebrates. Conservation Biology 10:263-270.

Eisenberg, J. F. 1963. The intraspecific social behavior of some cricetine rodents of the genus *Peromyscus*. American Midland Naturalist 69:240-246.

Ernest, K. A. and M. A. Mares. 1987. *Spermophilus tereticaudus*. Mammalian Species 274:1-9.

Fisher, A. K., L. H. Stejneger, C. H. Gilbert, C. V. Riley, C. H. Merriam, R. E. C. Stearns, and T. S. Palmer. 1893. The Death Valley Expedition: A Biological Survey of Parts of California, Nevada, Arizona, and Utah. Part II. Government Printing Office. Washington, D.C.

Geluso, K. N. 1999. Long-tailed pocket mouse, *Chaetodipus formosus*. Pages 511-512 *in* D. E. Wilson and S. Ruff, editors. The Smithsonian book of North American mammals. Smithsonian Institution Press, Washington, D.C.

Gist, C. S. and P. R. Sferra. 1978. Animal consumer roles in desert nitrogen cycles. Pages 152–164 *in* N. E. West and J. Skujins, editors. Nitrogen in desert ecosystems Dowden, Hutchinson and Ross, Pennsylvania, USA.

Kerley, G. I. H., W. G. Whitford, and F. R. Kay. 1997. Mechanisms for the keystone status of kangaroo rats: graminivory rather than granivory? Oecologia 111:422-428.

Grinnell, J. 1937. Mammals of Death Valley. Proc. California Academy of Science, Fourth Series 23:115-169.

Heske, E. J., J. H. Brown, and Q. Guo. 1993. Effects of kangaroo rat exclusion on vegetation structure and plant species diversity in the Chihuahuan Desert. Oecologia 95:520-524.

Hayssen, V. 1991. *Dipodomys microps*. Mammalian Species 389:1-9.

Johnson, D. W. and D. M. Armstrong. 1987. *Peromyscus crinitus*. Mammalian Species 287:1-8.

Jones, C., W. J. McShea, M. J. Conroy, and T. Kunz. 1996. Capturing mammals. Pages 115-155 *in* D. E. Wilson, F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster, editors. Measuring and monitoring biological diversity: standard methods for mammals. California Department of Forestry and Fire Protection, Sacramento, California, USA.

Jones, C. A. and C. N. Baxter. 2004. *Thomomys bottae*. Mammalian Species 742:1-14.

Jorgensen, E. E., S. Demarais, S. M. Sell, and S. P. Lerich. 1998. Modeling habitat suitability for small mammals in Chihuahuan Desert foothills of New Mexico. Journal of Wildlife Management 62:989-996.

Jorgensen, E. E. 2004. Small mammal use of microhabitat reviewed. Journal of Mammology 85:531-539.

Kelt, D. A., J. H. Brown, E. J. Heske, P. A. Marquet, S. R. Morton, J. W. Reid, K. A. Rogovin, and G. Shenbrot. 1996. Community structure of desert small mammals: comparisons across four continents. Ecology 77:746-761.

Krebs, C. J. 1999. Ecological methodology. Second edition. Benjamin Cummings, Menlo Park, California, USA.

Mantooth, S. J. and B. R. Riddle. 2005. Annotated checklist of the recent mammals of Nevada. Occasional Papers, The Museum of Texas Tech University 245:1-19.

McCarty, R. 1975. *Onychomys torridus*. Mammalian Species. 59:1-5.

Merriam, C. H. 1895. The geographic distribution of animals and plants of North America. United States Department of Agriculture, Division of Ornithology and Mammalogy, Washington, D.C.

Munger, J. C., M. A. Bowers, and W.T. Jones. 1983. Desert rodent populations: factors affecting abundance, distribution, and genetic structure. Great Basin Naturalist Memoirs 7:91-116.

Nowak, R. M. and J. L. Paradiso. 1983. Walker's mammals of the world. 4th Edition. The Johns Hopkins University Press, Baltimore, Maryland. Pages 554–757.

Noy-Meir, I. 1973. Desert ecosystems: environment and producers. Annual Review of Ecology and Systematics 4:25-51.

Otis Bay, Inc. and Stevens Ecological Consulting, LLC. 2006. Ash Meadows geomorphic and biological assessment. United States Department of the Interior, United States Fish and Wildlife Service, Ash Meadows National Wildlife Refuge, Final Report: 1-229.

Pavlik, B. M. 2008. The California deserts: an ecological rediscovery. Pages 17-96. University of California Press, Berkeley and Los Angeles, California, London, England.

Russell, W. C. 1933. Nevada–1933. Pages 1-23. The Museum of Vertebrate Zoology. Berkeley, California, USA.

Sanchez, P. G. 1981. Ash Meadows scenario. Pages 144-147. California-Nevada wildlife transactions. The Western Section of The Wildlife Society. Albany, California, USA.

United States Fish and Wildlife Service. 1990. Recovery plan for the endangered and threatened species of Ash Meadows, Nevada. United States Department of the Interior. Washington, D.C.

United States Fish and Wildlife Service. 1998. Recovery plan for upland species of the San Joaquin Valley, California. United States Department of the Interior. Washington, D.C.

United States Fish and Wildlife Service. 2005. Meadows fire burned area emergency stabilization plan. United States Department of the Interior. Washington, D.C.

United States Fish and Wildlife Service. 2008. Desert National Wildlife Refuge complex: Ash Meadows, Desert, Moapa Valley, and Pahranagat National Wildlife Refuges. Draft Comprehensive Conservation Plan and Environmental Impact Statement. United States Department of the Interior, Washington, D.C.

Verts, B. J. and L. N. Carraway. 2002. *Neotoma lepida*. Mammalian Species 699:1-12.

Webster, W. D. and J. K. Jones. 1982. *Reithrodontomys megalotis*. Mammalian Species 167:1-5.

West, N. E. and J. Skujins. 1978. Summary, conclusions and suggestions for further research. Pages 244-253 *in* N. E. West, and J. Skujins, editors. Nitrogen in desert ecosystems. Dowden, Hutchinson and Ross, Pennsylvania, USA.

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