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Composition of the Community of Small Mammals in the Great Basin Desert

Samantha Elizabeth Phillips
Brigham Young University

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Samantha Elizabeth Phillips

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Brock R. McMillan, Chair
Randy T. Larsen
Steve L. Petersen

Department of Plant and Wildlife Sciences

Brigham Young University

ABSTRACT

Community Composition of Small Mammals in the Great Basin Desert

Samantha Elizabeth Phillips
Department of Plant and Wildlife Sciences, BYU
Master of Science

Small mammals are a keystone guild in arid ecosystems; often exhibiting top-down control of the diversity and structure of plant communities. However, changing climate, shifting fire regimes, and the invasion of exotic plants are modifying the structure of arid systems. Environmental changes in these arid systems are likely altering small mammal communities, and therefore, their ecological role. We examined two aspects of the community composition of small mammals in the Great Basin: changes in community composition since large scale sampling of the region began in 1930, and the current population of a sensitive species of small mammal, the dark kangaroo mouse (*Microdipodops megacephalus*). In Chapter 1, we compared diversity and composition of present day small mammal communities to communities sampled between the years of 1930 and 1980. We sampled 234 historical locations across the eastern Great Basin region during the summers of 2014 and 2015. Our results indicated that diversity, richness, and evenness of small mammals in the Great Basin have declined significantly over the last century ($P=0.002$, $P=0.03$, $P=0.002$). The relative abundance of generalist species has increased, while specialist species have declined ($P<0.001$, $P<0.001$). Also, community composition at each site has changed significantly over the past century. Alterations in the community structure of small mammals may have cascading implications for the future of the Great Basin ecoregion. In Chapter 2, we conducted a region-wide survey for the dark kangaroo mouse in western Utah. Four teams sampled 232 locations across western Utah during the summers of 2014-2015. Of the 232 sites sampled, only 5 sites resulted in dark kangaroo mouse captures, totaling 15 individuals. These results could indicate a state-wide population decline for this species, both compared to historic population levels and to the populations surveyed less than ten years ago. The rapid decline may be a result of habitat degradation associated with invasive plant species and increasing fire frequency, the effects of which are exacerbated by the dark kangaroo mouse's life history as an ecological specialist. Unless large-scale habitat restoration and preservation is conducted for remaining populations, it is likely the dark kangaroo mouse will continue to decline within the state.

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CHAPTER 1

Comparison of Historical and Present-Day Small Mammal Communities in the Great Basin

Samantha E. Phillips[a], Eric Rickart[b], Robert N. Knight[c], Kimberly A. Hersey[d], and Brock R. McMillan[a]
[a]Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT
[b]Natural History Museum of Utah, University of Utah, Salt Lake City, UT
[c]Natural Resources Office, Dugway Proving Grounds, Dugway, UT
[d]Division of Wildlife Resources, Springville, UT

ABSTRACT

Small mammals are a keystone guild in arid ecosystems; often exhibiting top-down control of the diversity and structure of plant communities. However, changing climate, shifting fire regimes, and the invasion of exotic plants are modifying the structure of arid systems. Environmental changes in these arid systems are likely altering small mammal communities, and therefore, their ecological role. Our objective was to determine if there have been shifts in the small mammal communities of the Great Basin Desert over the past century. We compared diversity and composition of present day small mammal communities to communities sampled between the years of 1930 and 1980. We sampled 234 historical locations across the eastern Great Basin region during the summers of 2014 and 2015. Our results indicated that diversity, richness, and evenness of small mammals in the Great Basin have declined significantly over the last century ($P=0.002$, $P=0.03$, $P=0.002$). The relative abundance of generalist species has increased, while specialist species have declined ($P<0.001$, $P<0.001$). Also, composition of the community of small mammals at each site has changed significantly over the past century. Alterations in the community structure of small mammals may have cascading implications for the future of the Great Basin ecoregion.

INTRODUCTION

Small mammals are a keystone guild in arid ecosystems; often exhibiting top-down control of the diversity and structure of plant communities (Brown and Heske, 1990; St. Clair et al, 2016). In their role as seed predators, small mammals act to control the spread and propagation of plant species (Guo et al, 1995; Brown and Heske, 1990; Howe and Brown, 2001). Each small mammal species has a unique set of foraging, seed-handling, and consumption behaviors, including seed preference, type of cache, caching pattern, preferred foraging locations, and so forth. The foraging, seed predation and dispersal behaviors exhibited by each species results in a unique controlling effect on native plant propagation and dispersal (Brown and Leiberman, 1973). Small mammals often store seeds for later consumption, a behavior known as hoarding (Ostoja, 2008). Seeds may be kept in a few central locations known as larders, or they may be kept in several shallow holes scattered around the individual's home range, called scatter-hoarding (Ostoja, 2008). Species of small mammals that scatter-hoard tend to facilitate the propagation of their preferred prey species, while species that larder-hoard tend to retard the propagation of their prey species (Longland, et al 2001; Theimer, 2005; Ostoja, 2008). Given that scatter-hoarding results in highly favorable micro-climates for germination of several plant species, this process may be a critical component of seed dispersal and plant establishment in arid regions (Vander Wall, 1994; Vander Wall, 2010; Ostoja, 2008). On the other hand, plant species whose seeds are preferred for immediate consumption exhibit reduced propagation in comparison with less-preferred species, or with species whose seeds are preferred for hoarding (Brown et al, 1979; Vander Wall, 1992). In addition, each small mammal species is adapted to foraging in specific microhabitat conditions, either open canopy (bipedal species, such as *Dipodomys* or *Microdipodops*) or closed canopy (quadrupedal species, such as *Peromyscus*)

(Brown and Leiberman, 1973; Harris, 1986; Swartz, 2010). These foraging patterns influence the types of seed each species is likely to encounter or hoard (Brown and Leiberman, 1973; Ostoja, 2008). Changes in the species composition of small mammal communities are likely to indirectly result in altered patterns of native vegetation diversity and structure (Longland et al, 2001; St. Clair et al, 2016).

Changing climate and the spread of invasive plant species may alter the historical role of small mammal communities in ecosystem control. Current predictions of the effects of climate change in the Great Basin indicate an increase in overall precipitation, as well as an increase in the proportion of precipitation falling as rain during summer monsoons rather than as winter snow (Karl et al, 1996; Mote et al, 2005). Altered precipitation regimes may result in a significant change in current vegetation communities, even increasing susceptibility to invasion by non-native plant species (Weltzin et al, 2003; Chambers and Wisdom, 2009). The most problematic invasive plants in the Great Basin are generally fast-growing annuals that fill in inter-shrub spaces and vastly increase both the risk of fire ignition and the spread of existing fires (Brooks et al, 2004). More frequent and intense fire regimes are resulting in the removal of native shrubs and bunchgrasses from the landscape, as plants native to the Great Basin are generally fire-intolerant and are out-competed in burned areas by invasive species (Whisenant, 1990; Keane et al, 2002). The reduction in abundance of the native plant species used for forage and cover by small mammals may be creating a bottom-up forcing effect controlling the distribution of small mammal species (Stewart, 1949; Hall, 2012). Changes in available habitat and forage are reflected in the biodiversity of the small mammal species inhabiting these areas. Specialist species relying on specific habitat types or plant species tend to be reduced in areas of intense cheatgrass invasion, where adaptable generalist species tend to increase in abundance (Hall, 2012; Freeman et al, 2014).

The objective of this study was to identify shifts in the small mammal community of the Great Basin Desert over the past century. More specifically, we compared the diversity and species composition of small mammals in the early 20th century to the communities present in the same locations today. Given that the Great Basin region has experienced changes in climate and invasion by cheatgrass and other exotic species, we predicted that: 1) the diversity of small mammal communities would decrease, and 2) there would be a disproportionate loss of specialist species, while generalist species would be relatively unaffected.

METHODS

Study Area

During 2014 and 2015, we sampled small mammal communities at 234 sites across the Great Basin Desert of Utah (Fig. 1). Sites were located in Iron, Beaver, Millard, Juab, Tooele, and Box Elder counties, Utah, between 41˚30' N – 37˚31' N (north to south) and 114˚0' W – 112˚15' W (east to west). Each site was located on valley floors between 1,300 and 1,900 meters in elevation. Plant communities were generally shrubby and characterized by big sagebrush (*Artemisia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Ericameria nauseosa*), four-wing saltbush (*Atriplex canascens*), shadscale (*Atriplex confertifolia*), or greasewood (*Sarcobatus vermiculatus*), with minor herbaceous understories. Soils were primarily sandy to gravelly, ranging from unconsolidated dunes to hardpan.

Small Mammal Sampling Protocols

We sampled small mammals at each site for four consecutive nights. To sample small mammals, we established an array of two parallel transects 360 meters long, placed 100 meters apart (Fig. 2). Each transect contained 25 trap points spaced 15 meters apart, for a total of 50 trap points at each site. A trap point consisted of 2 traps placed approximately 1 meter to either side of the trap transect (100 total traps per site). Transects were oriented along natural habitat corridors in order to remain within one habitat type. We used 7.6 x 7.6 x 30.5 centimeter collapsible Sherman live traps baited with commercially available bird seed mix. Each trap was provided with 5 grams of polyester batting. Traps were closed each morning before daily temperatures rose above 23 °C and reopened each evening within 90 minutes of sunset. These precautions were taken to avoid potential heat-related mortalities. We identified captured small mammals to species and collected basic live-trap data for each individual (age, weight, sex, reproductive condition, etc). As a non-invasive temporary recapture marker, each individual was shaved on the right rump before release at the trap site. All sampling and handling procedures were approved by the IACUC at Brigham Young University.

Historical trapping efforts at our sample sites were widely varied and inconsistently recorded. Most records indicate a transect trap system of varying length, trapped for 1-4 consecutive nights using commercial snap traps. Little information has survived regarding bait types or trap placement. Due to a lack of complete records, we were unable to exactly match our trap protocols to those used at these sites previously (Fig. 3). However, we were able to use field journals to reconstruct trap effort at each site as quantified by trap nights (one trap open for one night). We then matched trap effort at each site as closely as possible. From our sample set, we selected a few study sites for direct comparison based upon records of historical trapping sites

collected in the Utah Heritage Database and the Natural History Museum of Utah (NHMU) (Fig. 4; Table 1). We selected only those sites with more than 50 specimen records. Using historical field notes and journals kept by NHMU, we then selected those sites with preserved records of trapping protocols and effort. After applying these filters, we were left with 6 sites at which we could directly match trap effort for an accurate comparison of community diversity. The remainder of our study sites were then used apply the comparison across the region.

Data Analysis

To assess the potential changes in the community of small mammals of the Great Basin, we calculated a series of standard diversity measures for both the current and historical sampling data. The measures of community diversity of small mammals we calculated at each site were species richness, species evenness, and species diversity. For richness, we used number of species at each site rather than rarefaction curves, given the very large sample effort and low relative diversity of the system. We then measured species evenness at each site, specifically using Pielou's measure of evenness (Alatalo, 1981). Next, we calculated diversity at each site using Shannon's diversity index. We chose to use Shannon's index over Simpson's diversity index because it is more sensitive to changes in rare species (Smith and Grassle, 1977).

We compared the diversity measures (richness, evenness, and diversity) of our six modern samples to those of the other 228 sites we sampled to determine if they were representative of the region. We used unpaired two-tailed Welch's unequal variance t-tests, the appropriate test for different sample sizes (Dannenburg et al, 1994). The six modern sites were then compared to the diversity measures of their six historical counterparts using paired two-tailed Student's t-tests.

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We examined relative abundances of each species present in our sample, as well as community composition across all six sites, current and historical. To do this, we calculated the percentage of total individuals represented by each species found across all sites. We then compared the current proportions of each species to its historical relative abundances using a paired two-tailed Student's t-test. Finally, we compared the species composition of each modern sample to its historical sample. We used Morisita's similarity index to compare the composition of each site to its previous self. We chose to use Morisita's index because it is independent of sample size and diversity (Wolda, 1981). This allowed us to compare each site despite potential changes in species diversity.

RESULTS

We captured 3,389 unique individuals over the course of 93,600 trap nights. The captured individuals included representatives from 14 species, 11 genera, and 4 families. In decreasing order of abundance, we captured: deer mouse (*Peromyscus maniculatus*), Ord's kangaroo rat (*Dipodomys ordii*), chisel-toothed kangaroo rat (*Dipodomys microps*), northern grasshopper mouse (*Onychomys leucogaster*), little pocket mouse (*Perognathus longimembris*), white-tailed antelope squirrel (*Ammospermophilus leucurus*), western harvest mouse (*Reithrodontomys megalotis*), long-tailed pocket mouse (*Chaetodipus formosus*), Great Basin pocket mouse (*Perognathus parvus*), desert woodrat (*Neotoma lepida*), dark kangaroo mouse (*Microdipodops megacephalus*), pinyon mouse (*Peromyscus trueii*), least chipmunk (*Tamius minimus*), and house mouse (*Mus musculus*).

The historical data included 826 individuals captured over approximately 12,450 trap nights. The captured individuals represented 15 species, 11 genera, and 4 families. In decreasing

order of abundance, the species represented were: deer mouse, Ord's kangaroo rat, dark kangaroo mouse, chisel-toothed kangaroo rat, long-tailed pocket mouse, little pocket mouse, western harvest mouse, desert woodrat, northern grasshopper mouse, least chipmunk, canyon mouse, montane vole, white-tailed antelope squirrel, pinyon mouse, and Great Basin pocket mouse.

Small mammal diversity, species richness, and species evenness were significantly different between the historical and modern times at the same locations. Species diversity (modern = 1.0255, historical = 1.9984, t = 5.72, p < 0.01), average species richness (modern = 7, historical = 11, t = 2.92, p = 0.03), and species evenness (modern = 0.5696, historical = 0.8479, t = 5.65, p < 0.01), were lower in the current communities than at the historical sites (Fig. 5; Fig. 6; Fig. 7). In addition, we compared the diversity indices of our 6 chosen locales to the other 228 sites and found that the chosen comparison sites had significantly more species diversity than the average location in the Great Basin (chosen sites = 1.0255, average = 0.6232, t = -3.06, p = 0.02). In other words, the most diverse communities now present in the eastern Great Basin were still significantly less diverse than their historical counterparts.

The relative abundances of each small mammal species were significantly different during the historical and modern times at the same locations. Of the 16 species represented in our dataset, 13 were present in significantly different proportions in modern communities than were observed in the historical data (Fig. 8). The three exceptions, *P. trueii*, *P. parvus*, and *M. musculus*, were not caught in sufficient numbers in either dataset to allow for statistical comparison. *P. maniculatus* (p < 0.01), *D. ordii* (p = 0.02), and *O. leucogaster* (p = 0.01) all showed significant increases in their relative abundance over their historical representation, while *D. microps* (p < 0.01), *R. megalotis* (p < 0.01), *N. lepida* (p < 0.01), *P. longimembris* (p < 0.01), *C. formosus* (p < 0.01), *A. leucurus* (p = 0.01), *M. megacephalus* (p < 0.01), and *T.*

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minimus (p < 0.01) showed significant decreases in relative abundance. *M. montanus* (p < 0.01) and *P. crinitus* (p < 0.01) were both completely absent from the modern sites.

The community composition of small mammals underwent significant changes at several of our sites since the collection of the historical data (Fig. 9). We compared the composition of the small mammal community at each site to its historical capture data and found that three sites were strongly dissimilar (Trout Creek: 0.1962; Desert Range Exp. Station: 0.2354; and Fish Springs: 0.3093). The other three sites were moderately dissimilar to the historical capture data (Tule Valley: 0.4828; N Granite Peak: 0.5371; and N 5 Mile Hill: 0.6822).

DISCUSSION

In accordance with our first prediction, the species diversity of small mammals declined over the past 80 years at all sites resampled. The decrease appears to have been most influenced by the decline of sensitive habitat specialists such as *M. megacephalus* and *C. formosus*. The average species richness and evenness of all sites have also declined at all resampled sites. Diversity and the measures thereof (diversity indices, richness, evenness) are considered important because of the effects changing diversity can have on the function of an ecosystem (Tilman, 1999; Tilman et al, 1997). High diversity in a guild or community can lead to increased ecosystem stability and resilience, while depauperate ecosystems are vulnerable to disturbance (Isbel et al, 2015; Lehman and Tilman, 2000; St Clair et al, 2016). Declining diversity measures prompt concern due to the importance of diversity in protecting ecosystem function. The changes in diversity of small mammals we have observed may be linked to changes in habitat or productivity (Abramsky, 1978), though at present we lack the data to quantify any potential long-term changes in local vegetation or soil qualities.

Decreasing diversity in small mammal communities appears to be representative of the current state of the Great Basin ecoregion. By comparing our six study sites to the other 226 sites we sampled across the eastern Great Basin, we determined that our resample sites were the most diverse locations in our study set. However, these most diverse sites were still significantly less diverse than they were 80 years prior, which suggests a widespread decline in small mammal species diversity across the entire region. A region-wide downward trend in diversity indicates that the cause of the decline is widespread and pervasive, rather than specific to certain vulnerable locations.

There are many potential culprits that may be causing declines in the species diversity of small mammals in the Great Basin. Three of the most prominent and likely drivers are climate change, invasive species, and altered fire regimes. Current predictions of the effects of climate change in the Great Basin indicate an increase in overall precipitation, as well as an increase in the proportion of precipitation falling as rain rather than as snow (Karl et al, 1996; Mote et al, 2005). Altered precipitation regimes may result in a significant change in current vegetation communities, even increasing susceptibility to invasion by non-native plant species (Weltzin et al, 2003; Chambers and Wisdom, 2009). The most problematic invasive plants in the Great Basin are generally fast-growing annuals that fill in inter-shrub spaces and vastly increase both the risk of fire ignition and the spread of existing fires (Brooks et al, 2004; Freeman et al, 2014). More frequent and intense fire regimes are resulting in the removal of native shrubs and bunchgrasses from the landscape, as plants native to the Great Basin are generally fire-intolerant and are out-competed in burned areas by invasive species (Whisenant, 1990; Keane et al, 2002; Horne et al, 2012). The reduction in abundance of the native plant species used for forage and cover by small mammals may be creating a bottom-up forcing effect controlling the distribution of small mammal species (Stewart, 1949; Hall, 2012; Freeman et al, 2014; Sharp et al, 2017). Changes in

available habitat and forage are reflected in the biodiversity of the small mammal species inhabiting these areas (Freeman et al, 2014). Specialist species relying on specific habitat types or plant species tend to be reduced in areas of intense cheatgrass invasion, where adaptable generalist species tend to increase in abundance (Hall, 2012; Freeman et al, 2014).

Overall abundance of small mammals has remained steady, but there has been a shift in composition. Abundance of specialist species has declined, while a few generalist species have increased in abundance. The observed changes in relative abundance appear to support current theories of zero-sum dynamics in the community composition of small mammals (Brown and Heske, 1990; Brown and Leiberman, 1973; Heske et al, 1993; Ernest et al, 2008). Where sensitive specialist species are in decline (*M. megacephalus, P. longimembris, C. formosus*), generalist species have increased to fill the gap of available biomass (*P. maniculatus, D. ordii*). The result is a community of small mammals that is less diverse, less specialized, and potentially less functional in the ecosystem. Our use of Morisita's dissimilarity index revealed major (>0.5) shifts in community composition at 3 out of 6 study sites, with moderate shifts at the other three (>0.25, <0.5). Shifts in community composition were observed even at sites with no significant differences in species richness, indicating a change in species assemblage. Major shifts in community composition may result in less functional ecosystems, as specialized species are replaced by species not previously found in the studied habitats.

As the diversity and composition of small mammal communities change, the function of the ecosystem may be altered (Vander Wall, 2010). Each species in a guild of small mammals has a unique set of foraging and seed caching behaviors, including seed selectivity, rates of immediate consumption, use of scatter hoards versus larder hoards, and placement of hoards (Hollander and Vander Wall, 2004). Each foraging strategy results in unique effects on the spread and propagation of local plant species (Harris, 1984; Jensen and Breck, 1998;

Ryszkowski, 1975). Notably, small mammal guilds are known to be effective in controlling certain invasive species of plants in the Great Basin (Longland, 2007; St. Clair et al, 2016), while enhancing seedling recruitment of desirable native plant species (Longland et al, 2001). When small mammal species are then removed from a guild, their unique vegetative controls are also removed (Brown and Heske, 1990; Heske et al, 1993). This may result in a less functional ecosystem, as the plant community is no longer being controlled and propagated in the same fashion by small mammals (Brown and Heske, 1990). The loss of small mammal controlling effects may even lead to an increased vulnerability to invasive plant species within the Great Basin (Freeman et al, 2014; St Clair et al, 2016).

Our study provides critical information concerning long term changes in the small mammal community of the Great Basin. The comparison of data from the early 20th century to data collected now is not precise; historical researchers used primarily snap traps over live trapping, placed traps largely opportunistically rather than as part of a transect, and were notoriously poor at recording the exact localities associated with their specimens, all of which hinder a direct comparison of trends. However, while snap traps placed opportunistically do have a slightly higher capture rate of certain small mammal species, the difference is not great enough to account for the observed differences in captures between the historical dataset and our current trap effort (Wiener and Smith, 1972). Even our imperfect comparisons offer unique insights into the reactions of small mammal guilds to large-scale, long-term changes in their habitat. It has become clear that communities of small mammals in the Great Basin are trending towards low-diversity assemblies with larger numbers of generalist species. As this shift in diversity occurs, the landscape of the Great Basin has undergone dramatic changes, with greater abundance of cheatgrass monocultures and a reduction of plant-diverse low-desert shrubland (Whisenant, 1990; Keane et al, 2002; Brooks et al, 2004). As the diversity of small mammal communities is

lost, the Great Basin may become even more vulnerable to increasing disturbance and invasion of cheatgrass, with severe potential implications for the functionality of the Great Basin ecoregion.

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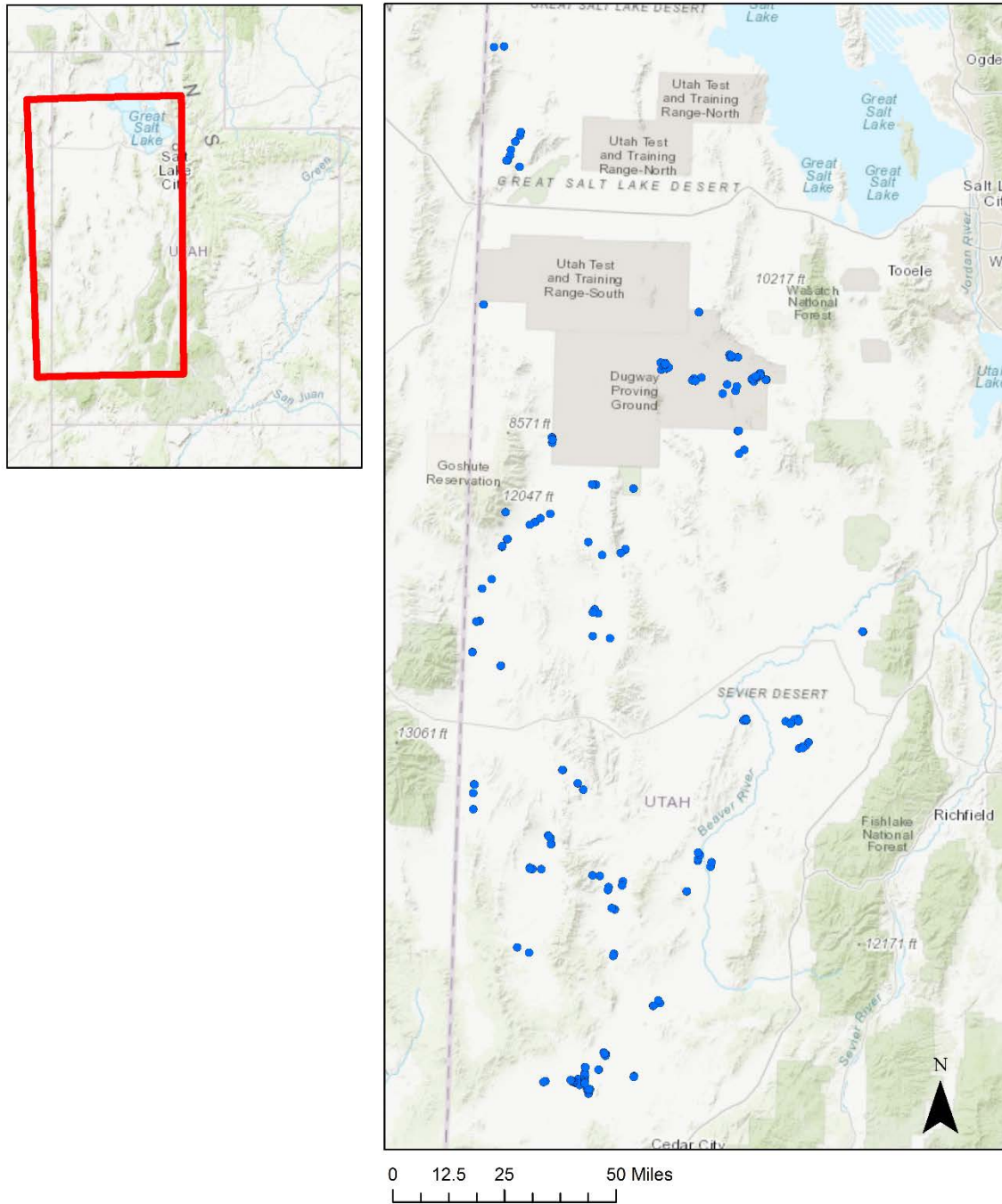
Figure 1- 1. A map of western Utah showing the 234 individual small mammal trap sites included in our 2014-2015 trapping effort. Sites ranged from Box Elder to Iron Counties, encompassing the entire West Desert region of Utah.
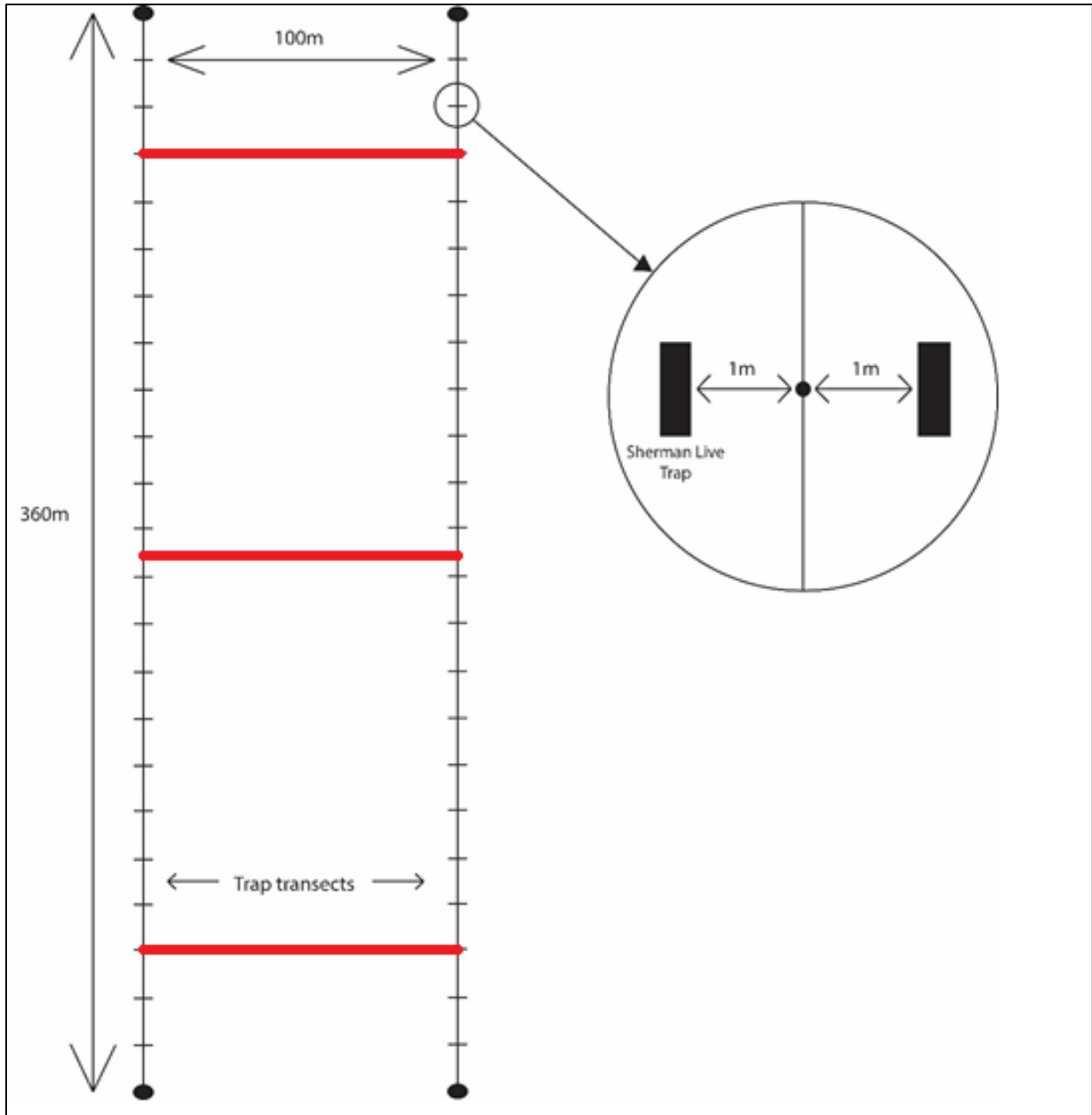
Figure 1- 2. A diagram of the transect design used to trap small mammals. We placed two parallel 360m transects 100m apart, and placed trap stations every 15m on each transect. Traps were placed two to a point, 1m to either side of the transect. 50 traps were placed on each transect, for a total of 100 traps per site.
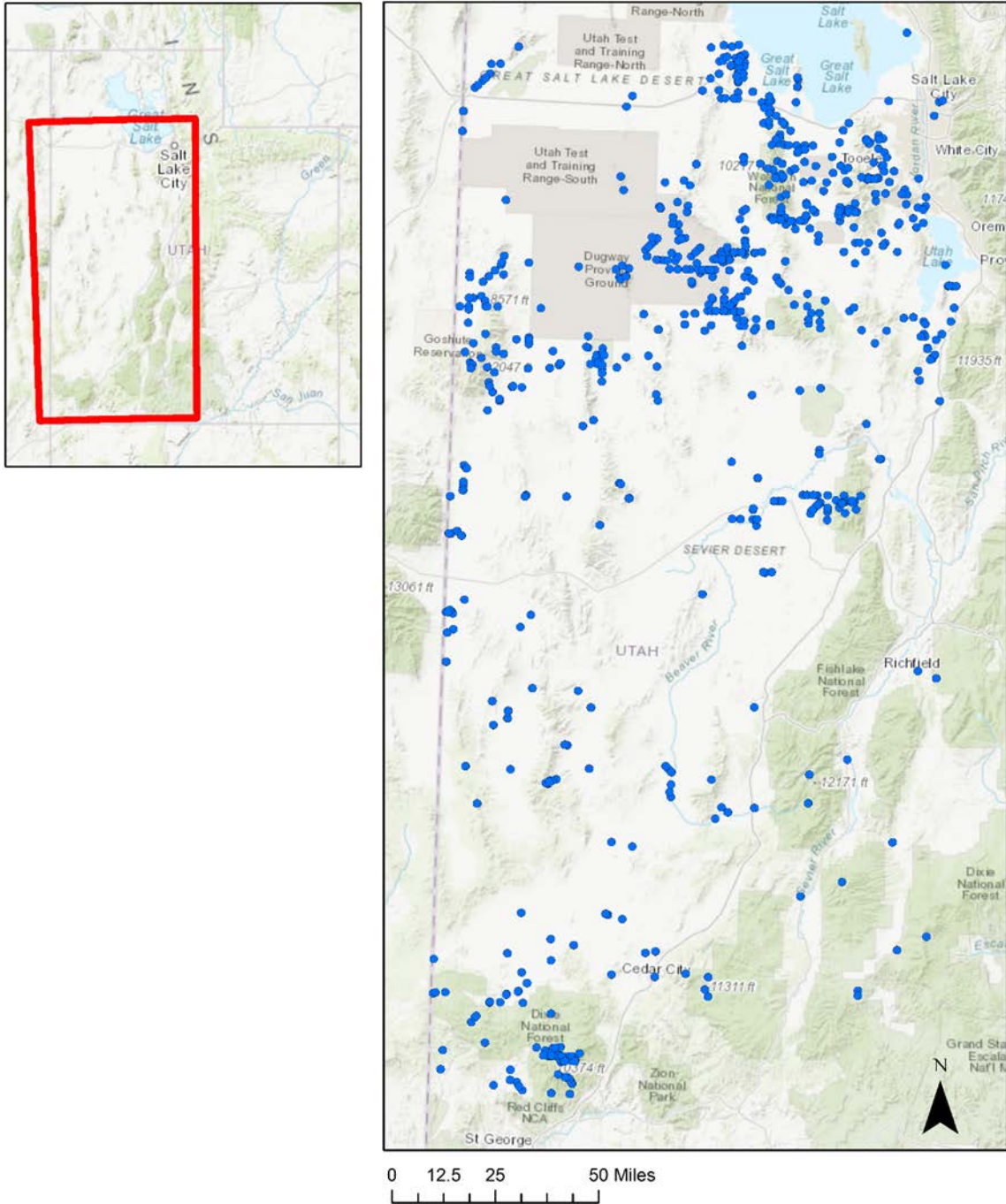
Figure 1- 3. A map of historical small mammal trap locations in the West Desert from 1930 through 1980, kept on record by the state of Utah and the Natural History Museum of Utah. Most of the shown locations are represented by only one or two specimen records.
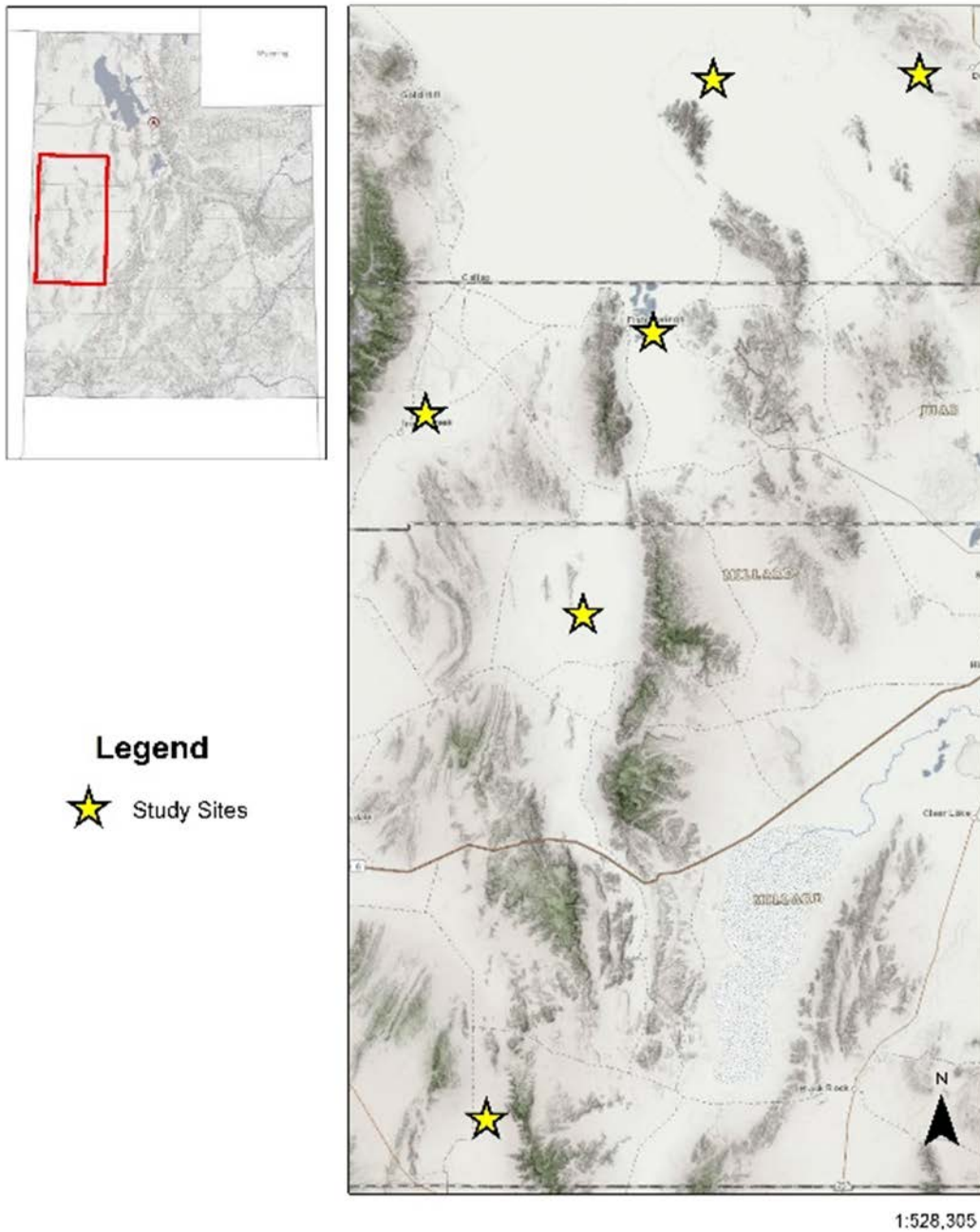
Figure 1- 4. A map of the six selected small mammal trap sites that met all criteria for comparison to the historical trap dataset: more than 50 recorded specimens associated with the historical trap site, adequate preserved historical field notes describing trap effort, and overlap with our 2014-2015 trap effort.
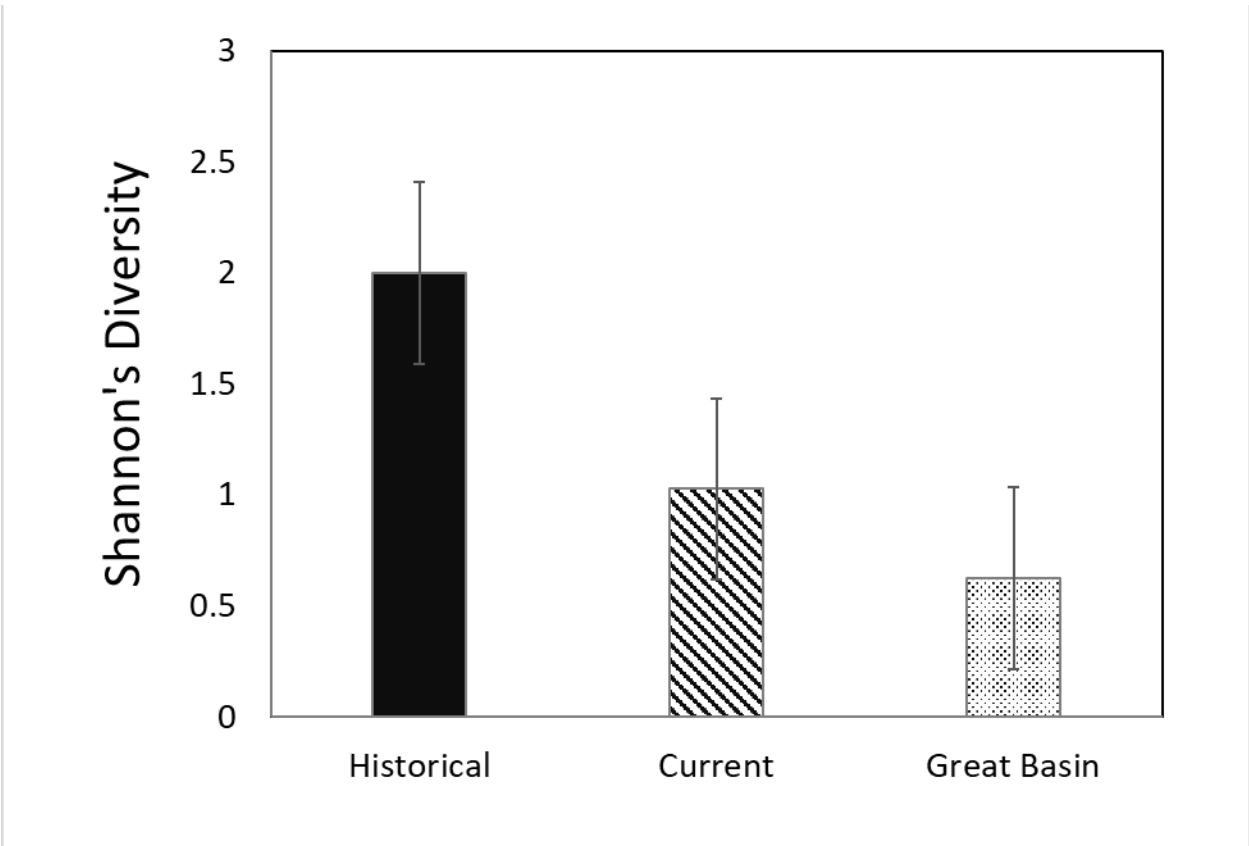
Figure 1- 5. The compared average diversity indices of the historical small mammal community, the current community at the same locations, and the average diversity of the rest of the locations trapped in 2014-15 in the Great Basin.
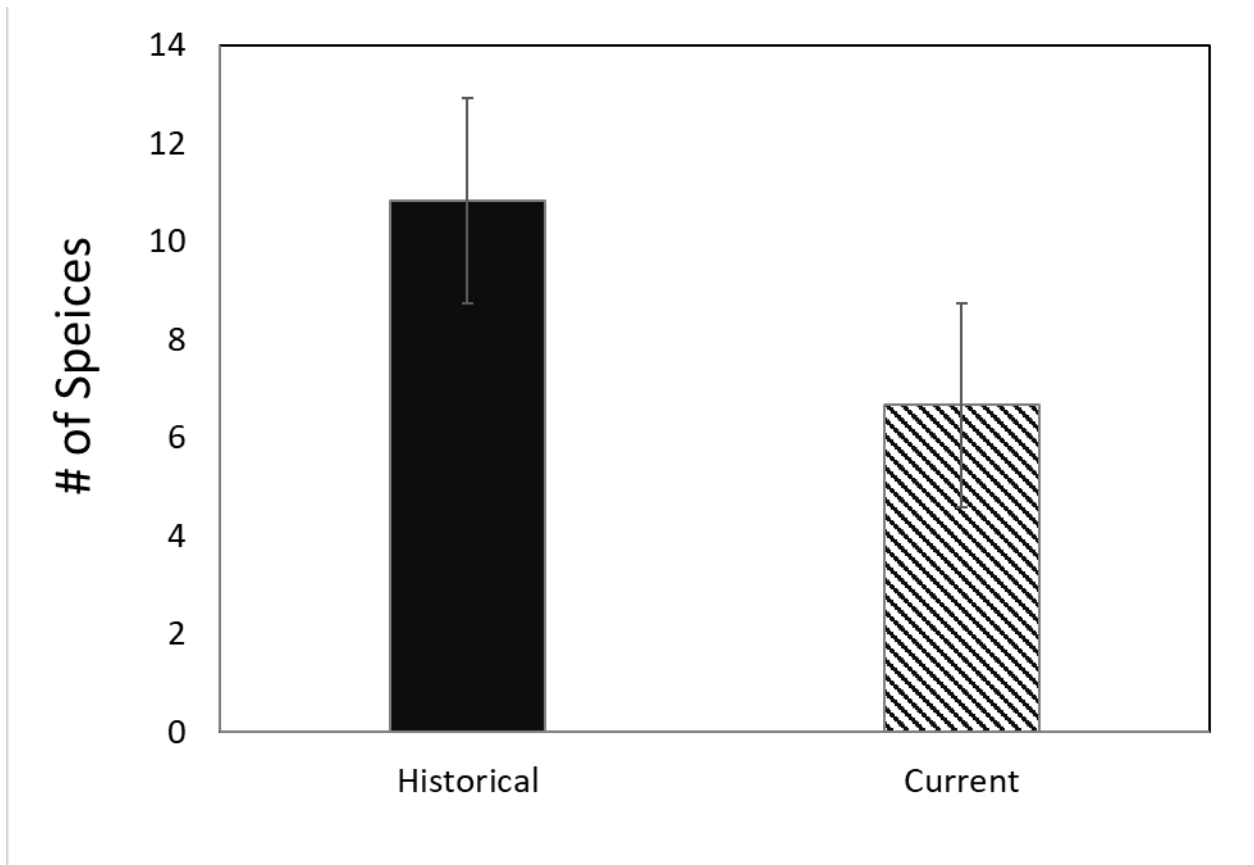
Figure 1- 6. The comparison between average species richness at our historical trap locations and the same locations trapped in 2014-15.
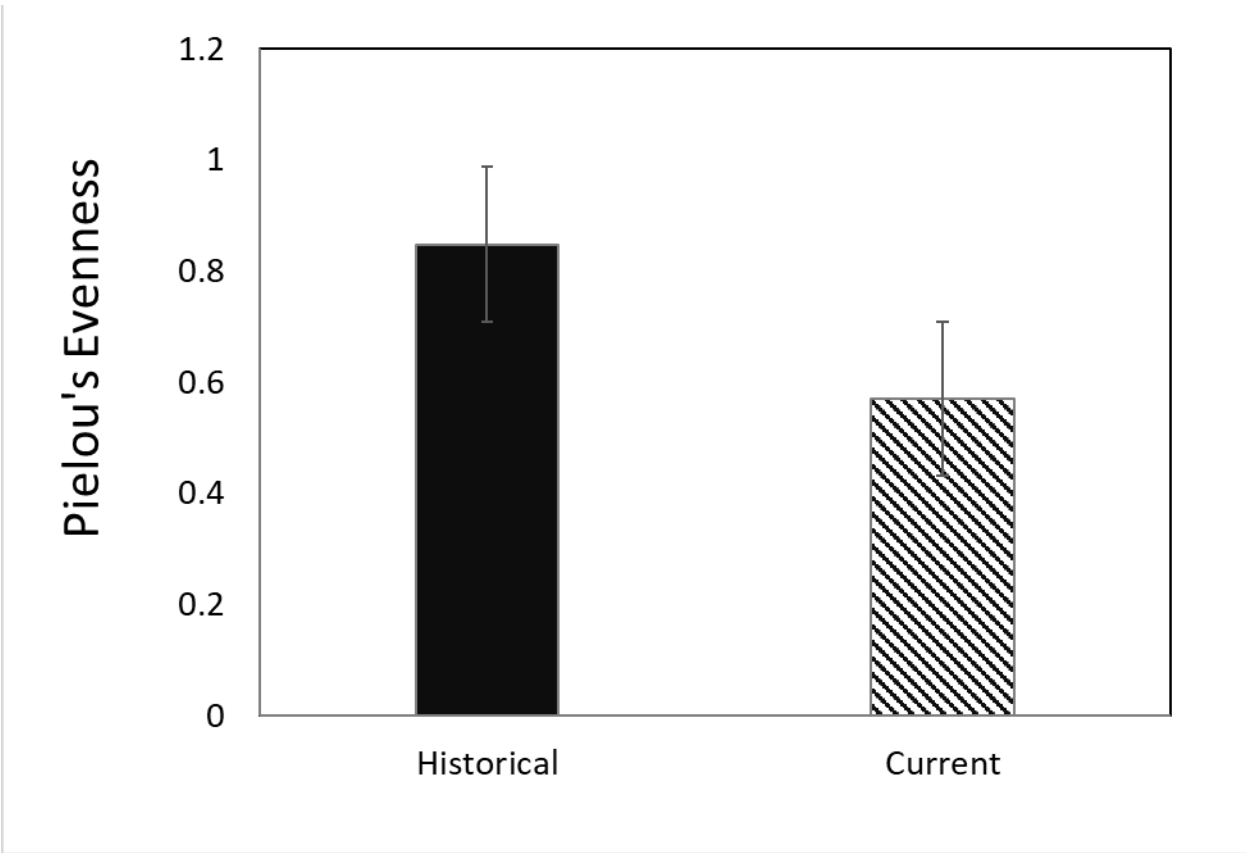
Figure 1- 7. The comparison between average species evenness at our historical trap locations and the same locations trapped in 2014-15.
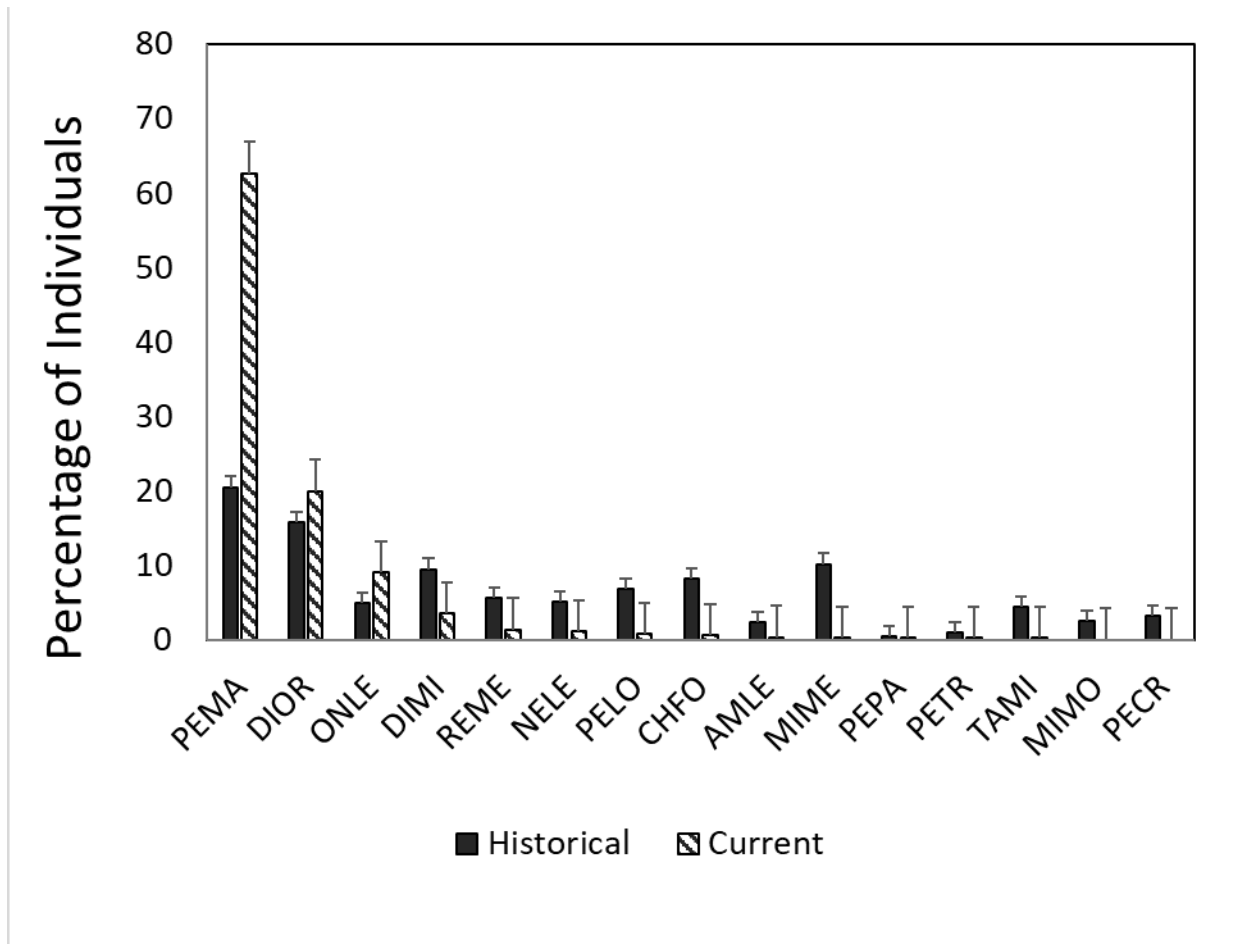
Figure 1- 8. A comparison of the relative abundances of each small mammal species caught at our study sites, both modern and historical. Species names are abbreviated to 4 letter codes from scientific name. PEMA: *Peromyscus maniculatus;* DIOR: *Dipodomys ordii*; ONLE: *Onochomys leucogaster*; DIMI: *Dipodomys microps*; REME: *Reithrodontomys megalotis*; NELE: *Neotoma lepida*; PELO: *Perognathus longimembris*; CHFO: *Chaetodipus formosus*; AMLE: *Ammospermophilus leucurus*; MIME: *Microdipodops megacephalus*; PEPA: *Perognathus parvus*; PETR: *Peromyscus trueii*; TAMI: *Tamius minimus*; MIMO: *Microtus montanus*; PECR: *Peromyscus crinitus*.
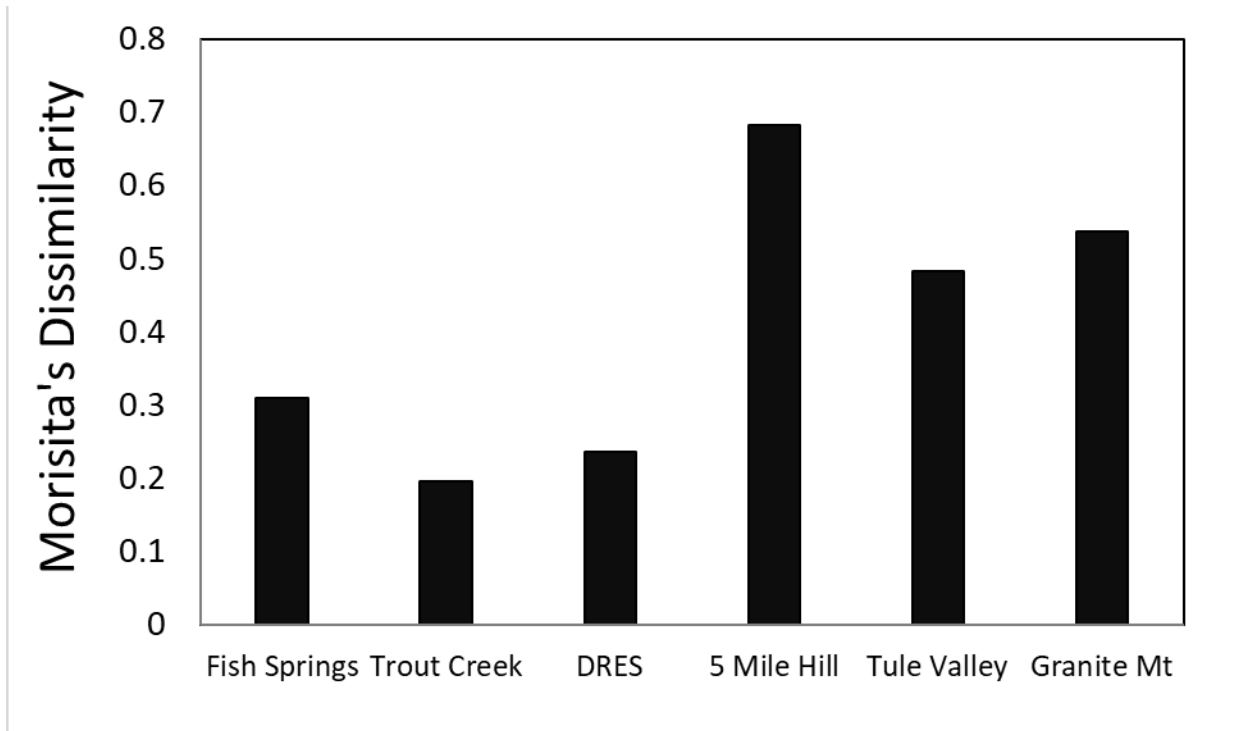
Figure 1- 9. Morisita's dissimilarity indices for each of the six sites selected for comparison to the historical dataset. Each site's capture data was compared to its historical counterpart to calculate how dissimilar the composition of the small mammal community was to its former self. Lower numbers are more dissimilar.

TABLES

Table 1- 1. The six modern trap sites chosen for comparison to the historical small mammal capture dataset. All six sites were trapped in both 2014 and 2015.

Site	Latitude	Longitude	Locality
DRES	38.6891	-113.6594	Desert Range Experimental Station, northern Pine Valley, Millard County, UT
TRCR	39.7054	-113.7861	Trout Creek/Partoun, Juab County, UT
TULE	39.3443	-113.4351	Southern Tule Valley, west of the House Range, Millard County, UT
FISP	39.8323	-113.3538	South of Fish Springs National Wildlife Refuge, Juab County, UT
MILE	40.2015	-112.8464	North of 5 Mile Hill, Dugway Proving Ground, Tooele County, UT
GRAN	40.2383	-113.2343	North of Granite Peak, Dugway Proving Ground, Tooele County, UT

CHAPTER 2

Dark Kangaroo Mouse Population Survey and Habitat Model in Western Utah

Samantha E. Phillips[a], Robert N. Knight[b], Kimberly A. Hersey[c], and Brock R. McMillan[a]
[a]Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT
[b]Natural Resources Office, Dugway Proving Grounds, Dugway, UT
[c]Division of Wildlife Resources, Springville, UT

ABSTRACT

The dark kangaroo mouse (*Microdipodops megacephalus*) is an ecological specialist, requiring a specific set of habitat conditions to survive. It is closely associated with vegetated dune habitats in the Great Basin desert. When first described in the late 1800's, the dark kangaroo mouse was considered locally common; today they are described as rare and declining. The state of Utah and the Department of Defense commissioned a multi-year population survey to ascertain the status and range of the dark kangaroo mouse within the state. Four teams sampled 232 locations across western Utah during the summers of 2014-2015. Of the 232 sites sampled, only 5 sites resulted in dark kangaroo mouse captures, totaling 15 individuals. These results could indicate a state-wide population decline for this species, both compared to historic population levels and to the populations surveyed less than ten years ago. The rapid decline may be a result of habitat degradation associated with invasive plant species and increasing fire frequency, the effects of which are exacerbated by the dark kangaroo mouse's life history as an ecological specialist. Unless large-scale habitat restoration and preservation is conducted for remaining populations, it is likely the dark kangaroo mouse will continue to decline within the state.

INTRODUCTION

The Great Basin is a sensitive ecoregion currently threatened by climate change, invasive species, and altered fire regimes. Current predictions of the effects of climate change in the Great Basin indicate an increase in overall precipitation, as well as an increase in the proportion of precipitation falling as rain rather than as snow (Karl et al, 1996; Mote et al, 2005). Altered precipitation regimes may result in a significant change in current vegetation communities, even increasing susceptibility to invasion by non-native plant species (Weltzin et al, 2003; Chambers and Wisdom, 2009). The most problematic invasive plants in the Great Basin are generally fast-growing annuals that fill in inter-shrub spaces and vastly increase both the risk of fire ignition and the spread of existing fires (Brooks et al, 2004). More frequent and intense fire regimes are resulting in the removal of native shrubs and bunchgrasses from the landscape, as plants native to the Great Basin are generally fire-intolerant and are out-competed in burned areas by invasive species (Whisenant, 1990; Keane et al, 2002). The reduction in abundance of the native plant species used for forage and cover by small mammals may be creating a bottom-up forcing effect controlling the distribution of small mammal species (Stewart, 1949; Hall, 2012). Changes in available habitat and forage are reflected in the biodiversity of the small mammal species inhabiting these areas. Specialist species relying on specific habitat types or plant species tend to be reduced in areas of intense cheatgrass invasion, where adaptable generalist species tend to increase in abundance (Hall, 2012; Freeman et al, 2014).

The Great Basin ecoregion contains several specialized endemic species, many of which may act as indicator species for the health of the ecoregion. The unique basin-and-range geology and relatively rapid historical habitat alterations of the ecoregion have resulted in several resident species with restricted ranges and fragmented populations (Andersen et al, 2013; Chambers and

Wisdom, 2009; Light et al, 2012). These specialized species may act as biological indicators for their specific habitats or ecosystems, provided they meet the following criteria: easily measured, sensitive to stresses on the system, respond to stress in a predictable manner, and anticipatory to large-scale ecosystem damage (Dale and Beyeler, 2001). Small mammal species often meet these criteria and are frequently identified as biological indicators, especially in semi-arid to arid ecosystems (Avenant, 2000; Leis et al, 2008; Andersen et al, 2013).

The dark kangaroo mouse, *Microdipodops megacephalus*, is a sensitive species and ecological specialist that may be an indicator for the health of the Great Basin. The dark kangaroo mouse requires fine gravelly soils, with a preference for shrubby landscapes dominated by sagebrush and rabbitbrush (Andersen et al, 2013; Hafner et al, 1996; Light et al, 2012). Significant dispersal barriers in the form of mountain ranges and other inhospitable habitats have resulted in the dark kangaroo mouse population being highly fragmented range-wide, with several isolated and genetically distinct populations scattered across the Great Basin (Light et al, 2012; Andersen et al, 2013). These populations are sensitive to disturbance in the form of agricultural development, invasion by weedy annuals, and increased intensity and frequency of fires, resulting in many previously abundant populations now being depauperate or extirpated (Hafner and Upham, 2011; Hafner and Hafner, 1996). Given the above characteristics and the criteria given by Dale and Beyeler (2001), the dark kangaroo mouse appears to be a biological indicator for the health of sandy and gravelly dune ecosystems in the Great Basin (Andersen et al, 2013).

The dark kangaroo mouse may be in decline across the state of Utah, leading to its designation as a state species of concern. The species has been found to be declining in abundance across its range since 1960 (Hafner and Upham, 2011; Andersen et al, 2013; Light et al,, 2012). This trend is especially apparent in Utah, with several formerly abundant population

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centers found to be nearly or totally extirpated (Auger and Black, 2006). As the dark kangaroo mouse may be an indicator species for its preferred habitat, it is possible that its decline is linked to greater ecological threats now present across the Great Basin. To inform appropriate management actions for the dark kangaroo mouse in Utah, we sought to better define the current population of dark kangaroo mice within the state. We also aimed to identify potential areas of critical habitat for future conservation focus.

The objective of this study was to delineate the population of the dark kangaroo mouse in the state of Utah. Secondly, we identified critical habitat criteria of the dark kangaroo mouse for use in a predictive occupancy model. Given the sensitivity of the species and recent population survey attempts within the state, we predicted that: 1) the range of the dark kangaroo mouse in Utah would be restricted in comparison to its historical extent, and 2) remaining populations of the dark kangaroo mouse would be found in close association with their preferred habitat, allowing for the creation of a strong predictive model.

METHODS

Study Area

During 2014 and 2015, we sampled small mammal communities at 234 sites across the Great Basin Desert of Utah (Fig. 1). Sites were located in Iron, Beaver, Millard, Juab, Tooele, and Box Elder counties, Utah. These sites were located between 41°30' N – 37°31' N (north to south) and 114°0' W – 112°15' W (east to west). Each site was located on valley floors between 1,300 and 1,900 meters in elevation. Plant communities were generally shrubby and characterized by big sagebrush (*Artemisia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Ericameria nauseosa*), four-wing saltbush (*Atriplex*

canescens), shadscale (*Atriplex confertifolia*), or greasewood (*Sarcobatus vermiculatus*), with minor herbaceous understories. Soils were primarily sandy to gravelly, ranging from unconsolidated dunes to hardpan.

Small Mammal Sampling Protocols

We sampled small mammals at each site for four consecutive nights. To sample small mammals, we established an array of two parallel transects 360 meters long, placed 100 meters apart (Fig. 2). Each transect contained 25 trap points spaced 15 meters apart, for a total of 50 trap points at each site. A trap point consisted of 2 traps placed approximately 1 meter to either side of the trap transect (100 total traps per site). Transects were oriented along natural habitat corridors in order to remain within one habitat type. We used 7.6 x 7.6 x 30.5 centimeter collapsible Sherman live traps baited with commercially available bird seed mix. Each trap was provided with 5 grams of polyester batting. Traps were closed each morning before daily temperatures rose above 23 °C and reopened each evening less than 90 minutes prior to sunset. These precautions were taken to avoid potential heat-related mortalities. We identified captured small mammals to species and collected basic live-trap data for each individual (age, weight, sex, reproductive condition, etc). As a non-invasive temporary recapture marker, each individual was shaved on the right rump before release at the trap site. Dark kangaroo mice caught in the Beryl region were ear-tagged for individual identification.

Vegetation Sampling Protocol

We sampled the surrounding vegetation at each site using a point-intercept method. Sampling was conducted within the trapping period for each location. We established an array of

three parallel transects, 100 meters long, placed perpendicular to the small mammal trapping array to span the distance between the trap lines. The three vegetation transects were evenly spaced along the 360 meter trap lines, beginning at trap points 4, 12, and 22 on the first line. Points were taken at one meter intervals along each transect, beginning at 1 meter, for a total of 100 points per transect. Plant species that touched the dropped pin flag (up to three, beginning at the canopy and moving down) were recorded, along with ground cover and soil texture at each point.

Data Analysis

As per the request of the Utah state DWR, we intended to calculate a population estimate of the dark kangaroo mouse, as well as a habitat selection model to be used in identifying critical conservation areas. We ran a capture-recapture analysis in Program Mark, using the Chapman estimator to reduce bias due to potentially small sample sizes. To identify areas of critical habitat value, we created a resource selection function (RSF) using ArcGIS. We included both biotic and abiotic variables in the RSF, with special focus on variables previously identified in the literature as critical to dark kangaroo mouse habitat: presence of sagebrush or rabbitbrush, and sandy or gravelly soils (Table 1). We also used non-metric multidimensional scaling (NMDS) to identify whether sites with dark kangaroo mouse populations were distinguishable from those without, using both biotic and abiotic site characteristics (Table 2).

RESULTS

We captured 3,389 unique small mammals over the course of 93,600 trap nights. The captured individuals included representatives from 14 species, 11 genera, and 4 families (Fig. 3).

In decreasing order of abundance, we captured: deer mouse (*Peromyscus maniculatus*), Ord's kangaroo rat (*Dipodomys ordii*), chisel-toothed kangaroo rat (*Dipodomys microps*), northern grasshopper mouse (*Onychomys leucogaster*), little pocket mouse (*Perognathus longimembris*), white-tailed antelope squirrel (*Ammospermophilus leucurus*), western harvest mouse (*Reithrodontomys megalotis*), long-tailed pocket mouse (*Chaetodipus formosus*), Great Basin pocket mouse (*Perognathus parvus*), desert woodrat (*Neotoma lepida*), dark kangaroo mouse, pinyon mouse (*Peromyscus trueii*), least chipmunk (*Tamius minimus*), and house mouse (*Mus musculus*).

We captured 15 individual dark kangaroo mice at five separate trap sites (Fig. 4). 3 of the sites with dark kangaroo mice were located in western Iron county and Millard county; the other 2 sites were located on Dugway Proving Ground in central Tooele county. Concurrent trapping efforts by the Natural Resources Program at Hill Air Force Base in northern Tooele county resulted in 9 individuals trapped on the southern Utah Test and Training Range. The northernmost Iron County location and the southernmost Tooele county location are separated by 181 kilometers, with no detected populations or movement corridors in-between.

We attempted to create a population estimate using Program MARK's capture-recapture modeling, but too few individuals were captured to allow for an adequate sample size. Additionally, the dark kangaroo mouse was captured at too few locations to allow for an accurate RSF habitat model. We created several NMDS models comparing capture locations to locations where dark kangaroo mice were absent, but no detectable differences were noted in any of the site characteristics measured (Fig. 5).

DISCUSSION

Our study has found current dark kangaroo mouse presence in the state to be severely limited in comparison to historical sampling or population sampling performed by Auger and Black in 2005-09. The dark kangaroo mouse was once considered one of the most common species found in sandy habitats of the Great Basin, according to field notes kept by the Natural History Museum of Utah from trap efforts in the West Desert between 1930 and 1980 (NHMU collections, unpub.). Field notes from the trapping efforts of Egoscue and Durant in the mid-20th century suggest that capture rates could exceed dozens of individuals per trap night in appropriate habitat (NHMU collections, unpub.). The population of dark kangaroo mice in Utah was already severely curtailed by the mid-2000s, when a statewide trapping effort resulted in 40 individuals captured at 4 sites out of 101 historical locations, with a total trap effort of just under 27,000 trap nights (Auger and Black, 2006). Comparatively, only 15 individuals were caught over nearly 94,000 trap nights at 234 locations in 2014-15, suggesting the decline in population has continued.

The remaining population centers of dark kangaroo mice in Utah appear to be widely scattered and unconnected by movement corridors, leaving the current populations vulnerable to extirpation. The five locations at which dark kangaroo mice were captured during the 2014-15 effort can be grouped into two loci: the Beryl population center, consisting of the two Iron county locations and the Millard county location, and the DPG/HAFB population center, consisting of the two locations on Dugway Proving Ground and adjacent to the southern UTTR. The two loci are separated by 181 km at their nearest detected points, and do not appear to have intermediate population centers or movement corridors between them. The apparent small size and isolation of both populations leave them vulnerable to potential extirpation through stochastic events, especially demographic variance (Caughley, 1994; Melbourne and Hastings,

2008; Traill et al, 2010). Small populations are especially susceptible to the effects of demographic heterogeneity, referring to random variation in birth or death rates of individuals in a population, and sex ratio stochasticity (Melbourne and Hastings, 2008). In addition, small populations are more vulnerable to extirpation due to the increased effects of environmental fluctuations, inbreeding depression, and loss of genetic diversity (Traill et al, 2010).

As the diversity and composition of small mammal communities change through the loss of specialist species such as the dark kangaroo mouse, the function of the ecosystem may also be changed (Vander Wall, 2010). Each species in a guild of small mammals has a unique set of foraging and seed caching behaviors, including seed selectivity, rates of immediate consumption, use of scatter hoards versus larder hoards, and placement of hoards (Hollander and Vander Wall, 2004). Each foraging strategy results in unique effects on the spread and propagation of local plant species (Harris, 1984; Jensen and Breck, 1998; Ryszkowski, 1975). Notably, small mammal guilds are known to be effective in controlling certain invasive species of plants in the Great Basin (Longland, 2007; St. Clair et al, 2016), while enhancing seedling recruitment of desirable native plant species (Longland et al, 2001). When small mammal species are then removed from a guild, their unique vegetative controls are also removed (Brown and Heske, 1990; Heske et al, 1993). This may result in a less functional ecosystem, as the plant community is no longer being controlled and propagated in the same fashion by small mammals (Brown and Heske, 1990). The loss of small mammal controlling effects may even lead to an increased vulnerability to invasive plant species within the Great Basin (Freeman et al, 2014, St Clair et al, 2016).

The dark kangaroo mouse may be considered an indicator species for the health of the Great Basin, and its apparent decline may be a warning sign of greater ecological problems. As an indicator species, the dark kangaroo mouse is sensitive to stresses on the ecosystem (Dale and

Beyeler, 2001; Andersen et al, 2013). The decline of the dark kangaroo mouse since the 1970s is likely a result of large-scale changes in the Great Basin ecoregion, potentially including increasing invasion of exotic plant species resulting in more frequent and intense fires (Hafner and Upham, 2011). Fast-growing invasive annuals such as cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola kali*) outcompete native forbs and grasses and fill in intershrub spaces, leading to fires that spread farther and burn more intensely (Brooks et al, 2004; Whisenant, 1990; Keane et al, 2002). Plants native to the Great Basin are generally fire intolerant, and so are often eradicated from areas with high amounts of invasive weeds (Whisenant, 1990; Keane et al, 2002). Habitat specialists such as the dark kangaroo mouse are often unable to cope with the removal of their preferred habitat, resulting in their decline and eventual extirpation from the ecosystem (Freeman et al, 2014; Hall, 2012). It is likely that, barring a large-scale restoration of pristine Great Basin vegetation, the dark kangaroo mouse will continue to decline in Utah and elsewhere.

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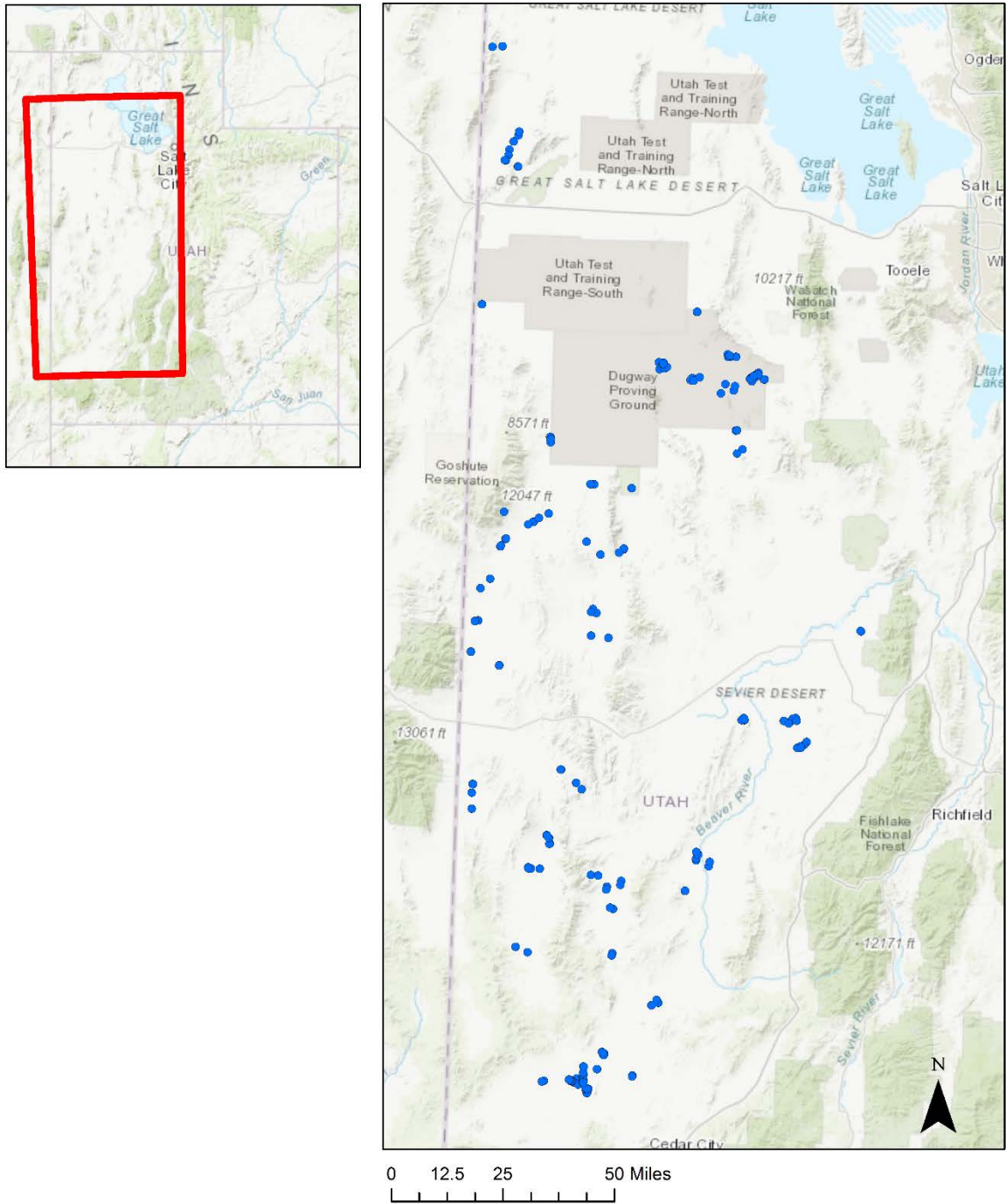
Figure 2- 1. A map of western Utah showing the 234 individual small mammal trap sites included in our 2014-2015 trapping effort. Sites ranged from Box Elder to Iron Counties, encompassing the entire West Desert region of Utah.
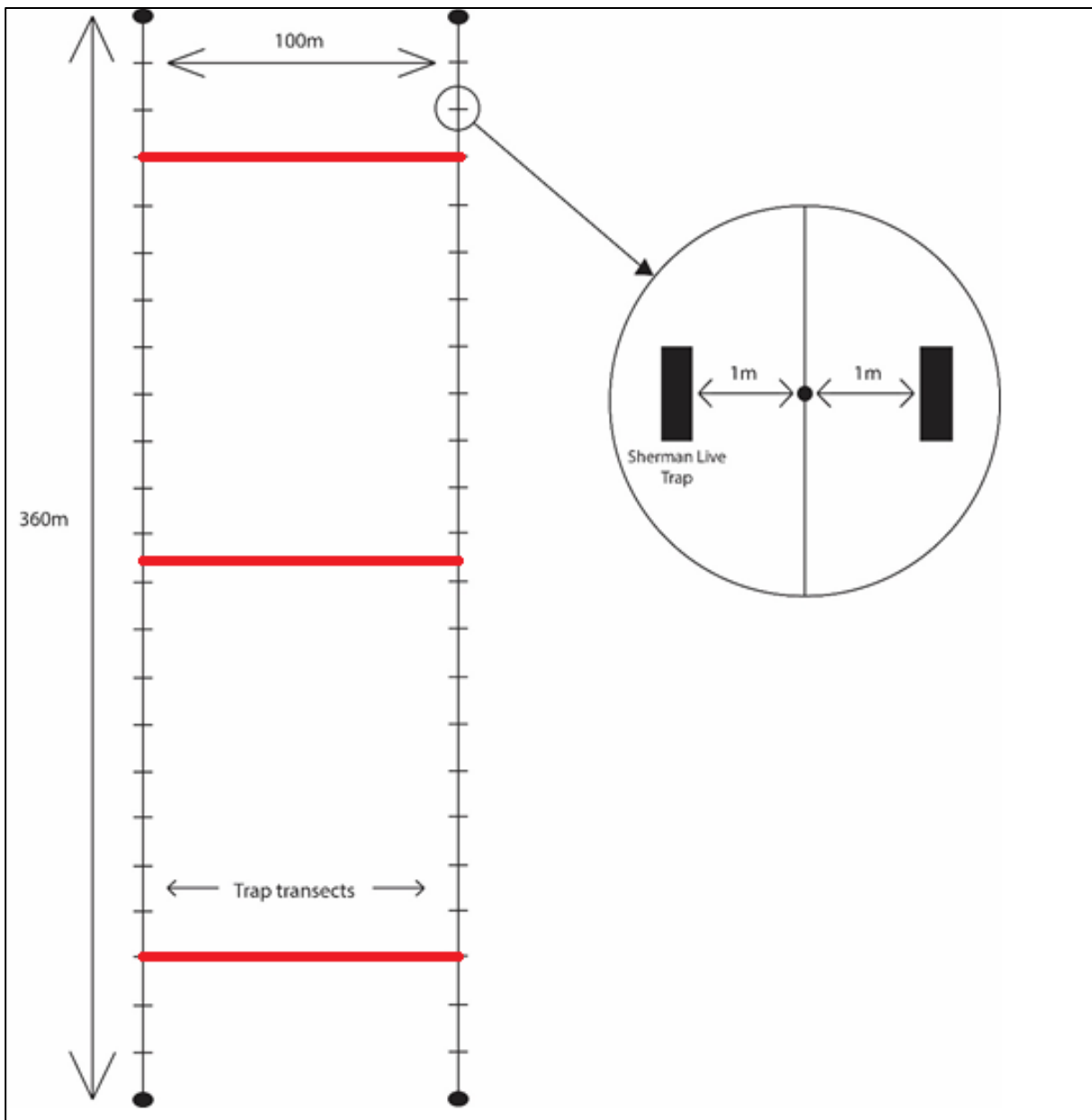
Figure 2- 2. A diagram of the transect design used to trap small mammals in our study area located in western Utah. We placed two parallel 360m transects 100m apart, and placed trap stations every 15m on each transect. Traps were placed two to a point, 1m to either side of the transect. 50 traps were placed on each transect, for a total of 100 traps per site.
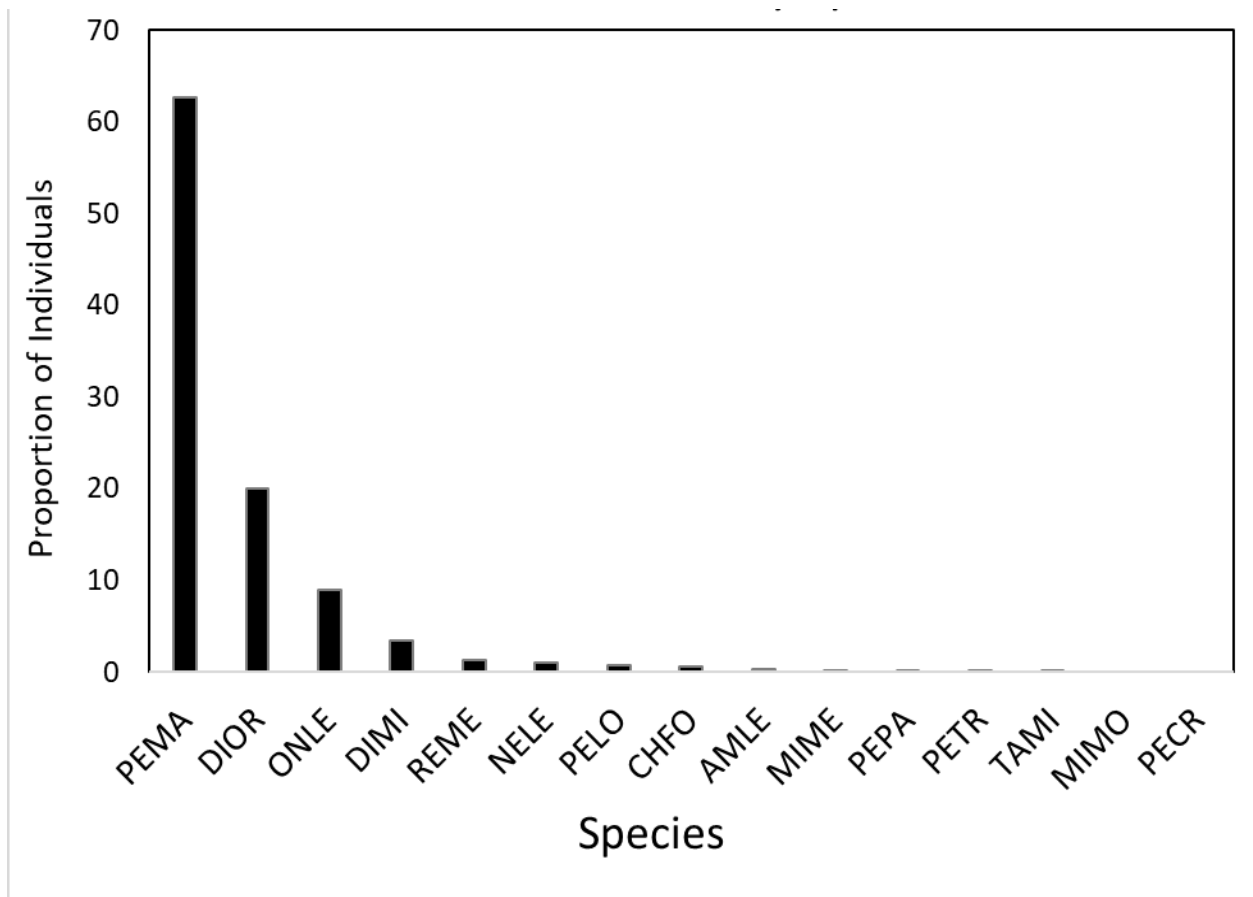
Figure 2- 3. Small mammal species caught at all trap sites in western Utah in 2014-15, in order of descending relative abundance. Species names are abbreviated to 4-letter codes from scientific names. PEMA: *Peromyscus maniculatus;* DIOR: *Dipodomys ordii*; ONLE: *Onochomys leucogaster*; DIMI: *Dipodomys microps*; REME: *Reithrodontomys megalotis*; NELE: *Neotoma lepida*; PELO: *Perognathus longimembris*; CHFO: *Chaetodipus formosus*; AMLE: *Ammospermophilus leucurus*; MIME: *Microdipodops megacephalus*; PEPA: *Perognathus parvus*; PETR: *Peromyscus trueii*; TAMI: *Tamius minimus*; MIMO: *Microtus montanus*; PECR: *Peromyscus crinitus*.
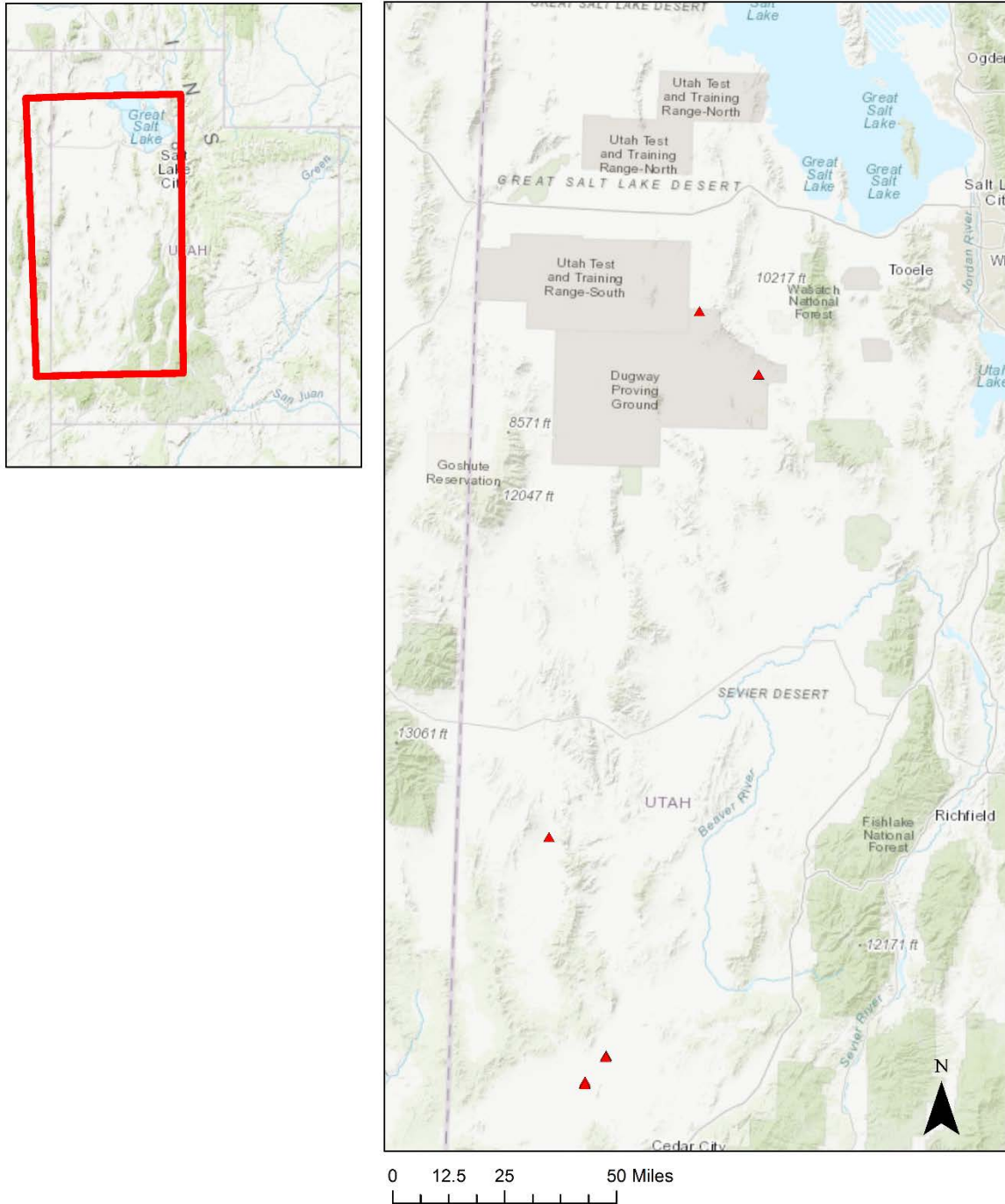
Figure 2- 4. Map of the five locations at which we captured dark kangaroo mice in western Utah during the trapping effort in 2014-15. These locations can be grouped into two distinct populations: the Beryl population, consisting of the southern three sites, and the DPG population, consisting of the northern two sites.
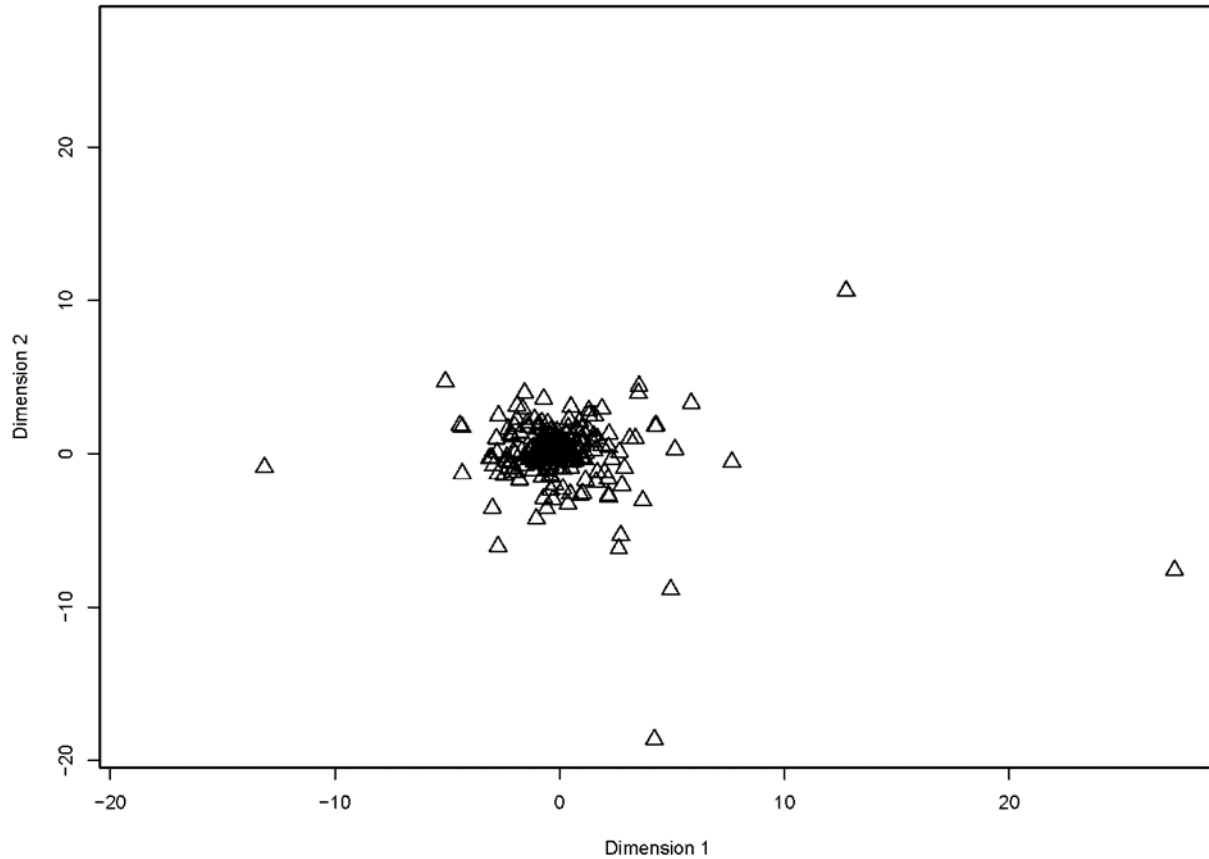
Figure 2- 5. A graph showing the results of the NMDS model we created to identify differences between sites with dark kangaroo mouse presence and sites without dark kangaroo mice. The five locations at which dark kangaroo mice were captured are marked with squares, and the sites without are marked with triangles. The sites with dark kangaroo mice are lost in the center of the cluster of other sites, indicating no detectable difference between them within the measured variables.

Table 2- 1. Resource selection function (RSF) model variables associated with small mammal capture sites in western Utah, 2014-2015. Model variables were used to identify habitat variables important or critical to dark kangaroo mouse presence.

Variable Name	Description
Topographic	
Elevation	Elevation of the capture site in meters
Aspect	Aspect of the capture site
Slope	Slope of the capture site in percent grade
Anthropogenic	
D.Road	Distance to the nearest road
Vegetative	
CanopyCover	Percent canopy cover
ShrubCov	Percent cover of shrubs
ForbCov	Percent cover of forbs
GrassCov	Percent cover of grasses
InvCov	Percent cover of invasives
ShrubPer	Percentage of vegetation as shrubs
ForbPer	Percentage of vegetation as forbs
GrassPer	Percentage of vegetation as grass
InvPer	Percentage of vegetation as invasives
LiCov	Percent cover of litter
SaCov	Percent cover of sand
HaCov	Percent cover of hardpan
BgCov	Percent cover of bare ground, uncategorized
CrCov	Percent cover of cryptobiotic soil
GrCov	Percent cover of gravel
RoCov	Percent cover of rocks
ClCov	Percent cover of clay
MoCov	Percent cover of moss
DuCov	Percent cover of dung
DominantGC	Dominant type of ground cover
DominantComm	Dominant vegetation community
DominantVegType	Perennial or annual dominant vegetation
VegSpecRich	Species richness of vegetation

Table 2- 2. Non-metric multidimensional scaling (NMDS) model variables associated with small mammal capture sites in western Utah, 2014-2015. Model variables were used to identify potential differences between sites where dark kangaroo mice were captured as compared to sites where dark kangaroo mice were absent.

Variable Name	Description
SiteID	Unique ID of sample site
Presence	DKM presence or absence, where 0=absence and 1=presence
CanopyCover	Percent canopy cover
ShrubCov	Percent cover of shrubs
ForbCov	Percent cover of forbs
GrassCov	Percent cover of grasses
InvCov	Percent cover of invasives
ShrubPer	Percentage of vegetation as shrubs
ForbPer	Percentage of vegetation as forbs
GrassPer	Percentage of vegetation as grass
InvPer	Percentage of vegetation as invasives
LiCov	Percent cover of litter
SaCov	Percent cover of sand
HaCov	Percent cover of hardpan
BgCov	Percent cover of bare ground, uncategorized
CrCov	Percent cover of cryptobiotic soil
GrCov	Percent cover of gravel
RoCov	Percent cover of rocks
ClCov	Percent cover of clay
MoCov	Percent cover of moss
DuCov	Percent cover of dung
DominantGC	Dominant type of ground cover
DominantComm	Dominant vegetation community
DominantVegType	Perennial or annual dominant vegetation
VegSpecRich	Species richness of vegetation