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Habitat Selection and Response to Disturbance by Pygmy Rabbits in Utah

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Master of Science

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ABSTRACT

Habitat Selection and Response to Disturbance by Pygmy Rabbits in Utah

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The pygmy rabbit (*Brachylagus idahoensis*) is a sagebrush (*Artemisia* sp.) obligate that depends on sagebrush habitats for food and cover throughout its life cycle. Invasive species, frequent fires, overgrazing, conversion of land to agriculture, energy development, and many other factors have contributed to recent declines in both quantity and quality of sagebrush-steppe habitats required by pygmy rabbits. Because of the many threats to these habitats and the believed decline of pygmy rabbit populations, there is a need to further understand habitat requirements for this species and how they respond to disturbance. This study evaluated habitat selection by pygmy rabbits in Utah and assessed response of this small lagomorph to construction of a large-scale pipeline (i.e. Ruby pipeline) in Utah.

We collected habitat data across Utah at occupied sites (pygmy rabbit occupied burrows) and compared these data to similar measurements at unoccupied sites (random locations within sagebrush habitat where pygmy rabbits were not observed). Variables such as horizontal obscurity, elevation, percent understory composed of sagebrush and other shrubs, and sagebrush decadence best described between occupied (active burrow) and unoccupied (randomly selected) sites. Occupied sites had greater amounts of horizontal obscurity, were located at higher elevations, had greater percentage of understory comprised of sagebrush and shrubs, and had less decadent sagebrush. When considering habitat alterations or management these variables should be considered to enhance and protect existing habitat for pygmy rabbits.

The Ruby pipeline was a large-scale pipeline project that required the removal of vegetation and the excavation of soil in a continuous linear path for the length of the pipeline. The area that was disturbed is referred to as the right of way (ROW). From our assessment of pygmy rabbit response to construction of the Ruby pipeline, we found evidence for habitat loss and fragmentation as a result of this disturbance. The size of pygmy rabbit space-use areas and homeranges decreased post construction, rabbits shifted core-use areas away from the ROW, and there were fewer movements of collared rabbits across the ROW. Mitigation efforts should consider any action which may reduce restoration time and facilitate movements of rabbits across disturbed areas.

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CHAPTER 1

Pygmy Rabbit (*Brachylagus idahoensis*) Habitat Selection in Utah: Does

Sagebrush (*Artemisia* sp.) Age Influence Selection?

ABSTRACT

The pygmy rabbit (*Brachylagus idahoensis*) is a sagebrush (*Artemisia* sp.) obligate that

depends on sagebrush habitats for food and cover throughout its life cycle. Invasive species,

frequent fires, overgrazing, conversion of land to agriculture, energy development, and many

other factors have contributed to recent declines in both quantity and quality of sagebrush

habitats required by pygmy rabbits. Given declining availability of sagebrush, there is a need to

identify characteristics of suitable pygmy rabbit habitat. Although habitat selection information

exists from several western states, data for pygmy rabbits in Utah is limited. Moreover, a better

understanding of sagebrush characteristics selected by pygmy rabbits at the extent of their range

would inform conservation efforts. We predicted occupied sites would have greater percentages

of sagebrush, greater amounts of cover, and greater mean sagebrush age compared to unoccupied

sites. We sampled 73 different habitat variables at occupied (n = 72) and unoccupied (n = 61)

sites in Utah. We then used random forests to determine which variables best discriminated

between occupied and unoccupied sites. Occupied sites had greater horizontal obscurity

(measure of cover), occurred at higher elevations, had greater percent understory comprised of

sagebrush and other shrubs, and lower percent sagebrush decadence than unoccupied sites.

Contrary to our predictions, sagebrush age at occupied sites was not an important variable (MDA

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≤ 1.0) and mean age did not differ by site type. We suggest managers use this information to help identify suitable pygmy rabbit habitats to further conservation of this imperiled lagomorph.

INTRODUCTION

Studies of habitat selection provide information that improves management practices by identifying areas and characteristics of preferred habitat for species of interest. The identification of such habitat characteristics is a fundamental element in the conservation and management of wildlife (Reynolds 1974). Habitat selection studies have become increasingly important as human influence continues to alter natural landscapes in ways that impact wildlife. These studies can help managers mitigate the effects of reductions in both extent and quality of remaining habitat. Habitat selection information is particularly useful for species that are habitat obligates because these species often have greater difficulty responding to habitat changes than generalists (Larrucea and Brussard 2008c, Crow and van Riper 2010). Habitat obligate species are also more vulnerable to degradation, fragmentation, and loss of specific ecosystem resources than are habitat generalists (Ingelfinger and Anderson 2004, Walker et al. 2007).

Pygmy rabbits (*Brachylagus idahoensis*) are small (400-500g) lagomorphs that only occur in mature sagebrush (*Artemisia sp.*) habitats (Roberts 2003, Shipley et al. 2006). Sagebrush is required by pygmy rabbits during all phases of their life cycle and it provides both food and cover for this obligate species (White et al. 1982, Thines et al. 2004, Shipley et al. 2006). Sagebrush comprises >95% of winter and >50% of summer diet for this specialized lagomorph (Green and Flinders 1980, Thines et al. 2004). Pygmy rabbits are also a semi-fossorial species that use burrows for shelter. They are one of only two rabbits in North America known to excavate their own burrows and thus require soils suitable for digging in addition to sagebrush (Dobler and Dixon 1990, Sanchez et al. 2009). Soil textures at pygmy rabbit occupied

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sites have been described as soft loamy soils that facilitate digging (Weiss and Verts 1984, Gabler et al. 2001).

Sagebrush habitats required by pygmy rabbits are declining in size and function throughout the western United States (Beetle 1960, Schneegas 1967, Vale 1975, Baker et al. 1976, Braun 1998, Miller 1999, Miller and Eddleman 2000, Braun et al. 2002, Bradley 2010). Factors attributed to this decline include changes in frequency and intensity of fire, invasive species, conversion of land to agriculture, overgrazing, and energy development (Barney and Frischknecht 1974, Miller 1999, Braun et al. 2002, Thines et al. 2004, Bradley 2010). Degradation of sagebrush habitats appears to be increasing because of invasive cheatgrass (*Bromus tectorum*) and other annual plants that have altered fire cycles (D'Antonio and Vitousek 1992, Brooks et al. 2004, Evans and Rollins 2008). These altered fire cycles negatively impact sagebrush communities and favor annual grasses unsuitable to sagebrush obligates such as pygmy rabbits. Loss and alteration of sagebrush habitats has resulted in the listing of pygmy rabbits as an endangered species in Washington State and a species of conservation concern in all other states within its geographic range (Lyman 1991, Gahr 1993, McAllister and Program 1995, USFWS 2003, Lyman 2004).

Given the ongoing loss of sagebrush habitats, it is important to identify characteristics of preferred habitat and locations of remaining suitable habitats to promote conservation of pygmy rabbits. Habitat requirements for pygmy rabbits have been described in several western states including California (Larrucea and Brussard 2008b), Idaho (Green and Flinders 1980), Nevada (Himes and Drohan 2007, Larrucea and Brussard 2008b), Oregon (Weiss and Verts 1984), Washington (Gahr 1993), and Wyoming (Katzner and Parker 1997). However, only limited habitat-selection work has been published for pygmy rabbits in Utah and identification of certain

characteristics associated with preferred habitats (i.e. sagebrush age) is lacking (Larrucea and Brussard 2008b, Wilson et al. 2010). Moreover, the distribution of pygmy rabbits in Utah extends across much of the state and represents the southeastern extent of the species distribution. More information on habitat selection by pygmy rabbits in Utah and closer examination of poorly understood characteristics of selection such as sagebrush age will fill an information gap for this region and contribute to broader understanding of this imperiled lagomorph.

Our objective was to characterize habitat occupied by pygmy rabbits in Utah with particular attention given to factors such as sagebrush age that have only received limited attention (Larrucea and Brussard 2008b). We hypothesized that pygmy rabbits would select taller and denser stands of sagebrush at locations with sandy soils when compared to unoccupied sagebrush habitats. We predicted that, as a result of preference for taller and denser stands of sagebrush, mean age of sagebrush in occupied habitat would be greater than that at unoccupied sites (Green and Flinders 1980, Himes and Drohan 2007, Larrucea and Brussard 2008b). This information will help identify characteristics of preferred habitat for pygmy rabbits in Utah and provide a better understanding of the ecological dynamics occurring within these habitats.

METHODS

Study Area

We collected habitat data at sites across the state of Utah (Figure 1) between May 2005 and August 2010. Elevation at these sites ranged from 1,494 m to 2,686 m. Based on climate data from 8 weather stations, which we selected to represent the regional climates of our sites, mean minimum annual temperatures ranged from -4°C to 6°C, mean maximum annual

temperatures ranged from 13°C to 20°C, and mean annual precipitation varied from 18 cm to 51 cm (Table 1; http://www.wrcc.dri.edu/summary/Climsmut.html). All of the sites we sampled occurred in sagebrush habitats. Some sites had upper hillsides which were dominated by either aspen (*Populous tremuloides*), juniper (*Juniperus* sp.), or pinyon pine (*Pinus edulis*). Lower elevations often consisted of wet, grassy valley bottoms, typically used for agriculture or grazing.

Big sagebrush (*A. tridentata*) communities in our study area were occupied by numerous species including other lagomorphs that may compete with pygmy rabbits such as black-tailed jackrabbits (*Lepus californicus*), cottontails (*Sylvilagus* sp.), and white-tailed jackrabbits (*Lepus townsendii*). Potential mammalian and avian predators of pygmy rabbits that occurred in these areas included badgers (*Taxidea taxus*), bald eagles (*Haliaeetus leucocephalus*), barn owls (*Tyto alba*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), ferruginous hawks (*Buteo regalis*), golden eagles (*Aquila chrysaetos*), great-horned owls (*Bubo virginianus*), long-eared owls (*Asio otus)*, long-tailed weasels (*Mustela frenata*), northern harriers (*Circus cyaneus*), prairie falcons (*Falco mexicanus*), ravens (*Corvus corax*), red foxes (*Vulpes vulpes*), red-tailed hawks (*Buteo jamaicensis*), rough-legged hawks (*Buteo lagopus*), short-eared owls (*Asio flammeus*), and Swainson's hawks (*Buteo swainsoni*).

Data Collection

We conducted this study in conjunction with a survey for pygmy rabbits throughout the state of Utah. This survey included investigating areas where pygmy rabbits occurred historically and searching in areas where potential pygmy rabbit habitat had been identified (Janson 2002). Survey work included multiple walk transects in historic or potential habitat to determine if identified areas were occupied by pygmy rabbits. We identified occupied sites by presence of fresh burrows, pellets, and evidence of pygmy rabbits observed on walk transects

(Larrucea and Brussard 2008a). Because pygmy rabbits spend most of their time in close proximity (< 100m) to burrows and are considered central-place foragers (Rosenberg and McKelvey 1999, Heady and Laundré 2005), we used active burrows as the center point for habitat measurements at occupied sites (Sanchez et al. 2009). For comparison, we evaluated habitat characteristics at random locations within areas determined to be unoccupied during survey work.

At each occupied and unoccupied site, we collected habitat measurements that included vegetative cover, horizontal obscurity, percent understory composition, and shrub density. For vegetative cover, we used the line intercept method along 15 m transects in each cardinal direction from the burrow or random point in unoccupied habitat. For horizontal obscurity measurements, we used a cover board with 36 squares (Bunnell et al. 2004). We placed the cover board at the burrow or random site, and then read the number of squares obscured by vegetation while kneeling down (to simulate height of a predator such as a coyote) from distances of 2.5 m, 5 m and 10 m in each cardinal direction. To determine percent composition of the understory, we used a ¼ m square quadrat (Daubenmire 1959) placed at the center point (burrow or random location) and 1 random point along the 15 m transect in each cardinal direction (5 quadrats per site). Within each quadrat, we made an ocular estimate of percent moss, bare ground, rock, litter, grasses, shrubs, trees, and forbs. We then calculated percent understory composition for each component at each site as the average of the five values from each plot.

To measure distances from the burrow or random point to the nearest human structure, possible raptor perch, and habitat edge, we used a laser rangefinder. Human structures were defined as buildings, power lines, fences, etc. We defined habitat edges as transitions from

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sagebrush to non-sagebrush habitats (e.g. roads, meadows, previous fire scars, etc.). We also collected soil at each site in order to assess any potential differences in soil texture between occupied and unoccupied sites. We collected soil samples at 15 cm in depth and then submitted them to the Brigham Young University soils lab to determine percent clay, sand, and silt for each sample. To determine sagebrush age at occupied and unoccupied sites, we collected sagebrush core samples (Ferguson 1964, Perryman and Olson 2000) from three different plants at each site. After removal of a cross section, we sanded and wetted (if necessary) the sample so that growth rings were visible. We then counted the growth rings in order to estimate age of each plant. We also included a separate estimate of age that accounted for missing parts of a core. When core pieces were obviously missing, we calculated this estimate of age by assuming equal spacing of rings in parts of the cores that were missing.

We coupled these measurements collected at each site with GIS-based metrics of aspect, curvature, elevation, and slope. To derive GIS-based measures of these features, we used ArcGIS version 10® (Esri. Inc., Redlands, CA) and UTM coordinates of each sample location. We generated aspect, curvature, elevation, and slope variables using a 30-m DEM obtained from the Utah GIS portal (http://agrc.its.state.ut.us). Because pygmy rabbits may select these habitat characteristics at multiple spatial scales, we generated buffers surrounding each location using a 100 m, 500 m, and 1,000 m radius. We then calculated the average value for each variable within each buffer and used these average values for statistical analysis. With information collected on the ground and the GIS-based metrics, we developed a list of 73 variables (Table 2) potentially useful in discriminating between occupied and unoccupied sites.

Data Analysis

To differentiate between occupied and unoccupied habitats, we used random forests (Cutler et al. 2007) in program R (R Development Core Team 2011). Random forests is a non-parametric classifier that builds multiple classification trees and then scrambles data for each explanatory variable in an iterative fashion to determine change in associated predictive ability for each variable. Compared to other classifiers (e.g. logistic regression or discriminant function analysis), random forests has high accuracy, the ability to model complex interactions, and produces an estimate of variable importance (MDA; mean decrease in accuracy) that is not affected by multi-collinearity (Cutler et al. 2007). To assess prediction accuracy, random forests computes an out-of-bag (OOB) error rate by withholding approximately 1/3rd of the data. We considered mean decreases in accuracy above 1.0 to be indicative of influential variables that successfully discriminated between occupied and unoccupied habitats. After identifying variables with the greatest ability to differentiate between occupied and unoccupied sites, we plotted means and confidence intervals (CI) for these variables by site type (occupied or unoccupied) to determine effect sizes (strength and direction).

RESULTS

We sampled 133 sites in Utah between May 2005 and August 2010 (Figure 1) to include 72 occupied and 61 unoccupied by pygmy rabbits. Eleven of the 73 variables (Table 2) had a mean decrease in accuracy (MDA) of 1.0 or greater (Figure 2). The variable with the greatest ability to differentiate between occupied and unoccupied sites was horizontal obscurity (Figure 2). Elevation was also important with an MDA above 1.0 for measurements at all three scales (Figure 2). Percent understory composed of shrubs and sagebrush and percent decadence of

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sagebrush were additional variables with MDAs above 1.0 (Figure 2). The "out of bag" (OOB) estimate of error rate was 6.02%.

Differences in mean horizontal obscurity between occupied and unoccupied sites were greatest near the burrow (2.5 m and 5 m). At shorter distances (2.5 m and 5m), mean horizontal obscurity values were almost twice as large at occupied sites compared to unoccupied sites (Figure 3). Similarly, understory composition at occupied sites included a higher mean percent composition of total shrubs and sagebrush than unoccupied sites (Figure 3). Elevation at occupied sites was also greater than at unoccupied sites whereas sagebrush decadence was lower at occupied sites in relation to unoccupied sites (see Figure 3).

Sagebrush age was not included in the list of variables with an MDA > 1.0 (Figure 2). Sagebrush maximum age (incorporating estimates from cores missing from sagebrush samples) had the highest MDA for age-related variables with a value of 0.78. Estimated ages at occupied sites were greater than estimates from unoccupied sites, but confidence intervals overlapped. Mean maximum age of sagebrush (95% CIs) at occupied sites was 42.30 (95% CI = 38.88 – 45.72) years compared to 39.64 (95% CI = 36.54 – 42.74) years at unoccupied sites. Similarly, soil textures had limited predictive ability with MDAs < 0.25. Mean soil composition at occupied sites was 0.44 sand (95% CI = 0.40 – 0.47), 0.31 silt (95% CI = 0.29 – 0.34), and 0.25 clay (95% CI = 0.23 – 0.27) compared to 0.44 sand (95% CI = 0.41 – 0.48), 0.30 silt (95% CI = 0.27 – 0.32), and 0.26 clay (95% CI = 0.24 – 0.28). Similarly, we found no evidence that distance to human structure, distance to natural and human edges, or distance to raptor perches differed between occupied and unoccupied sites.

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DISCUSSION

Horizontal cover measured at 2.5m and 5m from the burrow site was best able to discriminate between occupied and unoccupied habitats in our sample. Mean obscurity at these distances for occupied sites was nearly double that observed at unoccupied sites (Figure 3). The majority of this horizontal obscurity was comprised of shrub cover from sagebrush. These findings are consistent with others from California, Idaho, Nevada, Oregon, and Wyoming which have identified shrub cover as an important variable in site selection (Green and Flinders 1980, Weiss and Verts 1984, Katzner and Parker 1997, Larrucea and Brussard 2008b). In Nevada, islands of taller sagebrush and stands which provided greater cover could be used to identify sites where pygmy rabbits were likely to occur (Larrucea and Brussard 2008b). We also observed similar pockets of tall, dense sagebrush associated with occupied sites.

Interestingly, however, this selection for greater amounts of cover was not related to sagebrush age. Sagebrush age was low on the importance plot (Figure 2) with an MDA of 0.78 for maximum age. Moreover, we found significant overlap in confidence intervals around mean estimates of age for occupied and unoccupied sites. Greater amounts of cover at occupied sites; therefore, is more likely attributed to factors other than age. These factors may include variation in soil nutrients, water availability, or others that facilitate growth of such creating greater amounts of cover. Preliminary work in Nevada supports this interpretation for sagebrush ages, however, sample size was limited to only 7 sites (Larrucea and Brussard 2008b). It is possible that pygmy rabbits may positively influence growth of sagebrush near burrows due to nutrient input (feces, urine) and soil aeration (digging), however this idea remains untested and we suggest further work in this area. Average sagebrush age at occupied sites ranged between 23.98 and 42.30 years. These data suggest that 2-4 decades of sagebrush growth is required following

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disturbance such as fire or sagebrush manipulation before sagebrush habitats are again suitable for pygmy rabbits.

We found sagebrush at occupied sites less decadent than at unoccupied sites (Figure 3). This finding could be an indicator that in areas where pygmy rabbits do not exist, sagebrush has reached levels of decadence no longer suitable for pygmy rabbits. Increased levels of sagebrush decadence also likely decrease cover and reduce available food resources as sagebrush constitutes a majority of pygmy rabbit diet throughout the year (Green and Flinders 1980). Managers should make decisions which promote the health of a diverse stand of sagebrush plants including recruitment of new plants while preserving dense stands of sagebrush that provide sufficient cover for pygmy rabbits.

Soil textures at occupied and unoccupied sites were very similar with no difference in percent sand, silt, or clay. We measured only unoccupied sites within sagebrush steppe habitat which apparently have similar soil texture to occupied sites. The mean values we observed for soil texture were very similar to those found in Nevada (0.39 sand, 0.41 silt, and 0.20 clay) and Oregon (0.50 ± 3.9 sand, 0.27 ± 2.1 silt, and 0.23 ± 2.7 clay) (Weiss and Verts 1984, Larrucea and Brussard 2008b). A study done in Idaho, however, reported higher percent sand than we found in Utah with soils containing 0.81 sand, 0.14 silt, and 0.05 clay (Gabler et al. 2001). Our results and the variation in reported values above suggest that soil texture is unlikely to help in predicting pygmy rabbit presence within sagebrush communities at a fine scale. Perhaps other measures such as soil depth would provide more information than texture. These results are consistent with predictive habitat modeling efforts that often are successful in identifying non-habitat based on vegetation attributes (e.g. presence of sagebrush), but show weaknesses in predicting occupied habitat within sagebrush (Gabler et al. 2000, Rachlow and Svancara 2006).

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Elevation at all three scales ranked highly with MDAs > 1.0 (Figure 2). We consistently observed higher mean elevations for occupied sites in comparison to the nearest unoccupied sites at all spatial scales (Figure 3). In Nevada, a shift in pygmy rabbit habitat to higher elevations over the last few decades was reported—ostensibly due to warmer temperatures at lower elevations (Larrucea and Brussard 2008c). Increased temperatures may reduce the availability of snow pack for winter burrows, thus resulting in higher predation pressure and reduced access to food sources. Another possible explanation for our findings may be that with climatic change and warming at lower elevations, average summer temperatures are too high for pygmy rabbits. Pygmy rabbits are related to pika (*Ochotona princeps*), which are sensitive to temperature changes (Beever et al. 2003, Grayson 2005, Galbreath et al. 2009). Alternatively, poor sagebrush health or size at lower elevations could also explain this relationship. Further work should be conducted to evaluate thermal suitability of habitat for pygmy rabbits and possible implications of climate change on this species.

It is apparent from our study and others that the future of pygmy rabbits is directly connected with the loss, degradation, and fragmentation of sagebrush habitats (Thines et al. 2004, Grayson 2006, Shipley et al. 2006, Pierce et al. 2011). Given the multitude of threats to sagebrush habitats, it is essential that proactive management decisions be made that will mitigate impacts to pygmy rabbits and promote long-term conservation of sagebrush habitats (Barney and Frischknecht 1974, Thines et al. 2004, Bradley 2010). If we are to conserve pygmy rabbits in Utah and throughout their range, it will be essential to protect and maintain healthy sagebrush habitats.

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Table 1-1. Mean temperature (°C), mean maximum temperature (°C), mean minimum temperature (°C), and mean precipitation (cm) from 8 weather stations (1981-2010) found in close proximity to occupied and unoccupied pygmy rabbit (*Brachylagus idahoensis*) sample locations in Utah, USA where we measured soil, vegetative, and topographic features from 2005-2010. Information from http://www.wrcc.dri.edu/summary/Climsmut.html.

County	Weather Station (#)	Mean Temp.	Max. Temp.	Min. Temp.	Precip.
Tooele	Tooele (428771)	11.83	17.94	5.78	51.00
Rich	Woodruff (29595)	4.33	13.00	-4.33	25.50
Sevier	Koosharem (424764)	6.94	16.17	-2.28	25.60
Millard	Eskdale (422607)	10.56	19.28	1.78	17.50
Iron	Modena (425752)	10.22	19.67	0.72	29.44
Garfield	Panguitch (426601)	5.94	15.94	-4.00	24.92
Piute	Angle (420168)	6.56	16.22	-3.17	22.76
Wayne	Loa (425148)	6.78	15.67	-2.17	20.14

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Table 1-2. Topographic, vegetative, anthropogenic/predator, and abiotic attributes used to discriminate between occupied and unoccupied pygmy rabbit (*Brachylagus idahoensis*) sites in Utah, USA from 2005-2010.

Variables	Description
Topographic	
Aspect	Measured at 0 (sampling center point), 100, 500, and 1000 m scales
Curvature	Measured at 0 (sampling center point), 100, 500, and 1000 m scales
Elevation	Measured at 0 (sampling center point), 100, 500, and 1000 m scales
Slope	Measured at 0 (sampling center point), 100, 500, and 1000 m scales
Vegetative	
Understory composition	Mean percent forbs, grasses, lichen, litter, moss, shrubs, non-sagebrush shrubs, and sagebrush from $^1/_4$ m quadrats (n = 5) at each site
Sagebrush height	Mean height of 3 sagebrush plants sampled at each site
Sagebrush width	Mean width of 3 sagebrush plants sampled at each site
HO	Mean horizontal obscurity measured at 2.5, 5, and 10 m
Percent HO	Percent horizontal obscurity measured at 2.5, 5, and 10 m
Sagebrush age	Mean age, maximum age, and minimum age of sagebrush
Sagebrush decadence	Mean percent decadence of 3 sagebrush sampled at each site
Vegetation Structure	Shrub height and canopy width of closest shrub to sampling point
Shrub density	Number of shrubs rooted within a 3 m^2 at sampling point
Percent cover	Mean percent cover of forbs, grasses, moss, and shrubs from line transects
Percent sagebrush decadence	Mean percent shrub (sagebrush) decadence
Anthropogenic / Predator	
Distance edge	Distance (m) from sampling point to human and natural edge
Distance structure	Distance (m) from sampling point to nearest human structure
Distance raptor perch	Distance (m) from sampling point to nearest raptor perch
Distance cliff	Distance (m) from sampling point to nearest cliffs
Distance road	Distance (m) from sampling point to nearest road or ORV trail
Abiotic	

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Soil composition	Percent clay, sand, and silt from 15 cm depth
RSC	Rock size class value at sampling point
Percent rock	Mean percent rock from $^1/_4$ m Daubenmire quadrats (n = 5) at each site
Percent bare ground	Mean percent bare ground from $^1/_4$ m Daubenmire quadrats (n = 5) at each site
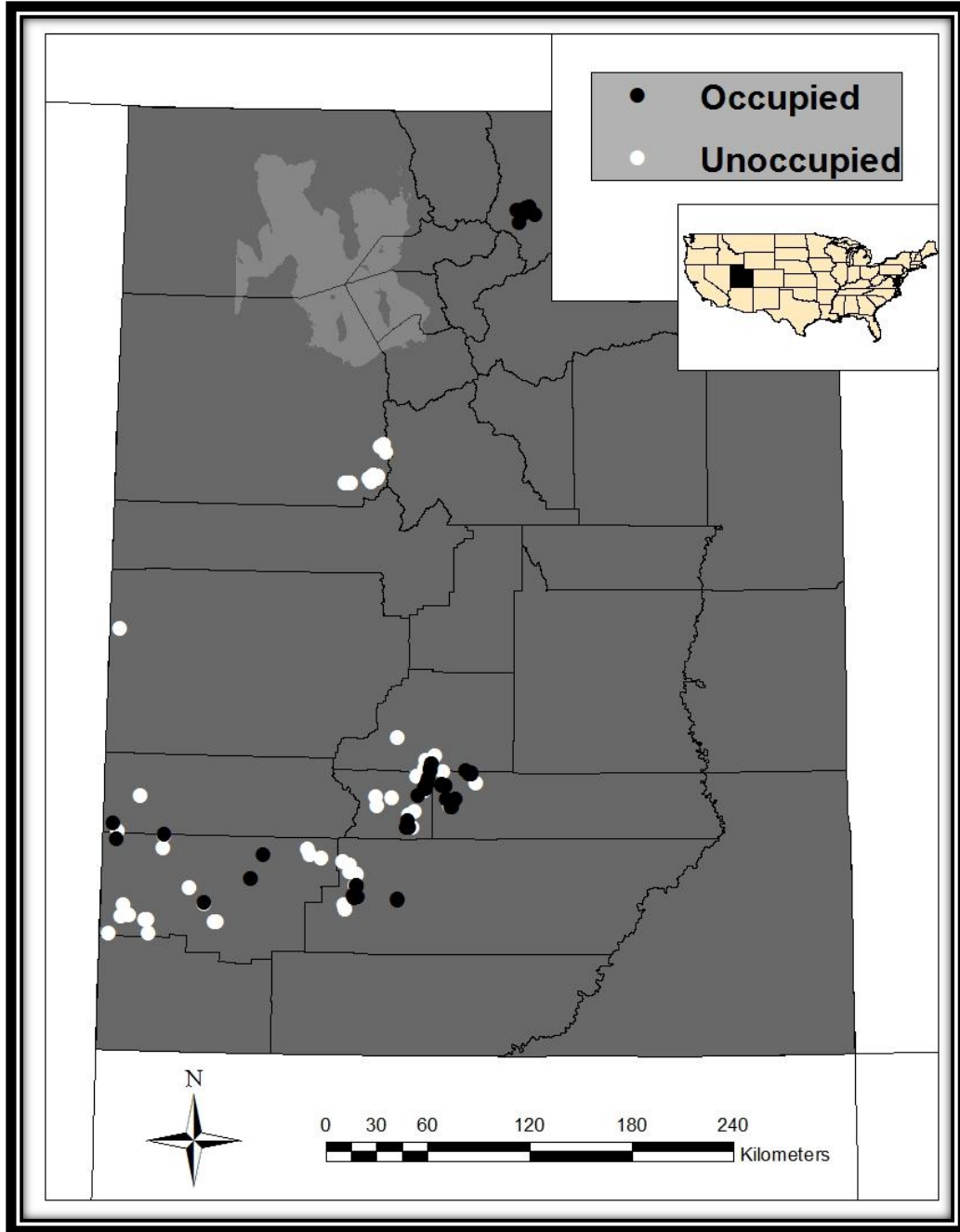
Figure 1-1. Locations in Utah, USA where we measured attributes of potential pygmy rabbit (*Brachylagus idahoensis*) habitat (i.e. sagebrush habitat) from 2005 – 2010. Black dots represent locations with active pygmy rabbit burrows whereas white dots represent locations without active burrows.
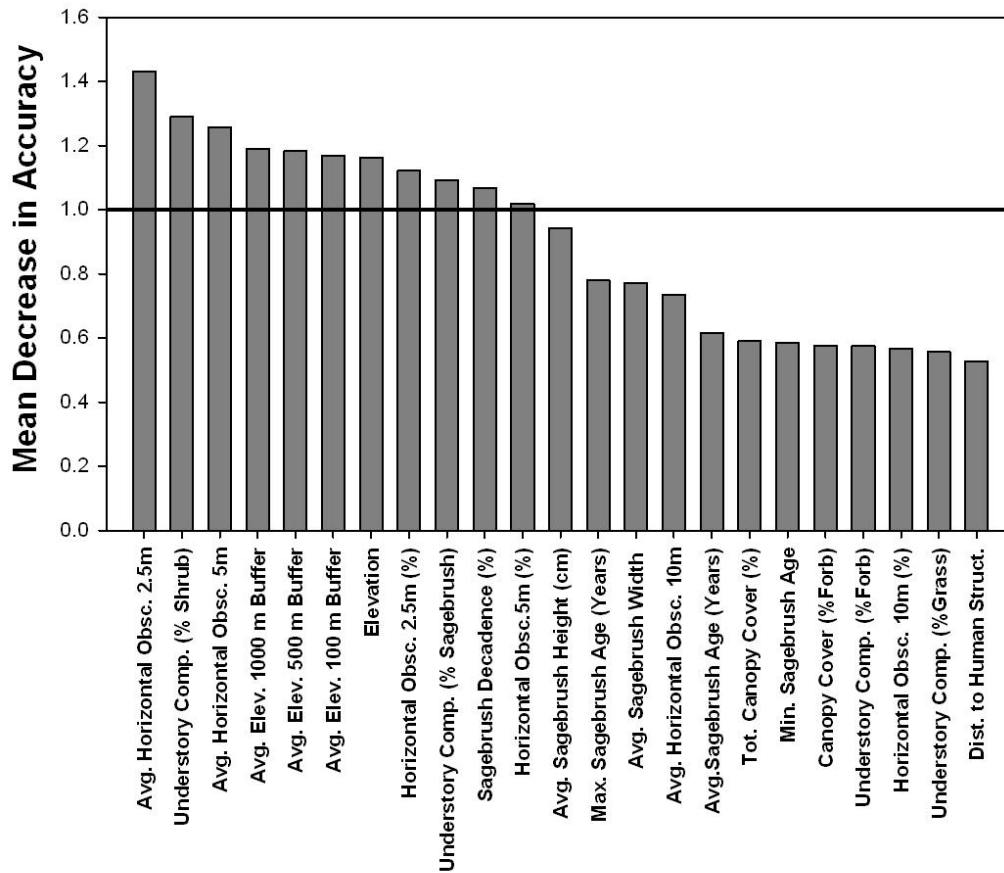
Figure 1-2. Ranking of habitat variables used to discriminate between occupied and unoccupied pygmy rabbit (*Brachylagus idahoensis*) habitat in Utah, USA from 2005- 2010. Represented are the most influential 23 variables on the x-axis (descending order) and their associated mean decrease in accuracy (MDA) on the y-axis from an analysis using random forests. MDAs above 1.0 are typically considered good discriminants.
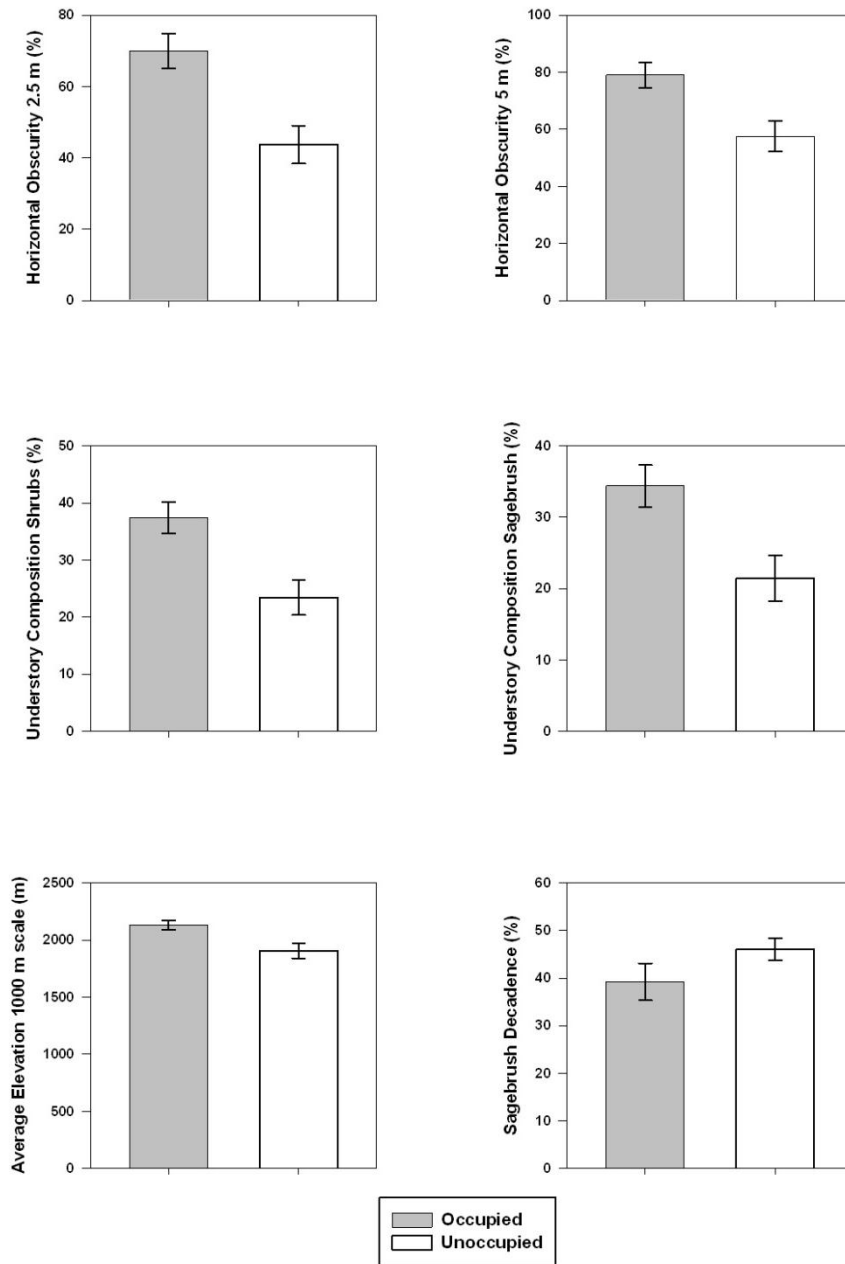
Figure 1-3. Mean (95% CI) values for variables identified as important discriminants (random forests mean decrease in accuracy > 1.0) of occupied and unoccupied pygmy rabbit (*Brachylagus idahoensis*) habitat in Utah, USA from 2005-2010.

CHAPTER 2

Pygmy Rabbit (*Brachylagus idahoensis*) Response to Construction

of the Ruby Pipeline in Northern Utah

ABSTRACT

The decline of sagebrush (*Artemisia* sp.) habitats throughout the western United States is an urgent conservation concern that threatens many species. Pygmy rabbits (*Brachylagus idahoensis)* are sagebrush obligates dependent on these habitats throughout all phases of their life cycle. Construction of the Ruby pipeline (a large natural gas pipeline) in northern Utah, USA provided an opportunity to assess pygmy rabbit response to disturbance and habitat loss commonly associated with energy development projects. We monitored the movements and survival of 108 adult pygmy rabbits (63 female, 45 male) over an 18-month period that included time before, during, and after construction of the pipeline. Some of these pygmy rabbits (n = 32) were captured prior to construction at burrow systems within the pipeline right of way (ROW) eventually cleared of vegetation. Core space-use areas of radio-marked rabbits shifted away from the disturbance ($\bar{x}$ = 68 m, 95% CI = 51 – 85 m) and 95% kernel density estimates of space use decreased (t = 2.70, df =17, *P*< 0.02) by an average of 74% after construction. Annual space use (95% fixed kernel density estimates) was nearly 50% larger (t = -2.35, df = 63, *P*< 0.02) for pygmy rabbits in our reference area compared to those impacted by construction. We also observed fewer crossings of the pipeline ROW by radio-marked pygmy rabbits after construction. Despite these impacts, however, we found no evidence for decreased survival associated with construction activities. Weekly estimates of survival at the ROW before (S = 0.95; 95% CI = 0.89 – 0.98), during (S = 0.96, 95% CI = 0.77 – 0.99), and after construction (S =

0.95, 95% CI = 0.94 – 0.97) were similar to those observed in our reference area (S = 0.94, 95% CI = 0.91 – 0.95). Linear disturbances in sagebrush habitats such as those associated with pipeline construction fragmented habitat and limited movements of pygmy rabbits. Mitigation for these disturbances should focus on maintaining or improving habitat connectivity.

INTRODUCTION

Habitat loss and fragmentation are associated with the decline and extinction of many species (Fahrig 1997, Franken and Hik 2004). Reductions in both extent and quality of habitat can reduce availability of food and shelter, thus increasing inter- and intra-specific competition (Menge and Sutherland 1976, Tilman et al. 1997, Marvier et al. 2004). These changes can lead to lower reproduction and survival which result in smaller population sizes (Brockelman 1975, Fahrig 1997). Smaller population sizes are more vulnerable to stochastic events and extinction (Shaffer 1981, Shaffer and Samson 1985, Lande 1993). In addition, habitat fragmentation can restrict emigration and immigration, which often reduces gene flow leading to lower genetic diversity (Fahrig 1997, Cushman 2006). Low genetic diversity can increase risk of extinction (Brook et al. 2002). Impacts from habitat loss and fragmentation can be profound—particularly when they occur in habitats that are rare or declining in size and ecological function (Oyler-McCance et al. 2001, Brooks et al. 2002, Ingelfinger and Anderson 2004, Holloran 2005).

Sagebrush (*Artemisia* sp.) habitats have been negatively influenced by a wide variety of impacts. Energy development, conversion to agriculture, overgrazing, invasive species, and changes in fire frequency have resulted in the loss and fragmentation of this ecotype across much of the western United States (Barney and Frischknecht 1974, D'Antonio and Vitousek 1992, Miller 1999, Braun et al. 2002, Thines et al. 2004, Evans and Rollins 2008, Bradley 2010). Both

extent and functionality of these habitats have declined in recent decades creating conservation challenges for a variety of species (Beetle 1960, Schneegas 1967, Vale 1975, Baker et al. 1976, Braun 1998, Miller 1999, Miller and Eddleman 2000, Braun et al. 2002, Bradley 2010). At greatest risk from the loss and decline of sagebrush habitats are obligate species found only in this ecotype (Oyler-McCance et al. 2001, Brooks et al. 2002, Ingelfinger and Anderson 2004, Holloran 2005).

Pygmy rabbits (*Brachylagus idahoensis)* are a sagebrush obligate species dependent on big sagebrush (*A. tridentata*) throughout all phases of their life cycle. Pygmy rabbits depend on sagebrush for >95% of their diet in winter and >50% in summer (Green and Flinders 1980). In addition to food, sagebrush provides both protective and thermal cover for pygmy rabbits and they select for increased sagebrush height and cover (Green and Flinders 1980, Katzner and Parker 1997, Camp et al. 2012). Pygmy rabbits are also a semi-fossorial species that uses burrows for shelter and thus require soils suitable for digging burrows in conjunction with sagebrush (Dobler and Dixon 1990, Sanchez et al. 2009). In relation to burrow systems, pygmy rabbits demonstrate attributes of a "central place" forager (Rosenberg and McKelvey 1999, Heady and Laundré 2005). Despite this designation, however, space-use estimates for this species are typically larger than those predicted by its body size (Sanchez and Rachlow 2008). Because of the loss of sagebrush habitats throughout the western United States, it is believed pygmy rabbits are declining (Lyman 1991, Gahr 1993, McAllister and Program 1995, USFWS 2003). Repeated petitions to the United States Fish and Wildlife service have argued pygmy rabbits deserve range-wide protection under the 1973 United States Endangered Species Act, and an isolated population from the Columbia Basin in Washington state is already listed (USFWS 2003, 2010). Given these challenges, there is a need to further understand how pygmy rabbits

respond to disturbances currently impacting sagebrush habitats.

Installation of the Ruby pipeline (a large natural gas pipeline) in northern Utah, USA provided an opportunity to assess pygmy rabbit response to disturbance associated with construction (e.g. heavy machinery, soil disturbance, vegetation removal) of a linear feature such as a pipeline or road. Our objectives were to monitor and assess short-term (18 month) response by pygmy rabbits to installation of the Ruby pipeline. We hypothesized that pygmy rabbits captured at burrow systems within the disturbed area would be impacted by construction because both burrow systems and vegetation around them were removed. Specifically, we predicted that pygmy rabbits would alter space use patterns in response to construction activities and demonstrate lower survival rates compared to a reference group not influenced by construction activities.

METHODS

Study Area

We evaluated pygmy rabbit response to installation of the Ruby pipeline west of the city of Woodruff in northern Utah, USA (Figure 1). We focused trapping efforts prior to construction within the 75 m right-of-way (ROW) eventually cleared of vegetation (ROW) (Figure 2). To provide a reference group for comparison, we also captured and radio-marked pygmy rabbits in an area 8 km to the north of the ROW on Bureau of Land Management (BLM) administered lands where no construction activity occurred. The reference area and ROW were separated by agricultural land and a highway; no interchange of radio-marked pygmy rabbits occurred during our study. Predominant shrubs at both sites included big sagebrush and Douglas rabbit brush (*Chrysothamnus viscidiflorus*). Both areas were seasonally grazed by cattle. Mean

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temperature measured from 1995-2005 at the Woodruff, UT weather station (429595) near our study sites was 3.52°C (95% CI = 3.15° – 3.89° C). Precipitation in this semi-arid region typically occurred as rain in the spring and snow in the winter (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utwood).

Both study sites were occupied by other lagomorphs including black-tailed jackrabbits (*Lepus californicus*), mountain cottontails (*Sylvilagus nuttallii*), and white-tailed jackrabbits (*Lepus townsendii*). Mammalian and avian predators of pygmy rabbits that occurred in these areas included badgers (*Taxidea taxus*), bald eagles (*Haliaeetus leucocephalus*), barn owls (*Tyto alba*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), ferruginous hawks (*Buteo regalis*), golden eagles (*Aquila chrysaetos*), great-horned owls (*Bubo virginianus*), long-eared owls (*Asio otus)*, long-tailed weasels (*Mustela frenata*), northern harriers (*Circus cyaneus*), prairie falcons (*Falco mexicanus*), red-tailed hawks (*Buteo jamaicensis*), rough-legged hawks (*Buteo lagopus*), short-eared owls (*Asio flammeus*), and Swainson's hawks (*Buteo swainsoni*).

Data Collection

We trapped pygmy rabbits from July 2010 through October 2011 using both active and passive methods (Green and Flinders 1979, Crawford et al. 2010). Once captured, we measured body mass, body length, and determined sex of each individual. We then radio-marked adult pygmy rabbits (mass > 300 g) with a 5g necklace-style radio transmitter (RM 1550, Advanced Telemetry Systems®, Isanti, MN). We attached collars around the neck of pygmy rabbits with a zip tie and wrapped the zip tie in rubber tubing to minimize abrasion (Crawford et al. 2010). Following radio attachment, we released pygmy rabbits at the point of capture. Capture and handling methods followed the care and use guidelines of the American Society of Mammalogists (Gannon and Sikes 2007), Brigham Young University's Institutional Animal

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Care and Use Committee (approval numbers 08-0202 and 11-0302), and the Utah Division of Wildlife Resources (COR permit 1BAND6890).

We used a 4-element Yagi antenna (Telonics Inc.®, Mesa, AZ) and R-1000 digital radio receivers (Communications Specialists Inc.®, Orange, CA) to obtain locations of radio-marked pygmy rabbits from the ground. Once individual pygmy rabbits were located, we recorded locations in Universal Transverse Mercator (UTM) coordinates using hand-held global positioning systems (GPS) (Garmin International, Inc.®, Olathe, KS). During the initial month prior to and after installation of the pipeline, we obtained 1 to 3 locations per day (before $\bar{x}$ = 1.73 locations per rabbit/day; after $\bar{x}$ = 1.52 locations per rabbit/day) staggered randomly throughout the day for each radio-marked rabbit. We limited data collection to daylight hours because it was difficult to locate rabbits in the dark before they flushed (Sanchez and Rachlow 2008). Following intense monitoring during the month prior to and directly after construction, we obtained 3 to 4 locations per week during the summer field season (May – August) and 1 to 2 locations every 2 weeks during fall and winter (September – April).

Data Analysis

We estimated space use separately for each rabbit during the month before and after construction and for the lifespan of each rabbit after construction (3 periods). We used the fixed-kernel analysis method (Worton 1989), but only included rabbits with ≥ 20 locations for each period (Sanchez and Rachlow 2008). We used Animal Space Use beta (Version 1.3; Horne 2005) to estimate the smoothing parameter (h) using likelihood cross-validation (CVh; Silverman 1986) as it performs better for datasets with modest sample sizes (e.g. ≤ 50 locations per individual; Horne and Garton 2006, Sanchez and Rachlow 2008). We used Hawth's tools within ArcGIS (Version 9.3; Environmental Systems Research Institute Inc.®, Redlands, CA) to

generate 95% fixed-kernel polygons and 50% fixed-kernel core areas for each site (ROW and reference area) and period (Beyer 2004). We then made comparisons of space use (*t* tests) before and after construction and across groups (ROW and reference area).

In order to determine if core-use areas shifted in relation to construction, we measured the distance of the centroid for each core area from the ROW before and after construction. We then compared these distances using a paired *t*-test. In addition, we counted the number of times radio-marked rabbits made movements across the ROW during the month before construction and compared this value to the number of crossings during the month after construction. We also compared the number of crossings during the month before construction to the number of times that these same rabbits crossed after construction throughout the duration of the 18-month study period. We used program R for all statistical tests involving space use (R Development Core Team 2011) and set alpha (α) = 0.05.

We used known fate models in Program MARK 6.1 (White and Burnham 1999, Franklin 2001) and model selection (Burnham and Anderson 2002) to evaluate hypotheses regarding survival of pygmy rabbits in relation to pipeline construction. First, we formatted encounter histories into weekly intervals beginning July 25, 2010 through January 22, 2012. We formatted site (ROW or reference area) as a group in the input file and included sex and a measure of fitness (mass / body length) at time of capture as individual covariates in our models (Bailey 1968). We followed standard model selection protocol and first made a list of *a priori* candidate models incorporating seasonal, group, and individual covariate influences (Table 1). Our list of *a priori* models included several with hypothesized differences in survival in relation to 3 seasons defined as spring (March – June), summer/fall (July – October), and winter (November – February) (Sanchez and Rachlow 2008, Crawford et al. 2010). For other models, we extended

the winter season to include the month of March. We also evaluated seasonal models where year was classified into breeding (February – June) and non-breeding (July – January) periods (Elias et al. 2006). To these seasonal models, we added group effects (ROW or reference area), trend influences associated with construction where we predicted declining survival rates following construction, and individual covariates (Table 1).

Next, we used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) and AIC_c model weight (w_i) to rank models and evaluate relative support for candidate hypotheses (Akaike 1973, Lebreton et al. 1992, Buckland et al. 1997, Burnham and Anderson 2002). In the presence of model-selection uncertainty, we obtained model-averaged estimates of survival for the various time periods and influences (Burnham and Anderson 2002). Finally, we adjusted interval lengths (each week representing $1/52^{nd}$ of a year) in Program MARK in separate analysis to obtain estimates of annual survival across our 18-month period for comparison with other studies (White and Burnham 1999, Cooch and White 2012).

RESULTS

We captured, radio-marked, and monitored 108 adult pygmy rabbits from July 2010 through January 2012. This sample included 63 adult female rabbits and 45 adult male rabbits; 59 pygmy rabbits were captured at the ROW and 49 at our reference area. We radio-marked 32 pygmy rabbits captured from within the ROW prior to construction. Mean body mass for captured pygmy rabbits was 438 g (95% CI = 429 – 448 g; range 310 – 500 g). Mean body length was 23.9 cm (95% CI = 23.6 – 24.2 cm; range 19.0 – 28.0 cm). Mean condition of pygmy rabbits at time of capture (body mass/body length) was 18.6 g/cm (95% CI = 18.1 – 19.0 g/cm; range 13.9 – 27.3 g/cm).

Movements and Space Use

Space use (95% kernel density estimates) for 18 pygmy rabbits (individuals with $\geq$ 20 locations per time period) captured at the ROW during the month prior to construction ($\bar{x}$ = 11,754 m^2, 95 % CI = 5,840 – 17,667 m^2) was larger (paired t = 2.70, df =17, P< 0.02) than that observed during the month after construction ($\bar{x}$ = 3,070 m^2, 95 % CI = 2,091 – 4,048 m^2). Similarly, core area size (50% kernel density estimate) for these 18 rabbits during the month before construction ($\bar{x}$ = 2,132 m^2, 95 % CI = 1,163 – 3,101 m^2) was larger (t = 2.97, df = 17, P< 0.01) than that observed following construction ($\bar{x}$ = 582 m^2, 95 % CI = 402 – 762 m^2) (Figures 3 and 4). Likewise, space use area (95% fixed-kernel estimates) for pygmy rabbits captured in or near the ROW (n = 40) throughout the 18-month period ($\bar{x}$ = 24,587 m^2, 95 % CI = 13,384 – 35,790 m^2) was smaller (t = -2.35, df = 63, P< 0.02) than similar estimates for pygmy rabbits (n = 25) at our reference area ($\bar{x}$ = 48,721 m^2, 95 % CI = 11,686 – 85,573 m^2). Core use area (50% kernel density estimates) for these same rabbits at the ROW ($\bar{x}$ = 4,131 m^2, 95 % CI = 2,432 – 5,830 m^2) was also smaller (t = -2.67, df = 63, P< 0.01) than that observed in the reference area ($\bar{x}$ = 8,836 m^2, 95 % CI = 2,296 – 15,376 m^2).

In addition to smaller space use, pygmy rabbits shifted the center of core use areas ($\bar{x}$ = 35 m, 95 % CI = 18 – 51 m) away from the impacted zone following construction (paired t = -4.03, df = 17, P< 0.01). Mean number of crossings during the month before construction ($\bar{x}$ = 1.00 crossing per rabbit, 95 % CI 0.32 – 1.68 crossings) was greater (paired t = 2.87, df = 21, P< 0.01) than that observed during the month after construction when no rabbits crossed the ROW. Likewise, mean number of crossings by these same rabbits throughout the duration of the study (17 months) following construction ($\bar{x}$ = 0.18 crossings, 95 % CI = -0.03 – 0.39) was lower (t = 2.21, df = 25.26, P< 0.04) than the number observed in the single month preceding construction.

Nine of 22 (41%) pygmy rabbits that survived both the month before and after construction crossed the pipeline ROW before vegetation was removed whereas 0 of these 22 (0%) crossed during the month after construction and only 3 rabbits (14%) crossed within the 17 months following pipeline installation.

Survival

Our top model of survival (36% of AIC$_c$ weight) included 3 seasons (year defined as spring [March – June], summer/fall [July – October], and winter [November – February]), group (area), and sex effects as well as an influence from our metric of condition (body mass / body length) (Table 2). The second most supported model (29% AIC$_c$ weight) had a similar structure, but without a difference in survival between areas (Table 2). We found no support for models that allowed for differences in survival in relation to construction activities or those that partitioned the year into different seasonal structure (e.g. breeding and non-breeding seasons) (Table 2). Similarly, models with 5 and 15 week trends related to construction had only limited support (top model with this structure was third with 14% AIC$_c$ weight; Table 2).

Despite group (area) effects in some of the supported models (Table 2), confidence intervals around average weekly estimates of survival at the ROW before (S = 0.95, 95% CI = 0.89 – 0.98), during (S = 0.96, 95% CI = 0.77 – 0.99), and after construction (S = 0.95, 95% CI = 0.94 – 0.97) overlapped those observed in the reference area (S = 0.94, 95% CI = 0.91 – 0.95). We found support for seasonal differences in survival with lower weekly survival rates during the winter (November – February) (S = 0.94, 95% CI = 0.92 – 0.97), and spring (February – June) (S = 0.93, 95% CI = 0.89 – 0.96), compared to summer/fall (July – October) (S = 0.97, 95% CI = 0.94 – 0.98), although slight overlap in confidence intervals occurred. In our area, males (coded as 1) were more likely to survive than females (β estimate 2.22, 95% CI = 0.88 –

3.56). Our metric of condition at time of capture (body mass/body length) was also a commonly observed influence in top models. The β estimate associated with this metric was positive (0.20), but confidence intervals overlapped zero slightly (95% CI = -0.08 – 0.49). Estimates of annual survival for females at the ROW (S = 0.04, 95% CI = 0.02 – 0.11) and at our reference area (S = 0.01, 95% CI = 0.00 – 0.05) were lower than those observed for males (ROW S = 0.25, 95% CI = 0.12 – 0.46; reference area S = 0.09, 95% CI = 0.03 – 0.25). The combined overall annual survival rate for males and females at both the ROW and reference area was 0.06 (95% CI = 0.03 – 0.11).

DISCUSSION

This study was the first of its kind to observe the response of pygmy rabbits to disturbance associated with the construction of a natural gas pipeline. We observed a shift in locations of core areas away from construction activities demonstrating habitat loss and avoidance of the area cleared during construction. Pygmy rabbits avoided open areas associated with mechanical treatment in studies where sagebrush was removed and our results support this consensus (Wilson et al. 2010, Pierce et al. 2011). Similarly, snowshoe hares (*Lepus americanus*) avoided disturbed areas in a study evaluating response to pre-commercial forest thinning (Abele et al. 2013). Moreover, other sagebrush obligates such as sage grouse (*Centrocercus urophasianus*) have also demonstrated avoidance of habitats impacted by energy development projects with a reduction of active leks near oil development (Braun et al. 2002, Walker et al. 2007). Mule deer (*Odocoileus hemionus*) were also less likely to occupy areas within close proximity to oil fields (Sawyer et al. 2006). Avoidance of disturbed habitats could lead to increased competition in areas not avoided and reduced resource availability (Shaffer and

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Samson 1985, Lande 1993, Fahrig 1997, Tilman et al. 1997).

We observed significantly fewer crossings of the ROW by pygmy rabbits in the 17 months after construction compared to the one month prior to construction suggesting construction had fragmented sagebrush habitat for pygmy rabbits. In Alaska, caribou (*Rangifer tarandus granti*) showed reluctance to cross beneath an elevated oil pipeline (Smith and Cameron 1985). Roads are also a common linear feature that has fragmented habitat for many species including hedgehogs (*Erinaceus europaeus*) and some bats, which avoided crossing roads (Andrews 1990, Rondinini and Doncaster 2002, Bennett and Zurcher 2013). Similarly, Grizzly bears (*Ursus arctos* horribilis) have also demonstrated avoidance of roads leading to habitat fragmentation (McLellan and Shackleton 1988). The restrictions in movements across the pipeline right of way we observed may have cascading influences on meta-population dynamics and genetic diversity (Brook et al. 2002).

Space-use estimates decreased in size following construction and were smaller at the ROW compared to our reference site. Estimates of space use from pygmy rabbits at the ROW ($\bar{x}$ = 24,587 m^2) were much smaller than those reported for females (approximately 40,000 m^2) and males (approximately 120,000 m^2) in Idaho (Sanchez and Rachlow 2008). Estimates at our reference area, however, were similar ($\bar{x}$ = 48,721 m^2) suggesting an effect from construction as opposed to regional variation in space use. This reduction in space-use occurred after construction of the pipeline removed available resources (i.e. burrows and sagebrush) for pygmy rabbits. If space use by pygmy rabbits was dependent on these two resources, we likely would not have observed a decrease in space use. This result suggests that space use by pygmy rabbits is influenced by other factors such as social interactions among conspecifics. Reduced space use following construction was likely a result of avoidance of the disturbed areas coupled with

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reluctance to utilize new areas. This reluctance to use new areas may be associated with presence of other pygmy rabbits (e.g. territorial behavior) or other unknown factors.

We expected to observe some direct mortality as a result of construction activities that included vegetation removal (brush hogging), soil excavation, and increased vehicle traffic. Direct mortality has been recorded in other studies evaluating wildlife response to disturbance (McCrary et al. 1986, Arnett et al. 2008). Bats and birds, for example, have been killed as a result of solar and wind energy development (McCrary et al. 1986, Osborn et al. 2000, Arnett et al. 2008) or in association with transmission lines (Ferrer et al. 1991). For other species, increased vehicle traffic along roads was associated with increased mortality (Dique et al. 2003, Malo et al. 2004, Lesiński 2008, Bennett and Zurcher 2013). Nonetheless, we did not observe any direct mortality of pygmy rabbits associated with construction. Moreover, contrary to our predictions, we found no evidence of decreased survival rates in association with construction of the Ruby pipeline (Dobler and Dixon 1990, Thines et al. 2004, Heady and Laundré 2005, Camp et al. 2012) as survival rates were similar between areas (ROW and reference area). Moreover, the survival rates we observed at both study sites were similar to values reported in the literature (Crawford et al. 2010). Pygmy rabbits abandoned burrows and moved away from potentially dangerous areas before they were injured or killed. Perhaps we did not detect a decrease in survival associated with construction of the pipeline because home range areas at the ROW (even after construction) were still above those predicted to maintain nutrient requirements for an herbivore the size of a pygmy rabbit (12,600 m^2) (Sanchez and Rachlow 2008). Our results may have been different if habitat loss was sufficient to restrict home ranges beyond this predicted threshold.

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We found weekly survival rates highest during the summer/fall months, and lowest during the winter and spring. This finding could be a result of increased vulnerability to predation when snow accumulated on the landscape during winter, which resulted in increased visibility of pygmy rabbits to predators. Also, increased movements during the breeding season (February – June) could increase vulnerability of pygmy rabbits to predation during these months (Sanchez and Rachlow 2008). Males had higher survival rates than females at both of our study sites. Similar differences (males with higher survival than females) were found at only 1 of 4 study sites in Oregon and Nevada (Crawford et al. 2010). Estimates of space use for male pygmy rabbits are typically larger than those for females which could increase predation risk (Sanchez and Rachlow 2008). Nonetheless, survival appears to vary by sex and study area (Crawford et al. 2010).

This study observed the short-term response of pygmy rabbits to construction of the Ruby pipeline and demonstrated both habitat loss and fragmentation. Our study, however, was limited in that we only evaluated response over 18 months. Moreover, logistical constraints and timing of funding availability limited assessment of pygmy rabbit survival and space use prior to construction to a single month. Nonetheless, significant differences in space use, location of core use areas, and number of crossings were observed. Furthermore, comparison of space use by pygmy rabbits with those at a reference area reinforced these findings. Future work should examine how long it takes pygmy rabbits to re-establish in disturbed areas. Other long-term effects from habitat loss and fragmentation could also be examined such as implications from potential reductions in gene flow.

MANAGEMENT IMPLICATIONS

To reduce the impacts to pygmy rabbits from construction of linear features such as the Ruby pipeline, we recommend minimizing the amount of vegetation removed to limit habitat loss. If pygmy rabbit burrow complexes can be identified prior to construction and construction can work around them, patches of mature sagebrush should be left surrounding these burrows. To reduce the influence of habitat fragmentation associated with these disturbances, we suggest that sections of important wildlife habitat be left connecting contiguous habitat from both sides of the linear feature. Rehabilitation of sagebrush communities could help where vegetation has been removed, however, for pygmy rabbits and other old growth obligates it may take decades before sagebrush is of sufficient size to meet species requirements (Larrucea and Brussard 2008).

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Table 2-1. A priori models used to evaluate hypothesis concerning pygmy rabbit (*Brachylagus idahoenis*) survival in relation to construction of the Ruby pipeline in northern Utah, USA, 2010 – 2012.

Model	Model Structure	Model Description
1	S (.)	Survival constant
2	S (g)	Survival differed by group (pipeline right of way or reference area)
3	S (sex)	Survival differed by sex
4	S (t)	Survival differed by weekly interval
5	S (g*t)	Survival differed by weekly interval with an interaction for area
6	S (g + sex)	Survival differed between area with an additive affect for sex
7	S (body mass)	Survival varied with individual body mass
8	S (month)	Survival varied by month
9	S (month*g)	Survival varied by month with an interaction for area
10	S (condition ratio)	Survival varied with condition ratio (body mass/body length)
11	S (before/after*g)	Survival differed by area in relation to pipeline construction
12	S (before/after*g+week6)	Survival varied by area in relation to construction with 6 week trend
13	S (breeding season)	Survival differed by breeding season (February – June)
14	S (breeding season*g)	Survival differed by breeding season (February – June) and area
15	S (3 seasons*g, before/after)	Survival varied by 3 seasons and area in relation to construction
16	S (3 seasons)	Survival varied across 3 seasons
17	S (3 seasons*g)	Survival varied by 3 seasons and area
18	S (3 seasons, winter thru March)	Survival differed by 3 seasons extended winter (November – March)
19	S (3 seasons*g, winter thru March)	Survival differed by 3 seasons (extended winter thru March) and area
20	S (3 seasons*g + sex + ratio)	Survival varied by 3 seasons with an interaction with area individual covariates for sex and condition (body mass/body length)
21	S (3 seasons*g)	Survival varied by 3 seasons with an interaction with area
22	S (3 seasons+10weekT+g)	Survival varied by 3 seasons with a 10 week linear trend, additive area effect
23	S (3 seasons+10weekTT+g)	Survival varied by 3 seasons with a 10 week quadratic trend and additive area effect
24	S (3 seasons+15weekT+g)	Survival varied by 3 seasons with a 15 week linear trend, additive area effect
25	S (3seasons+15weekT+ g+sex+condition)	Survival varied by 3 seasons with a 15 week linear trend, additive effects for area, sex, and condition (body mass/body length)

26	S (3 seasons+5weekT+g)	Survival varied by 3 seasons with a 5 week linear trend and additive area effect
27	S (3 seasons+5weekTT+g)	Survival varied by 3 seasons with a 5 week quadratic trend and additive area effect
28	S (3 seasons+74weekT+g)	Survival varied by 3 seasons with a 74 week linear trend and additive area effect
29	S (3 seasons + sex + ratio)	Survival varied by 3 seasons with additive effects for sex and condition (body mass/body length)

[a] Three season models identified the year as spring (March – June), summer/fall (July – October), and winter (November – February) unless otherwise noted.

Table 2-2. Supported ($\geq$ 0.01 AICc weight) models describing variation in survival of pygmy

rabbits (*Brachylagus idahoensis*) in relation to construction of the Ruby pipeline in northern

Utah, USA 2010 – 2012.

Model[a]	Model Structure	AIC$_c$[b]	ΔAIC$_c$[c]	w_i[d]	K[e]	Deviance[f]
20	S (season*g + sex+ratio)	665.26	0.00	0.36	6	653.21
29	S (season+sex+ratio)	665.69	0.44	0.29	5	655.66
25	S (season+15weekT+g+sex+ratio)	667.19	1.93	0.14	7	653.12
6	S (g+sex)	667.59	2.34	0.11	3	661.58
3	S (sex)	669.07	3.81	0.05	2	665.06
21	S (season*g)	672.21	6.95	0.01	4	664.18

[a] Model numbers correspond to those in Table 1.
[b] Akaike's Information Criterion adjusted for small sample sizes
[c] Difference in AIC$_c$ value from top model
[d] AIC$_c$ model weight
[e] Number of model paramters
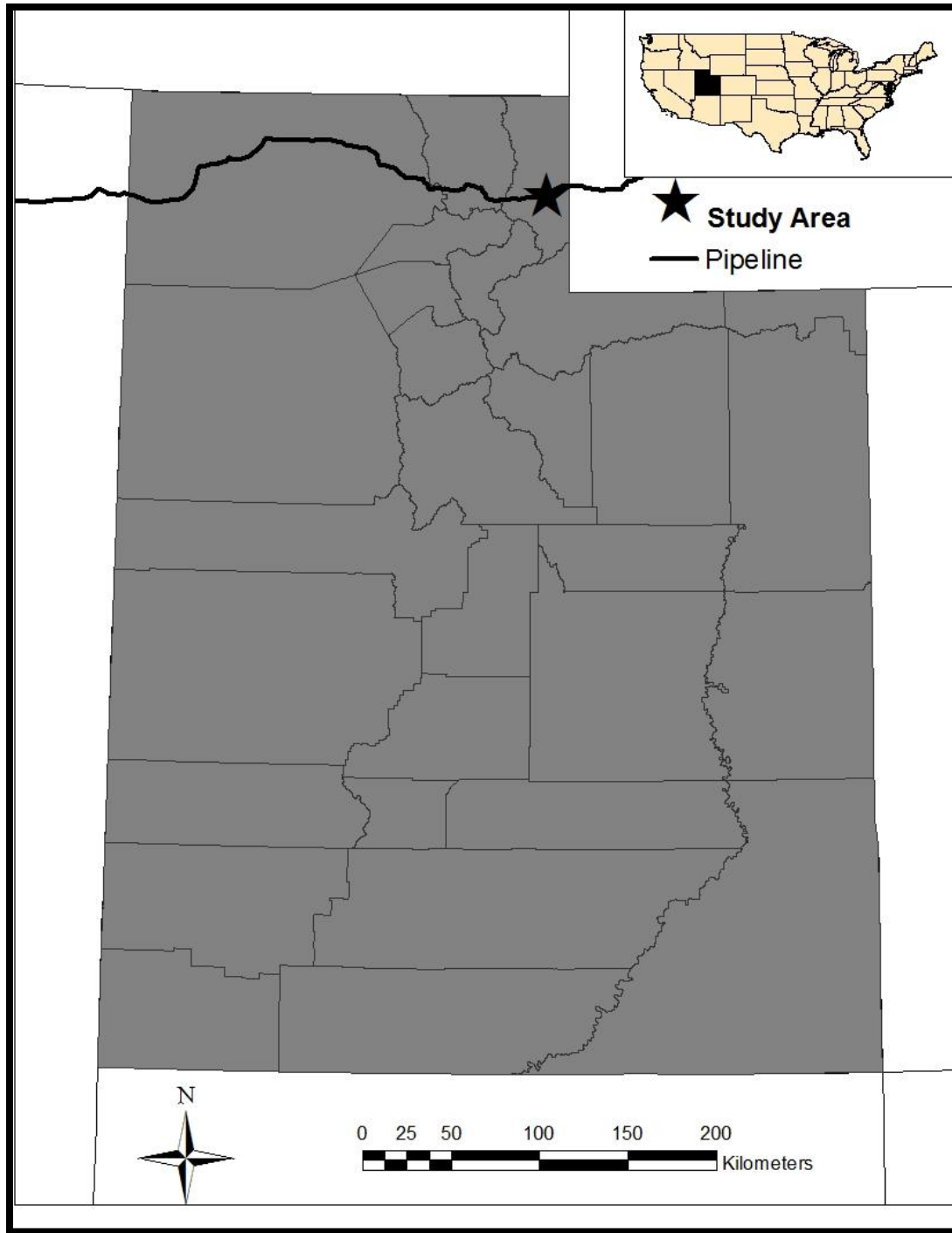[f] Model deviance

Figure 2-1. Study area (star) near Woodruff, Utah (USA) where we evaluated pygmy rabbit (*Brachylagus idahoensis*) response to construction of the Ruby pipeline 2010 – 2012.

Figure 2-2. Images depicting pipeline right of way (ROW) at the study site where we evaluated pygmy rabbit (*Brachylagus idahoensis*) response to construction of the Ruby pipeline in northern Utah, USA 2010 – 2012. Images of ROW before (top) and during (bottom) construction.
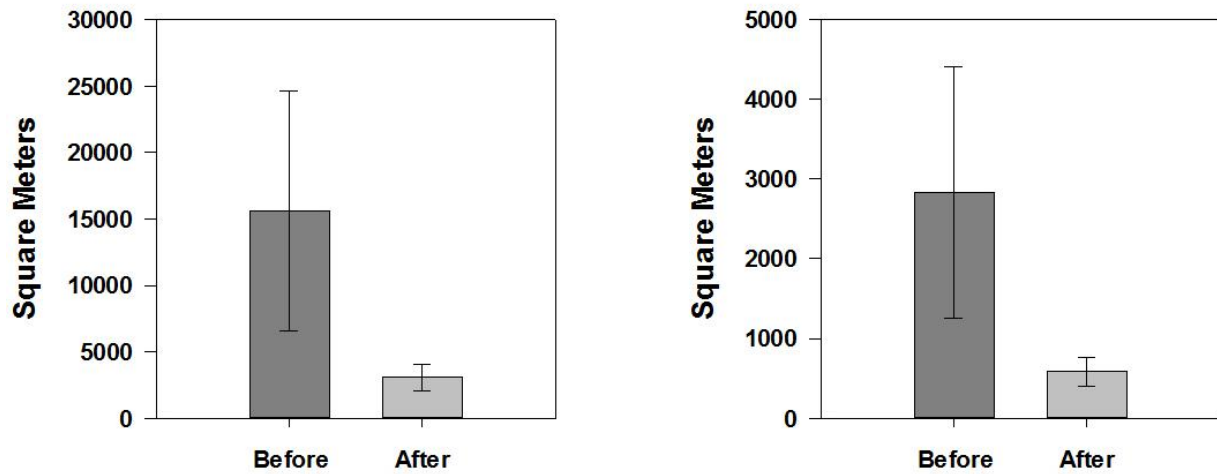
Figure 2-3. Estimates of space use for pygmy rabbits (*Brachylagus idahoensis*) measured during the month before and after construction of the Ruby pipeline near Woodruff Utah, USA (2010 – 2012). Boxplots show 95% fixed-kernel estimates (left) and 50% core-use area estimates (right).
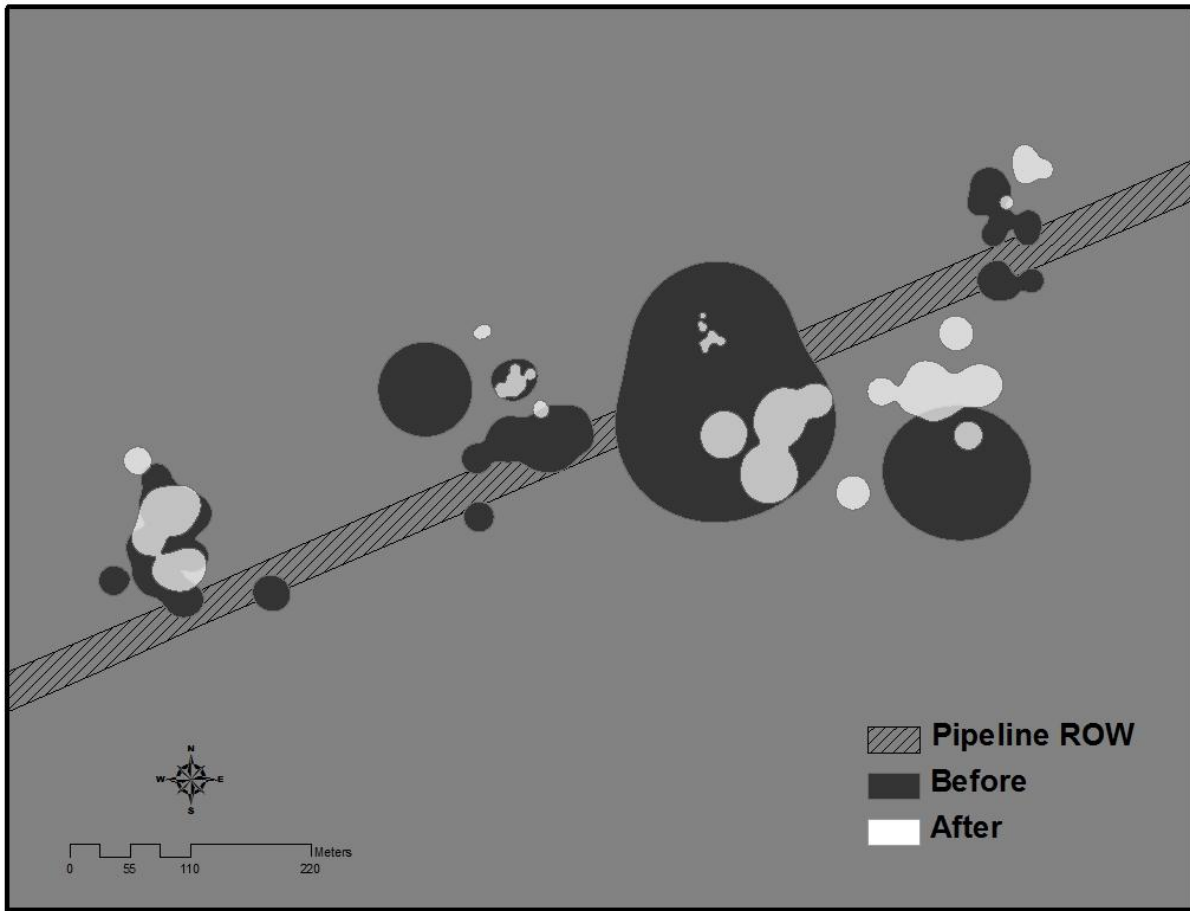
Figure 2-4. Polygons of space-use for a selection of pygmy rabbits (*Brachylagus idahoenis*) showing the month before (dark grey) and the month after (light grey) construction of the Ruby pipeline in northern Utah, USA 2010 – 2012.