HOME RANGES, MOVEMENTS, AND MULTI-SCALE HABITAT USE OF PYGMY RABBITS (BRACHYLAGUS IDAHOENSIS) IN SOUTHWESTERN IDAHO

By

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The thesis presented by Gregory S. Burak entitled Home Ranges, Movements, and Multi-Scale Habitat Use of Pygmy Rabbits (*Brachylagus idahoensis*) in Southwestern Idaho is hereby approved:

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CHAPTER 1 : PYGMY RABBIT (BRACHYLAGUS IDAHOENSIS) MOVEMENTS AND HOME RANGES IN THE OWYHEE UPLANDS OF SOUTHWESTERN IDAHO

Abstract

I studied pygmy rabbit (*Brachylagus idahoensis*) movements and home ranges during their breeding season in 2004 and 2005 in southwestern Idaho. Pygmy rabbits were trapped, radio-collared, and tracked daily to determine average, average minimum and average maximum distances moved between telemetry points. Three home range values were also estimated; 95% Minimum Convex Polygon (MCP), 95% Fixed Kernel (FK), and 50% FK home ranges. Estimates for movements and home ranges were tested between sexes and between years. Males traveled significantly longer distances between telemetry points (average distance: males = 220 m, females = 64 m; and average maximum distance: males = 736 m, females = 321 m) and had significantly larger home ranges than females (MCP: males = 24.9 ha, females = 1.8 ha; 95% FK: males = 4.5 ha, females = 1.6 ha; and 50% FK: males = 0.8 ha, females = 0.4 ha). Males also had significantly more core areas than females. Overlap of core areas was greater between sexes (male and females) as opposed to within sexes. Tests for differences between years in movements and home ranges identified only one significant difference; the average 95% FK values for females were significantly smaller in 2005 compared to 2004. While the major cause for this reduction is unknown, I did note that grass cover increased 4.5% in 2005, likely due to a 100% increase in precipitation in 2005 over 2004. Results of movements and home range analysis indicate that male pygmy rabbit movements are primarily driven by the spatial layout of female pygmy rabbits. Given the ability for this sagebrush obligate to travel relatively long distances, careful consideration should be

given to managing pygmy rabbit habitat so as to maintain habitat patches of adequate size and connectivity for this sensitive species.

Introduction

The sagebrush ecosystem in the western United States has undergone dramatic changes over the last century (Crawford et al. 2004). Native vegetation communities have been altered or lost due to \conversion of lands to agriculture, invasion of exotic species like cheatgrass (*Bromus tectorum*), altered and increased fire cycles, and increased fragmentation (Crawford et al. 2004). These changes have led to declines in many sagebrush obligates, including sage grouse (*Centrocercus urophasianus*) and passerines like the sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli)*, and brewers sparrow (*Spizella breweri*) (Braun, 1998, Knick and Rotenberry 2002).

Requiring tall and dense areas of shrub cover, primarily composed of big sagebrush (*Artemisia tridentata* sp.), pygmy rabbits (*Brachylagus idahoensis*) are considered a sagebrush obligate species (Wilde 1978, Green and Flinders 1980a, Weiss and Verts 1984, Gabler 1997). They construct their own burrow systems, of which they make extensive use, so they are additionally restricted to areas of loose and deep soils (Wilde 1978, Green and Fliners 1980b, Weiss and Verts 1984). Although populations of pygmy rabbits occur in parts of their historical range of the Intermountain West, their status, in terms of population levels, is unknown in many states, including areas of California, Idaho, Montana, Nevada, Oregon, Utah, and Wyoming (Federal Register 2005).

The pygmy rabbit is considered a species of greatest conservation need by the Idaho Department of Fish and Game, a sensitive species by the United States Forest Service, Region Four, and a range-wide/ globally imperiled species by the United States Bureau of Land Management (Idaho Department of Fish and Game 2005). In 2003, environmental organizations petitioned to have the pygmy rabbit listed as threatened or endangered throughout the Intermountain and Great Basin region (Fite and Criddle 2003). A 90-day finding determined that there was a lack of sufficient biological data for listing (Federal Register 2005). The Columbia Basin Distinct Population Segment in Douglas County, Washington, has been listed as Federally endangered, where it is believed that few, if any, rabbits are left in the wild (Federal Register 2003).

An animal's home range is defined as that area traversed by the individual in its normal activities of food gathering, mating, and caring for young (Burt, 1943). Its home range size and spatial configuration can been affected by several factors, including habitat quality and use and breeding opportunities, both of which can be spatially affected by gender and time of year (Harestad and Bunnel 1979, Ostfeld 1990). While preferred pygmy rabbit habitat is better understood in certain parts of their range, breeding activities for pygmy rabbits have just recently been investigated and understood (Oregon Zoo 2001, Lamson and Shipley 2002, Rachlow et al. 2005). The effects of both habitat quantity and quality, and breeding effects, on home range size and movements of pygmy rabbits are minimally understood.

Movements and home ranges by other species of rabbits have been shown to be influenced by habitat conditions and breeding opportunities. In Mississippi, Eastern cottontail rabbits (*Sylvilagus floridanus*) have been shown to alter movement rates under different habitat conditions (Bond et al. 2001), where researchers found that as species richness of food items and canopy cover increased, cottontail movements decreased. Bond et al. (2001) also found that males had larger breeding season home ranges compared to females (3.53 versus 1.39 ha), but home ranges for both sexes were similar during the nonbreeding season (0.95 versus 1.01 ha). Marsh rabbit (*Sylvilagus aquaticus*) home ranges in central Arkansas generally increased when an occupied habitat area was flooded (Zollner et al. 2000), while Forys and Humphrey (1996) found marsh rabbits spent most of their adult lives within one habitat patch, indicating populations existed as a metapopulation.

Previous home range estimates for pygmy rabbits have primarily been carried out via radio telemetry using different estimation techniques at different times of the year. Gahr (1993) used minimum convex polygon (MCP) and harmonic mean methods during the breeding season (January through June), Katzner and Parker (1997) utilized the adaptive kernel method during winter, and the grid method was used by Heady (1998) during summer (June through August). Gahr (1993) found home ranges, and distances traveled, by 14 adult rabbits to be greater for males than females during the breeding season. Katzner and Parker (1997) found average home range sizes for 10 rabbits differed between years, but differences between sexes was not tested, and they found home range core areas, where individuals spend the majority of their time and usually contain refuges and dependable food sources (Samuel et al. 1985), to overlap between and within years. Heady (1998) documented that areas used by males were larger than females, however, these results were based on a sample size of five individuals. While knowledge has been gained concerning space use by pygmy rabbits, variations in home range estimation methods during different seasons based on limited sample sizes have restricted comparisons of home range results among studies.

Recently, pygmy rabbit sign, including burrows and fresh pellets, identified areas currently inhabited in the Owyhee uplands of Southwestern Idaho (Ulmshneider, per. comm.). Data on space use and movement patterns are limited for the species throughout their range, and are lacking for this area. The general objectives of this chapter were to gain a better understanding of the movements and the size of the areas used by adult pygmy rabbits during the breeding season, and to investigate habitat characteristics that may influence home range size and movements. I hypothesized that: 1) male home ranges and movements will be dictated by the spatial arrangement of females, as opposed to female space use being dictated by the spatial arrangement of males; 2) male home ranges and movements will be larger than females due to breeding effects on movement patterns (i.e. males will be seeking reproductively active females for mating purposes), therefore causing increased distances moved and larger home ranges; and 3) core areas of the home ranges of males and females will overlap. The results of this chapter will increase our limited knowledge concerning home range size and space use for this poorly understood species. With this information concerning space use by pygmy rabbits, land managers will be able to make better informed decisions concerning management activities within active and potentially active pygmy rabbit habitat.

Methods

<u>Study Area</u>

The study area was located in the Owyhee uplands of Owyhee Co., Idaho (Figure 1.1). Field work was focused along Mud Flat road near the headwaters of Battle Creek, a tributary of the Owyhee River. This high elevation shrub-steppe region (1800 m), south of the Snake River Plain, is primarily rolling sagebrush (*Artemisia tridentata* sp.) interspersed with mountain mahogany (*Cercocarpus montanus*) and western juniper (*Juniperus scopulorum*). Deep soils are present in the valleys and swales, which are dominated by mountain big sagebrush-steppe vegetation (*Artemisia tridentata* ssp. vaseyana). The ridges are rocky, sandy, and composed of the low sagebrush (*Artemsisia arbuscula* ssp. *arbuscula*)/ bluebunch wheatgrass (*Agropyron spicatum*) community (Hironaka et al. 1983). Few invasive and noxious weeds are present throughout the study area, with the exception of cheat grass (*Bromus tectorum*), bur buttercup (*Ceratocephalus testiculatus*), and whitetop (*Cardaria draba*), which are present in small and isolated patches (personal observation). Average total precipitation is 53.7 cm/ year, with the most falling as snow during winter and rain in early spring. Average snowfall is 204.5 cm/ year. The average maximum and minimum temperature over the course of the year is 13.2 ^{o}C and 0.8 ^{o}C (Silver City, ID, Western Regional Climate Center).

Land use activities are mostly limited to grazing by livestock, which mainly occurs during the summer months. The land of my study area is primarily publicly owned and administered by the Bureau of Land Management, Owyhee Resource Area.

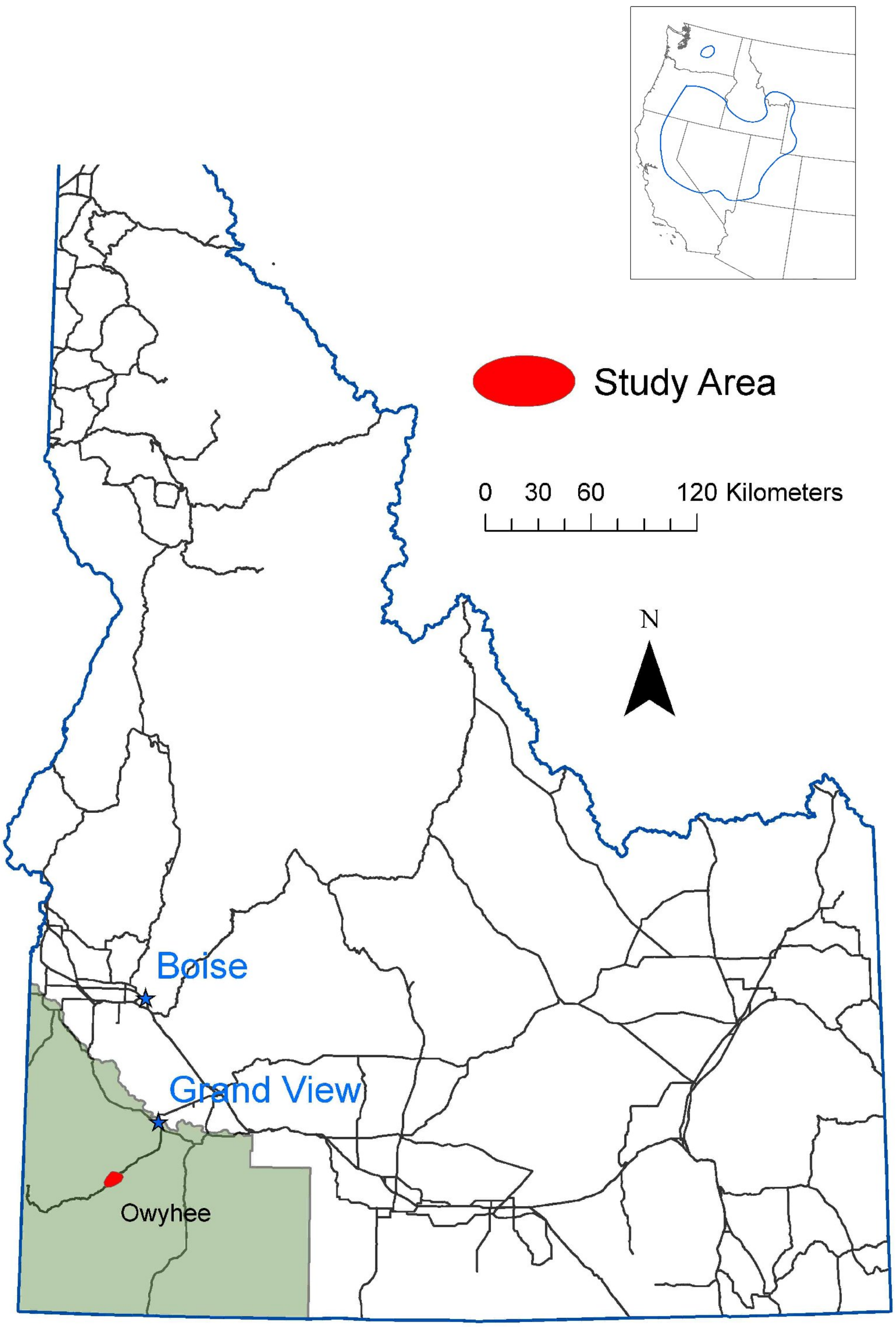

Figure 1.1: Pygmy rabbit distribution range (upper right hand corner) and map of study area in southwestern Idaho.

Pygmy Rabbit Home Ranges and Movements

Pygmy rabbits were trapped utilizing two techniques: the “burrow” technique and the “herding and wing” technique. The burrow technique involved pursuing individual rabbits into burrow systems and placing traps at the entrances of the occupied burrow. The second trapping technique, the “herding and wing” technique, involved pursuing rabbits into a wing that had traps set up so that the only means of escape for the rabbit was through an open trap. Both trapping methods involved finding and targeting rabbits, and did not rely on blind trapping, such as setting traps around burrows or among the sagebrush, or baiting. Rabbits were usually found by walking through suitable habitat (tall and dense sagebrush) with active pygmy rabbit signs (green fecal pellets and fresh burrow digging), although several rabbits were found using radio telemetry. On many occasions collared males would lead us to females, and when tracking females, un-collared males would sometimes be found within the general vicinity. During those instances, new un-collared rabbits were targeted for trapping. I attempted to collar all adult rabbits seen from April through May of each year. See Appendix A for detailed trapping methods.

Once an animal was captured it was transferred to a cotton mesh bag for handling. I then recorded the animal’s weight, right ear length, and right rear foot length (see Appendix C for measurements summary). In addition, a small tissue sample from one of the ears was obtained for a state-wide analysis of genetic structure being conducted at the University of Idaho.

Radio collar transmitters were provided by Holohil Systems Ltd. (Ontario, Canada) and Merlin Systems (Meridian, Idaho). Radio collars weighed four to five grams, which is about one percent (%) of an adult animal's body weight. Collars had a battery life of five to nine months and a line-of-sight transmitting distance of two to three miles. A nylon coated wire, TYGON tubing, and a brass crimp were used to attach the radio collar to the animals neck. A 21.6 cm whip antennae was used for signal transmission. Frequencies were in the 148 and 150-151 Mhz ranges.

A three element folding Yagi antennae (Telonics Inc., Mesa, Arizona) and an ICOM IC R-10 receiver (ICOM America, Bellevue, Washington) were used to track animals. Animals were tracked one to two times a day with a minimum of 1.5 hours between successive relocations, even though serial independence of data is not a requirement for kernel density estimates of home range size (Solla et al. 1999, Otis and White 1999).

The breeding season, determined by the photoperiod for males and vegetation condition for females, was the primary time collared rabbits were tracked (Wilde 1978). All tracking and relocation data were restricted to the daylight hours within that time period. Because one can closely approach wild pygmy rabbits residing in thick cover without flushing them, animals were tracked until observed or assured to be alive due movement. When animals were determined to be running ahead and out of sight, coordinates were obtained from an estimate of the rabbit's initial location. This was done to reduce a potential effect that researchers might have on the location coordinates used in the analysis of movements and home ranges. Coordinates were taken at the burrow system if the animal was found within. Using an Eagle Explorer ™ or a Garmin 12XL™ GPS receiver, location points were collected in the Universal Transverse Mercator (UTM) coordinate system, NAD 1927 datum. The date and time of relocations were also recorded along with any burrow use or behavioral observations, such as feeding or breeding behaviors.

Telemetry data were analyzed using The Home Range Tools (Rodgers et al. 2005) for ArcGIS 9.0 (Environmental Systems Research Institute, 2004). For average movement rates, I calculated interfix distances, the distance between consecutive telemetry relocation points, for each individual pygmy rabbit that was re-located at least 20 times (Rodgers et. al. 2005). Values for average minimum, average maximum, and mean distance moved were produced for each individual. The interfix distance is the straight line distance between two consecutive telemetry points, and likely underestimates actual distances traveled.

I produced 95% MCP home ranges for comparison to previous studies and Fixed Kernel (FK) utilization distributions for home range size and core area estimation. Kernel based estimators are useful as a non-parametric technique for determining home range estimates with respect to space use patterns and are less biased than the similar harmonic mean estimator (Worton, 1989, 1995). The FK method with least squares cross-validation (LSCV) for smoothing was chosen for 95 and 50 % FK density estimates, because it has been shown to produce home range area estimates with little bias and the lowest error

(Seaman and Powell 1996, Seaman et al., 1999). Fifty % FK density estimates were calculated for core area recognition and size.

A home range area curve was produced to estimate the minimum number of radio locations that were needed to adequately estimate home range size (Bond et al. 2001). Eight pygmy rabbits (four males and four females) that had a minimum of 40 locations were randomly chosen for this analysis during the breeding season. I plotted the average home range size [95% fixed kernel (FK) in hectares] at intervals of five locations (5, 10, 15, 20, 25, 30, etc.). Based on the home range area curve (Figure 1.2), animals with $n \geq 20$ locations for one breeding season were included in data analysis and results. Even though the area curve appeared to reach an asymptote at 15 locations, I believed that $n \geq 20$ would be a good compromise between the area curve results and $n \geq 30$, the minimum recommended by Seaman et al. (1999) for FK home range estimates.

I utilized Hawth's Analysis Tools (Beyer 2004) for ArcGIS 9.0 (Environmental Systems Research Institute, 2004) to estimate the percent overlap between core areas of individual home ranges (50% FK) by three possible groupings: male and male, female and female, and male and female. These results were then averaged by overlay group. I determined the total possible pairs of overlap by the same three groupings by examining the spatial proximity of individuals to each other. This was accomplished by examining the proximity of 95% FK home ranges of individuals in relation to neighboring animals while taking into account the average movement distances exhibited by males and females.

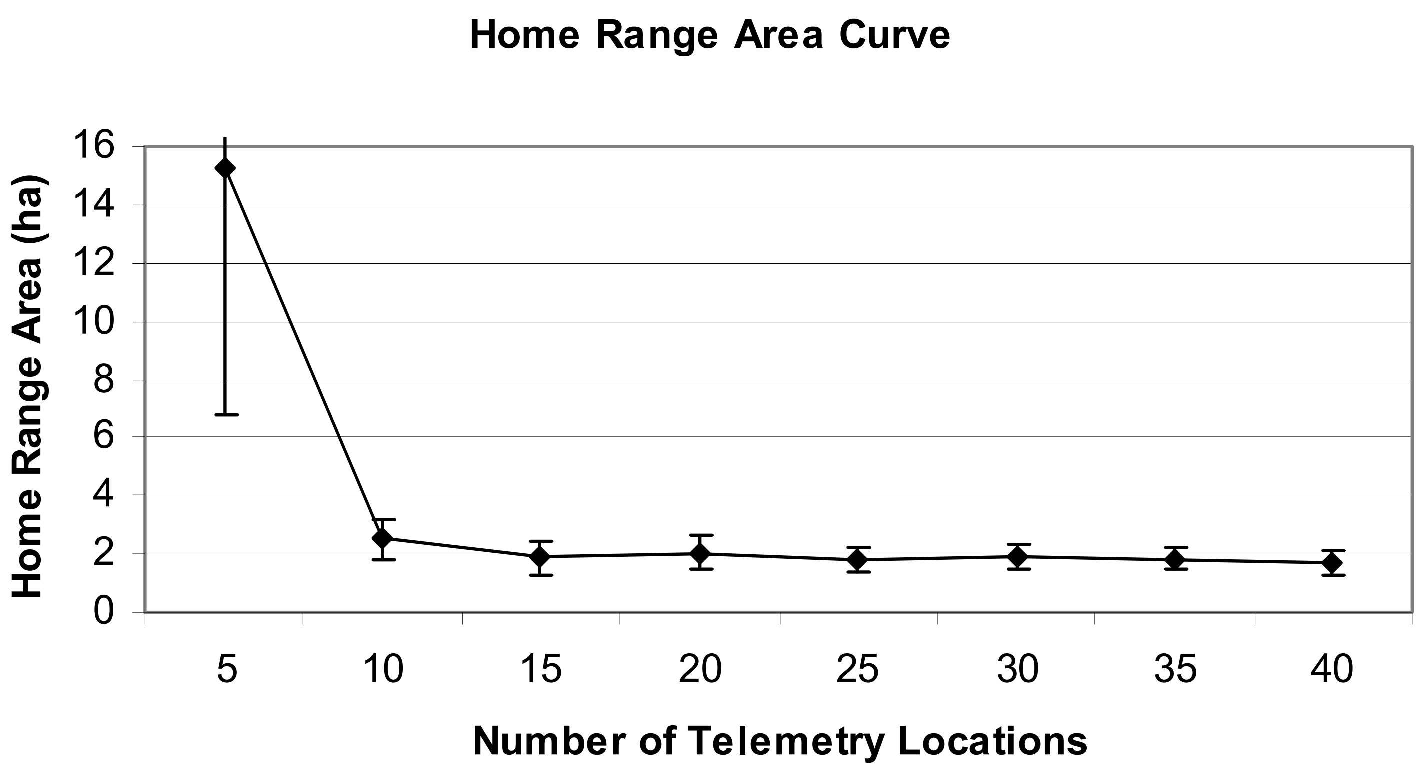

Figure 1.2: Mean home range area curve for eight randomly chosen pygmy rabbits (four males and four females). Home range estimates were for home ranges calculated as 95% fixed kernel areas. Animals with n≥20 locations for one breeding season were included in analysis.

Data were analyzed using SAS (SAS Institute, 2001). I used Mann-Whitney U tests (Zar, 1996) in SAS (PROC NPAR1WAY) to test for differences in average movement rates and home range estimates between the sexes and years of the study.

Habitat Characteristics of Pygmy Rabbit Home Ranges

For pygmy rabbits with defined home ranges, vegetation characteristics were quantified in the 50% FK home range core area. A 30-m baseline was placed within the core area to be sampled. A starting point within the first 10 m of the baseline was randomly selected to determine the placement of the first of three 25-m transects perpendicular to the baseline. The second and third transects were placed at 10 and 20 m, respectively, from the location of the first transect along the 30-m baseline. After completing an adequacy of sampling curve based on data collected in 2004, I found that 45 Daubenmire quadrats per core area would be adequate for cover estimation as opposed to 75 that I completed in 2004. Fifteen Daubenmire quadrats were placed at 1.5-m increments along each 25-m transect to determine canopy cover and species composition for all forb and grass species (Daubenmire 1959). Mean percent cover estimates of litter, soil, rock, and domestic cattle dung were also collected using this method. Each species of grass and forb, and total litter, bare soil, rock, and cow dung found within each plot frame was assigned to one of six coverage classes, as described by Daubenmire (1959).

While I could not statistically investigate differences in cover for shrub species between years due to different sampling methods employed, I was able to analyze percent cover for forbs, grasses, soil, and rock from across years. A posteriori Mann Whitney U test (Zar 1996) in SAS (PROC NPAR1WAY) was used to investigate differences in percent cover of forbs, grasses, soil, and rock between years. These data were used to explore factors potentially contributing to differences in home range sizes between years. A complete assessment of habitat characteristics of occupied pygmy rabbit sites is provided in Chapter 2.

Results

Pygmy Rabbit Home Ranges and Movements

During the breeding season of 2004, 20 pygmy rabbits were fitted with radio collars between April and June. In October and November of 2004, collars were exchanged on nine rabbits, eight that were initially trapped in the spring of 2004, and one new rabbit. Four individuals survived the winter of 2004 and 2005 to have new collars fitted in the spring of 2005. In addition, I collared 18 newly captured pygmy rabbits from March through May of 2005. While lacking population size estimates within my study area, I believe that in certain parts of my study area I had collared most (≥ 75%) adult pygmy rabbits present, while in other areas I believe I had ≤ 50% of adult rabbits collared. For movement and home range analysis, adequate data (i.e. ≥20 locations) were collected for five males and six females in 2004 and seven males and ten females in 2005. The average number of relocations per individual was 40, with a range of 21 to 57. The number of location points was ≥ 30 for 25 out of the 28 individuals used for analysis. I collected adequate relocation data to formulate home ranges for three rabbits for both years of the study: two females and one male. I included both years of data in the final analysis for two reasons. First, the size of areas used (95% MCP, 95% FK, and 50% FK) greatly differed between years (Table 1.1), which suggests animals made movement modifications based on some unknown factor. Second, spatial overlap and locations of home ranges differed. Although data for the same animal from two years are not completely independent, patterns of space use supported the contention that individuals selected home ranges differently in each study year.

Table 1.1: Home range sizes (Minimum Convex Polygon, MCP; Fixed Kernel, FK) for three pygmy rabbits tracked for two breeding seasons in southwestern Idaho.

Home Range Estimator	150.950 (female) 2004 / 2005	148.058 (female) 2004 / 2005	150.154 (male) 2004 / 2005
95% MCP	5.10 / 0.28	1.65 / 3.12	45.23 / 131.41
95% FK	2.62 / 0.51	1.88 / 0.79	6.19 / 17.06
50% FK	0.50 / 0.16	0.46 / 0.16	0.96 / 3.35

Distances moved by males exceeded those by females (Table 1.2). During the breeding season, distance between successive relocations for pygmy rabbits significantly differed between sexes for average distance moved (U=261.5, P<0.0001, n=28) and average maximum distance moved (U=243.0, P=0.0015, n=28), but did not significantly differ for average minimum distance moved (U=147.5, P=0.2203, n=28). Results between years for males and females indicated that average distance moved (females: U=58.0, P=0.481, n=16; males: U=33, P=1.00, n=10), average minimum distance moved (females: U=60.5, P=0.325, n=16; males: U=39.5, P=0.272, n=10), and average maximum distance moved (females: U=47.0, P=0.704, n=16; males: U=34.0, P=0.871, n=10) were not significantly different.

Males also utilized larger areas than females (Table 1.2). Breeding season home range estimates between sexes differed for the 95% MCP (U=265.0, P<0.0001, n=28), 95% FK (U=237.0, P=0.0037, n=28), and 50% FK estimates (U=226.0, P=0.0168, n=28). The average number of individual core areas per animal, determined from 50% FK results, indicated that males (mean=5.92±0.67, n=12) had significantly (P=0.0013) more individual core areas than females (mean=2.88±0.62; U=243.0, n=16). Areas frequented by collared males frequently coincided with collared females (Figure 1.3).

Patterns of space use were consistent between years for both sexes (Table 1.3). Home range sizes for females during the 2004 and 2005 breeding seasons did not significantly differ for 95% MCP (U = 59.0, P=0.4159, n=16). Based on 50% FK estimates, the sizes

Table 1.2: Patterns of space use during the breeding season for adult male (n=12) and female (n=16) pygmy rabbits in southwestern Idaho, in 2004 and 2005. Home range sizes were estimated using Minimum Convex Polygon (MCP) and Fixed Kernel (FK) analyses. Number of core areas was derived from 50% FK results. Means are reported ± standard error.

Movement Estimates	Male (n=12)	Female (n=16)	P-value
Average Distance Moved (m)*	219.75 ± 47.89	64.00 ± 4.62	<0.0001
Average Minimum Distance Moved (m)	3.33 ± 0.62	5.00 ± 0.90	0.2203
Average Maximum Distance* Moved (m)	736.00 ± 112.56	321.13 ± 64.85	0.0015
Home Range Estimates			
95% MCP (ha)*	24.9 ± 10.29	1.84 ± 0.38	<0.0001
95% FK (ha)*	4.49 ± 1.30	1.62 ± 0.33	0.0037
50% FK (ha)*	0.81 ± 0.25	0.35 ± 0.09	0.0168
Number of Core Areas*	5.92 ± 0.67	2.88 ± 0.62	0.0013

* significant difference between the sexes at P<0.05.

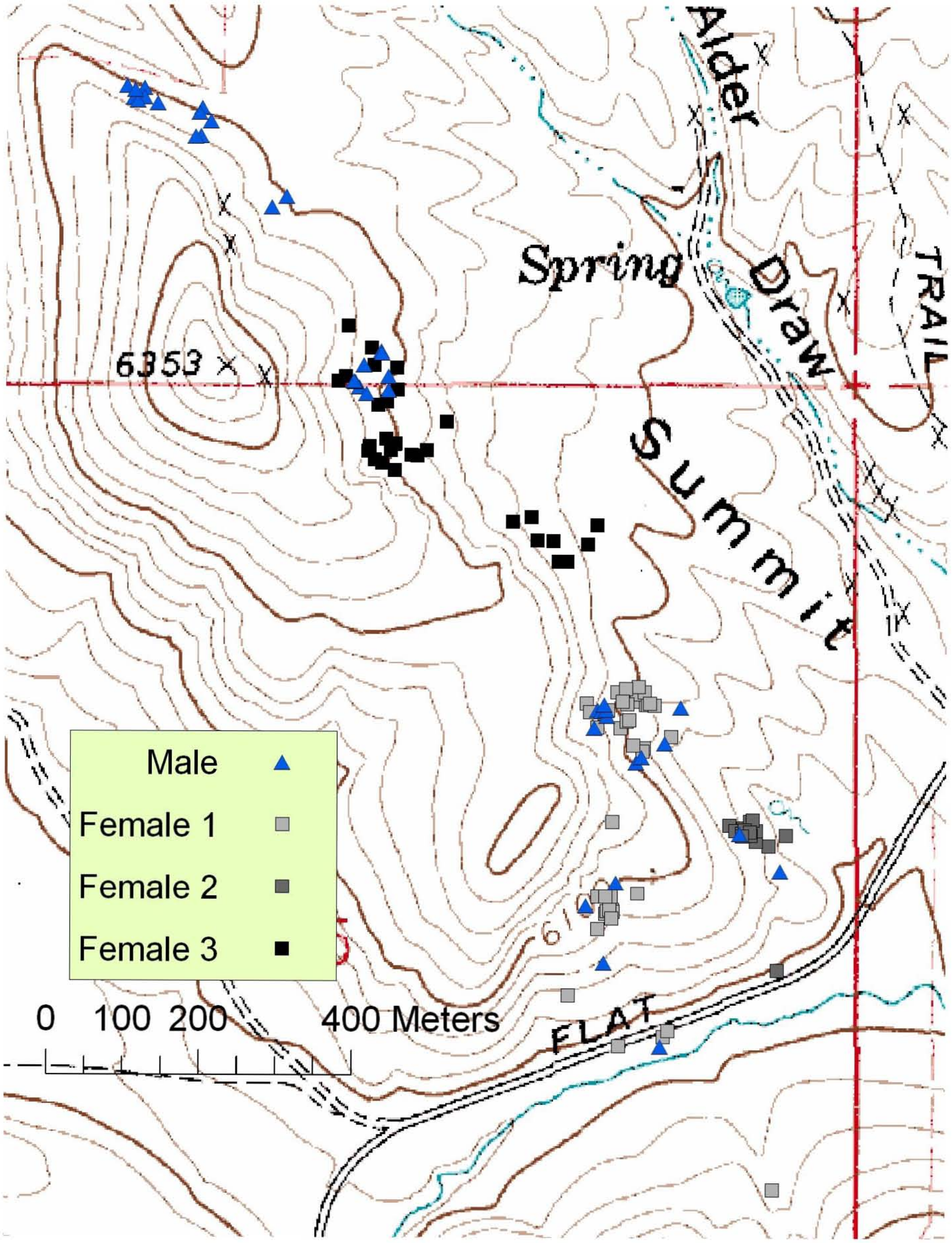

Figure 1.3: Example of the spatial arrangement of adult male and female pygmy rabbits. Telemetry locations for one male rabbit (blue) and three female rabbits (shades of light pink to red), illustrate substantial overlap between individual males and multiple females.

Table 1.3: Home range sizes (Minimum Convex Polygon, MCP; Fixed Kernel, FK) for adult female (n=16) and male (n=12) pygmy rabbits during the breeding season of 2004 and 2005 in southwestern Idaho. Means are reported ± standard error.

Sex		2004	2005	P-value
Female (16)	*95% MCP*	2.20±0.71 (6)	1.60±0.45 (10)	0.4159
	*95% FK**	2.50±0.72	1.10±0.18	0.0344
	50% FK	0.58±0.19	0.22±0.04	0.0577
Male (12)	*95% MCP*	20.20±7.55 (5)	28.20±17.35 (7)	0.8710
	95% FK	4.30±1.13	4.60±2.20	0.5160
	50% FK	0.74±0.17	0.86±0.42	0.5160

* significant difference between years at $P<0.05$.

of female core areas were not significantly different between years (U = 69.0, P=0.0577, n=16), although this P-value was close to significant. The 95% FK results for female rabbits, however, were significantly different between years (U = 71.0, P=0.0344, n=16). In 2005, female 95% FK home range size (mean=1.1 ± 0.18 ha, n=10) was significantly smaller than in 2004 (mean = 2.5 ± 0.72 ha, n = 6). Breeding season home range estimates for males did not significantly differ between years using any home range estimation method (Table 1.3).

Use of shared space occurred more frequently between sexes than within sexes. I documented one pair of males, two pairs of females, and 10 mixed-sex pairs that exhibited overlap between home range core areas. Mean percent of core area overlap between males (mean=20.10 ± 12.22, n=2) was less than between females (mean=30.57 ± 10.81, n=4). For male to female overlap, the percentage of female core areas overlapped by males (mean=19.41 ± 7.05, n=10) was greater than the percentage of male core area overlapped by females (mean=6.59 ± 2.11, n=10), which is most likely explained by males having larger home ranges than females. The potential pairs of overlap, determined from the proximity of individual animals to each other, indicate that their were four potential male to male overlaps, nine potential female to female overlaps, and 14 potential male to female overlaps. Chi-squared results, between potential and actual overlap within and between sexes, indicated significantly more between sex as opposed to within sex home range core area overlap (X^2=8.83, P<0.025).

Habitat Characteristics of Pygmy Rabbit Home Ranges

For analysis of habitat characteristics between years (Table 1.4), I found no significant difference in % cover of forbs (U=108.5, P=0.8734, n=27), grasses (U=90.0, P=0.2536, n=27), soil (U=106.0, P=0.7702, n=27), and rock (U=134.5, P=0.2421, n=27), but I did note that the mean percent cover of grass in 2005 (mean=24.2 ± 2.4, n=19) increased by 24% relative to 2004 values (mean=19.6 ± 2.5, n=8). Across years, however, there was no significant correlation between percent cover of grass and MCP (r = -0.19, P=0.51, n=14), 95% FK (r = -0.00, P=0.99, n=14), and 50% FK (r = 0.07, P=0.81, n=14) female home range size.

Table 1.4: Adult female pygmy rabbit home range values, estimated from Minimum Convex Polygons (MCP) and Fixed Kernel (FK) techniques, and % cover of grasses, forbs, soil, and rock in southwestern Idaho during the breeding season of 2004 and 2005. Sample sizes are in (). Mean ± standard error.

Home Range Estimate	*2004 (n=6)*	*2005 (n=10)*	P-value
95% MCP	2.20 ± 0.71	1.60 ± 0.45	0.4159
95% FK*	2.50 ± 0.72	1.10 ± 0.18	0.0344
50% FK	0.58 ± 0.19	0.22 ± 0.04	0.0577
Habitat Variable	*2004 (n=8)*	*2005 (n=19)*	P-value
Grass	19.60 ± 2.50	24.20 ± 2.40	0.2536
Forb	19.00 ± 3.10	19.70 ± 2.00	0.8734
Soil	12.60 ± 2.20	12.70 ± 1.30	0.7702
Rock	4.00 ± 2.00	1.20 ± 0.40	0.2421

* significant difference between years at P<0.05.

Discussion

Movements and home range estimates for pygmy rabbits in the Owyhee uplands indicated that males had more core areas and traveled longer distances than females (Table 1.2). For these reasons, males had much larger 95% MCP and 95% FK home ranges. In addition, observed overlap of core areas was greater between sexes than within, indicating that male movements were partially driven by the locations of females. This spatial patterning of male home ranges dictated by the arrangement of females (Figure 1.3) is likely the result of the study having taken place during the breeding season when males were moving among female ranges for reproductive purposes (Ostfeld 1990). Even though sizes of core areas were significantly different between males and females (males = 0.81, females = 0.35 ha), both sexes had 50% FK results less than one hectare (ha). While males traveled longer distances compared to females, once they were in a core area, their movements were confined and site specific. This is to be expected since the 50% FK value would represent areas of the highest use within a rabbit's home range (Ewer 1968).

The experimental design of Gahr (1993) is most similar to my study design, where movements and home range estimates were also determined for the breeding season. My results for average movements between successive re-location points (interfix distance) for adult pygmy rabbits in southwestern Idaho were greater than those documented by Gahr (1993) in Washington State. Within my study area, adult males moved an average distance of 220 m compared to 155 m in Gahr's (1993) study, and females moved roughly twice as far (64 m compared to 33 m). The maximum distance one male moved between re-location points in this study was 1521 m, over 300 m greater than documented by Gahr (1993). Similarly, the maximum distance that a female moved in my study was 1018 m, which is approximately four times greater than the maximum found by Gahr (1993). In general, adult pygmy rabbits in the Owyhee uplands moved longer distances than what was documented in Washington State.

Despite differences in distances moved, the home range estimates were similar for males in the Owhyee uplands and Washington. Gahr (1993) found adult male pygmy rabbits had a 95% MCP home range size of 24.9 ha, which is the same mean that I documented. In contrast, females within the Washington study area had a MCP home range size of 0.8 ha, close to four times less than in the Owyhee uplands (3.12 ha). This difference may be attributable a different home range estimator and/ or to different shapes and sizes of suitable habitat patches in each study area. Since pygmy rabbits are generally restricted to areas of dense and tall shrub and sagebrush patches (Chapter 2), the spatial layout of these patches may partially dictate the size of areas individual rabbits use. My study area was characterized by linear and elongated patches of sagebrush along the bases of slopes, and rolling topography with deeper soils and denser sagebrush found amongst rockier ridges.

The reduction in the size of the 95% and 50% FK home ranges for females documented in 2005 might be attributable to increased grass production in 2005 (Table 1.4). This increase in grass cover may be correlated with higher than normal precipitation in 2005. The total precipitation at the closest weather station, Reynolds, ID, from April through July in 2004 was 2.31 inches compared to 7.14 inches in 2005, an increase of greater than 100% (Western Regional Climate Center). This wetter pattern in 2005 likely contributed to the increase in grass production and cover in that year. Interestingly, males did not exhibit a similar reduction in home range size, potentially because male home ranges during the breeding season are largely a function of the distribution of females. Other reproductively active female small mammals have been shown to decrease the size of their home range with an increase of food resources and cover (Ims, 1987, Bond et al. 2001). Home range size of post-mating, adult female Mohave ground squirrels (*Spermophilus* mohavensis) were significantly larger during years of drought (Harris and Leitner 2004). This variation in home range size was attributed to the habitat-productivity hypothesis: as habitat productivity increases, a smaller area is required to meet resource needs, resulting in a smaller home range (Harestad and Bunnell 1979, Harris and Leitner 2004).

For both years of the study, vegetation characteristics were sampled prior to intensive cattle grazing. Even though I could not compare differences in sagebrush cover between years because of different sampling methods, greater precipitation also may have increased the amount and quality of sagebrush cover, which is a required food and cover source for pygmy rabbits (Green and Flinders 1980a). Green and Flinders (1980a) found that grass and sagebrush respectively made up 39% and 51% of the pygmy rabbit's diet in spring and summer. Gahr (1993) found that male pygmy rabbits had larger home ranges in grazed versus ungrazed areas, but differences in percent cover of grass between grazed and ungrazed sites were not tested. Since food gathering is part of Burt's (1943) definition of an animal's home range, the reduction of grass as a source of food or cover may increase the amount of area used by pygmy rabbits, thus causing animals to have increased energetic requirements and greater risk of predation, supporting the habitat-productivity hypothesis (Harestad and Bunnell 1979). Given relatively limited samples, these results should be interpreted with caution. Additional research is needed to gain an understanding of the effects of altering habitat conditions on pygmy rabbit movements and home ranges.

In my study area, females generally had more than one core area within their home range (Table 1.2). During the breeding season, several females moved their core area temporarily and returned to the original core area where they were first observed. During the two years of the study, I found four active natal burrows constructed by collared rabbits. Captive pygmy rabbit breeding programs first identified the construction of natal burrows (Oregon Zoo 2001, Lamson and Shipley 2002). Three of the four natal burrows that I found during the study were outside of the original home range core area for each female pygmy rabbit. For one of those natal burrows, that female stayed within a second core area that included the natal burrow, and returned to her original core area when the natal burrow became inactive. This pattern of establishing natal burrows away from the pygmy rabbit's core area is similar to the findings in Lemhi Valley, Idaho, where average distances between a natal burrow and an active burrow system were greater than 35 m (Rachlow et al. 2005). While I did not map active burrow systems within my study area, I found that the average distance between the edge of the major core home range area and the natal burrow for that particular female was 99.5 m. One possible explanation for this pattern is that females are locating natal burrows away from core areas to deter predation, thereby increasing their young's chances of survival until they are mobile enough to effectively escape predators on their own. See Appendix B for a more detailed account of natal burrow dimensions.

The large number of overlap pairings between males and females (10 out of 14 possible pairings) is likely the result of breeding activity; males were moving among females in search of breeding opportunities. The relatively low number of pairings for females and females (2 out of 9 possible pairings) may indicate that female pygmy rabbits exhibit territorial behavior. The same was true of males (1 out of 4 possible pairings), but larger sample sizes are needed to provide a critical test of this idea. Why female pygmy rabbits would exhibit territoriality is unknown; possible explanations include reliance on sagebrush and its relative abundance, distribution and slow renewal rate (Ostfeld 1990). Defense of kits from infanticide also might explain territoriality among females (Wolff 1993). Given an unknown explanation, additional pygmy rabbit behavioral studies, coupled with research on energetic requirements, could provide needed information to evaluate hypothesis about territoriality in this species.

Management Implications

Pygmy rabbits in the Owyhee uplands of southwestern Idaho were found to move longer distances, and females had larger home ranges, than previous estimates for this species during the breeding season. Even though the area that received the highest amount of use (50% FK) was less than one hectare for both sexes, rabbits readily traveled greater than one kilometer between core areas. Given the ability for this sagebrush obligate to travel long distances between core areas, careful consideration should be given to managing pygmy rabbit habitat so as to maintain suitable habitat patch size and connectivity for this sensitive species. Additional information concerning minimum viable population analysis, coupled with known habitat and size requirements, would possibly benefit land managers in charge of pygmy rabbit habitat.

During the breeding season male pygmy rabbit movements appear to be driven by the spatial arrangement of female rabbits. Movements by females also may be associated with breeding, especially in relation to the spatial placement of natal burrows. These effects of both sexes on their respective home range size falls under Burt's (1943) definition of a home range, "… mating, and caring for young." The role that adult females play in the wild in caring for young once they leave their natal burrow is unknown, so further field investigations are needed to determine the additional effect, if any, that caring for emerged young might have on movements by adult female pygmy rabbits.

In general, mating and resource availability play an important role in the size of home ranges for pygmy rabbits. In addition, habitat quality also may be a determining factor in home range size, with suitable habitat as a source for food and cover playing a role. Given this additional information for this little understood species, the spatial arrangement and size of remaining pygmy rabbit habitat patches should, at a minimum, be maintained at current levels. If increasing the number and size of populations is a management objective for this sensitive species, conservation and restoration of potential pygmy rabbit habitat should take into account its spatial requirements.

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CHAPTER 2 : HABITAT CHARACTERISTICS OF PYGMY RABBIT (BRACHYLAGUS IDAHOENSIS) HOME RANGE CORE AREAS IN THE OWYHEE UPLANDS OF SOUTHWESTERN IDAHO

Abstract (Chapters 2 and 3)

I investigated multi-scale habitat selection and preference of pygmy rabbits (*Brachylagus idahoensis*) in southwestern Idaho in 2004 and 2005. Animals were collared and tracked during the breeding season, April through July, for both years. At the finer, home range core area scale, I measured habitat variables in 2005 in occupied and unoccupied (n = 38) pygmy rabbit core areas and developed a model predicting pygmy rabbit habitat selection using binary logistic regression evaluated using Akaike's Information Criterion (AIC_c). At the home range and landscape scales, I used remotely sensed vegetation data and compositional analysis to rank 6 habitat classes based on radio telemetry results for 27 collared pygmy rabbits tracked during the breeding seasons of 2004 and 2005. Pygmy rabbit core areas had higher canopy cover and average height values for total shrub and sagebrush (*Artemesia tridentata* ssp. *vaseyana*) and lower canopy cover and average height for low sagebrush (*Artemisia arbuscula* ssp. *arbuscula*). Pygmy rabbit core areas had greater litter and forb cover and had less soil and rock cover. Logistic regression results indicated 3 top models ($AIC_c \leq 2.0$) out of 39 evaluated. Relative importance values for variables within models with $AIC_c \leq 4.0$ indicated that soil cover (w=0.842) was the most important indicator of pygmy rabbit habitat selection, followed by aspect of core area (w=0.474), total forb cover (w=0.316), average total shrub height (w=0.261), total grass cover (w=0.179), and rock cover (w=0.160). Compositional analysis results indicated non-random ($P < 0.05$) habitat preference at the landscape and home range scales. At the landscape scale, pygmy rabbits significantly ($P < 0.05$) preferred habitat class Mountain Sagebrush over the other 5 habitat classes. At the home range scale, big

sagebrush was ranked first, but not significantly over the next 4 habitat classes. mountain sagebrush was ranked fourth. Home range scale results were marginal due to similar proportions of used to available habitat classes. Multi-level habitat selection and preference results indicate that pygmy rabbits prefer habitat composed of dense and tall shrub stands (particularly sagebrush) with higher litter and forb canopy cover. Occupied areas and potential pygmy rabbit areas (not presently inhabited) exhibiting these preferred characteristics should be maintained as such if expanding and reintroducing pygmy rabbit populations is a management objective.

Introduction

The sagebrush ecosystem in the western United States has undergone extensive changes due to sagebrush fragmentation, degradation, and loss, which has led to declines in many sagebrush dependent species (Knick and Rotenberry 2002). Native vegetation communities have been altered or lost due to conversion of lands to agriculture, invasion of exotic species like cheatgrass (*Bromus tectorum*), altered and increased fire cycles, and increased fragmentation due to land management activities (Brooks and Pyke 2001). This has led to declines in many species, including sage grouse (*Centrocercus urophasianus*) and passerines like the sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli)*, and brewer's sparrow (*Spizella breweri*) (Braun 1998; Knick and Rotenberry 2002).

Pygmy rabbits (*Brachylagus idahoensis*), a sagebrush dependent species, have likely been impacted by this loss and degradation of sagebrush habitat, but population declines have been difficult to quantify due to the lack of past and present abundance and distribution data (Federal Register 2005). Interest in pygmy rabbits and their habitat has been increasing considerably as their range-wide population status comes under increased scrutiny (Fite and Criddle 2003).

The pygmy rabbit is considered a species of greatest conservation need by the Idaho Department of Fish and Game, a sensitive species by the United States Forest Service, Region Four, and a rangewide/ globally imperiled species by the United States Bureau of Land Management (Idaho Department of Fish and Game 2005). The Columbia Basin Distinct Population Segment in Douglas County, Washington, has been listed as Federally endangered, where it is believed that few, if any, rabbits are left in the wild (Federal Register 2003).

Pygmy rabbits inhabit parts of the Intermountain and Great Basin states of Oregon, California, Nevada, Utah, Wyoming, Montana, and Idaho, where they are patchily distributed in areas of loose and deep soils and a sagebrush steppe vegetation community (Green and Flinders 1980a, Weiss and Verts 1984). Their affinity for sagebrush as a source of food and cover rivals that of the sage grouse (Green and Flinders 1980a). Like sage grouse, pygmy rabbits require sagebrush in their diet throughout the year, composing up to 99 percent (%) of their diet during the winter (Green and Flinders

1980a). They are also known to consume grasses and forbs, but primarily during the non-winter months when it is more available (Green and Flinders 1980a).

Previous studies of pygmy rabbit habitat have highlighted the importance of dense stands of big sagebrush (*Artemisia tridentata* sp.) with greater vertical herbaceous structure and cover components preferred (Green and Flinders 1980a, Weiss and Verts 1984, Katzner and Parker 1997). This animal is known to construct and utilize extensive burrows, further restricting habitat requirements to areas with soil that is suitable for burrowing (Wilde 1978, Weiss and Verts 1984, Gahr 1993). These earlier studies of pygmy rabbit habitat have primarily been carried out at finer spatial scales of habitat use, such as at burrows and within home ranges. More recent research to better understand this species habitat distribution has recently increased, primarily through prediction and identification of potential pygmy rabbit habitat at larger spatial scales using models of remotely sensed and ground-truthed data (Gabler et al. 2000, Rachlow and Svancara 2006). Given that in many areas, occupancy of sagebrush steppe habitat by pygmy rabbits is unknown, models such as these have become very important in identifying potential pygmy rabbit habitat given the rabbit's conservation status and patchy distribution over large and remote landscapes spanning seven states (Green and Flinders 1980b).

Results from Chapter 1 indicate that males travel longer distances than females (average distance and average maximum distance moved). For these reasons, males had much larger minimum convex polygon and 95% fixed kernel (FK) home ranges. While the size of 50% FK home ranges were significantly different between males and females, both sexes had 50% FK home ranges that were less than one hectare (ha). Even though males moved more frequently and traveled greater distances compared to females, once they were in a core area, their movements were confined and site specific. This is to be expected since the 50% FK, or the home range core area, represents areas of the highest use within a rabbit's home range (Ewer 1968).

The goals of Chapters 2 and 3 are to present new information on occupied pygmy rabbit habitat in southwestern Idaho, specifically at three spatial scales of habitat selection and preference (Johnson 1980); the core home range, the home range, and the landscape scale.

At the finer core home range scale, I measured habitat variables in occupied and unoccupied pygmy rabbit core areas and developed a model predicting habitat selection based on habitat variables within the study area in southwestern Idaho. At the core area scale, I hypothesize that pygmy rabbits will prefer habitat composed of (1) taller sagebrush with greater canopy cover, (2) a greater amount of dead shrub material that is related to the taller and denser sagebrush component, (3) and increased cover of grasses and forbs that provides a source of food during spring/ summer.

At the larger home range and landscape scales, I attempted to rank habitat preference in the Owyhee uplands during the breeding season through a combination of pygmy rabbit home range analyses, vegetation cover data, and compositional analysis (Aebishcher et al. 1993). At the home range and landscape scales, I hypothesize that (1) pygmy rabbits will prefer habitat types composed of dense and tall stands of sagebrush at both scales of analysis, (2) habitat types composed of low and sparse sagebrush will be preferred less, and (3) habitat types without sagebrush as a component will be least preferred. This is the first study I am aware of that attempts to identify larger scale pygmy rabbit habitat preference using telemetry data from collared rabbits.

The results of this study will increase the knowledge of multi-scale habitat requirements of this little understood species in an area where virtually nothing is known. It will also provide needed insight into whether rabbits are selecting habitats at broader scales, and if so, will identify habitat characteristics selected by rabbits. This information will enhance land managers' ability to make better informed decisions within occupied pygmy rabbit habitat at multiple scales, and provide the needed information for habitat improvement programs in potential pygmy rabbit habitat.

Methods

Study Area

See methods from Chapter 1.

Pygmy Rabbit Home Ranges and Movements

See methods from Chapter 1.

Habitat Characteristics of Pygmy Rabbit Home Range Areas

For pygmy rabbits with defined home ranges, an occupied habitat plot was placed within a 50% FK home range core area to determine its vegetative characteristics. A second plot was placed in unoccupied habitat within an adjacent, randomly chosen area without any pygmy rabbit burrow systems.

For each occupied habitat plot, a 30-m baseline was placed within the core area to be sampled. Thirty meters was determined to be adequate size for data independence while still small enough to fit in a pygmy rabbit's core area. A starting point within the first 10 m of the baseline was randomly selected to determine the placement of the first of three 25-m transects perpendicular to the baseline. The second and third transects were placed at 10 and 20 m, respectively, from the location of the first transect along the 30-m baseline. Each transect crossed the baseline at its halfway point (12.5m). Along each 25-m transect, the line intercept method was used to estimate average height and canopy cover for each shrub species (Canefield, 1941). A visual estimate of vigor for each shrub intercepting the 25-m transect was taken based on one of six possible values: (1) > 75% alive; (2) 50-75% alive; (3) 25-50% alive; (4) < 25% alive; (5) dead; and (6) burnt.

Fifteen Daubenmire quadrats were placed at 1.5-m increments along each 25-m transect to determine canopy cover and species composition for all forb and grass species (Daubenmire 1959). Mean percent cover estimates of litter, soil, rock, and domestic cattle dung were also collected using this method. Each species of grass and forb, and total litter, bare soil, rock, and cow dung found within each Daubenmire quadrat were given one of the six following cover classes:

Results for each variable were averaged, using the corresponding midpoint of range values, to produce a mean value for that variable for each habitat plot. A total of 45 Daubenmire quadrats per plot were chosen for cover estimation based on sampling adequacy curves produced from data collected in 2004 (see Figure 2.1) and because Daubenmire (1959) recommended a minimum of 40 quadrats per site to accurately estimate canopy cover in rangelands. See Figure 2.2 for a schematic design of a habitat plot.

An area near each occupied plot but without pygmy rabbit burrows was randomly chosen to serve as a paired, unoccupied habitat plot. Its placement was chosen by randomly selecting a compass bearing and walking 75 m from the center of the occupied habitat plot. This area was then examined to confirm the absence of any pygmy rabbit burrows within an area large enough to support a habitat plot and to determine that the area to be sampled was outside of the pygmy rabbit use area based on radio telemetry locations. If no pygmy rabbit burrows were found, a second habitat plot was established and sampled. If pygmy rabbit burrows were found, I continued to walk along the same compass bearing until an area suitable in size for a habitat plot was found without pygmy rabbit burrows. The second, unoccupied habitat plot was usually placed within 200 m of the first, occupied habitat plot.

Data were analyzed using SAS (SAS Institute, 2001). A Mann-Whitney U test (Zar, 1996) in SAS (PROC NPAR1WAY) was used to analyze differences between the means of habitat variables collected. Table wide p-values were adjusted for significance using the sequential Bonferroni technique (Rice 1989)

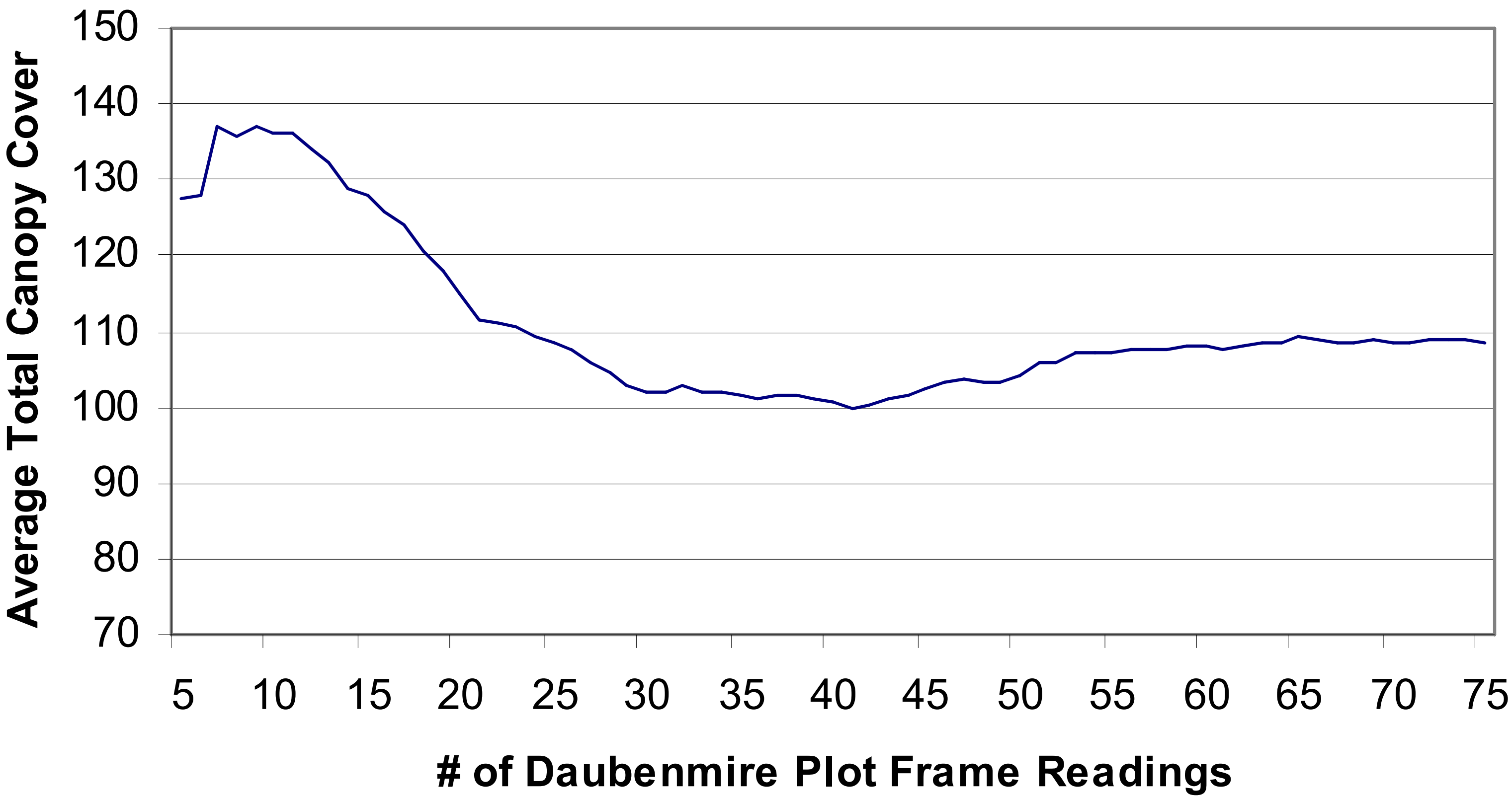

Figure 2.1: Vegetation sampling adequacy curve showing number of Daubenmire plot frame readings and running average total canopy cover. Data were collected during preliminary vegetation sampling conducted in June of 2004.

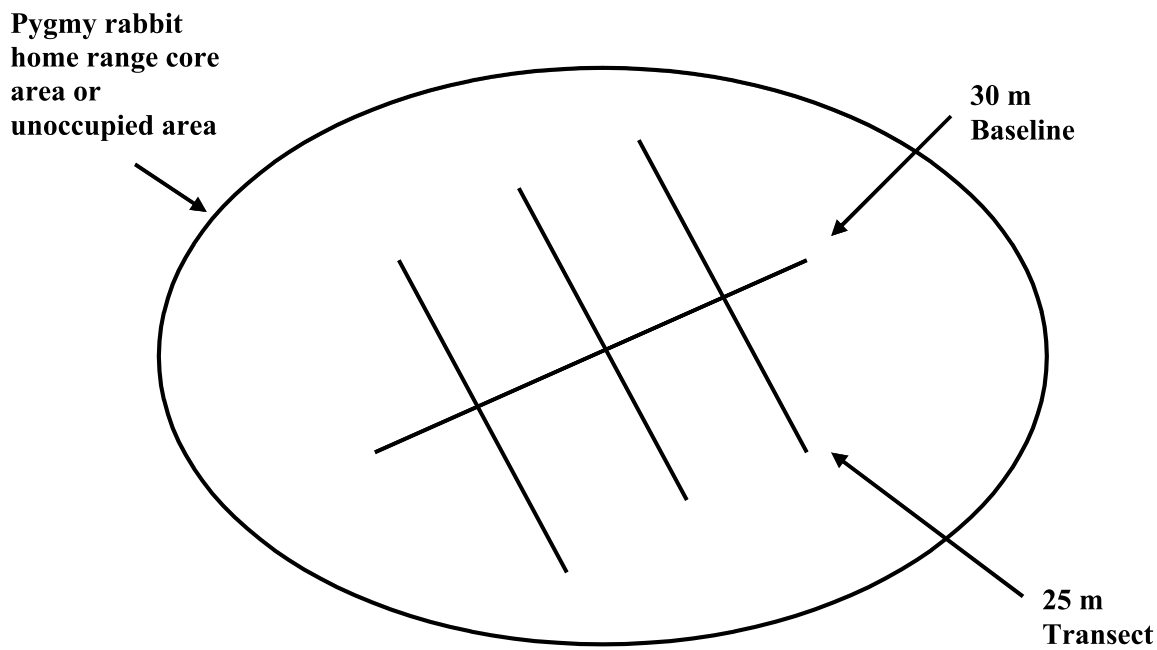

Figure 2.2: Occupied and unoccupied habitat plot sampling design.

Habitat Selection Model

Using habitat data collected in the field and logistic regression, models were constructed predicting pygmy rabbit habitat use based upon pygmy rabbit core area home range habitat characteristics (Hosmer and Lemeshaw 1989). Individual species for grasses and forb cover were grouped into functional groups (FORB and GRASS). Percent cover and average height for individual shrub species were grouped into functional groups (SHRUB and SHRUBHT). Aspect of vegetation plots were converted into a continuous value based on the number of degrees the plot faced from north (DEGFROMN), i.e., the closer the plot's aspect was to north, the lower the value, and the further the plot's aspect was from north, the greater the value.

Univariate logistic regression (PROC LOGISITIC) was utilized to determine individual habitat variables that would be included for further analysis (Hosmer and Lemeshow 1989). Variables with a Wald test p-value result less than 0.25 were retained for Pearson correlation analysis (PROC CORR) to investigate multicolinearity among the remaining habitat variables. Variables with correlation coefficients greater than +/- 0.50 were deemed to be correlated so those variables were not included together in the same model. I considered models with ≤ 3 main effect variables in the occupied versus unoccupied pygmy rabbit core area. Seven habitat variables were retained for model building purposes: SHRUB, SHRUBHT, FORB, GRASS, DEGFROMN, SOIL (percent soil cover), and ROCK (percent rock cover). Given the limited knowledge of preferred habitat variables available for pygmy rabbits and their home range core area, I erred on the side of caution when developing models and included more variable combinations than might be adequate for a species with a better understanding of core area habitat needs. Thirty-nine potential models were developed using the above model selection criteria and through field experience and literature review (Green and Flinders 1980a, Weiss and Verts 1984, and Katzner and Parker 1997).

Akaike's Information Criterion corrected for small sample size (AIC_c) was used to evaluate potential final models (Burnham and Anderson 2002). I considered models with $\Delta AIC_c \leq 2.0$ to be best supported, and $\Delta AIC_c \leq 4.0$ to be mildly supported. As a rule of thumb, $\Delta AIC_c < 2.0$ suggests substantial evidence for the best model; values between 4.0 and 7.0 indicate that the model has considerably less support; and $\Delta AIC_c > 10.0$ indicates that the model is very unlikely (Burnham and Anderson 2002). Model fit was assessed using Hosmer-Lemeshow goodness-of-fit test for the subset of the final models with $\Delta AIC_c \leq 4.0$ (Hosmer and Lemeshow 1989). For individual variables included in the subset of the mildly supported models ($\Delta AIC_c \leq 4.0$), Akaike weights (w) were calculated to rank the relative importance of the individual variables (Burnham and Anderson 2002).

Results

<u>Pygmy Rabbit Home Ranges and Movements</u>

See results from Chapter 1.

<u>Habitat Characteristics of Pygmy Rabbit Home Range Areas</u>

Thirty-eight habitat plots were completed in occupied pygmy rabbit core areas of the home range and unoccupied areas. All habitat plots included in analyses were conducted in 2005.

Results from Daubenmire plot vegetation sampling showed that four of six variables tested significantly differed between occupied and unoccupied pygmy rabbit areas (Table 2.1). Mean percent cover of forbs (U=278.5, P=0.0112) and litter (U=190.0, P=0.0001) were significantly greater in occupied versus unoccupied pygmy rabbit areas. Mean percent cover of soil (U=541.5, P=0.0001) and rock (U=544.0, P=0.0001) were significantly lower in occupied versus unoccupied areas. There were no significant differences in percent cover of grasses (U=422.0, P=0.1450) and cow dung (U=315.5, P=0.1196) between occupied and unoccupied areas.

Line intercept results for canopy cover showed that several species and total shrub cover differed between occupied and unoccupied pygmy rabbit areas (Table 2.2). Total shrub (U=208.0, P=0.0001) and sagebrush (*Artemisia tridentata* ssp. *vaseyana)* (U=207, P=0.0001) cover were significantly greater in occupied versus unoccupied pygmy rabbit areas. Snowberry (*Symphoricarpos oreophilus*) (U=296.0, P=0.0319), Rabbitbrush (*Chrysothamnus nauseosus*) (U=319, P=0.1447), bitter brush (*Pursha tridentata*) (U=414.0, P=0.2030), and average total shrub vigor (U=335.5, P=0.3191) did not significantly differ between occupied and unoccupied areas. Low sagebrush (*Artemisia tridentata* ssp. *arbuscula*) was absent in occupied areas sampled and therefore was significantly (U=503.5, P=0.0001) greater in unoccupied areas.

Table 2.1: Mean percent cover values determined by Daubenmire plots, ± standard error, measured at 19 occupied pygmy rabbit core areas and 19 unoccupied areas in southwestern Idaho in 2005.

Habitat Variable	Occupied	Unoccupied	P-value
Forbs*	19.66 ± 1.99	12.15 ± 1.33	0.0112
Grass	24.23 ± 2.40	28.94 ± 1.88	0.1450
Litter*	65.87 ± 2.31	25.51 ± 2.45	0.0001
Soil*	12.67 ± 1.26	38.65 ± 2.71	0.0001
Rock*	1.22 ± 0.35	11.68 ± 2.02	0.0001
Cow dung	1.01 ± 0.16	0.65 ± 0.11	0.1196

* indicates table-wide significance at $P<0.05$.

Table 2.2: 2005 mean percent total and dominant species of shrub cover determined by Line Intercept, ± standard error, measured at 19 occupied pygmy rabbit core areas and 19 unoccupied areas in southwestern Idaho.

Habitat Variable	Occupied	Unoccupied	P-value
Total Shrub Cover*	55.87 ± 1.61	30.28 ± 2.89	0.0001
Artemisia tridentata ssp. *vaseyana**	43.80 ± 3.32	11.39 ± 2.26	0.0001
Chrysothamnus nauseosus	4.70 ± 1.38	1.63 ± 0.54	0.1447
Pursha tridentata	4.37 ± 2.34	5.74 ± 1.92	0.2030
Symphoricarpos oreophilus	2.74 ± 0.81	1.39 ± 0.72	0.0319
Artemisia arbuscula ssp. *arbuscula**	0.00 ± 0.00	6.81 ± 1.64	0.0001
Average Total Shrub Vigor	2.88 ± 0.05	2.81 ± 0.05	0.3191
Degrees from north	74.89 ± 11.70	97.95 ± 11.10	0.1411

* indicates table-wide significance at $P<0.05$.

Line intercept results for shrub height indicated that average total shrub (U=218.5, P=0.0001) and sagebrush (*Artemisia tridentata* ssp. *vaseyana*) (U=212.0, P=0.0001) was significantly taller in occupied versus unoccupied pygmy rabbit areas (Table 2.3). There was no significant difference in rabbitbrush (*Chrysothamnus nauseosus*) (U=314.5, P=0.1134), snowberry (*Symphoricarpos oreophilus*) (U=319.0, P=0.1329), or bitterbrush (*Pursha tridentata*) (U=376, P=0.8811) height between occupied and unoccupied areas. Low sagebrush (*Artemisia tridentata* ssp. *arbuscula*) was absent in occupied areas sampled and therefore was significantly taller (U=503.5, P=0.0001) in unoccupied areas.

Habitat Selection Model

Among the 39 potential logistic regression models, three models were supported by a $\Delta AIC_c \leq 2.0$, and 10 were supported by a $\Delta AIC_c \leq 4.0$ (Tables 2.4 and 2.5). Hosmer-Lemeshow goodness-of-fit tests indicated that the subset of the final 10 models ($\Delta AIC_c \leq 4.0$) were all statistically fit (Hosmer and Lemeshow 1989). Among the top models ($\Delta AIC_c \leq 2.0$), the model with the lowest AIC_c was SOIL + DEGFROMN, followed by SOIL, and FORB + SOIL + DEGFROMN (Table 2.4).

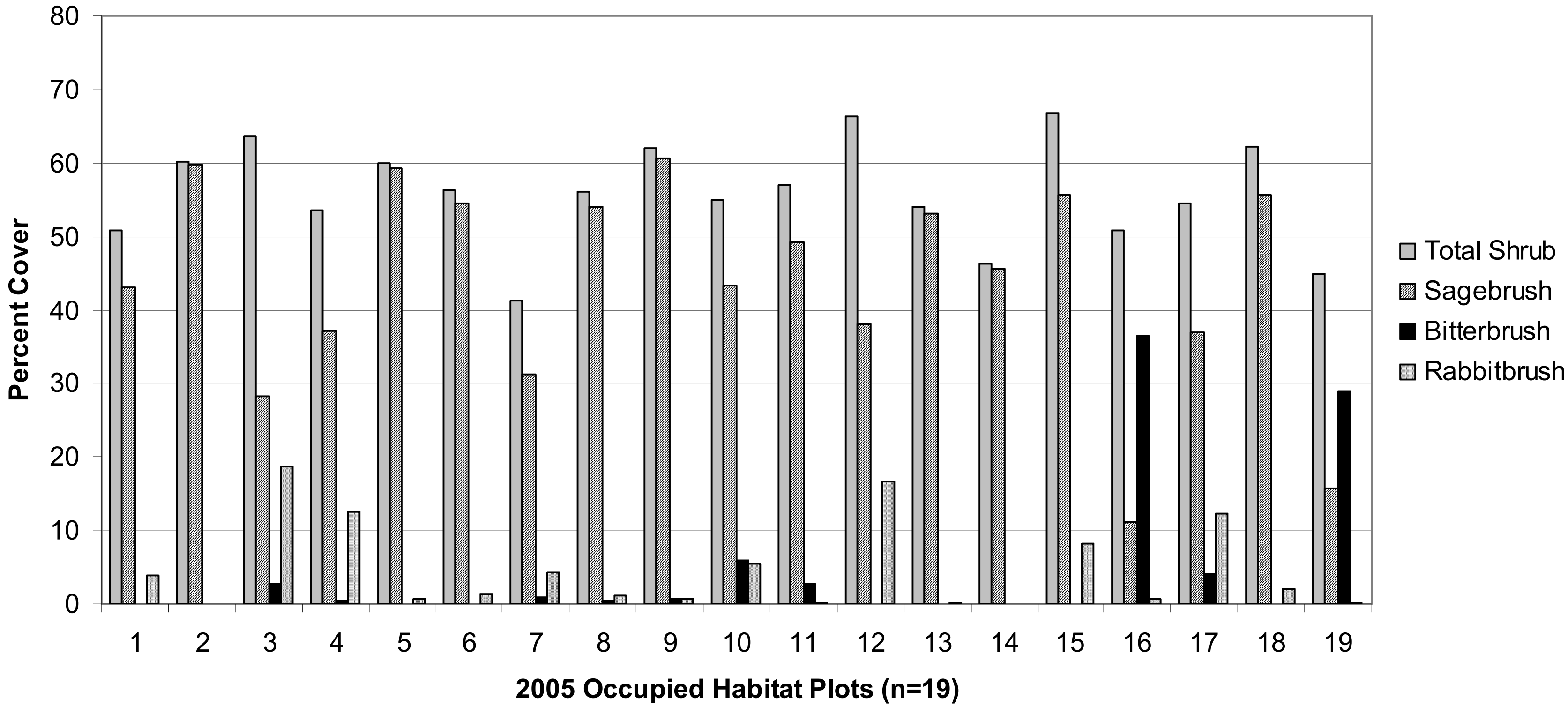

Figure 2.3: Total shrub, sagebrush (*Artemisia tridentata* ssp. *vaseyana*) , bitterbrush (*Pursha tridentata*), and rabbitbrush (*Chrysothamnus nauseosus*) percent cover in 19 occupied pygmy rabbit sites sampled with the Line Intercept method in southwestern Idaho.

Table 2.3: 2005 average shrub height (m) for occupied and unoccupied pygmy rabbit sites, measured at 19 occupied sites and 19 unoccupied sites in southwestern Idaho. Mean ± standard error.

Habitat Variable	Occupied	Unoccupied	P-value
Average Total Shrub Height*	0.63 ± 0.02	0.40 ± 0.04	0.0001
Artemisia tridentata ssp. *vaseyana**	0.66 ± 0.03	0.40 ± 0.03	0.0001
Chrysothamnus nauseosus	0.38 ± 0.04	0.31 ± 0.03	0.1134
Pursha tridentata	0.31 ± 0.07	0.36 ± 0.06	0.8811
Symphoricarpos oreophilus	0.39 ± 0.06	0.24 ± 0.07	0.1329
Artemisia arbuscula ssp. *arbuscula**	0.00 ± 0.00	0.16 ± 0.02	0.0001

* indicates table-wide significance at P<0.05.

Six habitat variables made up the final 10 models ($\Delta AIC_c \leq 4.0$): percent cover of bare soil (SOIL) was in eight models, percent cover of forbs (FORB) and average height of shrubs (SHRUBHT) in four models, percent cover of grasses (GRASS) in three models, aspect (DEGFROMN) in three models, and percent cover of rock (ROCK) in two models (Table 2.6). For the variables included in models with $\Delta AIC_c \leq 4.0$, relative importance values derived from Akaike weights indicated that SOIL (w=0.842) was the most important indicator of pygmy rabbit habitat selection, followed by DEGFROMN (w=0.474), FORB (w=0.316), SHRUBHT (w=0.261), GRASS (w=0.179), and ROCK (w=0.160) (Table 2.6).

For the final six variables supported by $\Delta AIC_c \leq 4.0$, SOIL was the only variable with odds ratio results without 1.0 in the 95% confidence interval (Table 2.7). While percent cover of rock had a low odds ratio estimate (0.150), it also had a large confidence interval and standard error. Even though aspect was the second most important variable according to Aikake weight results, the odds ratio was close to zero, indicating no general increase or decrease in pygmy rabbit habitat selection in response to aspect. For every 10% increase in forb cover, there is a 17% chance increase in finding occupied pygmy rabbit habitat. For every 0.10 m increase in total shrub height, there is a 24% increase in likelihood of pygmy rabbits occupying an area. For every 10% increase in soil, rock, and grass cover, the likelihood of pygmy rabbit presence decreases by 42%, 85%, and 4% respectively. In general, odds ratio results indicate that the odds of habitat being selected by pygmy rabbits increases with an increase in total shrub height and forb cover, and a decrease in percent soil and rock cover (Table 2.7).

Table 2.4: Summary of best supported logistic regression models ($\Delta AIC_c \leq 2.0$) predicting the presence of pygmy rabbits based on habitat characteristics of home range core areas collected in 2005 in southwestern Idaho.

Model	*k*	AIC_c	ΔAIC_c	w_i	Hosmer-Lemeshow (P-value)
SOIL[a]+DEGFROMN[b]	3	15.888	0.000	0.474	0.447
SOIL	2	16.837	0.949	0.295	0.298
FORB[c]+SOIL+DEGFROMN	4	17.332	1.444	0.230	0.855

[a] Percent soil cover.
[b] Degrees from north calculated from the aspect of the plot.
[c] Percent cover of all forb species.

Table 2.5: Summary of mildly supported logistic regression models ($\Delta AIC_c \leq 4.0$) predicting the presence of pygmy rabbits based on habitat characteristics of home range core areas collected in 2005 in southwestern Idaho.

Model	*k*	AIC_c	ΔAIC_c	w_i	Hosmer-Lemeshow (P-value)
SOIL+DEGFROMN	3	15.888	0.000	0.265	0.447
SOIL	2	16.837	0.949	0.165	0.298
FORB+SOIL+DEGFROMN	4	17.332	1.444	0.129	0.855
FORB+ROCK[a]+SHRUBHT[b]	4	18.211	2.323	0.083	0.976
GRASS[c]+SOIL+DEGFROMN	4	18.288	2.400	0.080	0.601
ROCK+SHRUBHT	3	18.358	2.470	0.077	0.439
FORB+SOIL+SHRUBHT	4	19.112	3.224	0.053	0.830
FORB+SOIL	3	19.198	3.310	0.051	0.295
GRASS+SOIL	3	19.199	3.311	0.051	0.297
GRASS+SOIL+SHRUBHT	4	19.302	3.414	0.048	0.998

[a] Percent rock cover.
[b] Average height of all shrub species.
[c] Percent cover of all grass species.

Table 2.6: Akaike weights of individual habitat variables for the subset of logistic regression models with $\Delta AIC_c \leq 4.0$ based on data collected in 2005 in southwestern Idaho.

Variable	Number of models included in with $\Delta AIC_c \leq 4.0$	*w* for models with $\Delta AIC_c \leq 4.0$
SOIL	8	0.842
DEGFROMN	3	0.474
FORB	4	0.316
SHRUBHT	4	0.261
GRASS	3	0.179
ROCK	2	0.160

Table 2.7: Odds ratios from $\Delta AIC_c \leq 4.0$ supported models. Variable odds ratio results were taken from the top models with the lowest AIC_c values.

Variable	Parameter Estimate	Standard error	Odds ratio	Lower 95% CI	Upper 95% CI
Intercept	8.151	3.175	-	-	-
SOIL	-0.543	0.243	0.581	0.361	0.935
DEGFROMN	0.042	0.028	1.043	0.987	1.101
FORB	0.156	0.199	1.168	0.791	1.727
SHRUBHT	0.221	0.141	1.247	0.946	1.643
GRASS	-0.037	0.116	0.964	0.769	1.209
ROCK	-1.896	1.059	0.150	0.019	1.195

Discussion

Occupied pygmy rabbit areas had significantly greater total shrub, sagebrush (*Artemisia tridentata* ssp. *vaseyana*), forb, and litter cover, and significantly less bare soil and rock cover than in unoccupied areas. Cover of grasses was slightly higher in unoccupied pygmy rabbit areas (29%), but was within 5 % of occupied areas (24%) and was not significantly different. Even with the significantly higher litter cover, which was primarily composed of dead shrub material, little difference in shrub vigor was found between occupied and unoccupied areas.

Katzner and Parker (1997) first noted the importance of dead shrub material within occupied pygmy rabbit areas. Even though litter may be the only variable that accounted for this dead shrub component, ocular estimates revealed a much higher amount of dead shrub material within occupied areas than what was accounted for through my estimates of shrub vigor. Formation of this relatively high amount of litter in occupied areas may be the result of the pygmy rabbits themselves, natural degeneration of the sagebrush, the result of domestic cattle grazing, or some combination of all three factors. I did note that percent cover of cow dung was slightly higher in occupied versus unoccupied pygmy rabbit areas, indicating slightly higher cattle use within occupied areas.

Total shrub, sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and snowberry (*Ymphoricarpos oreophilus*) cover was greater in occupied pygmy rabbit habitat. Height of total shrubs and sagebrush also was significantly higher in occupied areas. These results agree with past findings that pygmy rabbits prefer areas with tall and dense sagebrush cover (Green and Flinders 1980a; Weiss and Verts 1984; Gahr 1993; Katzner and Parker 1997). The range of specific values of sagebrush, however, varied among studies. Presumably this variability stems from natural variation in the vegetation in which this rabbit resides. One difference in shrub cover found in the Owyhee uplands was that in two of the 19 occupied pygmy rabbit plots, bitterbrush (*Pursha tridentata*) comprised the majority of total shrub cover (Figure 2.3). Among the 19 occupied sites, total shrub cover values ranged between 41% and 67%, a difference of 26%. Sagebrush cover values ranged from 12% through 60%, a difference of 48%. These differences in total range values for total shrub and sagebrush cover suggest that total shrub cover need not primarily be composed of sagebrush. Even though the pygmy rabbit has an obligatory need for sagebrush as a food source, total shrub cover seemed to be just as critical as sagebrush cover, allowing rabbits to inhabit areas once thought to be unsuitable. While it is unknown what minimum amount of sagebrush cover pygmy rabbits need to survive in other occupied areas, the minimum sagebrush cover I noted was 11%. It is still critically important to note that all of the occupied areas sampled contained some sagebrush cover, with the majority of sites studied dominated by sagebrush.

Results for sagebrush canopy cover and height varied compared to past results that investigated sagebrush cover. Weiss and Verts (1984), using the line transect (intercept) sampling method, found that in Oregon average total shrub cover in occupied areas was

28.8%, with a range from 21% to 36%. Average sagebrush cover was 23.7%, with a range from 16.3 to 33.2%. Average total shrub and sagebrush cover values (56% and 44%) in the Owyhee uplands were much higher than in Oregon, but average total shrub and sagebrush height (84.4 cm and 90.8 cm) were much greater in Oregon than in the Owyhee uplands (63cm and 66 cm). This difference may be attributable to the greater variety of *Artemisia tridentata* sub-species measured in the Oregon study. *Artemesia tridentata* ssp. *tridentata*, which I believe was relatively absent in my study area (Rosentreter per. com.), grows taller than the higher elevation growing *Artemesia tridentata* ssp. *vaseyana*, the predominant sagebrush I found (Rosentreter 2005). Results for total shrub height found in southeastern Idaho by Green and Flinders (1980a) more closely resembles values found in the Owyhee uplands. While pygmy rabbits prefer areas of relatively taller sagebrush, absolute height may be less important due to the differences of average sagebrush height found among this and previous studies.

Results from habitat selection models indicated that occupied pygmy rabbit habitat was associated with increasing total shrub height (SHRUBHT) and total forb (FORB) cover, and decreasing percent bare soil (SOIL), rock (ROCK), and grass (GRASS) cover. Aspect (DEGFROMN) was close to negligible for preference, but seemed to play an important role within the top models. Cover of grasses was negatively related to selection, but had a large odds ratio confidence interval encompassing 1.0. Total shrub cover (SHRUB), sagebrush height (SAGEHT) and sagebrush cover (SAGECOV), variables with results that were significantly higher in occupied versus unoccupied pygmy rabbit areas, all had Pearson correlation coefficients greater than 0.50 with all the other variables included in the model building process except grass cover and aspect. They were also highly correlated between each other. Given this multi-colinearity with the majority of the other top habitat variables, I chose to include only total shrub cover (SHRUB) in the final set of potential models. Percent cover of litter (LITTER) did not make the subset of candidate variables because it had a univariate logistic regression P-value greater than 0.25.

Within the mildly supported ($\Delta AIC_c \leq 4.0$) habitat selection models, percent cover of bare soil was the best predictor of occupied pygmy rabbit habitat. Given an increase of 10% bare soil cover, selection of habitat by pygmy rabbits decreased by 42%. Mean percent cover of bare soil was also significantly less in occupied versus unoccupied areas (13% versus 39%). Occupied pygmy rabbit areas had a diverse vegetative makeup, with large amounts of shrubs, litter, and forbs. This strong avoidance of areas with bare soil supports preference for other variables that fill that bare soil void: taller shrubs and greater shrub, sagebrush, forb, and litter cover. Total shrub height and forb cover were both positively related to selection by pygmy rabbits in the top models, but their odds ratio confidence intervals both contained 1.0. Pygmy rabbits require large amounts of sagebrush throughout the year for food and cover (Green and Flinders 1980a). During telemetry tracking sessions, I found pygmy rabbits climbing up to half a meter into sagebrush plants to eat the newer vegetative growth. This complex mixture of dead shrub and litter material lying on the ground, coupled with high sagebrush cover found in occupied areas, likely assisted rabbits with their climbing behavior.

Increased bare soil also may be negatively correlated with occupancy by pygmy rabbits because of predator avoidance. Increased vertical vegetative structure composed of taller shrubs, forbs and litter most likely enables this slower moving species to out maneuver predators (Bailey 1936; Orr 1940; Katzner and Parker 1997). I found this was true through trapping efforts to fit adults with radio collars. Pygmy rabbits continually eluded attempts at pursuing them down burrows to be trapped, instead utilizing the dense vegetation cover to escape. Researchers from the University of Idaho carrying out research at known occupied pygmy rabbit sites near Leadore, Idaho, observed that pygmy rabbits do not as readily go down burrows in areas of higher total shrub cover compared to areas of low shrub cover (Estes-Zumpf, Rachlow, Sanchez, per. com.). Average total shrub cover within my study area was 56%, with a range of 41% through 68%. This is over 30% higher than an average of 21% found by researchers from the University of Idaho, where pygmy rabbits were readily captured after being pursued down burrows.

Through trapping efforts, Wilde (1978) found that rabbits utilize burrows less in spring and early summer and more often during winter. He speculated that the increase in use during winter may be due to a decrease in cover, and because burrowing is an energy intensive activity, rabbits may choose to burrow only when needed. When I relocated collared rabbits through telemetry work, I noted whether rabbits were visible or not, and if not, whether they were down burrows or running out of sight. For 1158 relocation points taken between March and July in 2004 and 2005, pygmy rabbits were found in a burrow only 15 times. One possible explanation for this infrequent burrow use is that pygmy rabbits may use burrows less often in areas of higher total shrub cover. Although the hypothesis of decreased burrow use with increased total shrub cover seems likely given the data and anecdotal evidence, a stricter study design is needed to critically test this hypothesis.

Even though grass was negatively associated with use in the top models, and unoccupied pygmy rabbit areas had slightly higher, although not significant, grass cover than occupied areas, there probably is a moderate amount of grass that is preferred by pygmy rabbits. Twenty four percent was the mean grass cover I found in occupied areas in the Owyhee uplands. Through 139 feeding observations, I documented that rabbits fed on grass 45% of the time. Green and Flinders (1980a) found the pygmy rabbit's diet during summer was made up of 39% grass, with decreasing consumption through fall to winter. Therefore, while rabbits consume a certain amount of grass in spring and summer, too much grass cover could impede their ability to effectively avoid predators by reducing visability and maneuverability.

Cheatgrass, an invasive annual grass, made up little of the grass community within the entire study area. Cheat grass had an average cover value of one percent within occupied pygmy rabbit areas, and less than one percent in unoccupied areas. Given its ability to form dense stands of highly flammable material with limited nutritional value, it seems possible that pygmy rabbits would avoid these monoculture stands because such areas are unsuitable for pygmy rabbit occupancy.

Percent cover of rock was the lowest ranked variable among the top models. Areas with high percent rock cover may have a soil profile that restricts pygmy rabbits to construct burrows. The odds ratio results for rock indicate this outcome, but results are speculative given the large standard error for the parameter estimate and an equally large odds ratio confidence interval encompassing 1.0.

Management Implications

Areas possessing habitat conditions preferred by pygmy rabbits, dense and tall shrub stands (particularly sagebrush), should be managed for long term persistence. Potential pygmy rabbit areas (not presently inhabited) exhibiting these preferred characteristics should also be maintained as such if expanding and reintroducing pygmy rabbit populations is a management objective. Given the heightened concern over the status of the pygmy rabbit range wide, management practices that alter or decrease these preferred habitat conditions should be reevaluated so as not to diminish the remaining suitable habitat for this species.

The use of fire as a management tool in occupied and potential pygmy rabbit habitat, whether from anthropogenic or natural origin, should be scrutinized given its potential to drastically transform the landscape from a shrubsteppe to an annual grassland community (Brooks and Pyke 2001, Brooks et al. 2004). Where I found pygmy rabbits, there was very little cheatgrass and virtually no sign of historical fire episodes, which resulted in a dense and tall, mature sagebrush community with high amounts of litter and forbs and moderate grass cover. Until a method of controlling invasive, annual grasses from establishing a monoculture after fire in a shrubsteppe community is found, habitat occupied by pygmy rabbits should be carefully managed through alternate techniques.

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CHAPTER 3 : MULTI-SCALE HABITAT SELECTION BY PYGMY RABBITS (BRACHYLAGUS IDAHOENSIS) IN THE OWYHEE UPLANDS OF SOUTHWESTERN IDAHO

Introduction

The sagebrush ecosystem in the western United States has undergone extensive changes due to sagebrush fragmentation, degradation, and loss, which has led to declines in many sagebrush dependent species (Knick et al. 2003). Pygmy rabbits (*Brachylagus idahoensis*), a sagebrush dependent species, have likely been impacted by this loss and degradation of sagebrush habitat, but population declines have been difficult to quantify due to the lack of past and present abundance and distribution data (Federal Register 2005).

Research to better understand this species has recently increased, with work recently done predicting and identifying potential pygmy rabbit habitat at large spatial scales using models of remotely sensed and ground-truthed data (Gabler et al. 2000, Rachlow and Svancara 2006). Given that in many areas, occupancy of sagebrush steppe habitat by pygmy rabbits is unknown, models such as these have become very important in identifying potential pygmy rabbit habitat given the rabbit's patchy distribution over large and remote landscapes spanning seven states (Green and Flinders 1980b).

Pygmy rabbits inhabit parts of the Intermountain and Great Basin states of Oregon, California, Nevada, Utah, Wyoming, Montana, and Idaho, where they are found in areas of loose and deep soils and a sagebrush steppe vegetation community (Green and Flinders 1980a, Weiss and Verts 1984). Sagebrush makes up 99% and 51% of pygmy rabbit's diet in winter and summer, giving the rabbit a sagebrush obligate distinction

(Green and Flinders 1980a). Given that habitat selection by animals is multi-scale in nature (Johnson 1980), and finer scale pygmy rabbit habitat preference is better understood (Green and Flinders 1980a, Weiss and Verts 1984, Gahr 1993, Chapter 2), more work is needed to identify pygmy rabbit habitat preference at larger scales.

Results from Chapter 1 indicate that pygmy rabbits use relatively large areas in relation to their small size. Males were found to travel longer distances than females (average distance and average maximum distance moved). For these reasons, males had much larger minimum convex polygon and 95% fixed kernel (FK) home ranges. Even though 50% FK results differed significantly between males and females, both sexes had 50% FK ranges less than one hectare (ha). This indicates that while males traveled greater distances compared to females, once they were in a core area, their movements were confined and site specific.

Chapter 2 results indicated that at the pygmy rabbit home range core area, habitat was composed of denser and taller shrubs, with high forb and litter cover, results that are consistent with previous findings of finer scale pygmy rabbit habitat preference (Green and Flinders 1980a, Weiss and Verts 1984, Gahr 1993). In addition, rabbits exhibited an aversion to bare soil and rock cover (Chapter 2). The primary sagebrush species found within occupied pygmy rabbit sites was mountain sagebrush (*Artemisia tridentata* ssp. *vaseyana),* which was interspersed with rabbitbrush (*Chrysothamnus nauseosus*), bitterbrush (*Pursha tridentata*), and snowberry (*Symphoricarpos oreophilus)*.

Through a combination of pygmy rabbit home range analyses, vegetation cover data, and compositional analysis (Aebishcher et al. 1993), I attempted to rank habitat preference in the Owyhee uplands during the breeding season for pygmy rabbits at two spatial scales; the landscape and home range scales (Johnson 1980). This is the first study I'm aware of that attempts to identify larger scale pygmy rabbit habitat preference using telemetry data from collared rabbits. Using telemetry and remotely sensed vegetation data, I hypothesized that 1) pygmy rabbits will prefer habitat types composed of dense and tall stands of sagebrush at both scales of analysis, 2) habitat types composed of low and sparse sagebrush will be preferred less, and 3) habitat types without sagebrush as a component will be least preferred. Results will provide needed insight into whether rabbits are selecting habitats at broader scales, and if so, will identify what those habitat characteristics are.

Methods

Study Area

See methods from Chapter 1.

Pygmy Rabbit Home Ranges and Movements

See methods from Chapter 1.

Habitat Preference Analysis

While some studies of habitat selection using compositional analysis have relied on land cover maps that were constructed for a particular study, others have utilized existing geographical information system (GIS) coverage maps that include a greater landscape area and are readily available to interested parties (Shepherd and Lank 2004; Duchamp et al. 2004; Pendleton et al. 1998). For this study, I chose the latter method of utilizing an existing habitat map, the "Shrub Map: Current Distribution of Sagebrush and Associated Vegetation in the Columbia Basin and Southwest Regions", which is widely available for land managers and researchers (USGS 2005). More specifically, I used the Owyhee Upland Mapping Zone, which was classified into 39 land cover classes, based upon the International Ecological Classification Standard (NatureServe 2005), using multi-season satellite imagery (Landsat 7 ETM+ imagery), digital elevation model data sets, and ground sampling. The overall accuracy of the ShrubMap was 0.73, with overall omission and commission errors of 0.27 and 0.03, respectively (USGS 2005). A detailed description of the 39 land cover classes included in the Owyhee Upland Mapping Zone can be found at:

http://sagemap.wr.usgs.gov/FTP/Documents/Shrubmap_Legend_Decriptions.pdf.

To determine the amount of available habitat at the landscape scale, I used ArcGIS 9 (Environmental Systems Research Institute, 2004) with the Hawth's Tools extension (Beyer, 2004), to delineate a study area for the habitat classification and compositional analysis. I constructed a 100% "study area" Minimum Convex Polygon (MCP) using all pygmy rabbit telemetry relocation points for both years of the study. The study area

MCP allowed for determination of the proportional amount of habitat “available” to collared rabbits at the landscape scale.

I calculated an area of 1836 hectares for the 100% MCP for my study area. Fifteen out of 39 possible land cover classes from the Shrub Map fell within the study area (Table 3.1). From those 15 land cover classes, I developed six habitat classes by grouping land cover classes by major vegetation type; Mountain Sagebrush, Big Sagebrush, Low Sagebrush, Silver Sagebrush, Grassland, Woodland (Table 3.1).

I layered the 95% Fixed Kernal (FK) utilization distributions and the number of radio locations per individual over the Shrub Map to determine the proportion of habitat “used” relative to what was “available” at two scales (Johnson 1980). At the “landscape scale” , I defined “available” habitat from the proportion of habitat within the study area MCP to the proportion of “used” habitat that fell within an animal’s 95% FK utilization distribution (Millspaugh et al. 2006). At the second, “home range” scale, I compared the proportion of “available” habitat from the animal’s 95% MCP home range to the proportion of “used” habitat based on the radio locations for that individual within each habitat class.

Table 3.1: The 15 land cover classes and their descriptions that make up the six habitat classes used for the landscape and home range scale composition analysis of pygmy rabbit habitat preference in southwestern Idaho. The percentages of each available habitat and land cover classes at the landscape scale are listed in parenthesis.

Habitat Class	Land cover Class Number	Land Cover Class Description
Low Sagebrush (43.89%)	154 (43.71%)	Columbia Plateau Low Sagebrush Steppe
Low Sagebrush	44 (0.18%)	Columbia Plateau Scabland Shrubland
Big Sagebrush (33.36%)	54 (29.38%)	Inter-Mountain Basin Big Sagebrush Shrubland
Big Sagebrush	78 (3.08%)	Inter-Mountain Basin Big Sagebrush Steppe
Big Sagebrush	149 (0.90%)	Inter-Mountain Basin Big Sagebrush Shrubland Spp. Tridentata
Mountain Sagebrush (13.92%)	71 (13.92%)	Inter-Mountain Basin Montane Sagebrush Steppe
Woodland (5.74%)	50 (4.66%)	Inter-Mountain Basin Mountain Mahogany Woodland and Shrubland
Woodland	291 (0.98%)	Riparian
Woodland	23 (0.04%)	Rocky Mountain Aspen Forest and Woodland
Woodland	41 (0.03%)	Columbia Basin Western Juniper Woodland
Woodland	75 (0.03%)	Inter-Mountain Basin Juniper Savanna
Grassland (2.29%)	90 (2.07%)	Inter-Mountain Basin Semi-Desert Grassland
Grassland	133 (0.14%)	Northern Rocky Mountain Montane Grassland
Grassland	137 (0.08%)	Columbia Basin Foothill and Canyon Dry Grassland
Silver Sagebrush (0.79%)	142 (0.79%)	Columbia Plateau Silver Sagebrush Seasonally Flooded Shrub-Steppe

Using the script Bycomp.sas (Ott and Hovey 1997) in SAS (SAS Institute 2001), a compositional analysis was performed to estimate and rank the habitat class preference of pygmy rabbits from most to least preferred (Aebischer et al., 1993) at the landscape and home range scale. To determine habitat class preference, habitat classes were ranked against each other based on the use of the habitat class compared with its availability. Positive rankings indicated that a habitat class was selected, or preferred, over another after accounting for its availability. Using a one sample Student's *t* test, rankings were tested against zero, the value expected if habitat use was random. Significance ($P \leq 0.05$) was determined for all tests by comparing the t statistics to a randomized reference distribution.

Results

Pygmy Rabbit Home Ranges and Movements

For movement and home range analysis, adequate data were collected for five males and six females in 2004 and seven males and 10 females in 2005. The average number of relocation points per individual was 40, with a range of 21 to 57. The number of location points was >30 for 25 out of the 27 individuals used for analyses of habitat collection. I collected adequate relocation data to formulate home ranges for three rabbits during both seasons of the study, two females and one male.

For the three rabbits with more than one year of data, I chose to include both years of data for habitat analysis based on several points. First, the rabbits' areas of use for their 95% MCP, 95% FK, and 50% FK ranges greatly differed between years (Table 1.1, Chapter 1). Second, for analysis of habitat preference, the locations used by these rabbits differed between years. The range of overlap between home range core areas for the three animals between years ranged from 31% to 57%. Burt (1943) stated that the home range need not cover the same area during the life of the individual, with animals often moving from one area to another, therefore abandoning and setting up new home ranges. I believe that inclusion of those animals with two years of data was more important for habitat selection analysis and outweighed the risk of pseudo-replication and the violation of the independence of data.

Habitat Preference Analysis

Habitat class availability differed at the two scales of analyses (Table 3.2). The most abundant habitat class at the landscape scale was Low Sagebrush (43.9%) followed by Big Sagebrush (33.4%), Mountain Sagebrush (13.9%), Woodland (5.7%), Grassland (2.3%), and Silver Sagebrush (0.8%). Within the home range scale, Mountain Sagebrush (46.5%) had the highest availability, followed by Low Sagebrush (24.3%), Big Sagebrush (23.2%), Silver Sagebrush (2.8%), Woodland (1.9%), and Grassland (1.2%).

At the landscape scale, pygmy rabbits were selective of habitat type (Λ=0.20, $F_{5,22}$=43.14, P=0.001, Table 3.3). Mountain sagebrush (rank 1) was selected significantly over the other five land cover classes. No significant differences were found between the next three classes; Big Sagebrush (rank 2), Silver Sagebrush (rank 3), and Low Sagebrush (rank 4) (Table 3.3).

Table 3.2: Percentage mean available and mean used of the six habitat classes at the landscape and home range scales in southwestern Idaho.

Habitat Class	Low Sagebrush	Big Sagebrush	Mountain Sagebrush	Woodland	Grassland	Silver Sagebrush
Landscape Available	43.9	33.4	13.9	5.7	2.3	0.8
Landscape Used (n=27)	24.8 ± 6.5	20.4 ± 4.1	49.1 ± 7.0	0.7 ± 0.4	3.0 ± 2.0	2.1 ± 1.1
Home Range Available (n=27)	24.3 ± 6.1	23.2 ± 4.3	46.5 ± 7.2	1.9 ± 1.1	1.2 ± 0.7	2.8 ± 1.5
Home Range Used (n=27)	24.7 ± 7.0	21.6 ± 4.7	49.1 ± 7.6	0.1 ± 0.1	2.9 ± 2.2	1.6 ± 0.9

Mean ± standard error of the mean.

Table 3.3: Rankings of land cover habitat classes (1 to 6) determined from used versus availability at the landscape and home range scales in southwestern Idaho. Rankings with numbers in parenthesis indicate non-significant (P>0.05) differences between that class and those ranked classes in parenthesis.

Habitat Class	Low Sagebrush	Big Sagebrush	Mountain Sagebrush	Woodland	Grassland	Silver Sagebrush
Landscape						
• Available	1	2	3	4	5	6
• Used (n=27)	$4^{(5)}$	$2^{(3,4)}$	1	6	$5^{(6)}$	$3^{(4)}$
– Male (n=12)	$3^{(4,5,6)}$	$2^{(3,4,5,6)}$	$1^{(2,3)}$	$5^{(6)}$	6	$4^{(5)}$
– Female (n=15)	$4^{(5)}$	$2^{(3,4,5)}$	$1^{(2)}$	6	5	$3^{(4,5)}$
Home Range						
• Available	2	3	1	5	6	4
• Used	$2^{(3,4,5)}$	$1^{(2,3,4,5)}$	$4^{(5,6)}$	6	$3^{(4,5,6)}$	$5^{(6)}$

Separate analyses of habitat selection for males and females at the landscape scale indicated that for each sex, habitat selection was non-random (males: Λ=0.18, $F_{7,5}$=20.37, P=0.027, n=12; females: Λ=0.09, $F_{5,10}$=35.50, P=0.002, n=15, Table 3.3). For males, Mountain Sagebrush was ranked highest, but was not significantly preferred over Big Sagebrush (rank 2) or Low Sagebrush (rank 3). For females, Mountain Sagebrush was significantly preferred over the rest of the habitat classes except Big Sagebrush (rank 2). There was no significant difference between Big Sagebrush and the next habitat classes; Silver Sagebrush (rank 3), Low Sagebrush (rank 4), or grassland (rank 5). Woodland (rank 6) was the least preferred. I did not test for differences between male and female habitat preference because of relatively small sample sizes.

At the finer, home range scale, rabbits were selective of habitat type, but only marginally (Λ=0.65, $F_{5,22}$=11.80, P=0.04, Table 3.3). There was no significant difference between the top four habitat classes; Big Sagebrush (rank 1), Low Sagebrush (rank 2), Grassland (rank 3), and Mountain Sagebrush (rank4). There was little difference between mean available and mean used at the home range scale (Table 3.2). I did not perform a home range compositional analysis on males and females separately for the home range scale due to the marginal result for both sexes combined (Table 3.3).

Discussion

Landscape preference at the landscape scale was significantly non-random. Pygmy rabbits highly preferred Mountain Sagebrush over the other five classes (Table 3.4). This habitat class is primarily composed of mountain sagebrush with total shrub cover often exceeding 40%, with equally high grass and forb cover (NatureServe 2005). Such high shrub and forb cover, along with the primary sagebrush species being mountain sagebrush, was validated by the ground-based habitat data I collected within core areas of pygmy rabbit home ranges. These results are consistent with the preference of areas of taller and denser sagebrush with greater forb cover (Chapter 2).

Habitat class Big Sagebrush most closely resembled Mountain Sagebrush, and was ranked second overall. Silver Sagebrush (*Artemisia cana* sp.), which was ranked third overall, had a small available value (< 1%). This cover class was primarily found in wetlands, such as along intermittent stream channels or riparian meadows. These areas were found adjacent to pygmy rabbit core areas and were likely included in the FK home ranges.

For males and females, Mountain Sagebrush again was ranked first, but it was not significantly preferred over the other five habitat classes (Table 3.4). For females, Mountain Sagebrush was not significantly preferred over Big Sagebrush (rank 2). For males, selection for Mountain Sagebrush was not significantly greater than Big Sagebrush or Low Sagebrush (ranks 2 and 3). Habitat class Big Sagebrush is mainly composed of basin and wyoming big sagebrush (*Artemisia tridentata* ssp. *tridentata* and var. *wyomingensis*) as opposed to mountain sagebrush. The Low Sagebrush community (*Artemisia arbuscula* sp.) primarily occurs on shallow soils and stony areas (NatureServe 2005). In addition to areas of taller and denser sagebrush, pygmy rabbits are known to prefer areas of deep soil for construction of burrows, a characteristic of areas dominated by Mountain Sagebrush and Big Sagebrush, but not Low Sagebrush (Gahr 1993, Weiss and Verts 1984). Additionally, the Low Sagebrush habitat class does not possess the height and density of shrubs that pygmy rabbits appear to prefer (Green and Flinders 1980a, Weiss and Verts 1984). The Low Sagebrush habitat class had the greatest availability in the study area, but it was ranked fourth in the overall landscape level habitat selection, and statistically was no different than the Grassland habitat class (Table 3.4).

Suitable habitats, such as Mountain Sagebrush, were patchily distributed in the western half of the study area, but made up larger patches within the eastern half. Because males move among different females during the breeding season (Chapter 1), some areas within male home ranges were composed of a Low Sagebrush community. Once in an area, male pygmy rabbits primarily stayed in areas of dense and tall sagebrush, such as that found in Mountain Sagebrush. However, because part of the study area composed of preferred habitat was patchily distributed, 95% FK home range results for some males included large areas of Low Sagebrush. While it is unknown how pygmy rabbits traversed through, or around, patches of Low Sagebrush to patches of preferred habitat

(Mountain Sagebrush), inclusion of the habitat class Low Sagebrush in male home ranges most likely explains the higher ranking of this cover class for male pygmy rabbits. The home range scale compositional analysis showed moderately significant habitat preference. Mountain Sagebrush was actually ranked fourth out of six, but was not statistically different in terms of preference with the three classes ranked above it. This is not surprising since there was very little difference between mean habitat used and mean available at the home range scale (Table 3.3), indicating that the proportion of used versus available was close to 1.0 for all six habitat classes. Even though Mountain Sagebrush was used more, its availability was ranked highest, giving it a low preference result. This finding of equal habitat use to availability, and the effects it has on habitat class rankings, is a drawback to the use of compositional analysis (Boitani and Fuller 2000). While the results for home range habitat preference were significantly non-random, little information concerning habitat preference could be determined. At the home range scale, pygmy rabbits showed little preference for a particular habitat class, but primarily utilized the habitat class with the most availability, Mountain Sagebrush.

Management Implications

The compositional analysis results provide strong support for the use of the Shrub Map as a tool for identifying preferred habitat at broader spatial scales. While results from my analysis found a strong preference for Mountain Sagebrush (land cover class 71), these results may not be repeatable in areas of different elevation, rainfall patterns, and soil conditions. If this study was replicated in an area with different conditions as listed above, and habitat preference was found, the preferred land cover class or classes may be different than Mountain Sagebrush. It might be one of the classes found in Big Sagebrush (54, 78, or 149) or one that did not occur in my study area. My landscape scale results do further support findings that pygmy rabbits are using areas with a tall and dense shrub component (Green and Flinders 1980a, Weiss and Verts 1984, Chapter 2). Land cover classes found in areas that pygmy rabbits are known to reside in, or nearby, that possess these desired vegetation characteristics, may be the classes pygmy rabbits are using on the ground.

Given this unknown repeatability in different occupied pygmy rabbit areas, caution and care should be taken before applying the Shrub Map over very large spatial areas to identify suitable and/ or occupied habitat. To enhance the Shrub Map's applicability to identify areas that may be suitable to, and occupied by, pygmy rabbits, I would suggest that some sort of ground-truthing be carried out, such as gathering location data of pygmy rabbit burrows, pellets, or other sign. Overlaying this data onto the Shrub Map in a Geographical Information System would greatly assist in identifying any patterns of land cover class preference for an area, if in fact a pattern existed. Given my positive results though, I do believe the Shrub Map, coupled with the pygmy rabbit habitat suitability prioritization models recently created (Gabler et al. 2000, Rachlow and Svancara 2006), has potential as an additional management tool for delineating vegetative characteristics that pygmy rabbits find suitable, especially at large spatial scales, and could enhance efforts for identifying and prioritizing areas to be surveyed or targeted for conservation.

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APPENDIX A: Pygmy Rabbit (Brachylagus idahoensis) Trapping Techniques

Pygmy rabbits were trapped utilizing two techniques: the “burrow” technique and the “herding and wing” technique. The burrow technique involved pursuing individual rabbits into burrow systems and placing traps at the entrances. Once an animal was determined to be in a burrow, collapsible live-traps (Tomahawk Live Trap Co, Tomahawk, Wisconsin, USA) with a single door entrance (41x14x14 cm) were placed over the burrow entrance the rabbit was seen entering (Figure A.1). Pieces of burlap (61x61 cm) were then used to cover the trap so as to mimic an extension of the burrow. Other entrances of the same burrow system were either set with a trap or plugged with extra pieces of burlap to prevent escape. Waiting times varied from five minutes to up to four hours before an animal was captured or the traps were pulled.

The second trapping technique, the “Herding and Wing” technique, was implemented in 2005 only. I designed this technique because I was finding that the rabbits were not going down burrows as often as they do in other areas where pygmy rabbits were trapped by the burrow technique (Rachlow, per. comm.). The wing was made up of Dupont™ weed barrier that was 15.5 m in length and 1.24 m wide. The weed barrier was then folded in half lengthwise and stapled to 0.8 meter wooden stakes spaced 1.55 m apart. Once a pygmy rabbit was located, the wing was placed in a zig-zag fashion within the same dense sagebrush patch as the targeted rabbit was found in while attempting not to flush the rabbit (Figure A.2). The posts were driven into the ground so the wing created a barrier to movement (Figures A.3 and A.4). Collapsible Tomahawk live traps were then placed strategically between the fabric and the ground, with half the trap’s opening facing one way and the other half facing the other side of the wing. Open spaces between the wing and the ground were then filled with pieces of burlap (61x61 cm), wood debris, or cow dung, so that once the rabbit was within the wing trap, the only means of escape would be through one of the traps. Once the wing was set up, two to three people attempted to herd the targeted pygmy rabbit into one of the sides of the wing. Overall trapping time varied from 25 minutes to two hours.

Once a rabbit was captured in a trap, the trap was covered with burlap as quickly as possible to decrease the chance of the rabbit injuring itself. Since the herding and wing trapping is an “active” trapping method, as opposed to the more “passive” burrow trapping technique, rabbits entered the trap at a higher level of flight compared to entering the trap from the burrow. Covering the occupied trap with burlap seemed to greatly reduce the agitation experienced by the captured rabbits and seemed to reduce trapping related injuries.

On several trapping events using the herding and wing technique, pygmy rabbits experienced nose abrasions from running into the side of the traps that were placed under the wing. I found that placing woody debris against the side of the exposed traps reduced the possibility of collision by increasing the visibility of the traps for the pygmy rabbits.

Figure A.1: Close up view of a Tomahawk trap set at a burrow entrance.

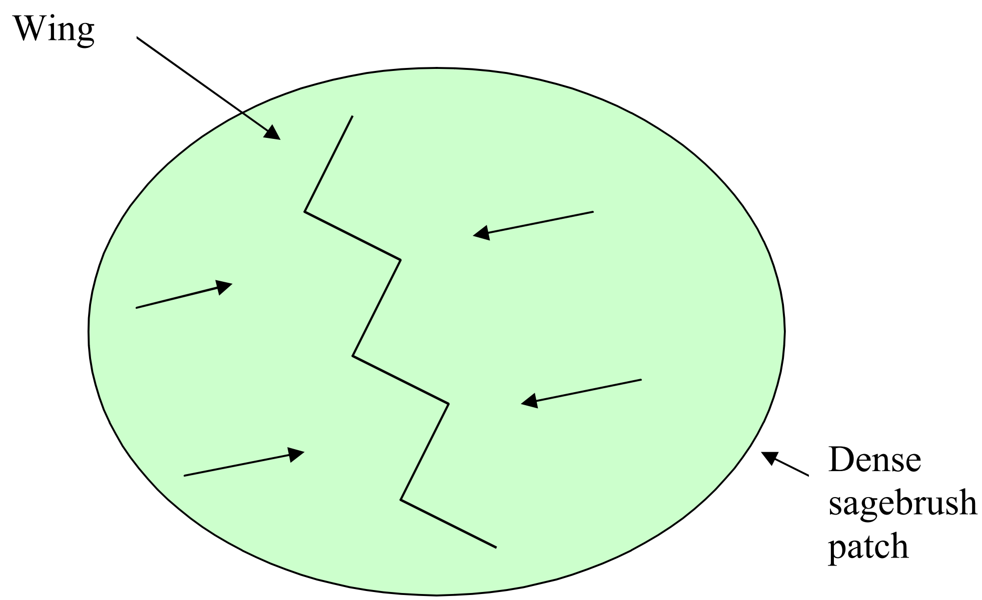

Figure A.2: Schematic of herding and wing setup. Arrows within the dense sagebrush patch denote the direction to focus efforts on herding the rabbit.

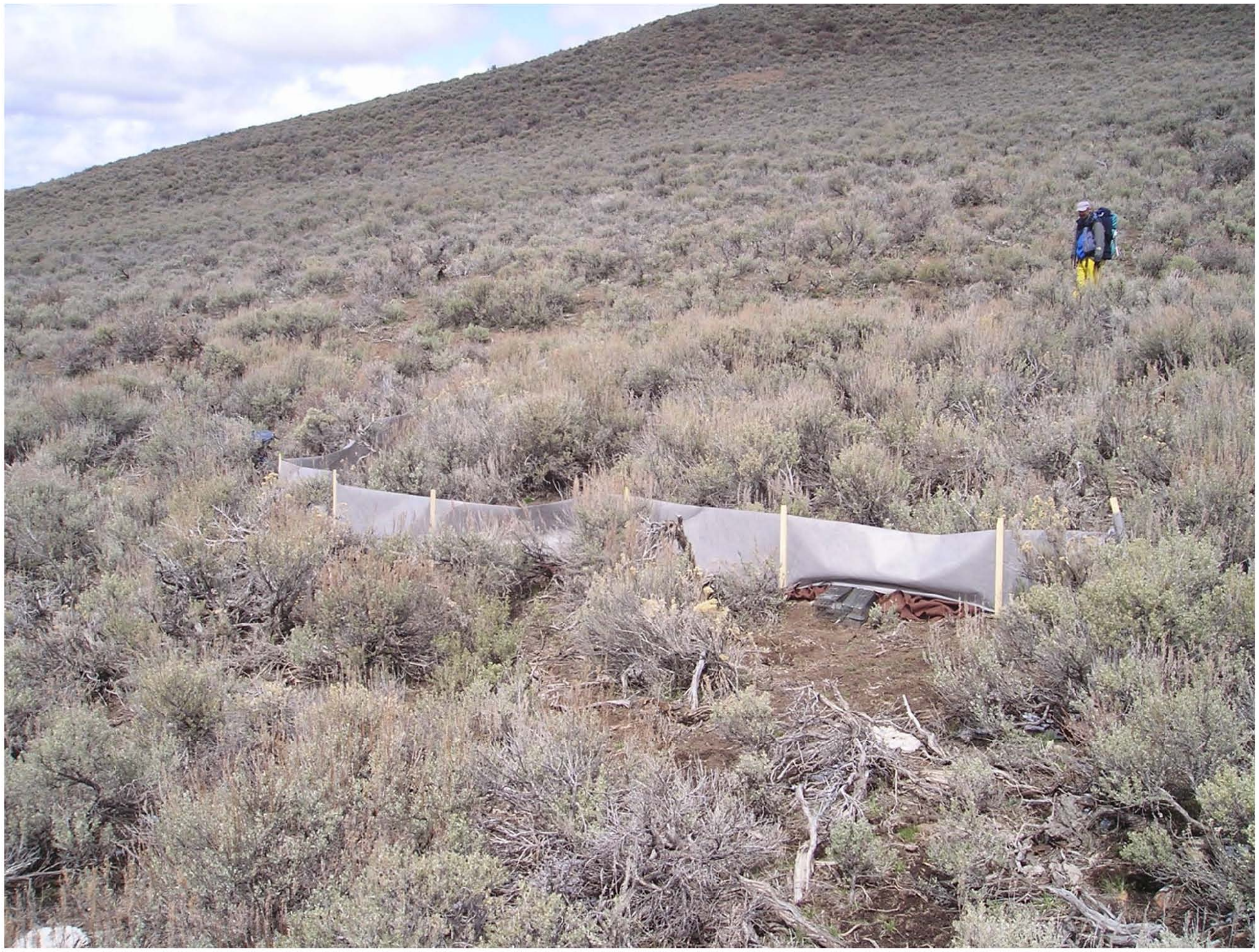

Figure A.3: The wing placed in a thick patch of sagebrush with an assistant attempting to herd the pygmy rabbit.

Figure A.4: Closer view of trap placement with burlap covering the openings next to the traps.

APPENDIX B: Pygmy Rabbit (Brachylagus idahoensis) Natal Burrow Dimensions

Four pygmy rabbit natal burrows were found during research activities. This is the second known area where natal burrows were found for free ranging pygmy rabbits (Rachlow et al. 2005). In general, my measurements for the tunnel entrance, nest chamber, and depth were smaller than found by Rachlow et al. (2005), while the angle of the entrance was slightly greater in my study area. These small differences may simply be attributable to different measurement techniques. Table B.1 provides measurement data for each natal burrow system.

The majority of information concerning the construction of natal burrows has been gained through captive breeding programs of pygmy rabbits. Females have been reported to construct natal burrows that ended in a chamber that was lined with grass and hair (Oregon Zoo 2001, Lamson and Shipley 2003). For the natal burrows in my study area, the adult female rabbit was still tending the natal burrow. I placed small twigs on top of the covered natal burrow and monitored daily for alterations. Monitoring ended when it was determined that burrows were open and vacant. Natal burrows were later excavated and the nesting material was removed for further analysis. One natal chamber contained the remains of small bones, presumably from the young. It is unknown whether the natal burrow was preyed upon, the young died from abandonment, or a natural event, such as a thunderstorm, caused this failure.

Table B.1: Dimensions for four natal burrows.

Natal Burrow #	Tunnel Height (cm)	Tunnel Width (cm)	Tunnel Angle (º)	Tunnel Aspect (º)	Chamber Entrance Width (cm)	Chamber Entrance Height (cm)
1	7	8	37	259	7.5	5
2	17	11	36	2	8	9
3	8	7.5	31	302	7.5	7
4	6.5	8	21	250	6	8.5
Average	9.6	8.6	31.3	203.3	7.3	7.4

Natal Burrow #	Chamber Height (cm)	Chamber Width (cm)	Chamber Length (cm)	Total Depth (cm)
1	9.5	14	15	21
2	12	14	11	23
3	8	10.5	13	na
4	7.5	13	9	na
Average	9.3	12.9	12	22

APPENDIX C: Pygmy Rabbit (Brachylagus idahoensis) Measurements

Thirty-eight adult and eight juvenile pygmy rabbits were successfully trapped during 2004 and 2005. The average weights, right ear and right hind foot measurements are listed below in Table C.1.

Table C.1: Right rear foot, right ear measurements (millimeters), breeding, and non-breeding weights (grams) of adult male, female, and juvenile pygmy rabbits. Sample sizes are in parentheses.

Measurement	Adult Male	Adult Female	Juvenile
Foot (mm)	67.3 (16)	70 (23)	54.2 (6)
Ear (mm)	49.5 (15)	51(23)	40.4 (6)
Breeding (g)	411 (16)	578 (23)	206 (6)
Non-breeding (g)	478 (6)	496 (13)	na

Adult females generally had larger right hind feet and right ear measurements compared to adult males. Adult females were much heavier than male pygmy rabbits during the breeding season, most likely from the effects of pregnancy. Weights between males and females were much closer during the non-breeding season, with females being generally heavier.

APPENDIX D: Pygmy Rabbit (Brachylagus idahoensis) Feeding Observation Data

I noted 139 feeding observations during the 2004 and 2005 breeding seasons (March through July). Table D.1 lists the percentage of total observations by shrub, grass, forbs, and unknown between and among years.

Table D.1: Percentages of feeding observation by shrub, grass, forbs, and unknown during the breeding season of 2004 and 2005.

Year	Shrub	Grass	Forbs	Unknown
2004	38%	40%	10%	12%
2005	38%	51%	12%	0%
Total	38%	45%	11%	6%

Table D.2: Feeding observations by known shrub and forb species.

	2004	2005	Total
Shrubs	28	23	51
Artemisia tridentata ssp. *vaseyana*	*21*	*23*	*44*
Chrysothamnus nauseosus	*7*	*2*	*9*
Forbs	8	7	15
Eriogonum heracleoides	*1*	*2*	*3*
Collinsia parviflora	-	*2*	*2*
Senecio integerrimus	-	*1*	*1*
Lupinus spp.	*7*	*2*	*9*

Green and Flinders (1980) found, through fecal pellet analysis, that the diet of pygmy rabbits during the summer was composed of 51% sagebrush, 39% grasses, and 10% forbs. From March through September, Gahr (1993) found through 82 feeding observations that pygmy rabbits ate shrubs 36% of the time, grasses 45 %, and forbs 19%. My results lie within the findings of both studies. The specific species of shrub I observed pygmy rabbits eating was primarily *Artemisia tridentata* ssp. *vaseyana* (mountain sagebrush), with *Chrysothamnus nauseosus* (rabbit brush) being eaten less frequently. On several occasions, rabbits were witnessed climbing sagebrush plants to eat. While this behavior seemed to increase the risk of avian predation, the benefits of the higher nutritional value received from recent vegetative growth may have been out weighed by the increased risk of predation.

The most common forb consumed was *Lupinus spp.* For all but one observations of lupine consumption, the stalks were the only vegetative part consumed with the leaf heads being left on the ground. I am unsure of why the primary component of lupine consumed was the stalks.