AN ABSTRACT OF THE THESIS OF

Justin A. Crawford for the degree of Master of Science in Wildlife Science presented on June 4, 2008.
Title: Survival, Movements and Habitat Selection of Pygmy Rabbits *(Brachylagus idahoensis)* on the Great Basin of Southeastern Oregon and Northwestern Nevada

Abstract approved:

Robert G. Anthony

I investigated survival, movements, home range sizes, and habitat selection of pygmy rabbits (*Brachylagus idahoensis*) in southeastern Oregon and northwestern Nevada from June 2005 to June 2007. I trapped 298 rabbits on four sites and fitted each with radio transmitters. More than 13,000 locations of telemetered rabbits were recorded. I used known fate models in program MARK to estimate survival of radio-marked pygmy rabbits from September 2005 – August 2006. The most appropriate model, based on Akaike's Information Criterion (AIC_c), indicated survival rates varied among study sites, sexes, and with monthly interval in a parallel pattern [model *S*(area * sex + t)]. The estimated annual survival rate on the four study sites was notably low, varying from 0.003 (SE = 0.003) to 0.173 (SE = 0.066). Predation on collared rabbits was high for both adult (88.6%) and juvenile (89.4%) rabbits. When the cause of mortality could be determined, the most common predators of pygmy rabbits were coyotes (*Canis latrans*)–19.6%, avian predators–18.5%, and weasels (*Mustela* spp.)–9.8%.

Spatial use by pygmy rabbits was strongly influenced by sex and season. Males used larger annual ($\bar{x}$ = 1.70 ha ± 0.69 SE) and breeding (1.67 ± 0.27 ha) home ranges than females (Annual: 0.90 ± 0.26 ha; Breeding: 0.92 ± 0.16 ha), likely influenced by mate-searching behaviors exhibited by males. Both sexes utilized larger home ranges during the breeding season than during the nonbreeding season (Male: 0.63 ± 0.11 ha; Female: 0.50 ± 0.09 ha). Core area sizes of males (0.10 ± 0.04 ha) also were larger than females (0.07 ± 0.03 ha). Twenty-four radio-marked individuals dispersed greater than 0.5 km, with a maximal observed dispersal distance of 8.5 km. The majority (62.5%) of these long distance movements were by juvenile males, which likely represented dispersal from natal areas. Many of these individuals apparently crossed low sagebrush *(Artemisia arbuscula)* communities and relatively open areas. The ability of this species to cross unsuitable habitats, previously considered barriers to movement, may suggest that fragmented populations of pygmy rabbits may not be as isolated as once thought.

To examine resource selection by pygmy rabbits, I sampled vegetative and soil characteristics at locations used by radio-marked rabbits (n = 178) and available (n = 100) sites and compared them using logistic regression. The top model, based on Akaike's Information Criterion (AIC_c), indicated that the increased density and height of live shrubs, higher silt content of soil, and lower clay content of soil were the primary variables related to pygmy rabbit occupation relative to available habitat. Habitat-use patterns also varied among study sites as I did not find a consensus model that described habitat selection among pygmy rabbits for each study site. Further, my analysis demonstrated that soils at pygmy rabbit burrows were deeper, had greater subsurface strengths, lower strengths at the surface, and lower clay composition than was randomly available in the study area.

The findings in this study provide needed information to management agencies making land-use decisions. Given the concern over the status of this species throughout its range, a more thorough understanding of survival rates, spatial use,

dispersal capabilities, and habitat associations of this sagebrush obligate species is essential to identify factors influencing their conservation.

Survival, Movements and Habitat Selection of Pygmy Rabbits *(Brachylagus idahoensis)* on the Great Basin of Southeastern Oregon and Northwestern Nevada

by

Justin A. Crawford

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APPROVED:

Major Professor, representing Wildlife Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Justin A. Crawford, Author

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CONTRIBUTION OF AUTHORS

Dr. Robert G. Anthony was involved in the design, analysis and editing of each chapter of this thesis. Todd Forbes and Glenn Lorton (BLM) were extensively involved in the collection of data, maintaining field logistics, and organizing field technician schedules.

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CHAPTER 1

GENERAL INTRODUCTION

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INTRODUCTION

Pygmy rabbits *(Brachylagus idahoensis)*, the smallest leporid in North America, measure 220-301 mm total length (Verts and Carraway 1998) and weigh 246-482 g. Females begin breeding at one year of age and produce 2–3 litters per year from late May to early August (Green and Flinders 1980a) with an average litter size of 5-6 young (Wilde 1978). The pygmy rabbit's unique ecology and behavior, in addition to its dental and cranial characteristics, is sufficiently divergent from cottontails *(Sylvilagus* spp.*)* that they belong to a monotypic genus, *Brachylagus* (Green and Flinders 1980a).

The pygmy rabbit is endemic to sagebrush-steppe communities within the Great Basin and adjacent Intermountain West of North America (Green and Flinders 1980a). The distribution of the species is disjunct within a geographic range that reaches its westernmost extent in Oregon (Hall 1981) (Figure 1.1). In Oregon, the geographic range of pygmy rabbits has declined from historical sites in Deschutes, Klamath, Crook, Lake, Grant, Harney, Baker, and Malheur counties (Olterman and Verts 1972, Verts and Carraway 1998). An isolated population in eastern Washington has been extirpated and is currently the focus of a captive breeding and reintroduction program. Overall, pygmy rabbit abundances are believed to be declining in most portions of its geographic range (Dobler and Dixon 1990).

B. idahoensis is an obligate of sagebrush *(Artemisia* spp.*)* communities and relies on big sagebrush *(Artemisia tridentata* spp.*)* for food and cover from thermal extremes and predators (Katzner and Parker 1998). Several investigators have identified the presence of taller, denser stands of big sagebrush, relative to surrounding unused areas, as an essential feature of pygmy rabbit habitat (Green and Flinders 1980a, Campbell et al. 1982, Weiss and Verts 1984). Green and

Finders (1980b) found that sagebrush was consumed throughout the year, although in lesser amounts in summer (51%) than in winter (99%). Grasses (39%) and forbs (10%) were eaten through the spring and summer and decreased to a trace amount during autumn and winter.

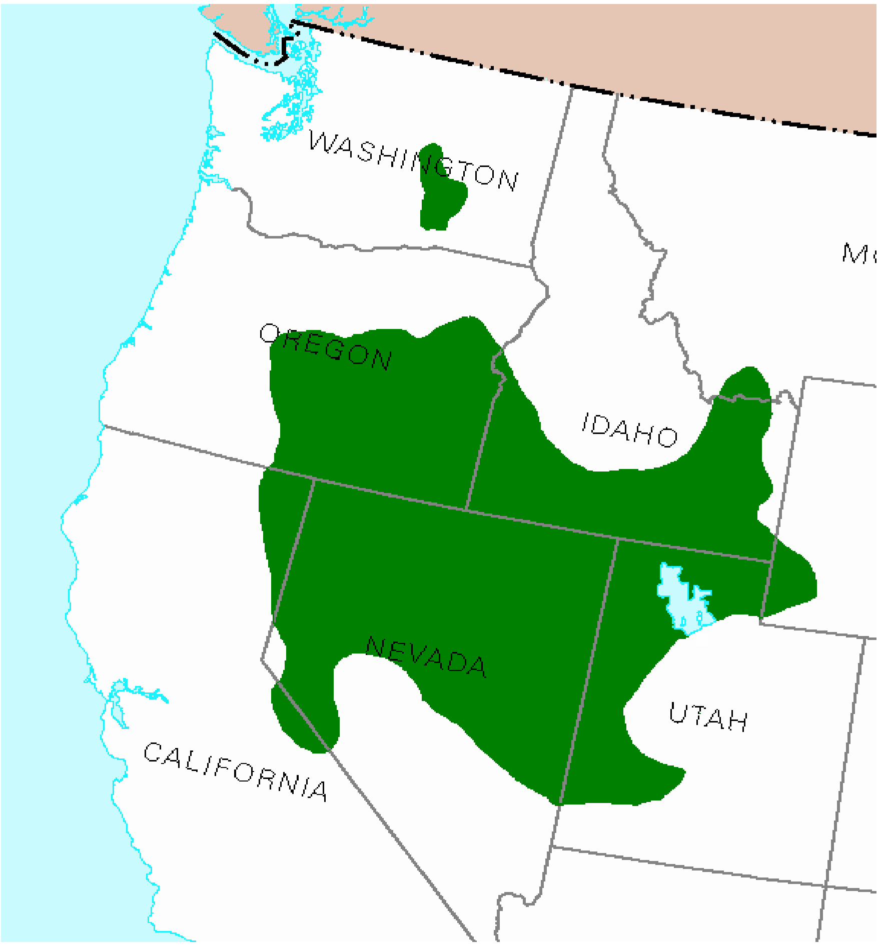

Figure 1.1. Distribution (in green) of the pygmy rabbit *(Brachylagus idahoensis)* (adapted from Dobler and Dixon 1990, Green and Flinders 1980a).

Pygmy rabbits are less mobile than larger leporids and are associated with dense shrub cover, thought to facilitate predator avoidance (Gabler et al. 2001). Weasels *(Mustela* spp.*)* readily enter burrows and traps containing pygmy rabbits (Wilde 1978), and are their principal predator (Green and Flinders 1980a). Extreme habitat specialization in combination with relatively large litter sizes and periodic dramatic declines in abundance suggest that mortality may be high in most pygmy rabbit populations (Weiss and Verts 1984). Dispersing juvenile rabbits, attempting to locate suitable home ranges, may be particularly vulnerable to predators (Wilde 1978).

In addition to its association with big sagebrush, this leporid has demonstrated an association with specific soil characteristics. Pygmy rabbits excavate their own burrow systems (Green and Flinders 1980a, Weiss and Verts 1984, Verts and Carraway 1998, Simons and Laundre 2004), a behavior exhibited by only one other native North American leporid, the volcano rabbit *(Romerolagus diazi)* of Mexico (Fa and Bell 1990). Weiss (1984) found the species to inhabit areas in Oregon where soils were significantly deeper ($\bar{x}$ = 51.0 cm, SE = 2.3, $P < 0.05$) and more friable than unoccupied adjacent sites ($\bar{x}$ = 31.0 cm, SE = 3.1). Soil depth and soil strength, more than soil texture, were physical properties that distinguished sites occupied by pygmy rabbits from unoccupied sites and likely were related to ease in excavating burrows. Wilde (1978) reported burrows having several entrances (most commonly two), a simple structure, and apparently no chambers. Slope and valley floor locations were preferred over plateaus and flats. Unique soil characteristics of areas used by pygmy rabbits for burrowing, in addition to its dependency on big sagebrush communities, likely play an important role in limiting the distribution of this species (Weiss and Verts 1984).

The pygmy rabbit has a broad distribution within sagebrush communities throughout the Great Basin and Intermountain West, but current populations are scattered and disjunct. Historically, pygmy rabbits had a greater distribution than they do today (Weiss and Verts 1984, Washington Department of Fish and Wildlife 1995). Bailey (1936) characterized the species as locally abundant where habitat conditions were favorable. Additionally, gaps in their range were described as a result of their absence from open areas where big sagebrush was not abundant.

The primary cause for the reduction in their distribution is considered to be habitat loss (Gabler et al. 2000). In recent decades, the availability of big sagebrush communities across much of its historic range has been reduced directly by the conversion of sagebrush-steppe to cropland or human dwellings, and indirectly by livestock grazing and weed encroachment (Gabler et al. 2000, Simons and Laundre 2004). Shrub cover has been reduced mechanically, chemically, by wildfires and the use of prescribed fire. Gabler et al. (2000) characterized the degradation and conversion of sagebrush communities as extensive throughout much of the basin communities of Idaho. Additionally, manipulations of sagebrush-steppe habitat that break down shrub cover and lead to loss of native grasses and forbs often lead to invasions of cheatgrass *(Bromus tectorum)* (Washington Department of Fish and Wildlife 1995). Due to their dependence on big sagebrush, populations of this species are likely vulnerable to sagebrush eradication and fragmentation (Holechek 1981, Katzner and Parker 1998), which renders habitat inadequate to support populations and may limit dispersal.

Variations in vegetative structure resulting from a natural patchy distribution of sagebrush communities, agriculture, grazing, and development practices (Heady et al. 2001) impact behavior, movements, and feeding habits of pygmy rabbits (Katzner and Parker 1997). These natural and anthropogenic factors have generated concern for the status and conservation of pygmy rabbit populations throughout most of its range. In Oregon, the pygmy rabbit is classified as *Sensitive-Vulnerable* and has been placed on the *Sensitive Animal Species List* by the Oregon Department of Fish and Wildlife (Oregon Natural Heritage Program 2001). It has also been designated as a *Federal Species of Concern* by the U.S. Fish and Wildlife Service (USFWS) and a *Special Status Species* by the Bureau of Land Management (BLM). These listings imply protective actions are needed to sustain current populations. The Columbia Basin pygmy rabbit, a distinct population segment in Washington, was listed as endangered by the USFWS in 2003 (U.S. Fish and Wildlife Service 2003). Due to its specialized habitat requirements and evidence of declining populations, the USFWS has been petitioned to list the species as threatened or endangered under the Endangered Species Act (ESA). To date, the USFWS has not considered any of the petitions to contain substantial information to justify listing under the ESA (U.S. Fish and Wildlife Service 2005). The vulnerability of pygmy rabbits in Oregon makes information regarding habitats occupied by the species of special interest to biologists and managers (Katzner and Parker 1997). Management agencies need a more thorough understanding of habitat associations, movements, home range sizes, and survival rates of this species to identify suitable habitat and prevent further loss and degradation of that habitat.

The need to understand the ecology of pygmy rabbits in eastern Oregon prompted a cooperative investigation by the BLM, the Oregon Department of Fish and Wildlife (ODFW), and the Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University. This investigation was designed to address three principal objectives: 1) estimate annual and monthly survival rates; 2) document the daily movements and estimate annual and seasonal home range and core-use areas; and 3) describe the habitat associations of pygmy rabbits, as they relate to terrestrial movements and the use of burrows. Results generated from this research provided information to guide management decisions related to pygmy rabbit conservation in sagebrush-steppe communities.

CHAPTER 2

STUDY AREA DESCRIPTION AND SITE SELECTION

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STUDY AREA DESCRIPTION

The Great Basin of southeastern Oregon is part of the Basin and Range and Owyhee Upland physiographic provinces (Anderson et al. 1998). The Bureau of Land Management (BLM) manages the majority of land (66%) in the region, while 29% is in private ownership. Agricultural crops and grazing of domestic livestock are the prominent activities on private lands, while grazing of domestic livestock is the dominant use on BLM-administered lands (Maser and Thomas 1983).

Study sites for this project were chosen from Sheldon National Wildlife Refuge (NWR) located in northwestern Nevada and the Beatys Butte Allotment (BLM) located in southeastern Oregon. Sheldon NWR is administered by the U.S. Fish and Wildlife Service (USFWS) and encompasses 232,294 ha. The Beatys Butte Allotment is administered by the BLM and consists of 220,301 ha. These areas are characteristic of shrub-steppe communities (West 1983) and consist of flat sagebrush plains interrupted by rolling hills, ridges, and draws. Elevations range from 1,200 – 2,400 m in each area. Annual precipitation and temperature averages 28 cm and 21^{o} C, respectively (Gregg 2006).

Both Sheldon NWR and the Beatys Butte Allotment support native species of mammals and birds such as pronghorn *(Antilocapra americana)*, mule deer *(Odocoileus hemionus)*, bighorn sheep *(Ovis canadensis)*, sage grouse *(Centrocercus urophasianus)*, pygmy rabbits *(Brachylagus idahoensis)*, waterfowl, songbirds and many small rodent species. Primary shrub species include Wyoming big sagebrush *(Artemisia tridentata ssp. wyomingensis)*, basin big sagebrush *(A. t. ssp. tridentata)*, mountain big sagebrush *(A. t. ssp. vaseyana)*, low sagebrush *(A. arbuscula)*, green rabbitbrush *(Chrysothamnus viscidiflora)*, grey rabbitbrush *(Ericameria nauseosa)* and bitterbrush *(Purshia tridentata)*. Stands of western juniper

(Juniper occidentalis), curl-leaf mountain mahogany *(Cercocarpus ledifolius)*, and aspen *(Populus tremuloides)* are found on both areas, but are more prevalent on Sheldon NWR. Grasses consist largely of bluegrass *(Poa* spp.*)*, bluebunch wheatgrass *(Pseudoroegneria spicata)*, needlegrass *(Stipa* spp.*)*, Idaho fescue *(Festuca idahoensis)*, giant wildrye *(Elymus cinereus)*, and bottlebrush squirreltail *(Elymus elymoides)*. Common perennial forbes include mountain-dandelion *(Agoseris* spp.*)*, milk-vetch *(Astragalus* spp.*)*, hawksbeard *(Crepis* spp.*)*, buckwheat *(Eriogonum* spp.*)*, lupine *(Lupinus* spp.*)*, and phlox *(Phlox* spp.*)* (Gregg 2006).

Domestic livestock grazing on Sheldon NWR averaged 16,317 animal unit months (AUMs) annually from 1980-1989 and was reduced to 1,564 AUMs annually from 1990-1993. Domestic livestock grazing was eliminated from the refuge in 1994 (Gregg 2006). Since 1994, prescribed fire has been the primary management tool used to manage refuge habitats. However, less than 6% of the refuge has been burned by wild or prescribed fires since the early 1980’s (Gregg 2006). Although livestock grazing was eliminated from the Refuge in 1994, an estimated population of 1,600 non-native horses and burros directly and indirectly impact wildlife and their habitats by consuming forage, trampling vegetation, and compacting soils (U.S. Fish and Wildlife Service 2007b). The herd’s annual growth rate ranges from 17–23%. The USFWS has instituted horse and burro roundups and adoptions in response to concerns that additional population growth will increase animal/human health and safety problems and continue to damage sensitive refuge habitats (U.S. Fish and Wildlife Service 2007a).

The Beatys Butte Allotment is bordered by Sheldon NWR to the south and Hart Mountain NWR to the northwest. Domestic livestock grazing is divided into two pastures that averaged 26,121 AUMs from 1983-1989 and 14,000 AUMs since 1989

(Gregg 2006). Each pasture is grazed during alternate years. Periodic wildfires have been part of the natural disturbance regime of shrub-steppe communities on Beatys Butte. Further, the Lakeview District BLM initiates prescribed burns as a management tool to reduce the accumulation of combustible material and alter habitat. In the north pasture, approximately 6,000 hectares were prescribed burned during 1999, and a wildfire burned an additional 14,400 hectares during 2000 (T. Forbes, BLM, personal communication). No fires occurred on the Beatys Butte Allotment during this study.

SITE SELECTIONS

Wildlife biologists with the BLM conducted aerial and walking surveys for pygmy rabbits and suitable sagebrush habitat throughout much of southeastern Oregon prior to the spring of 2005. Based on survey information and reconnaissance visits, I selected four study sites in southeastern Oregon and northwestern Nevada for detailed investigation (Figure 2.1). Locations with the greatest observed abundance of pygmy rabbits were chosen to maximize the likelihood of obtaining the desired sample size of 30 radio-marked rabbits per study site.

Of the four study sites chosen for this investigation, three were located on the Beatys Butte Allotment (BLM) in Oregon, and the fourth was on Sheldon NWR in Nevada. Grazing history, elevation, topographic position, and dominant and subdominant shrub species located on each of the four study sites are described in Table 2.1. Domestic livestock were grazed on parcels within the Beatys Butte Allotment as part of a two-year grazing rotation management plan. However, the Spaulding site was grazed every year because it was used for cattle gathering in the fall (L. Boothe and T. Forbes, BLM, personal communication).

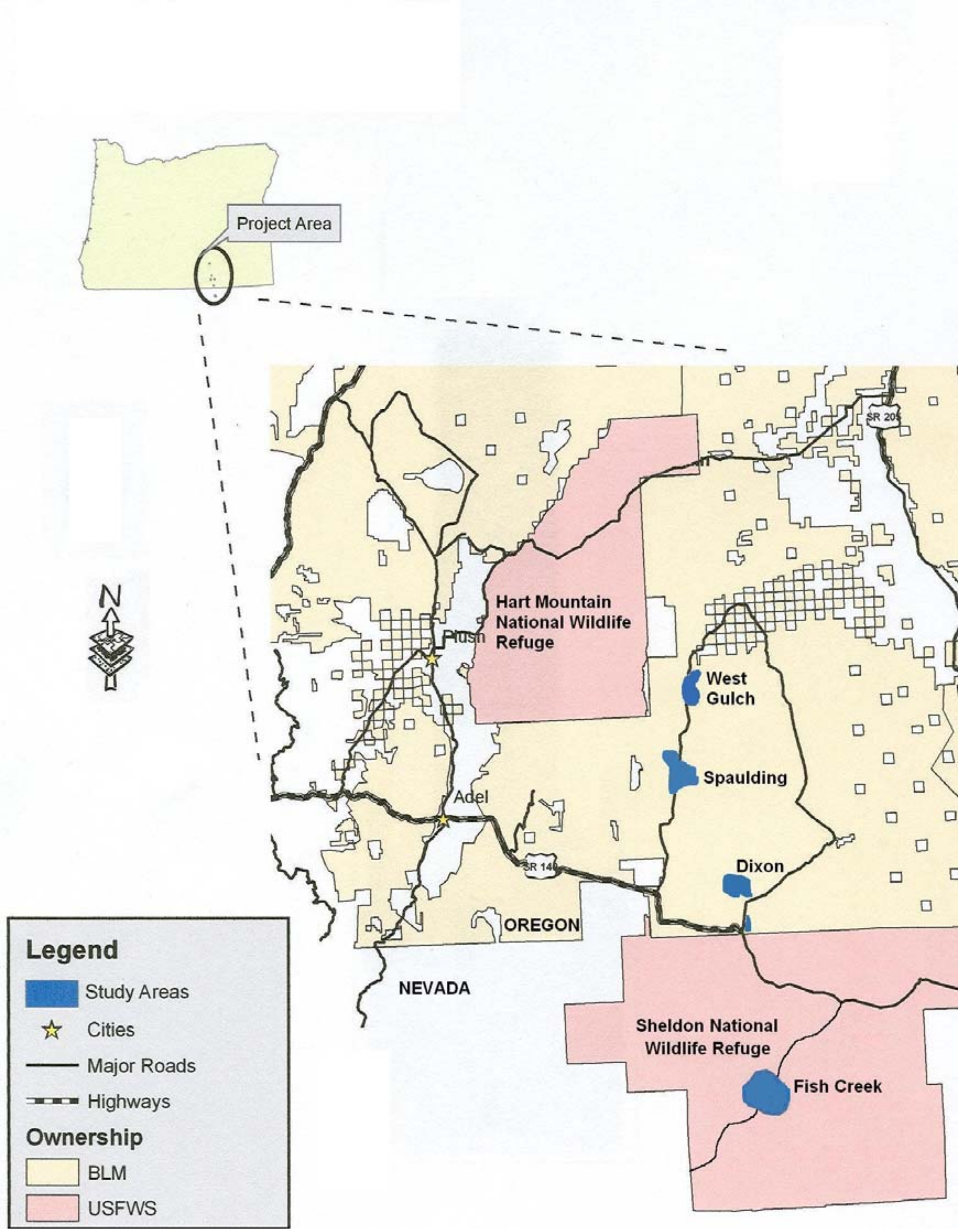

Figure 2.1. Four study sites chosen to investigate survival, movements, and habitat selection of pygmy rabbits in southeastern Oregon and northwestern Nevada from June 2005 – June 2007.

Table 2.1. Years livestock were present and grazed, elevation, topographic position, and dominant and subdominant shrub species on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – June 2007.

Study site	Livestock grazing year	Elevation (m)	Topographic position	Dominant shrub species	Subdominant shrub species
Dixon	2006	1780	bottom-land	Wyoming big sagebrush	low sagebrush and green rabbitbrush
Spaulding	2005 & 2006	1600	bottom-land and side-slope	Wyoming big sagebrush and basin big sagebrush	green rabbitbrush
West Gulch	2005	1650 – 1700	bottom-land and terrace	Wyoming big sagebrush and basin big sagebrush	green rabbitbrush
Fish Creek	N.A.	1860	bottom-land and side-slope	Wyoming big sagebrush and basin big sagebrush	bitterbrush and green rabbitbrush

CHAPTER 3

SURVIVAL AND CAUSES OF MORTALITY OF PYGMY RABBITS IN SOUTHEASTERN OREGON AND NORTHWESTERN NEVADA

Justin A. Crawford

INTRODUCTION

The pygmy rabbit *(Brachylagus idahoensis)*, the smallest member of the leporid family in North America, is endemic to sagebrush-steppe habitats within the Great Basin and adjacent intermountain areas of the western United States (Green and Flinders 1980a, Katzner and Parker 1998). The distribution of this species is disjunct within a geographic range that reaches its westernmost extent in Oregon (Hall 1981). However, the current range is thought to have shrunk substantially from historical distributions (Verts and Carraway 1998). This leporid is typically associated with dense, clumped stands of big sagebrush *(Artemisia tridentata* spp.*)* (Orr 1940, Green and Flinders 1980b, Weiss 1984, Katzner 1994) where soils usually are deep and friable (Orr 1940, Janson 1946, Green and Flinders 1980b, Campbell et al. 1982, Weiss 1984, Himes and Drohan 2007) and is considered a sagebrush obligate (Heady et al. 2001). Type and availability of required habitats are considered critical determinants of size, survival, and stability in populations of these rabbits (Katzner and Parker 1997). Pygmy rabbit abundances are believed to be declining throughout most of its range (Dobler and Dixon 1990).

Compared to larger leporids, pygmy rabbits are less mobile and may effectively elude predators when under a shrub canopy (Weiss 1984, Gabler et al. 2001). Dense shrub habitats reduce vulnerability to predation for relatively slow moving mammals whose abilities to evade predation in open areas are limited (Hallett 1982). This species utilizes tall, dense stands of big sagebrush that provide cover and facilitate avoidance of terrestrial and avian predators. During winter periods, pygmy rabbits use subnivean environments in dense shrub communities, created by the accumulation of drifting snow, which provides access to a relatively dependable food source and protection from most predators and temperature extremes (Weiss and Verts 1984, Katzner and Parker 1997).

Few studies have investigated annual or monthly survival of pygmy rabbit populations (Wilde 1978, Westra 2004, Sanchez 2007). Wilde (1978) estimated survival rates in southern Idaho from recapture data at two week intervals using a standard life table. Adult survival was lowest during the breeding seasons of January – March 1976, and January – August 1977. The lowest estimated two-week survival interval was 0.69 on 1 March 1976, and annual adult survival was 0.12 for males and females. The annual survival of captive-reared pygmy rabbits released at different time periods in Idaho was 0.32, which did not differ significantly between sexes (Westra 2004). Other investigations of leporid survival rates suggest 60-90% of the individuals die each year (French et al. 1965, Meslow and Keith 1968, Wagner and Stoddart 1972, Rose 1977, Gibb 1990, Bond et al. 2001), but these studies used different estimation methods, which makes comparisons difficult. Unlike pygmy rabbits (Green and Flinders 1980a), many leporid species undergo population cycles that influence estimates of annual survival.

Weasels *(Mustela* spp.*)* readily enter burrows and traps containing pygmy rabbits (Wilde 1978) and are their principal predator (Green and Flinders 1980a). Other carnivores and raptors known to prey on pygmy rabbits are bobcats *(Lynx rufus)*, coyotes *(Canis latrans)*, red foxes *(Vulpes vulpes)*, badgers *(Taxidea taxus)*, northern harriers *(Circus cyaneus)*, and owls *(Bubo* spp.*)* (Verts and Carraway 1998). Extreme habitat specialization, in combination with relatively large litter sizes and periodic dramatic declines in abundance, suggest that mortality may be high in most pygmy rabbit populations (Weiss and Verts 1984). Dispersing juvenile rabbits, attempting to locate suitable home ranges, are thought to be particularly vulnerable to predators (Wilde 1978).

Prior to estimating survival rates for pygmy rabbits, I considered the following relationships to potentially explain observed survival estimates. I hypothesized that survival rates would differ between sexes with male rabbits having a greater risk of predation due to their increased activity levels. Second, I hypothesized that survival rates would vary among monthly time intervals, being lowest during winter and spring periods when rabbits were potentially more likely to encounter predators. The study sites differed in grazing management, dominant vegetation, and elevation; therefore, I expected that survival rates would differ among study sites. I also hypothesized that survival rates would be influenced by weight and/or total length at time of capture. In this chapter, I report estimates of monthly and annual survival rates for pygmy rabbits and causes of mortality.

METHODS

Capture and Handling

Individual pygmy rabbits were live-trapped on four study sites from June to September 2005 to maximize the number of rabbits sampled post juvenile emergence. During early summer, trapping was conducted during morning hours (04:00 – 10:00) to minimize the risk of separating juveniles from nursing females. During late summer, after juveniles were weaned, trapping was conducted overnight (19:00 – 10:00) to maximize trapping effort. Collapsible traps (Tomahawk Live Trap Co., Tomahawk, WI, USA) with double doors (#203, 60 x 23 x 23 cm) or single doors (#201, 40 x 12 x 12 cm) were set in areas that exhibited rabbit activity, including burrow entrances and runways. Active areas were identified by fresh fecal pellets, diggings, and open burrow entrances. Traps were covered with brown burlap bags or white plastic feed sacks to provide protection from thermal stress and predators, and camouflaged with vegetation. Initially, 120 radio transmitters were evenly distributed among the four study sites to ensure a sufficient sample size. During Fall 2005, I observed substantial rabbit mortality due to predation; consequently, a concentrated effort to opportunistically trap new individuals was made to maintain a minimal number (15–20) of radio-marked rabbits on each study site from November 2005 – April 2007.

Captured rabbits were transferred from traps into a cloth bag to minimize stress during handling. A drawstring opening on one end of the bag allowed me to access the rabbits and reduce the likelihood of escape. Captured animals were marked with a uniquely numbered Passive Integrated Transponder (PIT) tag. VHF radio transmitters (164 and 165 MHz band, Model RI-2DM (7.1 g and 10.6 g), Holohil Systems Ltd., Carp, Ontario, Canada) were attached to all adult rabbits and juveniles weighing > 250 g. Transmitters were attached to each individual on a zip-tie encased in flexible rubber tubing (2.0 g) to minimize abrasion. Each transmitter was equipped with a motion sensitive switch that doubled the transmitters' pulse rate when inactive for twelve hours. Sex and age were recorded for each captured individual; age classifications (adult or juvenile) were based on the individuals' weight and relative coat condition. Reproductive condition, when discernable, was noted; males were classified as sexually active when testes were descended, and females were considered sexually active when lactating (when hair was matted around nipples or milk was observed) or had a perforate vagina. Weight, body length, right ear and right hind foot length were recorded for all individuals captured. Morphological measurements of male and female rabbits were summarized and tested for differences using two-sample t-tests (Ramsey and Schafer 2002). Additionally, an analysis of variance procedure (Ramsey and Schafer 2002) was used to examine monthly differences in mass/length ratios, an index of physical condition (Bailey 1968, Jakob et al. 1996). I used S-plus 7.0 (Insightful Corporation, Seattle, WA, USA) for all statistical analyses and differences were considered significant at the α level of 0.05. Finally, the condition of pelage and types and amount of ectoparasites were recorded.

Telemetry Monitoring

Locations and fate of radio-marked rabbits were monitored from June 2005 – April 2007 to estimate monthly and annual survival rates. Individuals were located four to five times per week using a hand-held receiver (Model R2000 receiver, Advanced Telemetry Systems, Isanti, MN, and Model TR-2 receiver, Telonics Inc., Mesa, AZ, USA) and a directional yagi antenna. Monitoring times of radio-marked rabbits varied to accumulate locations during crepuscular, mid-day, and occasionally night hours, which provided a more thorough representation of each individual's daily movements and avoided autocorrelation (Swihart and Slade 1985a;1985b, Otis and White 1999). When time permitted, individuals were located more than once per 24 hours with a minimum of 5.0 hours between successive relocations. Radio-marked animals were tracked to within 3 m, and positive visual identifications were made. Locations were recorded using a Global Positioning System (GPS) (Garmin International, Inc., Olathe, KS, USA). I recorded time, the rabbit's location within the habitat (on the surface or in a burrow), and behavior.

Dead rabbits were examined to identify causes of mortality when possible. Raptor predation was apparent from bird fecal sprays at the kill site and the presence of feathers. Other predator-caused mortalities were determined from examination of rabbit carcasses or tracks surrounding the location. Weasels tended to inflict distinctive injuries on the animal such as unique bite marks on the rabbit's neck or decapitation. Coyote kills were identified by presence of tracks near the carcass as well as scat and regurgitation.

Survival Analysis

Survival rates *(S)* were estimated for radio-marked individuals from September 1, 2005 – August 31, 2006 with known fate models in program MARK (White and Burnham 1999). This procedure allowed staggered entry and censoring of individuals that left the study area or could not be found. Pygmy rabbits were entered into the data set during the first complete month they were monitored, not the month they were captured, unless capture occurred during the first week of the month (Appendix A). Individuals were censored if during the first or last week of the month their fate was not known. Additionally, rabbits that had transmitter failure were censored, unless they were recaptured and fitted with a new transmitter. Survival was estimated on monthly intervals with data entered as either the individual survived the month, died during the month, or was censored during the month.

Program MARK used maximum likelihood estimation to optimize model parameters and to fit models to the data (White and Burnham 1999). I used the second-order Akaike Information Criteria, corrected for small sample sizes (AIC_c) and Akaike weights in program MARK for model selection (Burnham and Anderson 2002). I considered the model with the smallest AIC_c value to be the best model to fit the data and any model within 2 AIC_c values as a competing model (Burnham and Anderson 2002). To identify any competing models, I used the difference between the AIC_c value for the best model and the *i*th model (Δ_i), and the Akaike weights were used to assess the strength of evidence of one model versus another model. Pygmy rabbits are not considered to maintain strong social associations within populations. Furthermore, since individuals were captured at different times, I had no motive to consider any dependence among individuals. There is no appropriate Goodness-of-fit test for known fate data with individual covariates (G. C. White, personal communication); therefore, I assumed that there was little to no overdispersion in the data ($\hat{c}$ = 1.0) and did not use $QAIC_c$ for model selection. Additionally, I used the regression coefficients (β) and their 95% confidence intervals as evidence or lack thereof of an effect for various factors in competing models.

To test for potential effects on survival rates, a list of *a priori* candidate models was developed based on my hypotheses (Table 3.1). The most general model hypothesized that survival rates would vary among study sites, sexes, and over monthly time intervals [model *S*(area * sex * t)]. Additional hypotheses included: survival would be constant throughout the study (.), vary by monthly interval (t), follow linear (T) or quadratic (TT) trends from May through April, vary by sex (sex) or study site (area). To test models that incorporated differences in survival between sexes or among study sites, individuals were assigned to one of 8 possible groups. Analyses that included two or more groups explored additive (+) and interactive (*) effects between group variables and time effects. Models including individual covariates (X_i) were compared to model *S*(.) to determine if there was an improvement in the fit of the models to the data. Individual covariates included adult or juvenile age, weight (kg), ear length (cm), foot length (cm), total body length (m), and mass/length ratio (kg/m) at time of capture. I used the mass/length ratio as an index to physical condition (Bailey 1968).

Table 3.1. A list of *a priori* hypothesis and models for testing the effects of various factors on survival rates of pygmy rabbits in southeastern Oregon and northwestern Nevada, September 2005 – August 2006.

Hypothesis description	Model
1. Survival rates are different between sexes	*S*(sex)
2. Survival rates are different among study sites	*S*(area)
3. Survival rates are different among monthly time intervals	*S*(t)
4. Survival rates are constant among sites, monthly time intervals, and between sexes	*S*(.)
5. Survival rates decline linearly from May through April	*S*(T)
6. Survival rates fluctuate quadratically from May through April	*S*(TT)
7. Survival rates are different among study sites with an interaction with monthly intervals	*S*(area * t)
8. Survival rates are different between sexes with an interaction with study site	*S*(sex * area)
9. Survival rates are different between sexes with an interaction with monthly intervals	(sex * t)
10. Survival rates are different among study sites in a parallel pattern with monthly intervals	*S*(area + t)
11. Survival rates are different between sexes in a parallel pattern with monthly intervals	S(sex + t)
12. Survival rates vary between sexes in a parallel pattern with study sites	*S*(sex + area)
13. Survival rates vary among study sites, monthly time intervals, and between sexes	*S*(area * sex * t)
14. Survival rates vary among study sites and between sexes in a parallel pattern with monthly intervals	*S*(area * sex + t)
15. Survival rates vary between sexes in a parallel pattern with study sites and monthly interval	*S*(area + sex + t)
16. Survival rates vary by morphometric covariate(s)	$S(X_i)$[a]
17. Survival rates vary by adults and juveniles (covariate)	*S*(age)

[a] X_i represents the potential effects of weight (kg), right ear length (cm), right foot length (cm), total body length (m), and/or mass/length ratio (kg/m) at time of capture.

RESULTS

Trapping Success

I successfully radio-marked 121 pygmy rabbits from June – September 2005; 90 were evenly distributed among the Dixon, Spaulding, and West Gulch study sites, and 31 were marked on the Fish Creek site. Trapping effort needed to mark 30 rabbits was relatively consistent on 3 study sites: Fish Creek (15 trap days), Spaulding (16 trap days), and West Gulch (22 trap days). Trapping success on the Dixon site was considerably less, as it took 33 trap days to capture 30 collarable rabbits despite our efforts to vary trapping activities. However, trapping efficiency may have been influenced by timing of juvenile emergence and size of area trapped. Other species trapped included mountain cottontail rabbits *(Sylvilagus nuttalii)*, black-tailed jackrabbits *(Lepus californicus)*, Townsend ground squirrels *(Spermophilus townsendi)*, dark kangaroo mouse *(Microdipodops megacephalus)*, and long-tailed weasel *(Mustela frenata)*.

In early November 2005, I began to trap opportunistically to offset the substantial loss of radio-marked animals due to predation. From June 2005 – April 2007, I successfully trapped 337 individuals and radio-marked 298 rabbits (132 male, 166 female; Table 3.2). Trapping effort was substantially more effective during winter months, November – March, because I was able to locate active burrow use during periods of fresh snow and trap those individuals. I was able to confirm mortality of 265 (89%) of the 298 rabbits that were radio-marked.

Table 3.2. Pygmy rabbits captured, radio-marked, and confirmed mortalities during monitoring research on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

	Dixon	Fish Creek	Spaulding	West Gulch	Total
Total individual rabbits trapped	92	82	93	70	337
Total trapped and handled	151	120	112	87	470
Total rabbits radio-marked	83	74	80	61	298
Adult male	29	20	22	14	85
Adult female	26	16	34	25	101
Juvenile male	15	12	11	9	47
Juvenile female	13	26	13	13	65
Confirmed mortalities	77	67	72	49	265

Morphometrics

Adult males (n = 85) and females (n = 101) differed in total body length and weight (Table 3.3). Total body length (t = 2.52, df = 184, P = 0.0126) and weight of females (t = 5.69, df = 184, P < 0.0001) were significantly higher than those of males. Mean body weight of females was 39.3 g (95% CI: 25.7 – 52.9 g) more than that of males. On average, adult female pygmy rabbits were 7.0 mm (95% CI: 1.5 – 12.5 mm) longer than adult males. Mass/length index of physical condition of females was significantly (t = 3.97, df = 184, P = 0.0001) greater than that of males. The mean mass/length ratio of adult females was 0.115 g/mm (95% CI: 0.058 – 0.172 g/mm) higher than adult males. Additionally, there was no evidence of variation in the index of physical condition among months ($F_{11,211}$ = 1.05, P = 0.4080; Figure 3.1) as these data were quite variable. Nevertheless, monthly trends in mass/length ratios were prominent for both males and females, but ratios were highly variable and lacked the precision to detect differences (Figure 3.1). Mean morphological measurements of juveniles are reported but were not compared statistically because juveniles were of different ages and developmental stages, which resulted in highly variable measurements (Table 3.3).

Table 3.3. Morphology measurements ($\bar{x}$ ± SE) of adult male (n = 85), adult female (n = 101), and juvenile (n = 145) pygmy rabbits sampled on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007. Male and female averages were tested for a significant difference using a t-test. Juvenile averages were not tested. * = P <0.05.

Measurement	Adult ♂	Adult ♀	Juvenile
Body length (mm)	224.3 ± 1.9 *	231.3 ± 2.0 *	194.4 ± 2.0
Right hind foot length (mm)	67.7 ± 0.8	67.5 ± 1.1	60.4 ± 0.6
Right ear length (mm)	51.9 ± 0.6	50.5 ± 0.8	48.1 ± 0.4
Weight (g)	399.4 ± 4.3 *	438.7 ± 5.2 *	286.4 ± 5.6
Mass/Length Ratio (g/mm)	1.787 ± 0.020 *	1.901 ± 0.020 *	1.419 ± 0.027

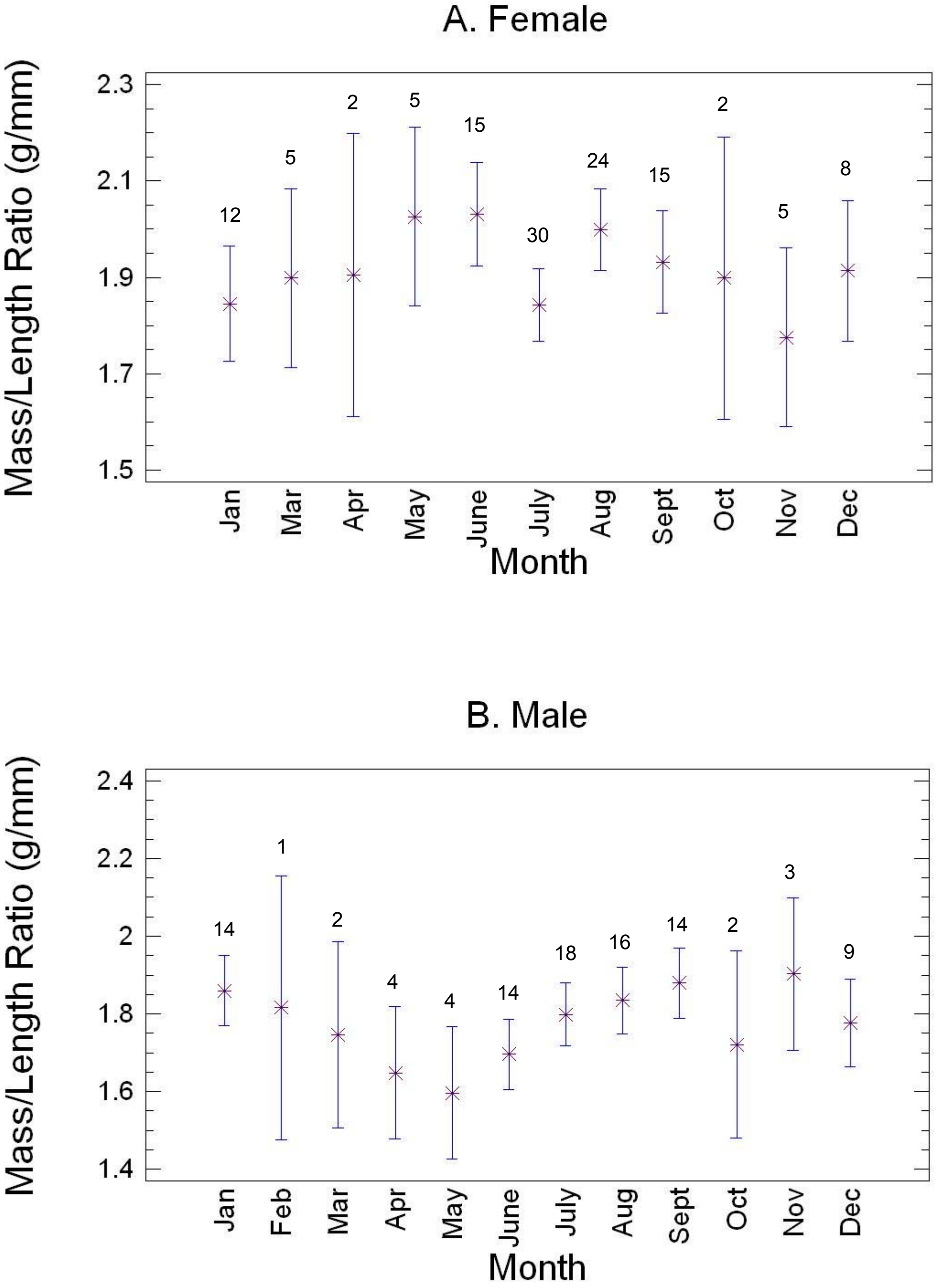

Figure 3.1. Mass/length ratios of adult (A) female (*n* = 123) and (B) male (*n* = 101) pygmy rabbits at monthly intervals. Error bars represent 95% confidence intervals around means (x). Individuals were sampled on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007. No adult females were captured during February. Numbers of pygmy rabbits sampled each month are listed above confidence intervals.

Survival

Annual and monthly survival rates were estimated from September 1, 2005 – August 31, 2006 because this period included the most radio-marked rabbits (*n* = 241; 110 males, 131 females). During this twelve month interval, 169 rabbits died due to predation. I censored seven rabbits from the dataset because they disappeared from the study area or their transmitters failed during the study. Therefore, the survival estimates were minimally biased due to right censoring when the censoring may have been associated jointly with transmitter failure and mortality (Murray 2006).

The top model for the data, based on $AIC_{c,}$ indicated that survival rates varied between sexes in a parallel pattern with study site and monthly time interval [*S*(area + sex + t)] (Table 3.4). This model accounted for 52% of the AIC_c weight of all models considered and was ~1.8 times more likely than the one competing but very similar model [*S*(area * sex + t)], which accounted for 28% of the AIC_c weight. The competing model, *S*(area * sex + t), suggested survival rates varied among study sites, sexes, and with monthly intervals in a parallel pattern and had a ΔAIC_c value of 1.24. I considered model *S*(area * sex + t) to be the best model for my data because it had a lower deviance (766.97) and fit the data better. Further, the area * sex interaction in model *S*(area * sex + t) does not constrain survival among sites and sexes to be parallel; rather, it is more biologically appropriate because it allows survival among sites and sexes to vary independently as was the case in my study.

Based on this analysis, there was no evidence that survival rates varied solely among monthly time intervals, among study sites, or only between sexes, as models *S*(t), *S*(area), and *S*(sex) had ΔAIC_c values > 8.0 (Table 3.4). Model *S*(age) had a ΔAIC_c value of 79.5, indicating no support for differences in survival rates between adults and juveniles. There also was no evidence for a linear or quadratic time trend in survival estimates from May through April, as both models *S*(T) and *S*(TT) had a ΔAIC_c values > 73.0. Finally, there was no evidence for an effect of individual covariates on survival rates; all models with individual covariates (weight, ear length, foot length, total body length, or mass/length ratio) had ΔAIC_c values > 79.0 and did not improve the fit to the data compared to *S*(.).

Table 3.4. Model selection results for estimation of survival rates of pygmy rabbits (*n* = 241) on four study sites in southeastern Oregon and northwestern Nevada from September 2005 – August 2006.

Model[a]	AIC_c	ΔAIC_c	AIC Weight	Model Likelihood	K[b]	Deviance
{S(area + sex + t)}	804.56	0.00	0.52	1.00	16	771.96
{S(area * sex + t)}	805.80	1.24	0.28	0.54	19	766.97
{S(area + t)}	806.76	2.20	0.17	0.33	15	776.23
{S(sex + t)}	811.31	6.75	0.02	0.03	13	784.91
{S(area * t)}	811.72	7.16	0.01	0.03	48	710.36
{S(t)}	814.56	10.00	0.00	0.01	12	790.22
{S(sex * t)}	826.68	22.12	0.00	0.00	24	777.35
{S(area * sex * t)}	864.72	60.17	0.00	0.00	96	650.31
{S(area + sex)}	877.41	72.85	0.00	0.00	5	867.34
{S(TT)}	878.25	73.69	0.00	0.00	3	872.22
{S(area)}	878.83	74.27	0.00	0.00	4	870.79
{S(sex * area)}	879.82	75.26	0.00	0.00	8	863.66
{S(sex)}	880.63	76.07	0.00	0.00	2	876.62
{S(.)}	882.83	78.27	0.00	0.00	1	880.82
{S(Total Length)}	883.80	79.24	0.00	0.00	2	879.78
{S(Ear Length)}	883.85	79.29	0.00	0.00	2	879.83
{S(Weight)}	884.01	79.45	0.00	0.00	2	879.99
{S(Age)}	884.10	79.54	0.00	0.00	2	880.09
{S(T)}	884.39	79.83	0.00	0.00	2	880.38
{S(Foot Length)}	884.51	79.95	0.00	0.00	2	880.50
{S(Mass Length Ratio)}	884.65	80.09	0.00	0.00	2	880.64

[a] Variable definitions: Time effects modeled as constant (.), variable time effects (t), linear time trends (T), and quadratic time trends (TT), study site (area), and sex (sex).
[b] Number of parameters

Based on model *S*(area * sex + t), annual survival rates from September 2005 – August 2006 varied from 0.003 (SE = 0.003, 95% CI: 0.0003 – 0.023) for males at Dixon to 0.173 (SE = 0.066, 95% CI: 0.078 – 0.342) for females at Spaulding (Table 3.5). Female rabbits had greater annual and monthly survival estimates than males on all study sites except Fish Creek (Table 3.5). There was evidence of a significant difference between sexes ($\hat{\beta}$ = 0.746, SE = 0.043, 95% CI: 0.663 – 0.829) based on model *S*(sex). The extremely low survival rates for males at Dixon and higher rates for females at Spaulding and West Gulch appeared to be responsible for the significance and inclusion of the sex parameter in the best model. In addition, male and female survival rates for Spaulding and West Gulch sites were higher than those for Dixon and Fish Creek (Figure 3.2). Monthly survival rates varied from 0.328 (SE = 0.085, 95% CI: 0.186 – 0.509) for males on Dixon in May 2006 to 0.988 (SE = 0.012, 95% CI: 0.916 – 0.998) for females on Spaulding in June 2006. Survival rates of male and female pygmy rabbits were low during November 2005 – January 2006 and April – May 2006, which supported my original hypotheses.

Table 3.5. Survival rates, standard errors, and 95% confidence intervals from model *S*(area * sex + t) for pygmy rabbits on four study sites in southeastern Oregon and northwestern Nevada from September 2005 – August 2006.

Group		Annual survival Estimate	Standard error	95% Confidence interval Lower	Upper
Dixon	♂	0.0027	0.003	0.000	0.023
	♀	0.0666	0.040	0.020	0.202
Fish Creek	♂	0.0564	0.037	0.015	0.190
	♀	0.0402	0.026	0.011	0.138
Spaulding	♂	0.0834	0.046	0.027	0.229
	♀	0.1734	0.066	0.078	0.342
West Gulch	♂	0.0998	0.064	0.027	0.309
	♀	0.1518	0.059	0.068	0.304

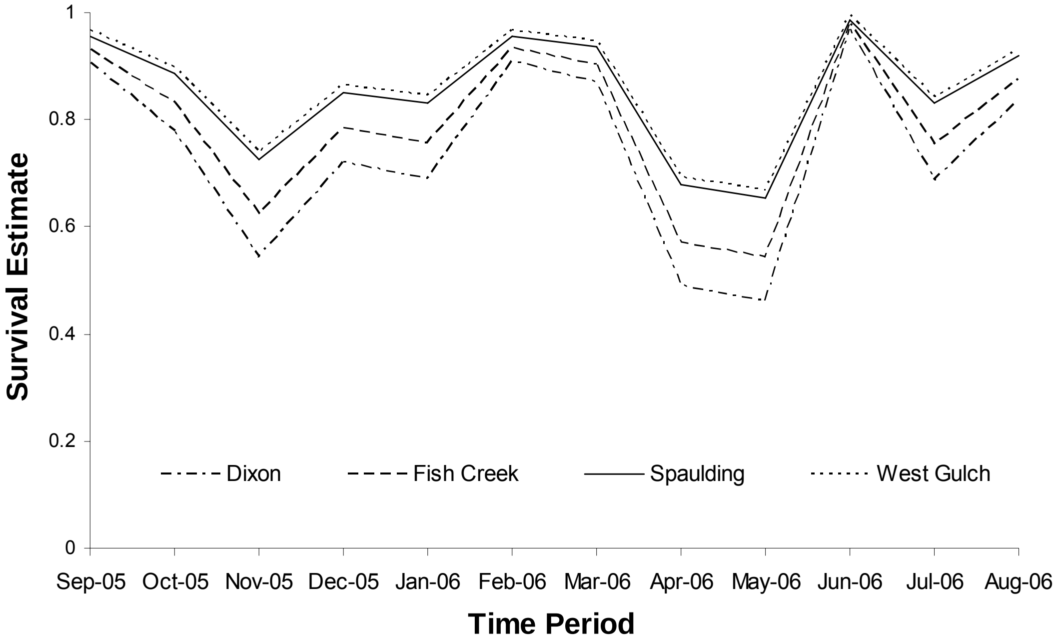

Figure 3.2. Monthly survival rates of pygmy rabbits from model *S*(area + t) on four study sites in southeastern Oregon and northwestern Nevada from September 2005 – August 2006.

Predation

Pygmy rabbits were subject to high levels of mortality due to predation during this study, as 265 of 298 (88.9%) radio-marked individuals were killed by predators. I was able to positively identify predators for 133 of the 265 (50.2%) mortalities (Table 3.6). I lost contact with 7 radio-marked rabbits during the survival analysis time period, September 2005 – August 2006, and an additional 21 individuals from September 2006 – April 2007. The unknown fate of these missing animals was a result of them leaving the study area or transmitter failure, either mechanical or predator caused. Coyotes *(Canis latrans)* and various raptors were the most common confirmed predators of radio-marked pygmy rabbits (Table 3.6). Northern harriers *(Circus cyaneus)*, golden eagles *(Aquila chrysaetos)*, and owls *(Bubo* spp.*)* were observed on the study sites and likely killed pygmy rabbits; however direct predation by these raptors was not documented. Other common predators included weasels *(Mustela* spp.*)* and badgers *(Taxidea taxus)*, and a bobcat *(Lynx rufus)* killed one rabbit.

Table 3.6. Number and proportion of the 265 radio-marked pygmy rabbits killed by various predators on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

Predator	Rabbits killed	Percentage of total rabbits killed (%)
Coyote	52	19.6
Avian	49	18.5
Weasels	26	9.8
Badger	6	2.3
Bobcat	1	0.4
Unknown	132	49.8

A comparison of the proportion of marked rabbits killed monthly by predators reveals three noteworthy patterns (Figure 3.3). Coyotes appear to be a relatively consistent predator of pygmy rabbits throughout the year. In contrast, the proportion of rabbits killed by weasels was greatest during the late fall and winter, October – January. Finally, the relative number of rabbits killed by avian predators was variable throughout the year but highest in May.

Different predators were responsible for two periods of low survival (Figure 3.2) on the four study sites (Figure 3.3). From November 2005 – January 2006, weasels and to a lesser extent coyotes were the most common predator of radio-marked rabbits, in addition to being the most common predator on the Dixon site during this study (Appendix B). In April and May 2006, avian predators were responsible for the majority of the mortality, in addition to being the most common predators on the Fish Creek and Spaulding sites during this study (Appendix B).

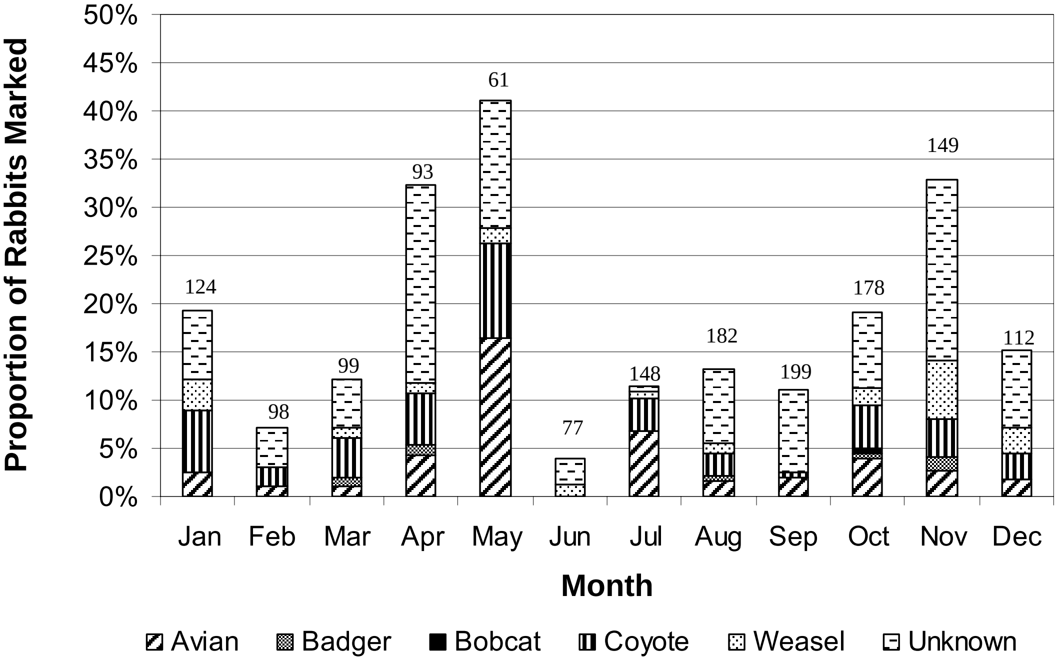

Figure 3.3. Proportion of radio-marked pygmy rabbits killed by predators by month on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007. Numbers of rabbits radio-marked each month are listed above histograms.

DISCUSSION

Morphometrics

The morphology of pygmy rabbits trapped in this study were similar to those in previous studies (Table 3.7). Generally, adult females ($\bar{x}$ = 438.7 g) were significantly heavier than adult males ($\bar{x}$ = 399.4 g) in my study. Similarly, female rabbits in Washington (Gahr 1993) and Idaho (Wilde 1978) were significantly heavier than males. An exception to this general size-sex pattern has been documented by studies in California (Orr 1940) and Wyoming (Purcell 2006) where males weighed slightly more than females. These exceptions may be due to small sample size (California: 6 adult males, 9 adult females; Wyoming: 6 males, 7 females) and not distinguishing individuals as adult or juvenile in the Wyoming study. Size-oriented sexual dimorphism is a common characteristic of leporids and has been noted previously for pygmy rabbits (Wilde 1978, Green and Flinders 1980a, Gahr 1993), *Sylvilagus* spp. (Schwartz 1942, Sowls 1957), and *Lepus* spp. (Hewson 1968, Parker 1977). Based on my results, weights are likely to be influenced by the season in which individuals are captured. I generally observed mean mass/length ratios of captured adult individuals to fluctuate throughout the year, but variation was high (Figure 3.1). Adult female rabbits had greater mass/length ratios in the late spring and summer than in winter and early spring, but many of the females captured during this time period may have been heavier because they were pregnant. Additionally, mass/length ratios of adult males were lowest during the spring and early summer, possibly due to increased activity during the breeding season. Wilde (1978) suggested that the greater size of adult females may be related to the increased demands of producing many large litters.

Table 3.7. Mean morphological measurements from previous pygmy rabbit studies compared to individuals sampled on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

Weight (g)		Total body length (mm)		Ear length (mm)		Hind foot length (mm)		State	Source
♂	♀	♂	♀	♂	♀	♂	♀		
399.4	438.7	224.3	231.3	51.9	50.5	67.7	67.5	OR/NV	*This study*
409.0	398.0	272.0	275.0	60.8	59.0	69.7	67.0	CA	(Orr 1940)
405.0	436.0	278.0	291.0	51.0	50.0	70.0	70.0	UT	(Janson 1946)
418.0	462.0	260.0	270.0	49.0	49.0	70.0	72.0	ID	(Wilde 1978)
391.0	426.0	247.0	253.0	50.0	49.0	72.0	74.0	WA	(Gahr 1993)
400.0	300.0	NA	NA	NA	NA	NA	NA	WY	(Purcell 2006)

Survival

Survival rates of radio-marked pygmy rabbits varied among study sites, sexes, and months in a parallel pattern, which generally supported my initial hypotheses. Further, survival estimates were not influenced by individual morphometric covariates.

Since rabbits were trapped throughout the year, morphometrics were variable and did not explain differences in survival rates in any of the top models. Additionally, there was no evidence of significant variation in the index of physical condition (mass/length ratio) among monthly intervals; therefore, rabbits killed by predators were not likely in poor condition and mortality was related to other factors.

There was strong evidence that survival varied among months in my study with the lowest survival occurring from November 2005 – January 2006 and April – May 2006. These two periods of low survival were likely associated with an increased likelihood of encountering predators, especially weasels during the winter and raptors in the spring. Similarly, Wilde (1978) and Sanchez (2007) documented low survival among pygmy rabbits in Idaho in late winter and early spring. Further, Wilde (1978) speculated that limited availability of food reserves and lack of new plant growth were factors restricting rabbit survival. In Idaho, mortality of pygmy rabbits peaked in the spring and may have been associated with increased foraging by both avian and terrestrial species (Sanchez 2007). Mate searching and elevated agonistic behavior during the breeding season may place additional stress on individuals (Gross et al. 1974). In this study, I found the highest survival occurring during September 2005, February and March 2006, and June through August 2006. Similarly, survival rates for pygmy rabbits in Idaho were highest (100%) in summer and early fall (Wilde 1978). At this time, grasses and forbs are prevalent food sources and stresses associated with reproduction may be limited after mid-August.

Timing of lowest survival is not consistent among leporids. Similar to pygmy rabbits, low periods of survival for *Sylvilagus floridanus* during winter have been documented (Trent and Rongstad 1974, Bond et al. 2001). However, populations of *S.*

bachmani experienced decreased survival from September to March (McKay and Verts 1978).

Annual survival of pygmy rabbits was highly variable across fine spatial scales. Differences in predator abundance, grazing management strategies, and habitat characteristics including dominant shrub species and food quality may have been responsible for variations in annual survival rates among my study sites. Additionally, my investigation was limited to the pygmy rabbit populations and did not attempt to estimate abundance of known predators. Study sites where grazing of domestic livestock was allowed had the highest (Spaulding, S = 0.173) and lowest (Dixon, S = 0.003) annual survival rates. The Spaulding site, however, received minimal pressure from livestock during the Fall 2005 and 2006 gathering events, whereas evidence of livestock grazing on the Dixon site was prominent while it was used as a common pasture from June – September 2006. Additionally, annual survival rates on Sheldon NWR, where domestic grazing was not permitted, but grazing by feral horses was sporadic, was relatively low (Fish Creek, S = 0.040 – 0.056). Similarly, Sanchez (2007) reported annual survival for pygmy rabbits in the Lemhi Valley of Idaho was greatly influenced by study site. Further investigation is needed to evaluate the effect of livestock grazing on survival of pygmy rabbits. Local populations may have their own unique characteristic dynamics that are ultimately determined by the local environment, similar to rabbit populations in Australia (Gilbert et al. 1987).

Female pygmy rabbits had considerably higher annual and monthly survival than males on three of the four study sites. Lower annual survival rates for male rabbits may be associated with a greater predation risk due to higher activity levels, particularly during the breeding season as males search for receptive females. In Idaho, Wilde (1978) and Sanchez (2007) found annual survival rates of male and female pygmy rabbits to be similar. Further, annual survival of a reintroduced pygmy rabbit population in Idaho was not statistically different between sexes (Westra 2004). In other leporids, variation in survival between sexes is not consistent. In California, *S. bachmani* had unequal survival between sexes (Connell 1954). However, penned *S. floridanus* in Wisconsin were reported to have equal survival rates between males and females (Rongstad 1966).

Pygmy rabbits in my study had a low annual survival ranging from 0.003 – 0.173 (SE: 0.003 – 0.066). These estimates are low but generally consistent with the few past survival studies of this species. Annual survival of pygmy rabbits in Idaho was reported to be 12% (Wilde 1978), which was calculated from recapture data and incorporated into a standard life table. Westra (2004) reported higher annual survival rates of 32% for pygmy rabbits reintroduced in Idaho, which may have benefited from availability of artificial burrows. Further, mean annual survival rates of pygmy rabbits in Idaho varied widely for each sex (Male S = 0.07 – 0.45; Female S = 0.09 – 0.44) (Sanchez 2007). Survival rates for *B. idahoensis* are generally below the range of estimates of annual survival for other leporids. Studies in southwestern Wisconsin, east-central Illinois, and Mississippi estimated annual survival rates of *S. floridanus* to be ~20% (Trent and Rongstad 1974, Rose 1977, Bond et al. 2001). Low estimates (S = 0.04) of annual survival were also reported for black-tailed jackrabbits *(Lepus californicus)* in southeastern Idaho (French et al. 1965). Because of the different methods used to estimate survival, comparisons of survival rates from my study to other studies were difficult.

Many other leporids undergo population cycles that influence estimates of annual survival. Although densities of populations may fluctuate dramatically among years, Green and Flinders (1980a) suggested that evidence for multiannual cycles was lacking for pygmy rabbits. A subsequent pygmy rabbit investigation on the same study sites that I researched provided an anecdotal comparison of temporal variation in species abundance. During the summer of 2007, surveys and trapping of rabbits revealed lower abundances than during my study (Tim Lawes, personal communication). Therefore, the extremely low survival rates observed in my study were likely from declining populations. Weiss and Verts (1984) observed a marked decrease in evidence of pygmy rabbit activity at 66% of their occupied sites, which were reexamined one year later. These results indicated that populations were susceptible to rapid declines and local extirpation. Although Weiss and Verts (1984) suggested such declines in abundance may be related to habitat loss and fragmentation of big sagebrush, they reported that population densities of this species may fluctuate dramatically. In Canada, similar declines in trapping efficiency were documented for cyclic populations of snowshoe hares *(Lepus americanus)* (Keith and Meslow 1968, Meslow and Keith 1968). Survival rates of snowshoe hare populations in Alberta, Canada, dropped from 22% to 13% in one year and then improved progressively over 3 years to 28%. Dramatic declines in local pygmy rabbit populations provides an impetus to investigate potential causes of multiannual fluctuations in this species.

Predation

Predators of pygmy rabbits during this investigation were coyotes, weasels, badgers, bobcats, and avian species including northern harriers and owls. These predators are similar to those from other studies of pygmy rabbits (Wilde 1978, Gahr 1993). In my study, the most common predators observed were coyotes (19.6%), raptors (18.5%), and weasels (9.8%). Conversely, weasels were identified as principal predators of this species in Idaho (Katzner 1994), and readily entered burrows and traps containing pygmy rabbits (Wilde 1978). We did not observe any rabbits being killed while trapped; however one trap, likely containing a pygmy rabbit, was carried off by a mountain lion *(Puma concolor)* and not recovered.

Different predators were responsible for two distinct periods of high predation and low survival of pygmy rabbits in my study. Weasel predation in this study was most common during winter months (November 2005 – January 2006), similar to studies in Idaho (Wilde 1978). Weasels may have been able to efficiently track rabbits by following scents left in foot tracks in the snow. Individuals located and killed by weasels may have been trapped in burrows, especially single-entrance burrows, or may have been dragged into burrows where rabbits were consumed. Based on snow tracking, weasels readily moved from burrow to burrow searching for and killing rabbits in my study. Similar weasel predation was noted on pygmy rabbits in Idaho (Wilde 1978). Avian predators were responsible for the majority of mortality of radio-marked rabbits during April and May 2006, the second distinct period of high mortality. Raptor abundances increase throughout this region during their spring and fall migrations and were responsible for high levels of pygmy rabbit mortality. Gahr (1993) reported only two instances of confirmed predation on radio-marked pygmy rabbits, both by avian predators in May and August. Coyote predation was relatively consistent throughout my study. Coyotes and badgers preyed upon some individuals by digging through and destroying pygmy rabbit burrows, which was similar to coyote predation on pygmy rabbits in Idaho (Wilde 1978).

Management Implications

Annual and monthly survival rates of pygmy rabbits in southeastern Oregon and northwestern Nevada were extremely low during my study. Survival rates varied monthly and across fine spatial scales, suggesting local populations are susceptible to rapid declines and local extirpation (Weiss and Verts 1984). Consequently, I recommend that land managers conduct repeated surveys of several populations during all seasons to account for both temporal and spatial variability and document local trends in pygmy rabbit abundances. The pygmy rabbit is designated as a *Federal Species of Concern* by the U.S. Fish and Wildlife Service and as a *Special Status Species* by the Bureau of Land Management. A more thorough understanding of factors influencing survival rates of this species may help management agencies understand population fluctuations. Future investigations should identify habitat characteristics that may influence survival of this species.

CHAPTER 4

HOME RANGE AND MOVEMENTS OF PYGMY RABBITS IN SOUTHEASTERN OREGON AND NORTHWESTERN NEVADA

Justin A. Crawford

INTRODUCTION

Pygmy rabbits *(Brachylagus idahoensis)* are small, sagebrush obligate lagomorphs (Heady et al. 2001) endemic to the Great Basin and neighboring intermountain areas of North America (Green and Flinders 1980a, Katzner and Parker 1998). Within sagebrush-steppe communities, pygmy rabbits are associated with tall, densely clumped stands of big sagebrush *(Artemisia tridentata* spp.*)* (Orr 1940, Green and Flinders 1980b, Weiss and Verts 1984, Katzner and Parker 1997) where soils usually are deep and friable (Orr 1940, Janson 1946, Green and Flinders 1980b, Campbell et al. 1982, Weiss and Verts 1984, Himes and Drohan 2007). Because of their specific habitat requirements, the distribution of this species is disjunct, and its current range is thought to have shrunk substantially from historical distributions (Verts and Carraway 1998). Pygmy rabbit abundances have declined throughout most of its range (Dobler and Dixon 1990) resulting in their designation as a *Federal Species of Concern* by the U.S. Fish and Wildlife Service (USFWS) and as a *Special Status Species* by the Bureau of Land Management (BLM). Consequently, degradation and loss of sagebrush-steppe habitat have become a concern (Dobler and Dixon 1990), and conservation efforts will benefit from an understanding of their spatial requirements and movements across the landscape.

Home range is the area traversed by an individual through its normal activities for foraging, mating, and caring for young (Burt 1943, Seaman and Powell 1996). In addition to determining the area an animal uses, home range studies indicate the type of habitats considered critical to the survival and stability of their populations (Katzner and Parker 1997). The amount of space a mammal uses during the nonbreeding season has been correlated with how easily it can meet energetic demands in a given area (McNab 1963, Reiss 1988). A large energy demand will necessitate a large area for food gathering, unless food exists in superabundance. Katzner and Parker (1997) determined that home ranges of pygmy rabbits included a more structurally diverse shrub component than adjacent unused areas; specifically, the occupied areas had a greater density and canopy cover of tall shrubs. Home range sizes of pygmy rabbits may be influenced more by the amount of vegetative cover of big sagebrush than by forage availability (Katzner and Parker 1997).

Home ranges for this species have been shown to fluctuate seasonally. During winter, pygmy rabbits in southwestern Wyoming remained localized around their burrows, with movements varying from 13 – 53 m (Katzner and Parker 1997). Previous investigations have suggested that spring and summer home range sizes were highly influenced by breeding activity and availability of food resources, and they were larger than winter home ranges (Gahr 1993, Heady et al. 2001).

Core use areas are sections used more frequently than other components of an individual's home range (Samuel et al. 1985) and are important for survival. Greater use of an area may be associated with maternal dens or a response to variation in resource availability. Core areas of concentrated use by pygmy rabbits during summer in Idaho commonly included burrow systems and dense shrub cover, which provided protection from predators (Heady 1998). Katzner and Parker (1997) found that core use areas were never >100 m from another individual's core use area, were commonly separated by <50 m, and often were visited by three or more rabbits concurrently. Movement among core areas was variable, occurring daily for some animals and only once for others (Katzner and Parker 1997). Delineating these areas of concentrated use may be particularly important to decipher how this leporid utilizes the landscape and micro-habitats.

Although previous studies have suggested pygmy rabbits have a low dispersal potential due to their small home ranges and apparent reluctance to cross open areas (Bradfield 1975, Weiss and Verts 1984), individuals have been observed traveling relatively long distances (Green and Flinders 1979, Katzner and Parker 1998). Estes-Zumpf (2008) observed median dispersal movements of 1.2 and 4.8 km and maximal dispersal movements of 6.4 and 12.1 km by juvenile male and female pygmy rabbits, respectively, in Idaho and southwestern Montana. During such movements, individuals likely used clumps of sagebrush as resting and foraging sites when crossing otherwise unsuitable areas (Katzner and Parker 1998). Documentation of this species' ability to cross unsuitable habitat may suggest that populations are not as isolated as previously described (Katzner and Parker 1998).

Due to their dependence on sagebrush communities, fragmentation and loss of this vegetation type has influenced movements of pygmy rabbits (Holechek 1981, Dobler and Dixon 1990, Katzner and Parker 1998). Habitat alterations will likely limit overall population sizes, isolate remaining populations, and reduce gene flow among populations (Gilpin 1991). In Washington, adult male pygmy rabbits occupying domestically grazed habitats with reduced shrub cover had larger home ranges than individuals in ungrazed habitats (Gahr 1993). Katzner and Parker (1997) suggested that movements between sagebrush patches may occur less frequently due to increased predation risk during travel.

I investigated home ranges and movements of pygmy rabbits between June 2005 and April 2007 using radio-telemetry. Specific objectives of this study were to: (1) compare male and female annual and seasonal home ranges, (2) delineate the core use areas of each pygmy rabbit within their annual home range, and (3) document long-distance movements and juvenile dispersals. I predicted that: (1) annual and breeding home ranges of male pygmy rabbits would be larger than those of females, (2) nonbreeding home ranges and core use areas of males and females would not differ significantly, and (3) annual and breeding home ranges would be larger than those during the nonbreeding season for both sexes.

METHODS

Capture and Handling

Individual pygmy rabbits were live-trapped on four study sites from June – September 2005 to maximize the number (~30) of rabbits sampled post juvenile emergence. During early summer, trapping was conducted during morning hours (04:00 – 10:00) to minimize the risk of separating nursing females from juveniles. During late summer, after juveniles were weaned, trapping was conducted overnight (19:00 – 10:00) to maximize trapping success. Collapsible traps (Tomahawk Live Trap Co., Tomahawk, WI, USA) with double doors (#203, 60 x 23 x 23 cm) or single doors (#201, 40 x 12 x 12 cm) were set in areas that exhibited rabbit activity, including burrow entrances and runways. Active areas were identified by fresh fecal pellets, diggings, and open burrow entrances. Traps were covered with brown burlap bags or white plastic feed sacks and camouflaged with vegetation to provide protection from thermal stress and predators. Initially, 120 radio transmitters were evenly distributed among the four study sites to ensure a sufficient sample size. During Fall 2005, I observed substantial rabbit mortality due to predation; consequently, a concentrated effort to opportunistically trap new individuals was made to maintain 15 – 20 of marked rabbits on each study site from November 2005 – April 2007.

Captured rabbits were transferred from traps into a cloth bag to minimize stress during handling. A drawstring opening on one end of the bag allowed us to access the rabbits and reduce the likelihood of escape. Captured animals were marked with a uniquely numbered Passive Integrated Transponder (PIT) tag, and VHF radio transmitters (164 and 165 MHz band, Model RI-2DM (7.1 g and 10.6 g) Holohil Systems Ltd., Carp, Ontario, Canada) were attached to all adult rabbits and juveniles weighing > 250 g. Transmitters were attached to each individual on a zip-tie encased in flexible rubber tubing (2.0 g) to minimize abrasion. Each transmitter was equipped with a motion sensitive switch that doubled the transmitters' pulse rate when inactive for twelve hours. Sex and age were recorded for each captured individual; age classifications (adult or juvenile) were based on the individuals' weight and relative coat condition. Weight, body length, right ear and right hind foot length were recorded for all individuals captured.

Telemetry Monitoring

Locations of radio-marked rabbits were recorded from June 2005 – April 2007 to allow estimation of annual and seasonal home ranges and core use areas. Individuals were located four to five times per week using a hand-held receiver (Model R2000 receiver, Advanced Telemetry Systems, Isanti, MN, and Model TR-2 receiver, Telonics Inc., Mesa, AZ, USA) and a directional yagi antenna. Monitoring times of radio-marked rabbits varied to accumulate locations during crepuscular, mid-day, and occasionally night hours, which provided a more complete representation of each individual's daily movements and avoided autocorrelation (Swihart and Slade 1985a;1985b, Otis and White 1999). When time permitted, individuals were located more than once per 24 hours with a minimum of 5.0 hours between successive relocations. Radio-marked animals were tracked to within 3 m, and positive visual identifications were made. Locations were recorded using a Global Positioning System (GPS) (Garmin International, Inc., Olathe, KS, USA). I recorded time, the rabbit's location within the habitat (on the surface or in a burrow), and behavior. Dead radio-marked rabbits were examined to identify causes of mortality when possible (see Chapter 3). Distances of long-range movements were estimated using a Geographic Information System (GIS) (Environmental Systems Research Institute, Redlands, CA, USA).

Home Range Analysis

Ninety-five percent fixed kernel estimates of home range size (Seaman and Powell 1996) were calculated in program KERNELHR using least squares cross validation (LSCV) to select the kernel bandwidth (Seaman et al. 1998, Seaman et al. 1999). Kernel methods (Worton 1989) are commonly used and are generally less biased than other methods, easier to compare, and allow for smaller sample-sizes (Gitzen et al. 2006). Additionally, fixed kernel estimates are preferred over adaptive kernels because they are less biased at outer contour levels, more reliable in accounting for peripheral locations, and provide superior surface overlap when contrasted against the true distribution (Seaman and Powell 1996, Seaman et al. 1999). Recent reviews suggest other methods used to select the kernel bandwidth (likelihood cross-validation and plug-in and solve-the-equation) may outperform LSCV. The LSCV method, however, produces estimates with better fit and less variability than alternatives with samples sizes >~50 (Horne and Garton 2006) which was common in this study. Furthermore, kernel bandwidth (smoothing factor) selected by LSCV performed better than plug-in and solve-the-equation methods when data points were clustered (Gitzen et al. 2006), which was frequently observed with pygmy rabbit locations.

Home ranges were estimated for annual, breeding (March 1st – August 14th) and nonbreeding (August 15th – February 28th) seasons using exact telemetry locations. Season dates were determined using published accounts (Orr 1940, Wilde 1978, Green and Flinders 1980a, Rachlow et al. 2005) and direct observations of breeding activity among radio-marked individuals. Seasonal home ranges were estimated for pygmy rabbits with ≥ 30 locations recorded during a season, as recommended by Seaman et al. (1999). Annual home ranges were estimated for individuals that were included in both the breeding and nonbreeding seasonal analyses. Core use areas were estimated for pygmy rabbits with sufficient data to generate an annual home range estimate. The boundaries of the core area were delineated in a subroutine of program KERNELHR named PLTCON4 that estimated the "greater than average observation density" (>AOD) contour. The >AOD therefore delimits an area of concentrated use (Seaman et al. 1997) and avoids arbitrary contour selections (e.g. 50% utilization distribution).

An analysis of variance (ANOVA) procedure with a two-factor (sex x study site) arrangement (Ramsey and Schafer 2002) was used to examine differences in annual and seasonal home range, as well as core use area size between male and female rabbits. Study sites were considered experimental blocks to account for variations in biotic and anthropomorphic factors. As part of this ANOVA procedure, backward elimination was used to remove non-significant parameters from the full model, which included interaction terms. Because home range estimates have been shown to be highly sensitive to sample size (Seaman et al. 1999), the number of observations was also considered in the fullest model to test for correlation between the area estimates and the number of observations for each individual. Further, I used a two-way ANOVA test (Ramsey and Schafer 2002) to examine differences among annual, breeding, and nonbreeding home ranges for each sex after accounting for study site. Because sample sizes were unequal, the Tukey-Kramer procedure was used to analyze differences among home ranges and core areas for each sex and among study sites. To accommodate the normal distribution assumption, a logarithmic transformation was performed to reduce the skewed distribution of home range size. I used S-plus 7.0 (Insightful Corporation, Seattle, WA, USA) for all statistical analyses, and differences were considered significant at the α level of 0.05.

RESULTS

I successfully captured and radio-marked 298 pygmy rabbits (132 male, 166 female) on four study sites between June 2005 and April 2007. More than 13,700 locations of telemetered rabbits were recorded during this study. Home ranges were estimated for 136 rabbits that had ≥ 30 locations recorded during a season; the number of locations per rabbit ranged from 30 to 222 ($\bar{x}$ = 73, SE = 3.75, n = 136). Many of the radio-marked rabbits were preyed upon early in the study (see Chapter 3), so it was not possible to collect enough locations on those individuals to estimate home range size. Further, home ranges were highly fragmented (Appendix C) and exhibited a strong associated with big sagebrush shrubs.

Home range sizes of individual pygmy rabbits varied considerably with male rabbits generally having larger home ranges than females (Table 4.1). Annual home ranges varied from 0.11 to 10.46 ha. Nonbreeding home ranges tended to be the smallest, ranging from 0.05 to 6.05 ha and often included areas close to a burrow system. Home range sizes during the breeding season were typically the largest, ranging from 0.06 to 7.49 ha and regularly included the entire nonbreeding range and additional areas.

Table 4.1. Annual, breeding, nonbreeding home ranges and core use estimates (ha, $\bar{x}$ ± SE) for male and female pygmy rabbits monitored on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

		Home Range Estimate			
		Annual	Breeding	Nonbreeding	Core Area
Male	$\bar{x}$ ± SE	1.70 ± 0.69$^{a\ d}$	1.67 ± 0.27$^{b\ e}$	0.63 ± 0.11$^{d\ e}$	0.10 ± 0.04^{c}
	Range	0.49 - 10.46	0.11 - 7.49	0.05 - 3.29	0.01 - 0.64
	n	14	33	35	14
Female	$\bar{x}$ ± SE	0.90 ± 0.26$^{a\ f}$	0.92 ± 0.16$^{b\ g}$	0.50 ± 0.09$^{f\ g}$	0.07 ± 0.03^{c}
	Range	0.11 - 7.55	0.06 - 7.10	0.08 - 6.05	0.01 - 0.81
	n	30	46	66	30
All	$\bar{x}$ ± SE	1.16 ± 0.28	1.24 ± 0.15	0.54 ± 0.07	0.08 ± 0.02
	Range	0.11 - 10.46	0.06 - 7.49	0.05 - 6.05	0.01 - 0.81
	n	44	79	101	44

Male and female area estimates were tested for significant differences using an ANOVA procedure that accounted for study site variation.

[a] Significant differences in annual home range between males and females.

[b] Significant differences in breeding home range between males and females.

[c] Significant differences in core use area between males and females.

Differences among annual and seasonal home ranges for each sex were tested using an ANOVA procedure that accounted for study site variation.

[d] Significant differences between annual and nonbreeding home ranges for males.

[e] Significant differences between breeding and nonbreeding home ranges for males.

[f] Significant differences between annual and nonbreeding home ranges for females.

[g] Significant differences between breeding and nonbreeding home ranges for females.

Differences were considered significant at $P < 0.05$.

Annual Home Ranges

Annual home ranges of male pygmy rabbits ($\bar{x}$ = 1.70 ha, SE = 0.69, range = 0.49 – 10.46 ha, n = 14) were significantly larger than females ($\bar{x}$ = 0.90 ha, SE = 0.26, range = 0.11 – 7.55 ha, n = 30; $F_{1,39}$ = 10.31, P = 0.0026; Figure 4.1). Mean annual home ranges of males were 1.88 times greater than those of females. Annual home ranges on the West Gulch study site ($\bar{x}$ = 2.13 ha, SE = 0.90, n = 13) were 1.67 ha larger than those on Fish Creek ($\bar{x}$ = 0.46 ha, SE = 0.13, n = 8; $F_{3,39}$ = 3.15, P = 0.0358; Table 4.2). The 95% simultaneous confidence intervals (Tukey-Kramer procedure) for differences among all other comparisons of annual home range size of study sites included zero, and therefore were not significantly different. There was no evidence of a correlation between annual home range size and number of locations per individual (r = 0.07, $F_{1,38}$ = 0.87, P = 0.3555); therefore, the minimum sample size of 30 locations per individual per season appeared to be sufficient for this study.

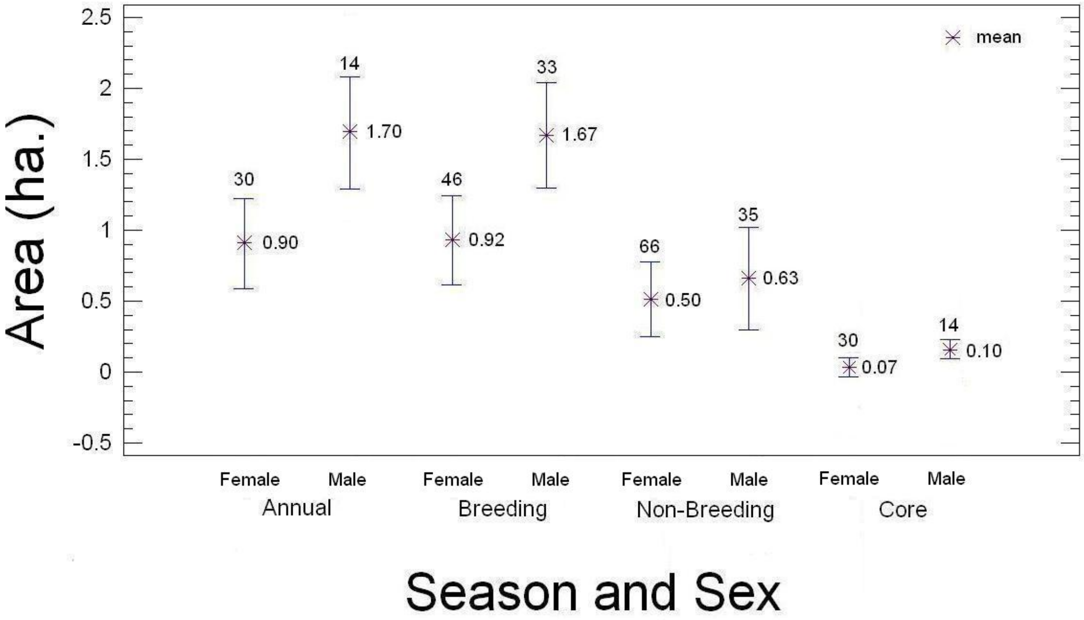

Figure 4.1. Annual, breeding, nonbreeding home ranges, and core use estimates (ha) for female and male pygmy rabbits monitored on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007. Error bars represent 95% confidence intervals around the mean ($\bar{x}$). Numbers of pygmy rabbits included in each area estimate are listed above error bars.

Table 4.2. 95% fixed kernel home ranges and core areas (ha, $\bar{x}$ ± SE) estimated for pygmy rabbits monitored on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

Study Site		Home Range Estimate			
		Annual	Breeding	Nonbreeding	Core Area
Dixon					
	$\bar{x}$ ± SE	0.98 ± 0.22	1.33 ± 0.30	0.52 ± 0.13	0.04 ± 0.01
	Range	0.48 - 2.92	0.11 - 6.14	0.09 - 2.45	0.02 - 0.07
	n	10	20	20	10
Fish Creek					
	$\bar{x}$ ± SE	0.46 ± 0.13[a]	0.78 ± 0.17[b]	0.46 ± 0.07	0.03 ± 0.02
	Range	0.11 - 1.30	0.06 - 2.53	0.05 - 1.42	0.01 - 0.15
	n	8	19	26	8
Spaulding					
	$\bar{x}$ ± SE	0.75 ± 0.09	0.93 ± 0.12	0.41 ± 0.06	0.04 ± 0.01
	Range	0.30 - 1.37	0.25 - 2.43	0.08 - 1.81	0.01 - 0.09
	n	13	20	28	13
West Gulch					
	$\bar{x}$ ± SE	2.13 ± 0.90[a]	1.87 ± 0.45[b]	0.78 ± 0.24	0.17 ± 0.07
	Range	0.21 - 10.46	0.31 - 7.49	0.13 - 6.05	0.01 - 0.81
	n	13	20	27	13

Area estimates were tested for significant differences among study sites using an ANOVA procedure (Tukey-Kramer multiple comparison procedure) that accounted for variation between sexes.

[a] Significant differences in annual home range between Fish Creek and West Gulch study sites.

[b] Significant differences in breeding home range between Fish Creek and West Gulch study sites.

Differences were considered significant at $P < 0.05$.

Breeding Season Home Ranges

Home range sizes of male pygmy rabbits during the breeding season ($\bar{x}$ = 1.67 ha, SE = 0.27, range = 0.11 – 7.49 ha, n = 33) were significantly greater than those of females ($\bar{x}$ = 0.92 ha, SE = 0.16, range = 0.06 – 7.10 ha, n = 46; $F_{1,74}$ = 12.37, P = 0.0007; Figure 4.1). Mean home range for males during the breeding season was 1.81 times larger than those of females. Additionally, home ranges during the breeding season were larger on the West Gulch study site ($\bar{x}$ = 1.87 ha, SE = 0.45, n = 20) than on Fish Creek ($\bar{x}$ = 0.78 ha, SE = 0.17, n = 19; $F_{3,74}$ = 5.23, P = 0.0024; Table 4.2). There was little evidence that differences among all other study site comparisons of home range size during the breeding season were significant, based on 95% simultaneous confidence intervals (Tukey-Kramer procedure). There was also no evidence of a correlation between home range size and number of locations per individual (r = 0.22, $F_{1,73}$ = 1.33, P = 0.2522) during the breeding season.

Nonbreeding Season Home Ranges

There was no evidence of a difference ($F_{1,96}$ = 2.45, P = 0.1212) in home ranges between male and female rabbits during the nonbreeding season (Figure 4.1). Mean home range of male pygmy rabbits during the nonbreeding season was 0.63 ha (SE = 0.11, range = 0.05 – 3.29 ha, n = 35) compared to 0.50 ha (SE = 0.09, range = 0.08 – 6.05 ha, n = 66) for females. Additionally, home ranges during the nonbreeding season were not significantly different ($F_{3,96}$ = 0.88, P = 0.4521; Table 4.2) among study sites. The sizes of these home ranges were not correlated with the number of locations per individual (r = 0.01, $F_{1,95}$ = 0.12, P = 0.7279).

Seasonal Comparisons

Significant differences were observed between the home range size during the nonbreeding season compared to both annual and breeding ranges for male ($F_{2,76}$ = 13.76, $P < 0.0001$, $n = 82$) and female ($F_{2,136}$ = 10.05, $P < 0.0001$, $n = 142$) pygmy rabbits (Table 4.1). In the breeding season, mean home ranges of males were an average of 2.65 times larger than those in the nonbreeding season. Mean annual home ranges of males were 2.70 times larger than those during the nonbreeding season. Female pygmy rabbits used 1.84 times more area during the breeding season than nonbreeding season and had annual home ranges 1.80 times larger than those during the nonbreeding season. There was no evidence of a difference between annual and breeding home ranges for either sex (Male: $F_{2,76}$ = 0.17, $P = 0.8635$; Female: $F_{2,136}$ = 0.75, $P = 0.4546$).

Core Use Areas

Core use areas were estimated for pygmy rabbits that had sufficient locations to calculate an annual home range ($n = 44$). Core use areas of males ($\bar{x}$ = 0.10 ha, SE = 0.04, range = 0.01 – 0.64 ha, $n = 14$) were significantly larger than those of females ($\bar{x}$ = 0.07 ha, SE = 0.03, range = 0.01 – 0.81 ha, $n = 30$; $F_{1,39}$ = 5.27, $P = 0.0271$; Figure 4.1). The mean core use area for male rabbits was 1.42 times larger than those of females. Further, there was minimal support of a significant difference ($F_{3,39}$ = 2.61, $P = 0.0652$; Table 4.2) among all comparisons of core use area size of study sites, based on 95% simultaneous confidence intervals (Tukey-Kramer procedure). There was no evidence of a correlation between core use area and number of locations per individual (r = 0.00, $F_{1,38}$ = 0.20, P = 0.6589). Core use areas were centered predominantly on burrow systems associated with dense clumps of big sagebrush and occasionally overlapped core areas of other individuals.

Long-distance Movements

Of the 298 pygmy rabbits radio-marked in this study, 24 individuals (16 male, 8 female) moved long distances (> 0.5 km), with a maximal observed dispersal distance of 8.5 km (Table 4.3). Although the exact routes taken by these individuals were not documented, many of these individuals apparently crossed low sagebrush *(Artemisia arbuscula* spp.*)* communities and relatively open areas. Twenty-one (88%) of these long-distance movements were classified as juvenile dispersals and occurred from June through October ($\bar{x}$ = 1.78 km, SE = 0.36, range = 0.50 – 8.50 km). The majority (71.4%) of these were by juvenile males ($\bar{x}$ = 1.42 km, SE = 0.26, n = 15), which dispersed significantly (t = 2.1323, P = 0.0462) shorter distances than females ($\bar{x}$ = 3.17 km, SE = 1.16, n = 6). However, this observed difference is likely due to the small sample size of juvenile females. Movements during this period were characteristic of juvenile individuals relocating to new areas after being reared. In February and March 2006, three adult individuals (1 male, 2 female) independently moved ≥ 0.5 km, which may have been induced by the onset of breeding.

Table 4.3. Long-distance movements (km) and date of dispersal for 24 radio-marked pygmy rabbits from June 2005 - April 2007 in southeastern Oregon and northwestern Nevada.

Animal ID#	Study Site	Sex	Age	Date	Movement distance (km)
S84	Spaulding	♀	J	14-Jun-2006	8.5
G70	West Gulch	♂	J	19-Jul-2006	4.2
G64	West Gulch	♀	J	18-Oct-2006	3.7
S22	Spaulding	♂	J	19-Jul-2005	3.0
D73	Dixon	♀	J	27-Jun-2006	2.6
F55	Fish Creek	♀	J	9-Jun-2006	2.3
D13	Dixon	♂	J	3-Oct-2005	1.9
F11	Fish Creek	♂	J	31-Oct-2005	1.7
F65	Fish Creek	♂	J	19-Jul-2006	1.5
F73	Fish Creek	♂	J	21-Jul-2006	1.5
S80	Spaulding	♂	J	16-Jun-2006	1.5
S87	Spaulding	♀	J	19-Oct-2006	1.4
S82	Spaulding	♂	J	15-Jun-2006	1.3
G16	West Gulch	♀	A	27-Feb-2006	1.1
G44	West Gulch	♂	A	8-Feb-2006	1.0
D29	Dixon	♂	J	10-Aug-2005	0.9
F14	Fish Creek	♂	J	30-Aug-2005	0.8
D85	Dixon	♂	J	20-Jul-2006	0.7
F06	Fish Creek	♂	J	25-Aug-2005	0.6
F24	Fish Creek	♂	J	7-Sep-2005	0.6
S12	Spaulding	♂	J	13-Jul-2005	0.6
D15	Dixon	♂	J	1-Aug-2005	0.5
G52	West Gulch	♀	A	16-Mar-2006	0.5
S08	Spaulding	♀	J	13-Jul-2005	0.5

A heavy precipitation event provided a unique opportunity to document this species' response to a flood. The study area received 36 hours of heavy rain and snow flurries on 27 and 28 February 2006. As a result of this precipitation, the Dixon study site was flooded under 5 – 8 cm of standing water that covered most of the area occupied by 17 radio-marked rabbits. The marked rabbits responded by using several earth-mounds that were slightly above the water line and associated with big sagebrush plants. These rabbits remained on the mounds and avoided predation over the next three days as flood waters subsided. Afterward, all radio-marked rabbits returned to their original home ranges.

DISCUSSION

I considered locations documented during this study to be independent as sufficient time had elapsed between observations for individuals to move from one end of their home range to the other (Swihart and Slade 1985a). When individuals were tracked twice a day, time between two locations was always greater than five hours. Gauging from my experience monitoring pygmy rabbits, this would allow ample time for the individual to travel to any part of its home range, independent of the previous location.

Home Range Size

Home ranges of male pygmy rabbits in my study were larger than those for females, which was consistent with my initial prediction. In this study, mean home range sizes of pygmy rabbits were generally smaller than home ranges reported elsewhere in the Great Basin. Following McNab's (1963) method of predicting approximate size of home range from basal metabolism and body size of mammals, the home range of the pygmy rabbit should be within 45 m of the burrow (0.81 ha), which was lower than the mean home range size (1.16 ha) for my study. Previous researchers suggested that pygmy rabbits rarely moved more than 30 – 50 m from their burrows (Orr 1940, Janson 1946, Bradfield 1975, Wilde 1978, Green and Flinders 1979). These estimates imply a home range of 0.30 – 0.80 ha, respectively, but were not based on radio telemetry. Temporal variation and inconsistent methodologies used to estimate these ranges made comparisons among them difficult. Variation in area estimates among these studies, as well as among study sites in my research, may also be related to geographical differences.

Male home ranges during the breeding season were almost twice those of females in this study. During this season, I observed females generally staying within a small area, while males made larger movements, likely to locate receptive females. Both of these observations were associated with the timing of breeding and rearing of young. Prior studies have documented similar range differences between sexes. Gahr (1993) reported home range sizes during the breeding season in Washington of 20.20 ha (SE = 3.98, $n = 7$) and 2.70 ha (SE = 0.89, $n = 7$) for males and females, respectively. Gahr's study site included both grazed and ungrazed areas, which accounted for variation in home ranges for individuals in grazed areas that traveled farther to reach suitable habitat patches or breeding partners. In Idaho, home ranges of males ($\bar{x}$ = 6.79 ha, SE = 1.04, $n = 3$) during the late breeding season (June – August) were almost twice those of females ($\bar{x}$ = 3.72 ha, SE = 1.20, $n = 6$) (Heady 1998). Both of their studies reported home range estimates larger than those observed in this study. These studies used 95% harmonic mean to identify areas utilized in normal activity (Gahr 1993) and grid methods (Heady 1998) to describe home range boundaries, which often incorporate larger areas of unsuitable habitat; therefore their home ranges are likely over-estimated.

Two recent pygmy rabbit studies in Idaho provide an opportunity to compare home range sizes calculated using a 95% fixed kernel method, similar to the one used in the present study. In southwestern Idaho, home range sizes during the breeding season were larger than those in this study (Male: $\bar{x}$ = 4.49 ha, SE = 1.30, $n = 12$; Female: $\bar{x}$ = 1.62 ha, SE = 0.33, $n = 16$) (Burak 2006). Burak (2006) estimated home ranges with LSCV smoothing in Animal Movements Extension for ArcView. In my study, home range sizes during the breeding season were more consistent with results reported for pygmy rabbits in the Lemhi Valley of Idaho by Sanchez (2007), who found that male ranges ($\bar{x}$ = 1.4 ha, SE = 0.4, n = 23) were larger than females ($\bar{x}$ = 0.6 ha, SE = 0.1, n = 40). Sanchez (2007) used multiple estimator techniques, including a 95% fixed kernel estimator with LSCV smoothing in program Animal Space Use. Differences in home range estimates between these studies and my study may reflect geographic variation, and/or disparity in the algorithms each respective program used to estimate area and/or site-specific habitat characteristics.

In my study, male and female home range estimates during the breeding season were roughly double those of their respective nonbreeding ranges, which supported my original prediction. These patterns were similar to those of pygmy rabbits in southwestern Wyoming, which had smaller home ranges during winter ($\bar{x}$ = 0.49 ha, SE = 0.17, range = 0.05 – 1.85 ha, n = 10) (Katzner and Parker 1997). Similarly, home range sizes during the nonbreeding season in Idaho were 0.4 ha (SE = 0.1, n = 8) and 0.3 ha (SE = 0.1, n = 18) for males and females, respectively (Sanchez 2007). Decreased activity during winter months has been noted previously for this species (Janson 1946, Bradfield 1975, Katzner and Parker 1997); individuals are not actively searching for breeding partners during the winter season, and the need to conserve heat and energy may limit activity. In my study, home ranges during the nonbreeding season were greatly influenced by the high density of locations around burrows. Winter snow depths may also affect movement, but snow depths in my study ranged from 0 – 16 cm and were typically < 5 cm. Greater snow amounts may force rabbits to use subnivean burrow systems, which provide access to persistent sagebrush shrubs, making it unlikely that food is limiting (Katzner and Parker 1997).

Katzner and Parker (1997) considered snow depth and the resulting amount of vegetation cover above the snow as the primary factors determining the size of winter home ranges for pygmy rabbits; decreased amounts of snow between years resulted in greater above-snow shrub cover and expanded home ranges. Minimal snow cover may explain why estimates in this study are larger than those observed in Wyoming. Further, Katzner and Parker (1997) used an adaptive kernel method to describe home range boundaries, which includes outer contour levels and may incorporate larger areas of unsuitable habitat.

Fixed kernel estimates of annual home range in my study were likely influenced by peripheral locations during the breeding season, which created high variability in male and female range sizes. Further, observations during the breeding season were less clustered and more widely dispersed than those during the nonbreeding season; therefore, the smoothing parameters for home ranges during the breeding season were larger than the parameters chosen for annual and nonbreeding estimates. Annual home range sizes in my study were similar to those reported for pygmy rabbits in the Lemhi Valley, Idaho, which were 1.4 ha (SE = 0.3, $n = 13$) for males and 0.6 ha (SE = 0.1, $n = 15$) for females (Sanchez 2007). In many Leporid species, males have been reported to move more widely than females, commonly due to breeding activity (Sanderson 1966). Male cottontail rabbits (*Sylvilagus floridanus*) have spring and summer home ranges 2 – 4 times those of females (Trent and Rongstad 1974), and ranges of male swamp rabbits (*Sylvilagus aquaticus*) were double the area of females (Kholhaug and Woolf 1988). In addition, male black-tailed jackrabbits *(Lepus californicus)* ranged more extensively than females in Utah (Smith 1990). In contrast, male and female Keys marsh rabbits *(Sylvilagus palustris hefneri)* had similar home ranges in Florida, despite each making relatively long juvenile dispersals (Forys and

Humphrey 1996). Home ranges of pygmy rabbits in my study were highly fragmented (Appendix C), suggesting a strong association between their spatial use and habitat characteristics. Although radio-marked rabbits were occasionally observed in open areas or low sagebrush communities, the majority of individuals were relocated in big sagebrush communities or near clusters of big sagebrush shrubs.

Annual and seasonal home range sizes of pygmy rabbits in my study varied among study sites and in comparison to previous investigations done throughout their geographic range (Gahr 1993, Katzner and Parker 1997, Burak 2006, Sanchez 2007). Individuals on the West Gulch study site had significantly larger annual and breeding home range sizes than those of individuals on the Fish Creek site. The marked variation in spatial use across a relatively fine spatial scale may be explained by differences in habitat characteristics or survival rates. In my study, important habitat characteristics that pygmy rabbits selected (see Chapter 5) included density and height of all live shrubs. The density of live shrubs was greater on West Gulch ($\bar{x}$ = 1.12 shrubs/m^2, SE = 0.08) than on Fish Creek ($\bar{x}$ = 0.92 shrubs/m^2, SE = 0.05), however, the height of live shrubs on Fish Creek ($\bar{x}$ = 66.7 cm, SE = 2.00) was greater than that on West Gulch ($\bar{x}$ = 60.75 cm, SE = 1.47). These results may suggest density of live shrubs facilitates greater spatial use than shrub height. Survival rates of pygmy rabbits on West Gulch (Male: S = 0.0998, SE = 0.064; Female: S = 0.1518, SE = 0.059) were also higher than those for Fish Creek (Male: S = 0.0564, SE = 0.037; Female: S = 0.0402, SE = 0.026; see Chapter 3), which suggests that low survival due to predation may restrict home range sizes. Associations between spatial use of pygmy rabbits and habitat characteristics or survival need to be tested further.

Core Use Areas

Pygmy rabbits in my study had relatively small core areas, which were often located near burrows. The strong association between areas of greatest use and burrow entrances is likely due to predation risk (Heady and Laundre 2005). Contrary to my predictions, core use areas of male pygmy rabbits were larger than those of females. This difference is likely attributable to the larger annual and breeding home range sizes for males, a product of greater movements associated with breeding. Core area sizes in my study (Male: $\bar{x}$ = 0.10 ha; Female: $\bar{x}$ = 0.07 ha) tended to be smaller than previous studies. Core area size of pygmy rabbits in Washington was similar between males ($\bar{x}$ = 0.70 ha, SE = 0.17, n = 7) and females ($\bar{x}$ = 0.30 ha, SE = 0.09, n = 7) based on a 50% harmonic mean method (Gahr 1993). Core area size in the present study was less than results reported by Sanchez (2007) in Idaho. Using a 50% fixed kernel estimator with likelihood cross-validation smoothing, Sanchez (2007) reported that males ($\bar{x}$ = 3.2 ha, SE = 0.9, n = 15) used a significantly larger core area than females ($\bar{x}$ = 0.6 ha, SE = 0.8, n = 18; F = 22.70, P < 0.0001). Similar to home range estimates from previous studies, the various methods used to estimate core areas made comparisons among them difficult; methods used by Gahr (1993) and Heady (1998) may tend to overestimate the area used.

Patterns of disproportionately high use within an individual’s home range may be a response to variation of available resources, including burrows and sagebrush cover (Heady 1998). Identifying areas of core use by this species may be particularly important, because the effects of habitat manipulation within the core area may be particularly deleterious. Further investigation is necessary to determine if pygmy rabbits are selecting core areas based on vegetative characteristics, burrow locations, or other factors.

Long-distance Movements

The long-distance movement patterns I observed represent minimal linear distances, since I did not monitor individuals continuously through the course of each dispersal event. Routes traveled by pygmy rabbits are usually non-linear, so the total distance traversed was slightly greater than observed. Many of these movements crossed open or low sagebrush habitat, vegetative communities generally considered unsuitable for pygmy rabbits, but were consistent with my predictions. Katzner and Parker (1998) suggested that individuals moving through relatively unsuitable habitat incorporated clumps of sagebrush as resting and foraging sites. In my study, routes taken by a few individuals crossed secondary roads and seasonal creeks; one individual was commonly observed crossing a paved highway (Highway 140). The willingness of this species to cross unsuitable habitats, previously considered barriers to movement, may suggest fragmented populations of *B. idahoensis* may not be as isolated as previously considered (Katzner and Parker 1998). Further, routes taken during long-distance movements suggest that the influence habitat fragmentation and natural heterogeneity may have on dispersal patterns should be considered on the relative scale of spatial use for this species.

In this study, dispersal and long-distance movements of pygmy rabbits were greater than most previous estimates. Male and female pygmy rabbits in Idaho made maximal movements of 0.5 and 0.3 km, respectively (Green and Flinders 1979). Gahr (1993) reported a maximal distance between locations of 1.2 km and suggested this individual crossed habitats not generally used by this species. A male in southwestern Wyoming traveled a minimal distance of > 3.5 km, and the route included areas of low sagebrush and islands of big sagebrush that were used as resting and foraging sites when crossing open habitat (Katzner and Parker 1998). They suggested this movement was induced by the onset of the breeding season. Six radio-marked rabbits also traveled > 3.5 km, in the Lemhi Valley, Idaho (Sanchez 2007). Dispersal distances reported for 26 radio-marked juvenile pygmy rabbits (12 males, 14 females) in Idaho and southwestern Montana (Estes-Zumpf 2008) were similar to my study. Estes-Zumpf (2008) documented median dispersal movements of 1.2 and 4.8 km and maximal movements of 6.4 and 12.1 km by juvenile males and females, respectively. The majority of juvenile dispersals in this study were by juvenile males and occurred in summer and early fall. The predominance of dispersals by juvenile males is consistent with the dispersal patterns of many polygynous mammal species (Dobson 1982), and may be a response to inbreeding avoidance, competition for mates, and/or resources (Dobson and Jones 1985). Juvenile dispersals corresponded with a movement from natal areas to new areas where they maintained a consistent home range.

Management Implications

I identified spatial use and movement patterns of pygmy rabbits in sagebrush-steppe communities of southwestern Oregon and northwestern Nevada which will be useful to management of this species and its habitat. Considering the obligate tendencies of this species for sagebrush communities, the relatively small home range sizes and core areas used, and the fragmented space use observed in this study, habitat manipulations within the areas used by pygmy rabbits may negatively influence their spatial use patterns and survival. This prediction needs to be tested further. In addition, observed movements and dispersal distances were greater than in most previous studies and included vegetative communities without shrub cover. Further, routes taken during long-distance movements suggest that habitat fragmentation and natural heterogeneity may influence dispersal patterns, and this should be considered in the management of habitat for the species. Due to the known population fluctuations and the dispersal abilities and spatial use reported in this study, I recommend that land mangers conduct thorough and repeated surveys for this species prior to any habitat manipulations that could further reduce and fragment tall sagebrush communities. Information on movement capabilities and barriers to dispersal for pygmy rabbits will improve our understanding of their role in maintaining gene flow between subpopulations.

CHAPTER 5

HABITAT SELECTION OF PYGMY RABBITS IN SOUTHEASTERN OREGON AND NORTHWESTERN NEVADA

Justin A. Crawford

INTRODUCTION

Pygmy rabbits *(Brachylagus idahoensis)* are small, sagebrush obligate lagomorphs (Heady et al. 2001) endemic to the Great Basin and neighboring intermountain areas of North America (Green and Flinders 1980a, Katzner and Parker 1998). Within sagebrush-steppe communities, pygmy rabbits are associated with tall, densely clumped stands of big sagebrush *(Artemisia tridentata* spp.*)* (Orr 1940, Green and Flinders 1980b, Weiss and Verts 1984, Katzner and Parker 1997) where soils usually are deep and friable (Orr 1940, Janson 1946, Green and Flinders 1980b, Campbell et al. 1982, Weiss and Verts 1984, Himes and Drohan 2007). As a result of their specific habitat requirements, the distribution of this species is disjunct and its current range is thought to have shrunk substantially from historical distributions (Verts and Carraway 1998). Pygmy rabbit abundances have declined throughout most of its range (Dobler and Dixon 1990) resulting in their designation as a *Federal Species of Concern* and multiple attempts to list the species range-wide (U.S. Fish and Wildlife Service 2005; 2008). Consequently, degradation and loss of sagebrush-steppe habitat are a cause for concern (Dobler and Dixon 1990), and conservation efforts will benefit from a more thorough understanding of their habitat associations.

B. idahoensis is a habitat specialist, relying on big sagebrush *(Artemisia tridentata* spp.*)* for food resources and protective cover from thermal extremes and predators (Katzner and Parker 1998, Heady et al. 2001). Pygmy rabbits are less mobile than larger leporids and are associated with dense shrub cover that facilitates predator avoidance (Gabler et al. 2001). Several investigators have identified the presence of taller, denser stands of big sagebrush, relative to surrounding unused areas as an essential feature of pygmy rabbit habitat (Green and Flinders 1980a, Weiss and Verts 1984, Katzner and Parker 1997, Heady et al. 2001, Meisel 2006).

Sites with pygmy rabbit activity in Oregon had significantly greater mean shrub cover and shrub height than unoccupied sites (Weiss and Verts 1984). Weiss and Verts (1984) also reported that the percent basal area of perennial grasses and density of annual grasses, forbs, and cryptogam cover in sites occupied by pygmy rabbits did not differ significantly from adjacent unoccupied sites. In Idaho, areas with pygmy rabbit burrows had greater forb cover (Heady et al. 2001) and proportion of bare ground but lower cover of ground litter and microbiotic crust than in low-use areas (Heady and Laundre 2005). This species consumed sagebrush throughout the year with lesser amounts during summer (51%) than winter (99%) (Green and Flinders 1980b); they showed no preference for either *A. t. tridentata* or *A. t. vaseyana* subspecies of big sagebrush (White et al. 1982). Grasses (39%) and forbs (10%) represented a substantial proportion of pygmy rabbit diet throughout the spring and summer in Idaho, but decreased to trace amounts during autumn and winter (Green and Flinders 1980b).

In addition to its association with big sagebrush, this leporid demonstrates an association with specific soil characteristics related to its burrowing behavior. Pygmy rabbits excavate their own burrow systems (Weiss and Verts 1984, Simons and Laundre 2004) or modify burrows of other mammals (Green and Flinders 1980a, Verts and Carraway 1998). Soil depth and strength, more than soil texture, were physical properties that distinguished sites occupied by pygmy rabbits from unoccupied sites in Oregon (Weiss and Verts 1984). In Idaho, burrows typically had several entrances (most commonly two), a simple structure, and no chambers apparent (Wilde 1978). Slope and valley floor locations were preferred over plateaus and flats. Unique soil characteristics used by pygmy rabbits for burrowing and their dependency upon big sagebrush communities likely play an important role in limiting the distribution of this species (Weiss and Verts 1984).

The primary cause for the reduction in this species' distribution is considered to be the fragmentation, degradation, and loss of sagebrush communities in western North America (Gabler et al. 2001). These alterations have also contributed to declines in other sagebrush dependent species, including sage-grouse *(Centrocercus* spp.*)*, Brewer's sparrow *(Spizella breweri)*, and sage sparrow *(Amphispiza belli)* (Knick et al. 2003). Native vegetative communities have been modified or lost due to the conversion of lands to agriculture, domestic livestock grazing, invasion of exotic species such as cheatgrass *(Bromus tectorum)*, altered and increased wildfire cycles, urbanization, energy development, and the expansion of road networks (Crawford et al. 2004). These alterations have pushed many sagebrush communities beyond thresholds from which recovery to a pre-Eurasian-settlement state is unlikely (Knick et al. 2003, Briske et al. 2005). The dependence of pygmy rabbits on structurally diverse sagebrush communities has made this species particularly vulnerable to the destructive impacts of these land-use practices (Katzner and Parker 1997). Concurrent with these habitat changes has been a generalized decline in pygmy rabbit populations throughout most of its range (Dobler and Dixon 1990, Katzner and Parker 1997). The lack of past and present abundance and distribution data have made it difficult to quantify population declines (U.S. Fish and Wildlife Service 2005).

I investigated habitat selection of pygmy rabbits from June 2005 – June 2007 using rabbit locations from radiotelemetry and field measurements of vegetation. Specific objectives of this study were to: (1) compare vegetative and soil characteristics of locations used by rabbits to those areas available on each study site, (2) evaluate differences in soil characteristics among used locations, active burrow locations, and areas available, and (3) document the fine spatial scale of variation in soil characteristics. I predicted that: (1) pygmy rabbits would select tall, dense shrub cover, areas of greater grass and forb cover and deep, sandy soils, (2) active burrows would have deeper and sandier soils than both used surface locations and available areas, and (3) soil characteristics measured within small spatial scales will not vary significantly. In this chapter, I report those habitat characteristics selected by pygmy rabbits and provide estimates of vegetation and soil measures taken at locations used by pygmy rabbits versus those available on each study site.

METHODS

Capture, Handling and Telemetry Monitoring

Individual pygmy rabbits were live-trapped on four study sites from June 2005 – April 2007. Collapsible traps (Tomahawk Live Trap Co., Tomahawk, WI, USA) with double doors (#203, 60 x 23 x 23 cm) or single doors (#201, 40 x 12 x 12 cm) were set in areas that exhibited rabbit activity, including burrow entrances and runways. I trapped as needed to maintain 15 – 20 radio-marked rabbits on each study site. VHF radio transmitters (164 and 165 MHz band, Model RI-2DM (7.1 g and 10.6 g), Holohil Systems Ltd., Carp, Ontario, Canada) were attached to all adult rabbits and juveniles weighing > 250 g. Transmitters were attached to each individual on a zip-tie encased in flexible rubber tubing (2.0 g) to minimize abrasion. Initially, 120 radio transmitters were evenly distributed among the four study sites to ensure a large sample size.

Radio-marked rabbits were monitored from June 2005 – April 2007 to obtain locations four to five times per week using a hand-held receiver (Model R2000 receiver, Advanced Telemetry Systems, Isanti, MN, and Model TR-2 receiver, Telonics Inc., Mesa, AZ, USA) and a directional yagi antenna. Monitoring times of radio-marked rabbits varied to accumulate locations during crepuscular, mid-day, and occasionally night hours, which provided a more complete representation of each individual's daily movements and avoided autocorrelation (Swihart and Slade 1985a;1985b, Otis and White 1999). Radio-marked animals were tracked to within 3 m and positive visual identifications were made. Locations were recorded using a Global Positioning System (GPS; Garmin International, Inc., Olathe, KS, USA). I recorded time, the rabbit's location within the habitat (i.e. on the surface or in a burrow), and behavior.

Determining Habitat Sampling Locations

Vegetative and soil characteristics are considered important parameters in pygmy rabbit habitat selection (Green and Flinders 1980b, Weiss 1984, Katzner 1994, Gabler 1997, Heady 1998, Meisel 2006, Purcell 2006). To investigate resource selection by pygmy rabbits, I compared vegetative and soil characteristics at areas used (referred to as 'used plots') by individuals to those available (referred to as 'available plots') on each study site (Manly et al. 2002, Thomas and Taylor 2006). Used plots were established only for pygmy rabbits with ≥ 30 locations recorded during telemetry monitoring. For each of these rabbits, one fixed observation was randomly chosen via a random number generator (Microsoft® Office Excel) to serve as a used plot for habitat sampling. Recent studies have suggested that pygmy rabbits are capable of making long-distance movements > 3.5 km (Katzner and Parker 1998); therefore, I considered the area within each study site to be available to all radio-marked individuals (Thomas and Taylor 2006). For each study site, 25 available plots were chosen randomly by overlaying a 10 x 10 m grid on a polygon that encompassed all telemetered rabbit locations in a Geographic Information System (GIS; Environmental Systems Research Institute, Redlands, CA, USA). Grid intersections located within this polygon were assigned sequential numbers. Finally, a random number generator (Microsoft® Office Excel) was used to select 25 grid intersections on each study site to serve as available habitat plots.

Vegetation Sampling

Vegetative structure and composition were sampled at 278 plots (178 used, 100 available) from September 2006 – April 2007 when snow cover was absent. Each sampling plot was composed of two-20 m perpendicular transects that intersected at the center point of each transect (Appendix D). The position of the first transect (A) was determined from the random toss of a pencil. Aspect and slope were recorded using a compass and clinometer. Each plot was categorized by dominant and sub-dominant shrub species and topographic position (ridgetop, side-slope, terrace, and bottom-land; Appendix D). A perpendicular transect provided an overlapping sample area at the intersection point. To eliminate the potential of over-sampling this area, only the intersecting area along Transect A was sampled.

The line-intercept method (Canfield 1941, Elzinga et al. 2001) was used along each transect to estimate live and dead canopy cover for shrubs ≥ 30 cm tall. Each intersecting big sagebrush plant was identified to subspecies; other shrubs were identified to species. A shrub was considered alive if any part of it contained green leaves. Height (cm) of each live and dead shrub intercepted was measured from the ground to the top of the shrub canopy. For each sampling plot, all habitat variables were averaged by species or for big sagebrush, by subspecies. Density counts of all live and dead shrubs and ant mounds were made along two-2 x 20 m rectangular belt quadrants centered along each transect (Appendix D). Only shrubs rooted within the belt quadrant were counted; similarly, ant mound cones must have been contained in the belt quadrant to be included. To estimate density, counts of shrubs and ant mounds were divided by the area of the belt quadrants (76 m^2, corrected for overlap).

Percent cover of understory vegetation was visually estimated at nine quadrats, equidistantly spaced at 5 m intervals along each transect, using a 20 x 50 cm sampling frame (Daubenmire 1959). Ground cover attributes were estimated according to functional groups, including perennial native grasses, perennial non-native grasses, annual grasses, forbs, shrub species (< 30 cm tall), bare ground (soil particles < 1 cm diameter), rock (particles > 1 cm diameter), litter, moss, and biological crust. Cover was estimated to the nearest 5% for cover representing $\geq$5%, and 1% when present in trace amounts. Transects were treated as sampling units; therefore, plot estimates of understory cover for each functional group were averaged among the nine quadrats sampled.

Soil Sampling

Soil sampling was conducted at the center point of each used (n = 178) and available (n = 100) plot during June 2007. To evaluate the soil attributes affecting site selection for burrow construction, a single 'burrow plot' was established for each radio-marked rabbit observed in a burrow (n = 125). For each of these individuals, the location of the burrow plot was randomly chosen from all recorded burrow locations using a random number generator (Microsoft® Office Excel). To assess the soil variation within habitat plots (referred to as 'variation plot'), two used and two available plots from each study site were randomly selected to collect three additional sampling points, randomly chosen from three of the four transect end points (Appendix E). All random variation plots and transect end points were chosen using a random number generator (Microsoft® Office Excel).

Soil samples from each plot were collected at 44 – 45 cm below the surface (soil depth permitting), and soil depths to 100 cm were recorded using a 2” diameter auger. If the maximal depth reached was less than 45 cm due to an obstructing restrictive layer, soil samples were then collected at this maximal depth and noted. Soil samples from burrows were collected 1 m behind the burrow entrance. Particle-size analysis of soil samples was conducted using the hydrometer method (Gee and Bauder 1986) at the Oregon State University Central Analytical Lab to determine the percent sand, silt, and clay content of each sample. Soil strength (bulk density) at the surface was measured with an Eley Volumeter (Model 29-4450 (CN-940), ELE International, Inc., Loveland, CO, USA). Bulk density estimates for soil samples collected below the surface were calculated using the results of the soil texture analysis (Saxton et al. 1986).

Vegetation and Soils Analysis

I used logistic regression to test for differences in vegetative and soil attributes of used (n = 178) and available (n =100) plots (Manly et al. 2002, Thomas and Taylor 2006). I combined density, mean maximal height, and percent canopy cover of shrub species and subspecies into three functional groups (Big sagebrush, Dead shrubs, and Total live shrubs). This procedure reduced the number of potential variables I considered in the model selection process (Burnham and Anderson 2002) and was consistent with previous studies (Weiss and Verts 1984, Meisel 2006).

To test for potential influences on resource selection by rabbits, habitat variables were initially organized into three categories (Shrub, Understory, Soil; Table 5.1), which were analyzed using logistic regression (Ramsey and Schafer 2002) and a backward elimination procedure in SAS (PROC LOGISTIC, SAS Institute Inc., Cary, NC, USA). In the backward elimination procedure, the initial rich model contained all habitat variables and sequentially eliminated variables that were insignificant until a final model was reached that included only significant variables. During this initial analysis, differences were considered significant at the liberal α level of 0.15 to avoid eliminating parameters that may be biologically important but not statistically significant.

Table 5.1. Habitat categories and variables used to develop models of resource selection using logistic regression for pygmy rabbits at four study sites in southeastern Oregon and northwestern Nevada, September 2006 – June 2007.

Shrub variables	Understory variables	Soil variables
Density (#/m^2)	% Cover	% Clay
Big sagebrush	Annual grasses	% Sand
Total live shrubs	Biological crust	% Silt
Dead	Forbs	Maximal depth (cm)
Mean height (cm)	Litter	Bulk density (g/cm^3)
Big sagebrush	Moss	Subsurface
Total live shrubs	Perennial native grasses	Surface
Dead	Perennial non-native grasses	
% Canopy cover	Rock	
Big sagebrush	Shrub species (< 30 cm tall)	
Total live shrubs	Soil (bare ground)	
Dead		

Parameters included in the top model of each habitat category (Table 5.1) were pooled and included in the overall resource selection model. This process allowed me to reduce the total number of variables tested in the final model. The effects of these pooled variables were again analyzed using logistic regression and a backward elimination procedure in SAS (PROC LOGISTIC). Each model considered during the backward elimination procedure was then analyzed using second-order Akaike Information Criteria corrected for small sample sizes (AIC$_c$) and Akaike weights to select the most parsimonious model (Burnham and Anderson 2002). The model with the smallest AIC_c value was considered to be the best model to fit the data and any model within 2 AIC_c values was identified as a competing model (Burnham and Anderson 2002). I used the regression coefficients (β) and their 95% confidence intervals as evidence, or lack thereof, of an effect for various factors in competing models. Logistic regression allowed me to determine how the odds of a habitat being used (response variables) changed as a function of the vegetative and soil characteristics (explanatory variables). Parameter estimates for the best approximating model were exponentiated, and the results were reported as log odds ratios (Keating and Cherry 2004). Model selection procedures were performed for each study site to determine if pygmy rabbits selected habitat variables at a finer spatial scale and across the four study sites. Finally, Pearson correlation coefficients were calculated for variables of each habitat category to clarify any correlations among these variables.

Analyses of soils at burrows and within plot variation of soil parameters were performed on the soil variables sampled. I used a two-way ANOVA test (Ramsey and Schafer 2002) to examine differences in soil characteristics measured at used, burrow, and available plots after accounting for study site. Because sample sizes were unequal, the Tukey-Kramer procedure was used to analyze differences in soil parameters among plot types. Arcsine transformations were performed on all variables measured as percents (Zar 1999); however, nontransformed estimates are reported herein. I further assessed the within plot variation of soils to determine if measuring soil parameters once in each plot was adequate to describe those parameters throughout the plot. Within each of these plots, soil parameters measured at the center point (n = 16) were compared to the averaged value of that measurement for all four sampling points using a paired t-test (Ramsey and Schafer 2002) in S-plus 7.0 (Insightful Corporation, Seattle, WA, USA). Differences were considered significant at the α level of 0.05. None of the differences between the center point and averaged measurement were significant (Appendix F), which verified that the single soil sample from the center adequately represented each habitat plot.

RESULTS

I successfully captured and radio-marked 298 pygmy rabbits (132 male, 166 female) on four study sites between June 2005 and April 2007. More than 13,000 locations of radio-marked rabbits were recorded during this study. Single locations used by 178 individuals were included in the analysis of habitat selection. Contamination of available plots located near used plots was minimal; however, resource selection models incorporating use-availability designs allow for the possibility that resource units may appear in both samples (Johnson et al. 2006).

Study Site Specific Habitat Selection

As expected, I did not find a consensus model that described habitat selection among pygmy rabbits for each study site. Forty-seven individual pygmy rabbits were included in the analysis of habitat selection on the Dixon study site. The top model for Dixon indicated that pygmy rabbits used areas with taller dead shrubs, increased live shrub cover, and greater subsurface soil bulk density than other available areas (Table 5.2; Appendix G). This model accounted for 34.4% of the AIC_c weight of all models considered. The variables introduced by the two competing models (% Cover litter: Odds = 1.079, 95% CI: 0.993 – 1.172, P = 0.0729, X^2 = 3.2161; and % Cover bare ground: Odds = 1.043, 95% CI: 0.988 – 1.102, P = 0.1291, X^2 = 2.3038) contributed little to these models as each odds ratio estimate had 95% confidence intervals that included one. All of the top models included cover of all live shrubs, height of dead shrubs, and bulk density of soil at the maximal depth, and the AIC_c weights of these models combined was > 0.98. The odds that a pygmy rabbit on Dixon selected an area increased 1.035 times (95% CI: 1.010 – 1.061, P = 0.006; Figure 5.1) for every 1.00 cm increase in the height of dead shrubs. For every 1% increase in the cover of all live shrubs, the odds of rabbit use increased by 1.098 times (95% CI: 1.009 – 1.195, P = 0.031; Figure 5.1). Pygmy rabbits were 2.990 times more likely (95% CI: 1.069 – 8.390, P = 0.037; Figure 5.1) to select an area with every 0.1 g/cm^3 increase in bulk density at the maximal depth.

Table 5.2. Study site specific habitat selection models for pygmy rabbits on four study sites in southeastern Oregon and northwestern Nevada, September 2006 - June 2007.

Study Site	Model[a]	AICc	ΔAICc	AIC Weight	K[b]
Dixon	CT HD SBDD	69.107	0.000	0.344	4
	CT UL US HD SBDD	69.635	0.529	0.264	6
	CT UL HD SBDD	69.857	0.750	0.237	5
	CT UL UPNATG US HD SBDD	71.541	2.434	0.102	7
	CT UL UPNATG UR US HD SBDD	73.546	4.440	0.037	8
	CT UL UPNATG UR US HD SBDS SBDD	75.897	6.790	0.012	9
	CT UL UPNATG UR US HD SD SBDS SBDD	78.430	9.323	0.003	10
	CT UBC UL UPNATG UR US HD SD SBDS SBDD	80.997	11.890	0.001	11
Fish Creek	DT HBSB UM	61.246	0.000	0.555	4
	DT HBSB UM US	62.342	1.096	0.321	5
	DT HBSB UM US SBDS	64.758	3.512	0.096	6
	DT HBSB UM UR US SBDS	67.239	5.992	0.028	7
Spaulding	CD CBSB DT DD HT	65.523	0.000	0.560	6
	CD CBSB DT DD HT SBDS	66.617	1.094	0.324	7
	CD CBSB DT DD HT CLAY SBDS	69.214	3.691	0.089	8
	CD CBSB DT DD HT CLAY SBDS SBDD	71.599	6.076	0.027	9
West Gulch	CLAY UM DT	63.541	0.000	0.383	5
	CLAY UM DT HT	64.191	0.650	0.277	4
	CLAY UM CT DT HT	64.746	1.205	0.210	6
	CLAY UM CT DT HT HD	66.190	2.649	0.102	7
	CLAY UF UM CT DT HT HD	68.667	5.126	0.029	8

[a] CBSB - % Canopy cover of big sagebrush
CD - % Canopy cover of all dead shrubs
CLAY - % Clay
CT - % Canopy cover of all live shrubs
DBSB - Density of big sagebrush
DD - Density of all dead shrubs
DT - Density of all live shrubs
HBSB - Mean height of big sagebrush
HD - Mean height of dead shrubs
HT - Mean height of all live shrubs
SBDD - Bulk density at subsurface
SBDS - Bulk density at surface
SD - Maximal soil depth
UBC - % Cover biological crust
UF - % Cover forbs
UL - % Cover litter
UM - % Cover moss
UPNATG - % Cover perennial native grasses
UR - % Cover rock
US - % Cover bare ground

[b] Number of parameters

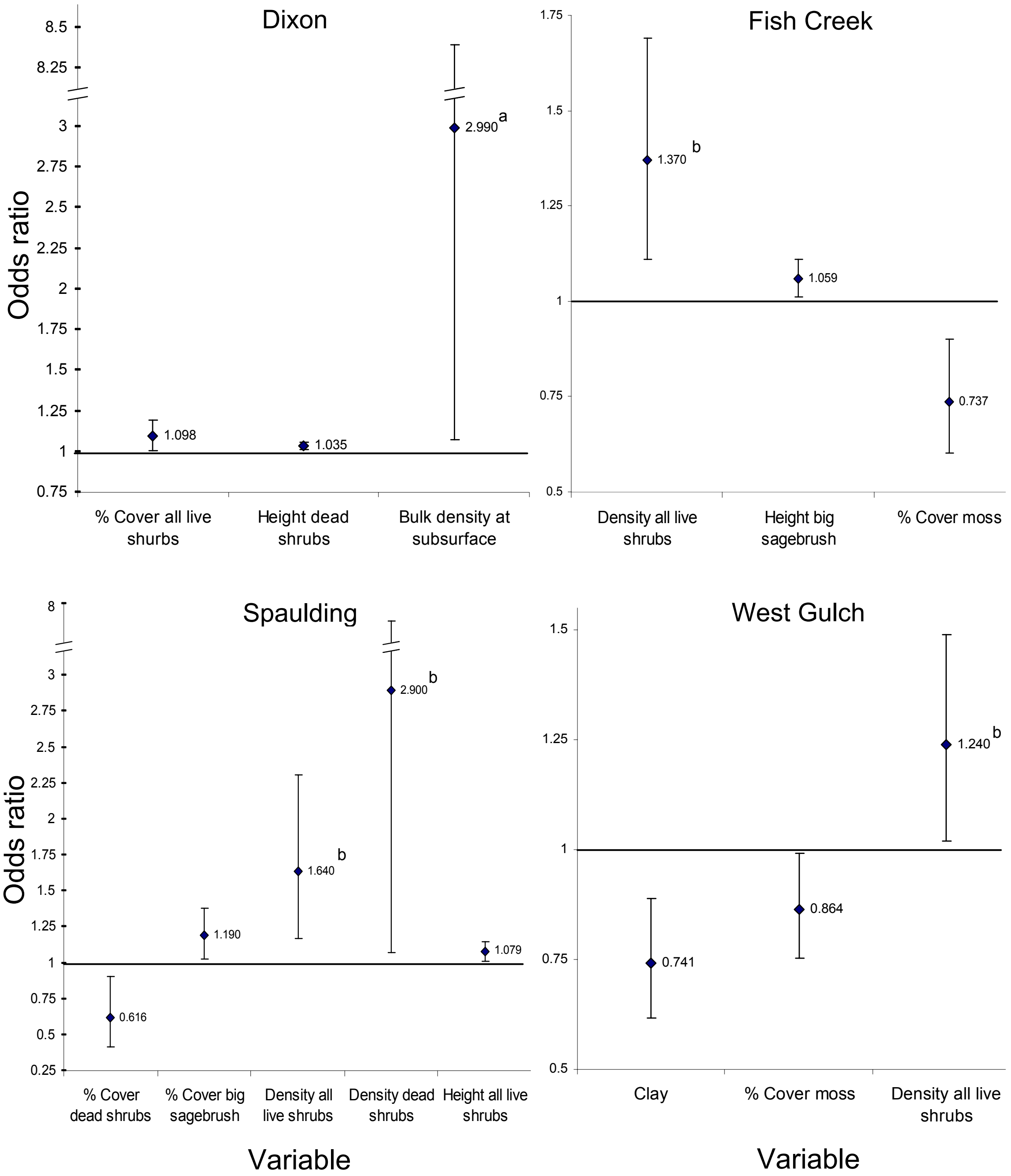

Figure 5.1. Odds ratios of pygmy rabbits using a location based on habitat variables considered in the global model for habitat selection on four study sites. Odds ratios are reported for variables included in the top model for each study site. Error bars represent 95% confidence intervals around the odds ratio.

[a] Odds ratio of selection calculated for 0.1 g/cm^3 increase in bulk density

[b] Odds ratio of selection calculated for 10% increase in density

I included 44 rabbits in the analysis of habitat selection on the Fish Creek study site. The top model indicated that areas with greater densities of live shrubs, taller big sagebrush, and less moss cover than random locations were selected by pygmy rabbits on Fish Creek (Table 5.2; Appendix H). The top model accounted for 55.5% of the AIC_c weight of all models considered and was ~1.7 times more likely than the one competing model [DT HBSB UM US], which accounted for 32.1% of the AIC_c weight. This competing model included percent bare ground, but this variable was statistically insignificant (Odds = 0.976, 95% CI: 0.936 – 1.018, $P = 0.2642$, $X^2 = 1.2466$). All of the top models included density of all live shrubs, height of big sagebrush, and moss cover, and the AIC_c weights of these models combined was > 0.99. Rabbits on Fish Creek were 1.370 times more likely (95% CI: 1.105 – 1.691, $P = 0.004$; Figure 5.1) to use an area with every 10% increase in the density of live shrubs. For every 1.00 cm increase in the height of big sagebrush, the odds of rabbit use increased 1.059 times (95% CI: 1.010 – 1.111, $P = 0.018$; Figure 5.1). Individuals were 0.737 times less likely (95% CI: 0.603 – 0.901, $P = 0.018$; Figure 5.1) to select an area with every 1% increase in moss cover.

Forty-five rabbits were included in the analysis of habitat selection on the Spaulding study site. The top model demonstrated that radio-marked rabbits on Spaulding used areas with taller live shrubs, greater densities of live and dead shrubs, increased cover of big sagebrush, and less dead shrub cover (Table 5.2; Appendix I). This best model accounted for 56.0% of the AIC_c weight of models considered and was ~1.7 times more likely than the most competitive model [CD CBSB DT DD HT SBDS] which accounted for 32.4% of the AIC_c weight. Inclusion of soil bulk density at the surface (Odds = 0.053, 95% CI: <0.001 – 8.523, $P = 0.2566$, $X^2 = 1.2869$) in this competing model contributed little to the differences between used and available plots. All of the top models included cover of big sagebrush and dead shrubs, density of all live and dead shrubs, and height of all live shrubs, and the AIC$_c$ weights of these models combined was > 0.99. Pygmy rabbits on Spaulding were 1.079 times (95% CI: 1.012 – 1.151, P = 0.020; Figure 5.1) more likely to use an area with every 1.00 cm increase in the height of live shrubs. The odds that an individual selected an area increased 1.640 times (95% CI: 1.172 – 2.305, P = 0.004; Figure 5.1) for every 10% increase in the density of live shrubs, and 2.900 times (95% CI: 1.066 – 7.880, P = 0.037; Figure 5.1) for every 10% increase in the density of dead shrubs. For every 1% increase in big sagebrush cover, the odds that a rabbit would use a location increased 1.190 times (95% CI: 1.026 – 1.380, P = 0.022; Figure 5.1). Rabbits were 0.616 times less likely (95% CI: 0.418 – 0.908, P = 0.015; Figure 5.1) to use an area for every 1% cover of dead shrubs.

Locations from 42 pygmy rabbits were included in the analysis of habitat selection on the West Gulch study site. The top habitat selection model indicated that locations having greater densities of live shrubs, though less moss cover and clay content than random locations, were used by individuals on West Gulch (Table 5.2; Appendix J). This model accounted for 38.3% of the AIC$_c$ weight of all models considered and was ~1.4 and ~1.8 times more likely than the two competing models [CLAY UM DT HT and CLAY UM CT DT HT], respectively. These competing models included the additive effects of height (Odds = 1.061, 95% CI: 0.989 – 1.138, P = 0.0937, X^2 = 2.8094) and cover (Odds = 0.940, 95% CI: 0.843 – 1.047, P = 0.2609, X^2 = 1.2642) of all live shrubs to the variables included in the top model, which contributed little to the differences between used and available plots as they were statistically insignificant. All of the top models included clay content, moss cover, and density of live shrubs, and the AIC$_c$ weights of these models combined was > 0.98. The odds that a rabbit selected an area on West Gulch increased 1.240 times (95% CI: 1.023 – 1.495, P = 0.028; Figure 5.1) for every 10% increase in live shrub density. Radio-marked individuals were 0.864 times less likely (95% CI: 0.754 – 0.991, P = 0.037; Figure 5.1) to select an area with every 1% increase in moss cover. For every 1% increase in clay content, the odds of rabbit use decreased by 0.741 times (95% CI: 0.618 – 0.890, P = 0.001; Figure 5.1).

Study-wide Habitat Selection

I developed a set of candidate models that described habitat selection across the four study sites for each unique habitat category: shrub, understory, soils (Table 5.1). The top model for selection of shrub characteristics included the height of dead and live shrubs and the density of live shrubs (Appendix K). Vegetative variables included in the top model for selection of understory characteristics included percent cover of biological crust, litter, perennial native grasses, rock, and bare ground (Appendix K). The top model that described differences in soil characteristics included maximal soil depth, bulk density measured at the surface, and percent silt and clay content (Appendix K).

Significant parameters included in the top model of analysis for each habitat category were pooled and included in the study-wide model of resource selection. The best study-wide model for habitat selection of pygmy rabbits included density and height of all live shrubs and percent silt and clay content in the soil (Table 5.3). This model accounted for 36.8% of the AIC$_c$ weight of all models considered and was ~2.0 times more likely than the most competitive model [SILT CLAY DT HT UBC], which had a ΔAIC_c value of 1.360. This competing model, however, did not include a significant variable (% Cover biological crust: Odds = 1.015, 95% CI: 0.980 – 1.052, P = 0.3989, X^2 = 0.7117) that was not included in the best model. All of the top models included density and height of all live shrubs and percent silt and clay content, and these models had a combined AIC_c weight > 0.95.

Table 5.3. Habitat selection models for pygmy rabbits across four study sites in southeastern Oregon and northwestern Nevada, September 2006 – June 2007.

Model[a]	AICc	ΔAICc	AIC Weight	K[b]
SILT CLAY DT HT	284.766	0.000	0.368	5
SILT CLAY DT HT UBC	286.126	1.360	0.186	6
SILT CLAY DT HT UBC UL UPNATG UR US	287.263	2.498	0.106	10
SILT CLAY DT HT UBC US	287.805	3.039	0.081	7
SILT CLAY DT HD HT UBC UL UPNATG UR US	287.995	3.229	0.073	11
SILT CLAY DT HT UBC UL UR US	288.147	3.381	0.068	9
SILT CLAY DT HT UBC UL US	288.485	3.719	0.057	8
SILT CLAY SBDS DT HD HT UBC UL UPNATG UR US	288.942	4.176	0.046	12
SILT CLAY SD SBDS DT HD HT UBC UL UPNATG UR US	291.143	6.377	0.015	13

[a] CLAY - % Clay
DT - Density of all live shrubs
HD - Mean height of dead shrubs
HT - Mean height of all live shrubs
SBDS - Bulk density at surface
SD - Maximal soil depth
SILT - % Silt
UBC - % Cover biological crust
UL - % Cover litter
UPNATG - % Cover perennial native grasses
UR - % Cover rock
US - % Cover bare ground
[b] Number of parameters

All habitat parameters included in the top model had P-values < 0.05 and 95% confidence intervals of odds ratios that did not overlap 1.0 (Table 5.4; Figure 5.2). For every 10% increase in the density of live shrubs, the odds of rabbit use increased by 1.307 times (95% CI: 1.195 – 1.429, P <0.0001; Table 5.4). Individuals selected areas that were more densely occupied by live shrubs ($\bar{x}$ = 1.15 shrubs/m^2, 95% CI: 1.07 – 1.23) than other available areas ($\bar{x}$ = 0.74 shrubs/m^2, 95% CI: 0.66 – 0.82; Table 5.5). The odds that a pygmy rabbit selected an area increased 1.055 times (95% CI: 1.032 – 1.080, P <0.0001; Table 5.4) for every 1.00 cm increase in the height of live shrubs. Rabbit locations ($\bar{x}$ = 67.14 cm, 95% CI: 65.10 – 69.18) had taller live shrubs than random locations ($\bar{x}$ = 58.27 cm, 95% CI: 54.78 – 61.76; Table 5.5). For every 1% increase in silt content, the odds that a pygmy rabbit would use a location increased 1.052 times (95% CI: 1.011 – 1.095, P = 0.013; Table 5.4). The silt content in areas used by rabbits ($\bar{x}$ = 27.41%, 95% CI: 26.26 – 28.56) was higher than random locations ($\bar{x}$ = 24.89%, 95% CI: 23.27 – 26.51; Table 5.5). Pygmy rabbits were 0.95 times less likely (95% CI: 0.906 – 0.991, P = 0.018; Table 5.4) to select an area with every 1% increase in clay content. Additionally, used locations ($\bar{x}$ = 16.76%, 95% CI: 15.79 – 17.73) contained 2.55% less clay content than random locations ($\bar{x}$ = 19.31%, 95% CI: 17.77 – 20.85; Table 5.5). The influence of understory vegetation on resource selection was minimal as these variables were not included in the top model (Table 5.3); however, there was some evidence that percent cover of perennial grasses was higher at rabbit locations versus those at randomly selected plots (Figure 5.2).

Table 5.4. Parameter estimates for the best model explaining habitat selection for pygmy rabbits on four study sites in southeastern Oregon and northwestern Nevada, September 2006 – June 2007.

Parameter[a]	Estimate	SE	P -value	Odds [b]	95% CI Odds Ratio [b]
Intercept	-5.70	1.17	<.0001	NA	NA
CLAY	-0.05	0.02	0.018	0.947	0.906 - 0.991
SILT	0.05	0.02	0.013	1.052	1.011 - 1.095
HT	0.05	0.01	<.0001	1.055	1.032 - 1.080
DT	2.68	0.46	<.0001	1.307[c]	1.195 – 1.429[c]

[a] CLAY - % clay in soil

DT - Density of all live shrubs

HT – Mean height of all live shrubs

SILT - % silt in soil

[b] Odds ratio (e^{β}) = odds of selection increase or decrease by this factor for each unit increase in the explanatory variable.

[c] Odds ratio of selection calculated for 10% increase in density, allowing odds ratios to be reported on a smaller scale.

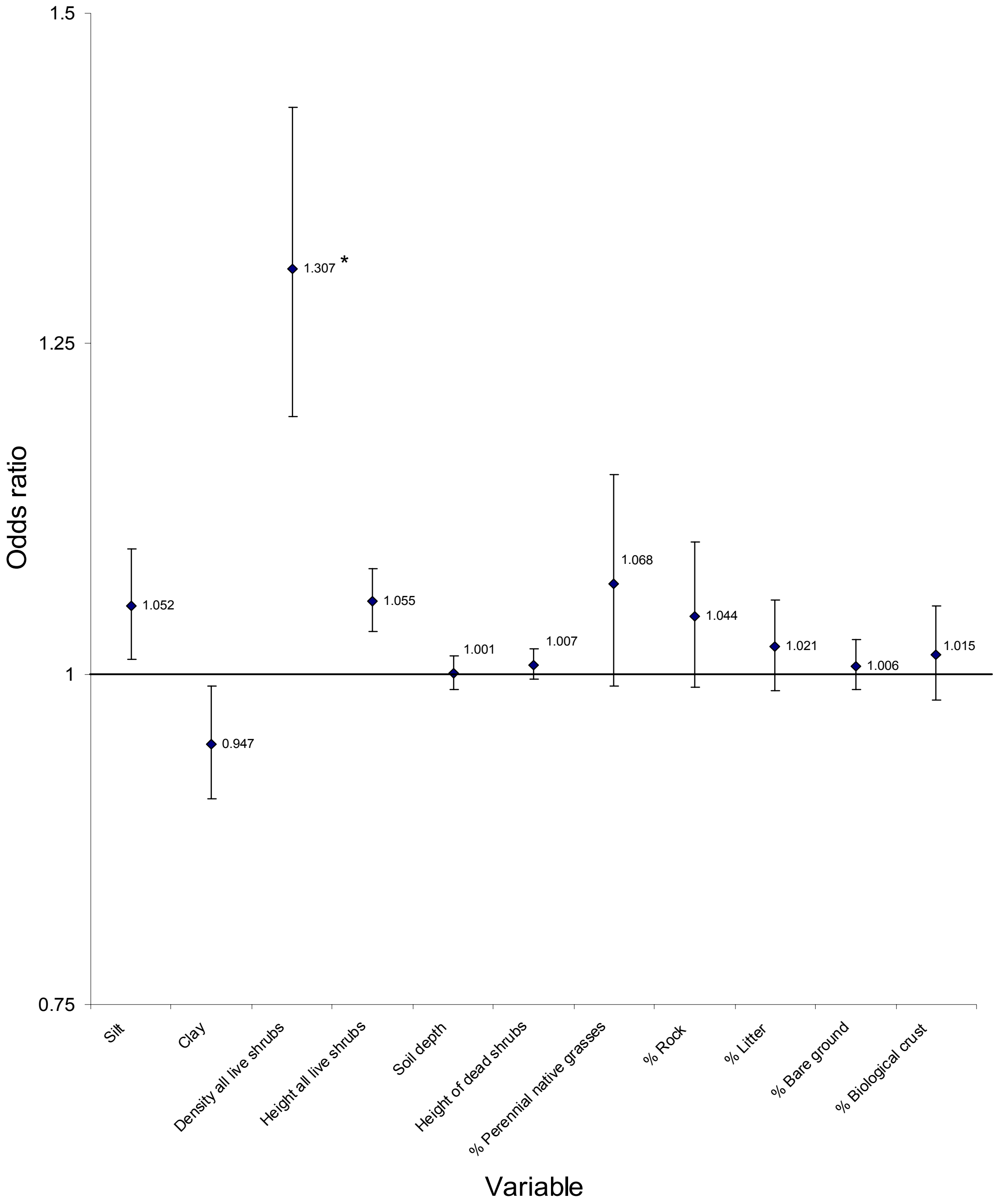

Figure 5.2. Odds ratios of pygmy rabbits using a location based on habitat variables considered in the global model for habitat selection. Odds ratios for variables included in the top model (Silt, Clay, Density of all live shrubs, and Height of all live shrubs) are reported from the top model, while odds ratios of all other variables are reported from the global model. Surface soil bulk density was excluded from this figure due to its very large 95% confidence interval (0.030 – 2.659). Error bars represent 95% confidence intervals around the odds ratio.

[*] Odds ratio of selection calculated for 10% increase in density, allowing odds ratios to be reported on a smaller scale.

Table 5.5. Vegetative and soil characteristics ($\bar{x}$, SE, Range) measured in areas used by pygmy rabbits and areas of available habitat on four study sites in southeastern Oregon and northwestern Nevada, September 2006 – June 2007.

		Available (n = 100)			Used (n = 178)		
Variables		$\bar{x}$	SE	Range	$\bar{x}$	SE	Range
Shrub density (#/m^2)	Big sagebrush	0.43	0.03	0.00 – 1.51	0.74	0.03	0.00 – 279
	Total live shrubs	0.74	0.04	0.00 – 2.62	1.15	0.04	0.26 – 3.18
	Dead	0.11	0.01	0.00 – 0.45	0.17	0.01	0.00 – 0.99
Mean shrub height (cm)	Big sagebrush	60.01	2.75	0.00 – 96.56	71.95	1.58	0.00 – 124.33
	Total live shrubs	58.27	1.77	0.00 – 89.00	67.14	1.03	35.16 – 124.33
	Dead	41.85	3.18	0.00 – 129.75	58.34	1.69	0.00 – 112.00
% Shrub cover	Big sagebrush	14.80	1.03	0.00 – 40.68	23.22	0.90	0.00 – 61.26
	Total live shrubs	20.53	1.19	0.00 – 64.00	32.28	1.00	6.42 – 72.74
	Dead	2.58	0.28	0.00 – 11.76	3.91	0.24	0.00 – 16.39
% Understory cover	Annual grasses	0.25	0.09	0.00 – 5.00	0.35	0.11	0.00 – 18.44
	Biological crust	4.32	0.84	0.00 – 60.56	4.99	0.71	0.00 – 60.00
	Forbs	1.86	0.21	0.00 – 11.33	1.57	0.14	0.00 – 11.44
	Litter	19.36	1.05	0.00 – 50.55	25.88	0.98	2.44 – 61.11
	Moss	5.63	0.57	0.00 – 31.67	3.94	0.35	0.00 – 26.67
	Perennial native grasses	9.57	0.59	0.00 – 30.56	8.11	0.43	0.11 – 31.11
	Perennial non-native grasses	0.02	0.02	0.00 – 2.22	0.01	0.01	0.00 – 1.11
	Rock	9.09	1.20	0.00 – 55.00	4.79	0.55	0.00 – 42.78
	Shrubs (< 30 cm tall)	3.04	0.53	0.00 – 22.78	1.62	0.20	0.00 – 13.33
	Soil (bare ground)	46.90	1.96	5.44 – 100.00	49.02	1.35	1.66 – 90.00
Soil characteristics	% Clay	19.31	0.78	2.50 – 57.50	16.76	0.49	5.00 – 37.50
	% Sand	55.80	1.20	21.25 – 82.50	55.84	0.80	27.50 – 80.00
	% Silt	24.89	0.82	0.00 – 50.00	27.41	0.58	10.00 – 50.00
	Maximal depth (cm)	45.83	2.57	11 – 100	62.63	2.12	10 – 100
	Subsurface bulk density (g/cm^3)	1.45	0.01	1.22 – 1.77	1.48	0.01	1.30 – 1.66
	Surface bulk density (g/cm^3)	1.24	0.02	0.90 – 1.80	1.17	0.01	0.55 – 1.50

Soils Characteristics at Burrows

Texture of soils at burrows and used and available areas were principally sandy loam. The mean compositions of sand ($\bar{x}$ = 58.98%, 95% CI: 56.98 – 60.98), silt ($\bar{x}$ = 26.00%, 95% CI: 24.40 – 27.61), and clay ($\bar{x}$ = 15.02%, 95% CI: 13.97 – 16.07) were relatively consistent for soil samples taken from burrow locations on all four study sites (Figure 5.3). Randomly selected locations had a significantly higher ($F_{2,397}$ = 12.30, P < 0.0001) component of clay ($\bar{x}$ = 19.31%, 95% CI: 17.77 – 20.85) than did burrow locations ($\bar{x}$ = 15.02%, 95% CI: 13.97 – 16.07; Figure 5.3). However, there was little evidence of a difference in subsurface sand and silt composition between burrows and available locations based on 95% simultaneous confidence intervals (Tukey-Kramer procedure; Figure 5.3). Burrows ($\bar{x}$ = 68.34 cm, 95% CI: 63.85 – 72.84) had soils 22.51 cm deeper than randomly selected locations ($\bar{x}$ = 45.83 cm, 95% CI: 40.76 – 50.90; $F_{2,397}$ = 21.64, P < 0.0001; Figure 5.3). The soil strength at the surface was significantly less ($F_{2,397}$ = 21.99, P < 0.0001; Figure 5.3) at burrow sites ($\bar{x}$ = 1.12 g/cm^3, 95% CI: 1.10 – 1.13) than at available sites ($\bar{x}$ = 1.24 g/cm^3, 95% CI: 1.20 – 1.28). Conversely, the soil strength at maximal depth was higher at burrow sites ($\bar{x}$ = 1.50 g/cm^3, 95% CI: 1.48 – 1.52) than at available sites ($\bar{x}$ = 1.45 g/cm^3, 95% CI: 1.44 – 1.47; $F_{2,397}$ = 9.35, P = 0.0001; Figure 5.3).

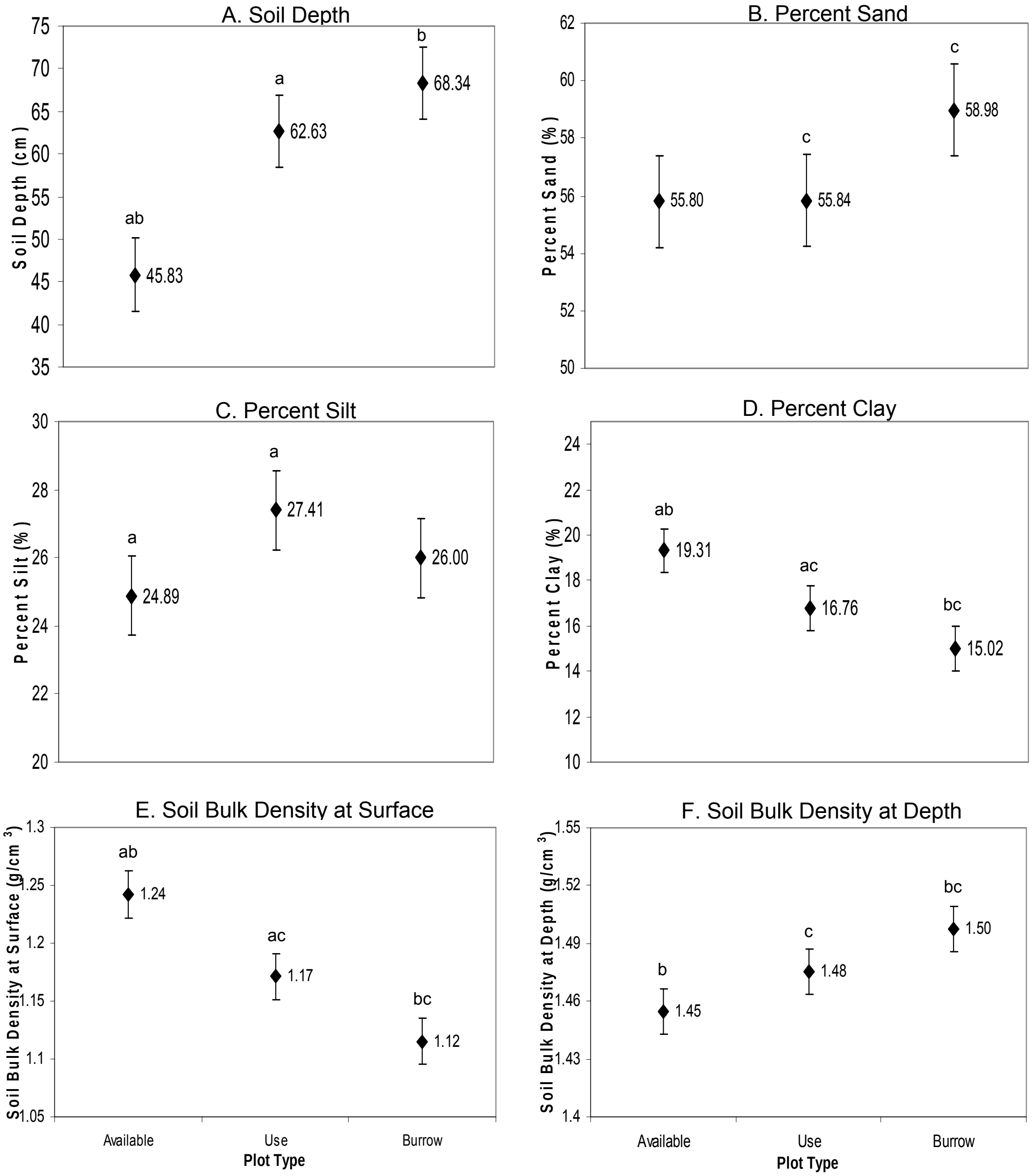

Figure 5.3. Soil variables measured at available (n = 100), used (n = 178), and burrow (n = 125) plots on four study sites in southeastern Oregon and northwestern Nevada, June 2007. Parameters include: (A) Soil depth (cm), (B) Percent sand, (C) Percent silt, (D) Percent clay, (E) Soil bulk density at surface (g/cm^3), and (F) Soil bulk density at depth (g/cm^3). Error bars represent 95% confidence intervals around the mean ($\bar{x}$). Soil parameters were tested for differences among available, used, and burrow plots using an ANOVA procedure (Tukey-Kramer test for multiple comparisons) that accounted for study site variation. Differences considered significant at $P < 0.05$.

[a] Significant differences between available and use sites.

[b] Significant differences between available and burrow sites.

[c] Significant differences between use and burrow sites.

DISCUSSION

Previous investigations (Green and Flinders 1980b, Weiss and Verts 1984, Katzner and Parker 1997, Gabler et al. 2001, Heady and Laundre 2005, Burak 2006, Meisel 2006, Purcell 2006, Himes and Drohan 2007, Sanchez 2007) have documented a strong association of pygmy rabbits with specific vegetative and soil characteristics. Green and Flinders (1980b), Weiss and Verts (1984), Gabler et al. (2001), Heady and Laundre (2005), Meisel (2006), Purcell (2006), Himes and Drohan (2007), and Sanchez (2007) used areas with active sign (burrows and fecal pellets) to examine habitat associations of rabbits, which may be biased toward areas of high rabbit density. Katzner and Parker (1997) and Burak (2006) used home ranges and core areas of radio-marked pygmy rabbits, respectively, to study habitat associations, which may have included unsuitable habitat. In addition, these previous studies compared areas with active sign or individual home ranges to adjacent unused or unoccupied areas, which may be biased because of the uncertainly of equivocally determining unused locations (Johnson et al. 2006). The use of exact locations determined by radiotelemetry to examine habitat associations of pygmy rabbits distinguishes my study from previous investigations. I also tested for differences in vegetative and soil attributes of used and available areas that were randomly chosen on each study site. In my study, pygmy rabbits selected areas with greater densities and taller live shrubs and soils with high silt and low clay content, which supported my initial predictions. These four variables were included in all of the models that I considered and were commonly included in, or correlated with, variables in the best models for each study site. My results suggest that these variables were the principal determinants of habitats selected by this species in southern Oregon and northern Nevada.

Study Site Specific Habitat Selection

I did not find a consensus model that described habitat selection of pygmy rabbits for each study site. However, specific variables or functional categories that were included in the study-wide habitat selection model were generally represented in the best models for each study site. Greater density of live shrubs was included in the habitat models for Fish Creek, Spaulding, and West Gulch, while percent cover of live shrubs, a correlate with density (r = 0.61; Appendix L), was included in the model for Dixon. Analysis of vegetative characteristics associated with active pygmy rabbit burrows in Idaho found that cover of Wyoming big sagebrush *(Artemisia tridentata* spp. *wyomingensis)* and three-tip sagebrush *(A. tripartita* spp. *tripatata)* differed between two study sites (Cedar Gulch and Rocky Canyon), whereas total sagebrush and total shrub cover did not differ (Sanchez 2007). Mean shrub cover in Idaho ranged from 17.4 (Cedar Gulch in 2004, SE = 6.4, n = 30) to 24.3% (Rocky Canyon in 2005, SE = 8.6, n = 30) (Sanchez 2007), while mean total shrub cover in habitats used by rabbits in my study was greater and ranged more widely from 25.0 (SE = 1.00, n = 47) to 44.0% (SE = 3.00, n = 44) on Dixon (Appendix O) and Fish Creek (Appendix P), respectively. Further, height of live shrubs, big sagebrush, or dead shrubs were included in the models for Dixon, Fish Creek, and Spaulding. Shrub height in areas used by pygmy rabbits in Idaho did not differ between the Cedar Gulch ($\bar{x}$ = 47.0 cm, SE = 2.0, n = 30) and Rocky Canyon sites ($\bar{x}$ = 47.4 cm, SE = 1.9, n = 30) (Sanchez 2007), while in my study, rabbits used areas with taller shrubs, ranging in mean height from 61.69 (SE = 2.49, n = 42) to 71.96 cm (SE = 2.62, n = 44) on West Gulch (Appendix R) and Fish Creek (Appendix P), respectively. Pygmy rabbits used habitats with greater shrub cover, yet results from my study suggest that this species tolerates site-specific differences in relative shrub composition, density, cover, and height.

Study-wide Habitat Selection

Tall, dense shrub communities were selected by pygmy rabbits over open areas and low sagebrush communities. The best models did not include any variables associated with percent cover of big sagebrush or all shrubs (alive or dead); however, measures of shrub density were strong surrogates of shrub cover as they were positively correlated (Big sagebrush: r = 0.64; Live shrubs: r = 0.61; Dead shrubs: r = 0.64; Appendix L). Similarly, density, cover, and height of all live shrubs explained more variation between used and available plots as they included and were positively correlated with measurements of big sagebrush (Density: r = 0.76; Cover: r = 0.80; Height: r = 0.82; Appendix L). Patterns of habitat selection I observed were consistent with those of pygmy rabbits in eastern and southeastern Oregon, which occupied (n = 13) sagebrush communities that were significantly taller ($\bar{x}$ = 84.4 cm, SE = 5.8, P < 0.05) and provided more cover ($\bar{x}$ = 28.8%, SE = 1.4, P < 0.05) than adjacent unused areas (Height: $\bar{x}$ = 52.7 cm, SE = 5.3; Cover: $\bar{x}$ = 17.7%, SE = 1.2; n = 21) (Weiss and Verts 1984). My study found the mean height of live shrubs was considerably less in areas used by this species ($\bar{x}$ = 67.14 cm, SE = 1.03) than reported by Weiss and Verts (1984). Shrub communities in areas inhabited by pygmy rabbits (n = 8) in Wyoming were also significantly more dense ($\bar{x}$ = 1.25 shrubs/m, SE = 0.06, P < 0.001) with greater coverage ($\bar{x}$ = 42.9%, SE = 3.0, P < 0.001) and taller shrubs ($\bar{x}$ = 55.2 cm, SE = 3.7, P = 0.004) than in adjacent unused areas (Density: $\bar{x}$ = 0.09 shrubs/m, SE = 0.03; Cover: $\bar{x}$ = 16.5%, SE = 2.0; Height: $\bar{x}$ = 27.6 cm, SE = 7.0; n = 8) (Katzner and Parker 1997). Areas used by pygmy rabbits in my study, however, had considerably less shrub cover ($\bar{x}$ = 32.28%, SE = 1.00, n = 178) and greater mean shrub height ($\bar{x}$ = 67.14 cm, SE = 1.03, n = 178) than those reported for rabbits in

Wyoming (Katzner and Parker 1997). Habitat selection results in my study were also consistent with those in Idaho where this species used significantly greater ($P \leq 0.01$) woody vegetation cover ($\bar{x}$ = 46.0%, n = 6) than sites selected at random ($\bar{x}$ = 27.8%, n = 30) (Green and Flinders 1980b). In my study, however, mean shrub cover in areas utilized by pygmy rabbits ($\bar{x}$ = 32.28%, SE = 1.00, n = 178) was less than estimates reported by Green and Flinders (1980b). Differences in habitat measurements among these pygmy rabbit studies may reflect the different methods used and/or fine scale vegetative differences among study sites. In addition to this species' dependence on big sagebrush for food, pygmy rabbits may select taller and more structurally diverse shrub communities because they facilitate predator avoidance (Katzner and Parker 1997). Shade provided by greater shrub cover may also enable this species to regulate body temperatures during thermal extremes (Green and Flinders 1980b, Katzner and Parker 1997).

Due to the burrowing behavior of pygmy rabbits, specific soil characteristics also influenced their habitat selection. Soils comprised of greater silt and less clay were selected in this study. Sand content in the soil was not directly selected for by pygmy rabbits in this study; however, the loose soils found in areas with lower clay content would facilitate burrowing. Additionally, sand content was negatively correlated with silt (r = -0.77) and clay (r = -0.70) content (Appendix N). These patterns were more similar to those reported for pygmy rabbits in eastern and southeastern Oregon (Weiss and Verts 1984) than for those in Wyoming (Purcell 2006). Weiss and Verts (1984) reported that areas occupied ($\bar{x}$ = 22.8%, SE = 2.7, n = 13) by this species in Oregon had significantly ($P < 0.05$) less clay content in subsurface soils than adjacent unused areas ($\bar{x}$ = 30.5%, SE = 3.5, n = 21), while sand and silt content did not differ. In contrast, rabbits in Wyoming used areas that had similar surface and subsurface soil textures to unused areas (Purcell 2006). Sampling plots representing use in my study were randomly chosen from surface locations of radio-marked individuals, which may not assess soil characteristics used by this species as well as samples collected directly from active burrows (see below).

There was little evidence to suggest that the amount of understory cover of annual grasses, forbs, litter, bare ground, rocks, moss, short shrubs (<30 cm), or biological crust were important in habitat selection by pygmy rabbits. Contrary to my predictions, annual grass and forb cover were not factors that distinguished sites used from other available areas in this study. In my study, the absence of annual grass and/or forb cover from the habitat selection models may be due to the timing of sampling, which occurred from September 2006 – April 2007. However, there was some evidence that the species was associated with higher cover of perennial native grasses. Grasses and forbs have been shown to be important foods during the spring and early summer (Green and Flinders 1980b). Cover of perennial native grasses, rocks, litter, and bare ground had 95% CI for odds ratios that minimally included 1.0 (Figure 5.2) suggesting they may be biologically important determinants of rabbit use, but I lacked the sample size and precision to detect significant differences. The percent basal area of perennial grasses, density of annual grasses, and density of forbs were also not significantly different between areas pygmy rabbits occupied and adjacent unused areas in eastern and southeastern Oregon (Weiss and Verts 1984). In contrast, forb cover ($\bar{x}$ = 7.06%, SE = 1.09, n = 9) at pygmy rabbit burrows in southeastern Idaho was significantly (F = 5.39, P = 0.01) greater than low use areas ($\bar{x}$ = 4.51%, SE = 0.59, n = 8) (Heady et al. 2001), both of which were greater than within used areas in my study ($\bar{x}$ = 1.57%, SE = 0.14, n = 178). In addition, this species rarely used low sagebrush *(Artemisia arbuscula)* communities that often occur on shallow soils in rocky areas, as these shrubs do not reach heights and densities that pygmy rabbits appear to select, or occur on soils that are not conducive to burrow construction (see below). However, radio-marked rabbits were occasionally observed foraging on forbs and low sagebrush in these vegetative communities.

Soils Characteristics at Burrows

Attributes of soils at burrows used by pygmy rabbits may more appropriately evaluate those soil characteristics that influence habitat selection. In this study, soils at burrows had less clay content than available sites, which may be associated with easier burrow excavation. Similarly, areas rarely used ($\bar{x}$ = 14.4%, n = 9) by pygmy rabbits in Idaho had a significantly (F = 5.540, P = 0.010) greater clay component than burrows ($\bar{x}$ = 5.1%, n = 9) (Heady et al. 2001), which was less than burrows in my study ($\bar{x}$ = 15.02%, SE = 0.53, n = 125). There was no evidence of a difference in sand or silt content between burrows and available plots in my study. In contrast, rabbit burrows on Hart Mountain National Antelope Refuge, Oregon, had a significantly (95% CI Odds Ratio: 1.06 – 1.34) greater proportion of sand ($\bar{x}$ = 50.16%, SE = 1.05, n = 45) than unoccupied areas ($\bar{x}$ = 45.52%, SE = 1.19, n = 45) (Meisel 2006). Soils at burrows were also significantly ($F_{2,397}$ = 21.64, P < 0.0001) deeper than available areas in this study, a result consistent with pygmy rabbit burrows in eastern and southeastern Oregon, which were 20.0 cm deeper than unused areas (Burrow: $\bar{x}$ = 51.0 cm, SE = 2.3, n = 13; Unused: $\bar{x}$ = 31.0 cm, SE = 3.1, n = 21) (Weiss and Verts 1984). Soil depths at burrows in my study, however, were considerably deeper ($\bar{x}$ = 68.34 cm, SE = 2.27, n = 125) than those reported by Weiss and Verts (1984). My results were also consistent with areas exhibiting active burrows and fresh evidence of pygmy rabbit use in Nevada, which had significantly (P = 0.012) deeper soils than sites without sign (Himes and Drohan 2007). In Nevada, deep soils ($\bar{x}$ = 123 cm, SE = 1.82), conducive to rabbit burrowing, accumulated near perennial streams and on northerly aspects, where southerly prevailing winds, common to the Great Basin, tended to deposit more wind-blown soil (Wilde 1978, Himes and Drohan 2007). Finally, soil strength at the surface was lower at burrows than available sites in this study, while soil strength at subsurface depths was greater at burrows than soils in available sites. Low soil strength at the surface likely facilitates burrowing, while greater strengths below the surface may contribute to the long-term stability of burrows. In contrast, pygmy rabbit burrows (n = 13) in eastern and southeastern Oregon had lower soil strengths at the surface ($\bar{x}$ = 0.8 kg/cm^2, SE = 0.2) and subsurface ($\bar{x}$ = 3.8 kg/cm^2, SE = 0.3) than unused areas (Surface: $\bar{x}$ = 1.9 kg/cm^2, SE = 0.4; Subsurface: $\bar{x}$ = 4.6 kg/cm^2, SE = 0.2; n = 21) (Weiss and Verts 1984). Further investigation is needed to evaluate the effect of soil strength on burrow construction of pygmy rabbits.

Management Implications

Results from this study and previous investigations (Green and Flinders 1980b, Katzner and Parker 1997, Gabler et al. 2001, Heady and Laundre 2005, Himes and Drohan 2007) indicate that this species should be considered a habitat specialist within shrub-steppe communities. Based on the narrow vegetative and soil characteristics pygmy rabbits select, segments of this species' current geographic range are probably not suitable habitat. Further, existing vegetative and soils information available throughout the Great Basin is generally coarse, limiting the success of GIS modeling in identifying areas of potential use by pygmy rabbits (Gabler et al. 2000, Meisel 2006).

Conservation of this species is incumbent on our ability to identify suitable habitat and areas occupied by this species.

Habitat use patterns of pygmy rabbits in this study may be useful to manage this species and their habitat in sagebrush-steppe communities. The high habitat specificity of this species and the heterogeneous distribution of tall, dense stands of big sagebrush throughout the Great Basin substantially limits the areas that are considered suitable habitat within this species' range. Given the heightened concern over the status of this species throughout its range, and notably low annual survival (see Chapter 3), conservation efforts should focus on the long-term persistence of suitable habitat and identification of active pygmy rabbit populations. Prior land-use practices have directly (i.e. human development and agricultural conversions) and indirectly (i.e. grazing, spread of invasive plants, and wildfire) impacted the habitat of pygmy rabbits and other sagebrush obligate species (Knick et al. 2003, Crawford et al. 2004). Consequently, practices that alter or diminish suitable habitat conditions should be evaluated, and restoration of these habitats should be considered. Careful consideration should also be given to minimize habitat fragmentation and maintain habitat patches of adequate size and connectivity for the conservation of this species.

CHAPTER 6

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Justin A. Crawford

SUMMARY

The pygmy rabbit *(Brachylagus idahoensis)* is a big sagebrush *(Artemisia tridentata* spp.*)* habitat specialist for which data on survival, movements, and habitat associations are limited (Dobler and Dixon 1990, U.S. Fish and Wildlife Service 2005). As a result of their specific habitat associations, the distribution of this species is disjunct, and its current range is thought to have shrunk substantially from historical distributions (Verts and Carraway 1998). Pygmy rabbit abundances have declined throughout most of its range (Dobler and Dixon 1990) resulting in their designation as a *Federal Species of Concern* by the U.S. Fish and Wildlife Service (USFWS). Given the concern over the status and conservation of this species throughout its range, I investigated survival, movements, home range sizes, and habitat selection of pygmy rabbits (*Brachylagus idahoensis*) in southeastern Oregon and northwestern Nevada from June 2005 to June 2007. I trapped and radio-marked 298 pygmy rabbits (132 male, 166 female) on four study sites (Dixon, Fish Creek, Spaulding, and West Gulch). More than 13,000 locations of radio-marked rabbits were recorded during my study.

I used known fate models in program MARK to estimate survival of radio-marked pygmy rabbits from September 2005 – August 2006. The most appropriate model, based on Akaike's Information Criterion (AIC_c), indicated survival rates varied among study sites, sexes, and with monthly interval in a parallel pattern [model *S*(area * sex + t)]. The estimated annual survival rate on the four study sites was notably low, varying from 0.003 (SE = 0.003, 95% CI: 0.0003 – 0.023) to 0.173 (SE = 0.066, 95% CI: 0.078 – 0.342). Monthly survival rates varied from 0.328 (SE = 0.085, 95% CI: 0.186 – 0.509) for males on Dixon in May 2006 to 0.988 (SE = 0.012, 95% CI: 0.916 – 0.998) for females on Spaulding in June 2006. Annual and monthly survival rates of female rabbits were significantly greater than those of males ($\hat{\beta}$ = 0.746, SE = 0.043,

95% CI: 0.663 – 0.829) based on model *S*(sex). Predation of radio-marked rabbits was high for both adult (88.6%) and juvenile (89.4%) rabbits. When cause of mortality could be determined, the most common predators of pygmy rabbits were coyotes (*Canis latrans*)–19.6%, avian predators–18.5%, and weasels (*Mustela* spp.)–9.8%. Different predators were responsible for two periods of low survival during November 2005 – January 2006 and April – May 2006. During the winter, weasels and to a lesser extent coyotes were the most common predator, whereas raptors were responsible for the majority of the mortality during spring.

Spatial use by pygmy rabbits was strongly influenced by sex and season. Males used larger annual ($\bar{x}$ = 1.70 ha, SE = 0.69) and breeding ($\bar{x}$ = 1.67 ha, SE = 0.27) home ranges than females (Annual: $\bar{x}$ = 0.90 ha, SE = 0.26; Breeding: $\bar{x}$ = 0.92 ha, SE = 0.16). Both sexes utilized larger home ranges during the breeding season than during the nonbreeding season (Male: $\bar{x}$ = 0.63 ha, SE = 0.11; Female: $\bar{x}$ = 0.50 ha, SE = 0.09). Mate-searching behaviors likely were responsible for the larger home range sizes of males and may have influenced their poorer survival. Core area sizes of males ($\bar{x}$ = 0.10, SE = 0.04) were also larger than females ($\bar{x}$ = 0.07, SE = 0.03). Additionally, there was evidence of a difference in annual and breeding home range sizes among study sites, which may be explained by differences in habitat characteristics. Twenty-four radio-marked individuals dispersed greater than 0.5 km, with a maximal observed dispersal distance of 8.5 km. Twenty-one (88%) of these long-distance movements were classified as juvenile dispersals and occurred from June through October ($\bar{x}$ = 1.78 km, SE = 0.36, range = 0.50 – 8.50 km); the majority (71.4%) of these dispersals were by juvenile males. Although the exact routes taken by these individuals were not documented, many of these individuals apparently crossed low sagebrush *(Artemisia arbuscula* spp.*)* communities and relatively open areas, vegetative communities generally considered unsuitable for pygmy rabbits. The ability of this species to cross unsuitable habitats, previously considered barriers to movement, may suggest fragmented populations of *B. idahoensis* may not be as isolated as once thought (Katzner and Parker 1998).

To examine resource selection by pygmy rabbits, I sampled vegetative and soil characteristics at locations used by radio-marked rabbits ($n = 178$) and available ($n = 100$) sites and compared them using logistic regression. Habitat selection varied among study sites, as I did not find a consensus model that described habitat selection of pygmy rabbits for each study site. Specific variables or functional categories that were included in the study-wide habitat selection model were, however, generally represented in the best models for each study site. Consistent with the study-wide model, greater density of live shrubs was included in the Fish Creek, Spaulding, and West Gulch habitat models, while percent cover of live shrubs, a surrogate of density ($r = 0.61$), was included in the Dixon model. The top model describing study-wide habitat selection indicated that increased density and height of live shrubs, high silt content of soil, and lower clay content of soil were the primary factors related to pygmy rabbit occupation. Individuals selected areas that were more densely occupied by live shrubs ($\bar{x} = 1.15$ shrubs/m^2, 95% CI: 1.07 – 1.23) than other available areas ($\bar{x} = 0.74$ shrubs/m^2, 95% CI: 0.66 – 0.82) and had taller live shrubs ($\bar{x} = 67.14$ cm, 95% CI: 65.10 – 69.18) than random locations ($\bar{x} = 58.27$ cm, 95% CI: 54.78 – 61.76). The silt content of soils in areas used by rabbits ($\bar{x} = 27.41\%$, 95% CI: 26.26 – 28.56) was higher than random locations ($\bar{x} = 24.89\%$, 95% CI: 23.27 – 26.51), while occupied sites ($\bar{x} = 16.76\%$, 95% CI: 15.79 – 17.73) contained 2.55% less clay than randomly selected areas ($\bar{x} = 19.31\%$, 95% CI: 17.77 – 20.85). My analysis further demonstrated that soils at pygmy rabbit burrows were deeper ($\bar{x} = 68.34$ cm, 95% CI:

63.85 – 72.84), had a lower clay content ($\bar{x}$ = 15.02%, 95% CI: 13.97 – 16.07), greater subsurface strengths ($\bar{x}$ = 1.50 g/cm^3, 95% CI: 1.48 – 1.52), and lower strengths at the surface ($\bar{x}$ = 1.12 g/cm^3, 95% CI: 1.10 – 1.13) than was randomly available in the study area (Depth: $\bar{x}$ = 45.83 cm, 95% CI: 40.76 – 50.90; Clay: $\bar{x}$ = 19.31%, 95% CI: 17.77 – 20.85; Subsurface strength: $\bar{x}$ = 1.45 g/cm^3, 95% CI: 1.44 – 1.47; Surface strength: $\bar{x}$ = 1.24 g/cm^3, 95% CI: 1.20 – 1.28).

MANAGEMENT RECOMMENDATIONS AND FUTURE RESEARCH

Annual and monthly survival rates of pygmy rabbits in southeastern Oregon and northwestern Nevada were extremely low during my study. Survival rates varied monthly and across fine spatial scales, suggesting local populations are susceptible to rapid declines and local extirpation (Weiss and Verts 1984). Consequently, I recommend that land managers conduct repeated surveys of several populations during all seasons to account for both temporal and spatial variability and document local trends in pygmy rabbit abundances. A more thorough understanding of factors influencing survival rates of this species may help management agencies understand population fluctuations. Future investigations should identify habitat characteristics that may influence survival of this species. Additionally, research is needed to evaluate the effects that habitat alterations (burning, mowing, chemical) and livestock grazing may have on survival.

Due to the habitat associations of pygmy rabbits with tall sagebrush, the relatively small home range sizes and core areas used, and the fragmented space use observed in this study, habitat manipulations within these areas may negatively influence their spatial use patterns and survival. This prediction needs to be tested further. My study reports apparent movements and dispersal distances that were greater than most previous studies, as well as travel across vegetative communities without shrub cover. Further, routes taken during long-distance movements suggest that habitat fragmentation and natural heterogeneity may influence dispersal patterns, and this should be considered in the management of habitat for this species. Due to the known population fluctuations and the dispersal abilities and spatial use reported in this study, I recommend that land mangers conduct thorough and repeated surveys for this species prior to any habitat manipulations that could further reduce and fragment tall sagebrush communities. Information on movement capabilities and barriers to dispersal for pygmy rabbits will improve our understanding of their role in maintaining gene flow between subpopulations. To this end, future studies should investigate these barriers and the genetic relatedness of neighboring subpopulations. Pygmy rabbit populations may function as metapopulations (Gilpin 1991), which may explain how populations of this species are maintained over generations.

The high habitat specificity of this species and the heterogeneous distribution of tall, dense stands of big sagebrush throughout the Great Basin limits the areas that are considered suitable habitat within this species' range. Given the concern over the status of this species throughout its range, conservation efforts should focus on the long-term persistence of appropriate habitat and identification of active pygmy rabbit populations. Human land-use practices directly (i.e. human development and agricultural conversions) and indirectly (i.e. grazing, spread of exotic plants, and wildfire) impact the management and conservation of pygmy rabbits and other sagebrush obligate species (Knick et al. 2003, Crawford et al. 2004). Consequently, maintenance of sustainable populations of this species should be a management objective, so practices that alter or diminish habitat should be evaluated and restoration of modified habitats should be considered. Careful consideration should also be given to minimize habitat fragmentation and maintain habitat patches of adequate size and connectivity for the conservation of this species.

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APPENDICES

Appendix A. Input file for survival analysis in program MARK.

```
/* SE Oregon; NW Nevada Pygmy Rabbit Telemetry Data; September 2005 - August 2006
 Animal #; September 2005 - August 2006 Survival
 Groups:  Dixon (M/F); Fish Creek (M/F); Spaulding (M/F); West Gulch (M/F)
 Covariates:  Adult; Juvenile; Weight (kg); Ear Length (cm); Foot Length (cm); Total Length (m);
Mass/Length (kg/m) */

/* D01 */ 101011000000000000000000 0 1 0 0 0 0 0 0 1 0 0.515 5.1 6.7 0.250 2.060 ;
/* D02 */ 101011000000000000000000 0 1 0 0 0 0 0 0 1 0 0.380 5.1 6.7 0.240 1.583 ;
/* D03 */ 101100000000000000000000 0 1 0 0 0 0 0 0 1 0 0.440 5.1 6.7 0.240 1.833 ;
/* D04 */ 101011000000000000000000 1 0 0 0 0 0 0 0 1 0 0.375 5.2 6.7 0.230 1.630 ;
/* D05 */ 101010101010101010101100 0 1 0 0 0 0 0 0 1 0 0.410 5.1 6.7 0.270 1.519 ;
/* D06 */ 101100000000000000000000 1 0 0 0 0 0 0 0 0 1 0.332 5.2 6.4 0.214 1.551 ;
/* D12 */ 100000000000000000000000 0 1 0 0 0 0 0 0 0 1 0.335 5.0 6.6 0.209 1.603 ;
/* D13 */ 101011000000000000000000 1 0 0 0 0 0 0 0 0 1 0.315 4.7 5.0 0.227 1.388 ;
/* D14 */ 101100000000000000000000 1 0 0 0 0 0 0 0 0 1 0.336 4.6 6.5 0.215 1.563 ;
/* D15 */ 101100000000000000000000 1 0 0 0 0 0 0 0 0 1 0.353 5.3 6.7 0.217 1.627 ;
/* D16 */ 101011000000000000000000 0 1 0 0 0 0 0 0 1 0 0.518 4.8 7.0 0.281 1.843 ;
/* D19 */ 101100000000000000000000 1 0 0 0 0 0 0 0 0 1 0.330 5.1 6.9 0.205 1.610 ;
/* D21 */ 101010110000000000000000 1 0 0 0 0 0 0 0 1 0 0.444 5.2 7.3 0.228 1.947 ;
/* D22 */ 101100000000000000000000 0 1 0 0 0 0 0 0 0 1 0.245 4.8 6.5 0.189 1.296 ;
/* D26 */ 101010101010101010101010 0 1 0 0 0 0 0 0 1 0 0.509 5.1 7.0 0.229 2.223 ;
/* D27 */ 110000000000000000000000 1 0 0 0 0 0 0 0 1 0 0.420 5.2 6.7 0.217 1.935 ;
/* D28 */ 101011000000000000000000 0 1 0 0 0 0 0 0 1 0 0.425 5.2 7.3 0.235 1.809 ;
/* D29 */ 101010110000000000000000 1 0 0 0 0 0 0 0 1 0 0.403 4.7 6.6 0.213 1.892 ;
/* D30 */ 110000000000000000000000 0 1 0 0 0 0 0 0 1 0 0.528 5.0 6.7 0.210 2.514 ;
/* D31 */ 101011000000000000000000 1 0 0 0 0 0 0 0 1 0 0.415 5.1 6.7 0.202 2.054 ;
/* D32 */ 101011000000000000000000 1 0 0 0 0 0 0 0 0 1 0.345 5.2 6.9 0.213 1.620 ;
/* D33 */ 101100000000000000000000 1 0 0 0 0 0 0 0 1 0 0.422 5.7 7.5 0.242 1.744 ;
/* D34 */ 101100000000000000000000 0 1 0 0 0 0 0 0 0 1 0.260 5.0 6.0 0.191 1.361 ;
/* D35 */ 101100000000000000000000 0 1 0 0 0 0 0 0 1 0 0.530 5.7 7.1 0.225 2.356 ;
/* D38 */ 100000000000000000000000 1 0 0 0 0 0 0 0 0 1 0.342 5.3 6.4 0.200 1.710 ;
/* D39 */ 101100000000000000000000 1 0 0 0 0 0 0 0 0 1 0.280 5.1 5.9 0.201 1.393 ;
/* D40 */ 110000000000000000000000 0 1 0 0 0 0 0 0 0 1 0.269 4.6 5.4 0.200 1.345 ;
/* D41 */ 000011000000000000000000 0 1 0 0 0 0 0 0 0 1 0.315 5.0 6.5 0.194 1.624 ;
/* D42 */ 000010101010101100000000 0 1 0 0 0 0 0 0 0 1 0.345 5.4 7.0 0.218 1.583 ;
/* D43 */ 000010110000000000000000 1 0 0 0 0 0 0 0 1 0 0.435 4.9 6.9 0.220 1.977 ;
/* D44 */ 000010110000000000000000 1 0 0 0 0 0 0 0 0 1 0.325 5.2 7.1 0.245 1.327 ;
/* D45 */ 000010110000000000000000 1 0 0 0 0 0 0 0 1 0 0.410 5.3 7.1 0.205 2.000 ;
/* D47 */ 000000101010101100000000 1 0 0 0 0 0 0 0 1 0 0.405 5.0 7.0 0.234 1.731 ;
/* D48 */ 000000101010101010101010 0 1 0 0 0 0 0 0 1 0 0.420 5.4 7.1 0.215 1.953 ;
/* D49 */ 000000101010101100000000 0 1 0 0 0 0 0 0 1 0 0.395 5.4 6.9 0.195 2.026 ;
/* D50 */ 000000101010101011000000 0 1 0 0 0 0 0 0 1 0 0.420 5.5 7.1 0.211 1.991 ;
/* D53 */ 000000001010101100000000 1 0 0 0 0 0 0 0 1 0 0.405 5.8 7.6 0.215 1.884 ;
/* D54 */ 000000001100000000000000 1 0 0 0 0 0 0 0 1 0 0.385 5.4 6.4 0.220 1.750 ;
/* D55 */ 000000001010110000000000 0 1 0 0 0 0 0 0 1 0 0.365 5.0 7.4 0.210 1.738 ;
/* D57 */ 000000000010101010101011 0 1 0 0 0 0 0 0 1 0 0.390 5.4 7.2 0.213 1.831 ;
/* D58 */ 000000000010110000000000 1 0 0 0 0 0 0 0 1 0 0.420 5.5 6.8 0.215 1.953 ;
/* D60 */ 000000000010101010101100 0 1 0 0 0 0 0 0 1 0 0.385 4.4 6.9 0.240 1.604 ;
/* D61 */ 000000000010101100000000 0 1 0 0 0 0 0 0 0 1 0.340 5.2 7.1 0.204 1.667 ;
/* D62 */ 000000000010101011000000 1 0 0 0 0 0 0 0 1 0 0.420 5.5 7.1 0.225 1.867 ;
/* D63 */ 000000000010101010101010 0 1 0 0 0 0 0 0 1 0 0.410 5.4 6.7 0.256 1.602 ;
/* D64 */ 000000000010101010101010 1 0 0 0 0 0 0 0 1 0 0.455 5.4 7.5 0.210 2.167 ;
```

Appendix A. continued.

```
/* D65 */ 000000000000110000000000 1 0 0 0 0 0 0 0 0 1 0.350 5.0 7.2 0.205 1.707 ;
/* D66 */ 000000000000000011000000 1 0 0 0 0 0 0 0 1 0 0.339 5.2 6.8 0.212 1.599 ;
/* D67 */ 000000000000000011000000 1 0 0 0 0 0 0 0 1 0 0.348 5.2 6.7 0.223 1.561 ;
/* D69 */ 000000000000000011000000 0 1 0 0 0 0 0 0 1 0 0.432 5.2 7.4 0.227 1.903 ;
/* D70 */ 000000000000000000101100 1 0 0 0 0 0 0 0 1 0 0.290 5.0 6.6 0.205 1.415 ;
/* D71 */ 000000000000000000101010 0 1 0 0 0 0 0 0 1 0 0.465 5.8 7.1 0.242 1.921 ;
/* D72 */ 000000000000000000101010 1 0 0 0 0 0 0 0 1 0 0.355 5.1 6.8 0.210 1.690 ;
/* D73 */ 000000000000000000001010 0 1 0 0 0 0 0 0 0 1 0.290 4.6 5.1 0.210 1.381 ;
/* D74 */ 000000000000000000101010 1 0 0 0 0 0 0 0 1 0 0.380 5.2 6.5 0.250 1.520 ;
/* D75 */ 000000000000000000101100 1 0 0 0 0 0 0 0 1 0 0.390 5.2 6.8 0.240 1.625 ;
/* D77 */ 000000000000000000001010 1 0 0 0 0 0 0 0 1 0 0.420 5.3 6.3 0.235 1.787 ;
/* D78 */ 000000000000000000001010 1 0 0 0 0 0 0 0 0 1 0.210 4.6 4.9 0.170 1.235 ;
/* D79 */ 000000000000000000001010 0 1 0 0 0 0 0 0 0 1 0.285 4.6 5.5 0.205 1.390 ;
/* D80 */ 000000000000000000001010 1 0 0 0 0 0 0 0 1 0 0.420 5.3 6.5 0.235 1.787 ;
/* D81 */ 000000000000000000001100 1 0 0 0 0 0 0 0 1 0 0.455 5.3 6.8 0.230 1.978 ;
/* D83 */ 000000000000000000001010 0 1 0 0 0 0 0 0 0 1 0.330 5.1 6.2 0.210 1.571 ;
/* D84 */ 000000000000000000000010 1 0 0 0 0 0 0 0 0 1 0.265 4.6 5.9 0.200 1.325 ;
/* D85 */ 000000000000000000000011 1 0 0 0 0 0 0 0 0 1 0.255 4.9 5.9 0.195 1.308 ;
/* D86 */ 000000000000000000000010 0 1 0 0 0 0 0 0 0 1 0.335 4.9 6.1 0.220 1.523 ;
/* F04 */ 110000000000000000000000 0 0 0 1 0 0 0 0 0 1 0.282 4.7 6.2 0.165 1.709 ;
/* F05 */ 101010101010101100000000 0 0 0 1 0 0 0 0 1 0 0.437 5.0 6.7 0.214 2.042 ;
/* F06 */ 101010101011000000000000 0 0 1 0 0 0 0 0 0 1 0.305 5.0 6.5 0.184 1.658 ;
/* F07 */ 101010101010101100000000 0 0 0 1 0 0 0 0 0 1 0.360 5.1 6.2 0.192 1.875 ;
/* F11 */ 101010101010110000000000 0 0 1 0 0 0 0 0 0 1 0.339 5.4 6.6 0.193 1.756 ;
/* F14 */ 101010101010101100000000 0 0 1 0 0 0 0 0 0 1 0.328 5.3 6.9 0.191 1.717 ;
/* F16 */ 101011000000000000000000 0 0 0 1 0 0 0 0 0 1 0.375 5.0 6.6 0.200 1.875 ;
/* F17 */ 101011000000000000000000 0 0 1 0 0 0 0 0 0 1 0.362 5.5 7.0 0.191 1.895 ;
/* F18 */ 101010101010101100000000 0 0 0 1 0 0 0 0 1 0 0.505 5.2 7.1 0.257 1.965 ;
/* F19 */ 101010101010101011000000 0 0 1 0 0 0 0 0 1 0 0.420 5.3 6.9 0.211 1.991 ;
/* F20 */ 101011000000000000000000 0 0 1 0 0 0 0 0 1 0 0.379 5.2 7.0 0.235 1.613 ;
/* F21 */ 101011000000000000000000 0 0 1 0 0 0 0 0 0 1 0.259 5.1 5.9 0.189 1.370 ;
/* F22 */ 101010101011000000000000 0 0 0 1 0 0 0 0 0 1 0.287 5.1 5.8 0.175 1.640 ;
/* F23 */ 101011000000000000000000 0 0 0 1 0 0 0 0 0 1 0.362 4.8 6.6 0.204 1.775 ;
/* F24 */ 101010101010101100000000 0 0 1 0 0 0 0 0 0 1 0.344 5.1 6.8 0.230 1.496 ;
/* F25 */ 101010101010101100000000 0 0 0 1 0 0 0 0 1 0 0.435 5.0 6.3 0.217 2.005 ;
/* F26 */ 101011000000000000000000 0 0 1 0 0 0 0 0 1 0 0.414 5.3 7.0 0.197 2.102 ;
/* F27 */ 101011000000000000000000 0 0 0 1 0 0 0 0 0 1 0.319 5.4 6.4 0.204 1.564 ;
/* F28 */ 101011000000000000000000 0 0 0 1 0 0 0 0 0 1 0.380 5.2 6.3 0.220 1.727 ;
/* F29 */ 101010101010101100000000 0 0 0 1 0 0 0 0 0 1 0.376 5.2 6.5 0.209 1.799 ;
/* F30 */ 001010101010101100000000 0 0 1 0 0 0 0 0 1 0 0.424 5.4 6.6 0.216 1.963 ;
/* F31 */ 001010110000000000000000 0 0 1 0 0 0 0 0 1 0 0.407 5.3 6.8 0.212 1.920 ;
/* F32 */ 001011000000000000000000 0 0 0 1 0 0 0 0 1 0 0.402 5.0 6.5 0.215 1.870 ;
/* F33 */ 001010101100000000000000 0 0 0 1 0 0 0 0 1 0 0.392 5.5 7.2 0.215 1.823 ;
/* F34 */ 001100000000000000000000 0 0 0 1 0 0 0 0 1 0 0.431 5.5 7.3 0.220 1.959 ;
/* F35 */ 001010101010110000000000 0 0 0 1 0 0 0 0 0 1 0.331 5.1 6.3 0.199 1.663 ;
/* F38 */ 001011000000000000000000 0 0 1 0 0 0 0 0 1 0 0.390 5.0 7.1 0.230 1.696 ;
/* F39 */ 001010101010101011000000 0 0 0 1 0 0 0 0 1 0 0.440 5.3 7.4 0.195 2.256 ;
/* F40 */ 000000000010101011000000 0 0 1 0 0 0 0 0 1 0 0.385 5.0 6.5 0.230 1.674 ;
/* F41 */ 000000000010101011000000 0 0 1 0 0 0 0 0 0 1 0.320 5.3 6.8 0.195 1.641 ;
/* F42 */ 000000000010101010101100 0 0 1 0 0 0 0 0 1 0 0.420 5.4 7.1 0.225 1.867 ;
/* F43 */ 000000000010101100000000 0 0 1 0 0 0 0 0 1 0 0.420 5.1 7.4 0.230 1.826 ;
/* F44 */ 000000000010101011000000 0 0 0 1 0 0 0 0 0 1 0.325 4.9 6.0 0.200 1.625 ;
```

Appendix A. continued.

```
/* F45 */ 000000000010101011000000 0 0 0 1 0 0 0 0 1 0 0.375 4.9 6.8 0.205 1.829 ;
/* F46 */ 000000000010101100000000 0 0 0 1 0 0 0 0 0 1 0.340 5.0 6.8 0.235 1.447 ;
/* F47 */ 000000000010110000000000 0 0 1 0 0 0 0 0 1 0 0.390 5.4 7.1 0.220 1.773 ;
/* F48 */ 000000000010101100000000 0 0 1 0 0 0 0 0 1 0 0.395 5.6 7.0 0.210 1.881 ;
/* F49 */ 000000000010101100000000 0 0 0 1 0 0 0 0 1 0 0.380 5.4 6.8 0.205 1.854 ;
/* F51 */ 000000000000001100000000 0 0 0 1 0 0 0 0 1 0 0.465 5.2 7.0 0.210 2.214 ;
/* F53 */ 000000000000000000101010 0 0 0 1 0 0 0 0 1 0 0.395 5.1 6.9 0.207 1.908 ;
/* F54 */ 000000000000000000110000 0 0 0 1 0 0 0 0 1 0 0.455 5.5 7.2 0.240 1.896 ;
/* F55 */ 000000000000000000001010 0 0 0 1 0 0 0 0 0 1 0.245 4.7 5.2 0.205 1.195 ;
/* F57 */ 000000000000000000101010 0 0 0 1 0 0 0 0 0 1 0.220 4.2 4.9 0.180 1.222 ;
/* F60 */ 000000000000000000101010 0 0 1 0 0 0 0 0 1 0 0.360 5.2 6.5 0.235 1.532 ;
/* F64 */ 000000000000000000001010 0 0 1 0 0 0 0 0 1 0 0.335 5.3 6.4 0.220 1.523 ;
/* F65 */ 000000000000000000001010 0 0 1 0 0 0 0 0 0 1 0.300 4.8 6.4 0.210 1.429 ;
/* F67 */ 000000000000000000001011 0 0 0 1 0 0 0 0 0 1 0.270 4.7 6.0 0.190 1.421 ;
/* F69 */ 000000000000000000001010 0 0 0 1 0 0 0 0 0 1 0.270 5.0 6.2 0.182 1.484 ;
/* F70 */ 000000000000000000001010 0 0 1 0 0 0 0 0 0 1 0.295 4.9 6.0 0.210 1.405 ;
/* F71 */ 000000000000000000000010 0 0 1 0 0 0 0 0 1 0 0.395 5.3 6.8 0.240 1.646 ;
/* F72 */ 000000000000000000000011 0 0 0 1 0 0 0 0 0 1 0.255 4.7 6.3 0.175 1.457 ;
/* F73 */ 000000000000000000000010 0 0 1 0 0 0 0 0 0 1 0.295 5.3 6.3 0.215 1.372 ;
/* F76 */ 000000000000000000000011 0 0 1 0 0 0 0 0 1 0 0.355 5.3 7.2 0.225 1.578 ;
/* F77 */ 000000000000000000000010 0 0 1 0 0 0 0 0 1 0 0.350 5.3 7.0 0.205 1.707 ;
/* F78 */ 000000000000000000000010 0 0 0 1 0 0 0 0 0 1 0.320 5.2 7.1 0.186 1.720 ;
/* F79 */ 000000000000000000000010 0 0 0 1 0 0 0 0 1 0 0.480 5.0 6.0 0.227 2.115 ;
/* G02 */ 101010101010101100000000 0 0 0 0 0 0 0 1 1 0 0.500 5.1 6.9 0.258 1.938 ;
/* G04 */ 101100000000000000000000 0 0 0 0 0 0 1 0 0 1 0.365 4.2 6.7 0.216 1.690 ;
/* G05 */ 101010110000000000000000 0 0 0 0 0 0 0 1 1 0 0.445 4.6 6.5 0.242 1.839 ;
/* G07 */ 101010101010101010101100 0 0 0 0 0 0 0 1 1 0 0.370 5.0 6.5 0.260 1.423 ;
/* G08 */ 101010101100000000000000 0 0 0 0 0 0 0 1 1 0 0.505 4.5 6.9 0.258 1.957 ;
/* G09 */ 101010101010101011000000 0 0 0 0 0 0 1 0 0 1 0.295 4.7 6.0 0.215 1.372 ;
/* G10 */ 101100000000000000000000 0 0 0 0 0 0 1 0 1 0 0.435 4.9 6.3 0.235 1.851 ;
/* G12 */ 101011000000000000000000 0 0 0 0 0 0 0 1 1 0 0.470 5.1 7.2 0.261 1.801 ;
/* G13 */ 101010101100000000000000 0 0 0 0 0 0 0 1 1 0 0.515 5.0 7.7 0.250 2.060 ;
/* G15 */ 101010101010101100000000 0 0 0 0 0 0 0 1 1 0 0.400 5.4 6.8 0.229 1.747 ;
/* G16 */ 101010101010101010101010 0 0 0 0 0 0 0 1 1 0 0.440 5.2 5.9 0.246 1.789 ;
/* G17 */ 101011000000000000000000 0 0 0 0 0 0 0 1 1 0 0.515 5.1 6.7 0.239 2.155 ;
/* G19 */ 101010101010101011000000 0 0 0 0 0 0 0 1 1 0 0.457 5.5 6.8 0.235 1.945 ;
/* G20 */ 101011000000000000000000 0 0 0 0 0 0 1 0 1 0 0.480 4.8 6.7 0.292 1.644 ;
/* G22 */ 101010101010101100000000 0 0 0 0 0 0 0 1 1 0 0.371 5.0 6.7 0.213 1.742 ;
/* G23 */ 100000000000000000000000 0 0 0 0 0 0 1 0 1 0 0.395 5.1 6.5 0.220 1.795 ;
/* G24 */ 101010101100000000000000 0 0 0 0 0 0 0 1 1 0 0.340 5.0 6.7 0.226 1.504 ;
/* G26 */ 101010101010101100000000 0 0 0 0 0 0 1 0 1 0 0.295 4.7 6.0 0.203 1.453 ;
/* G27 */ 101010101010101010101011 0 0 0 0 0 0 0 1 0 1 0.360 4.9 6.4 0.235 1.532 ;
/* G28 */ 001010101010101100000000 0 0 0 0 0 0 0 1 0 1 0.320 4.9 6.1 0.209 1.531 ;
/* G31 */ 101011000000000000000000 0 0 0 0 0 0 0 1 0 1 0.322 4.7 6.5 0.218 1.477 ;
/* G32 */ 101010101010101100000000 0 0 0 0 0 0 0 1 1 0 0.460 4.8 6.8 0.243 1.893 ;
/* G33 */ 101010101100000000000000 0 0 0 0 0 0 1 0 1 0 0.425 5.5 7.2 0.227 1.872 ;
/* G35 */ 101011000000000000000000 0 0 0 0 0 0 0 1 1 0 0.410 5.3 6.8 0.209 1.962 ;
/* G36 */ 101010101100000000000000 0 0 0 0 0 0 1 0 1 0 0.382 5.0 6.4 0.230 1.661 ;
/* G37 */ 001010101010101010101100 0 0 0 0 0 0 1 0 0 1 0.310 5.2 6.9 0.197 1.574 ;
/* G38 */ 101011000000000000000000 0 0 0 0 0 0 0 1 1 0 0.460 5.0 6.8 0.242 1.901 ;
/* G39 */ 001011000000000000000000 0 0 0 0 0 0 0 1 0 1 0.330 4.7 6.5 0.172 1.919 ;
/* G40 */ 001011000000000000000000 0 0 0 0 0 0 0 1 0 1 0.349 5.0 6.1 0.174 2.006 ;
```

Appendix A. continued.

```
/* G41 */ 001010101010110000000000 0 0 0 0 0 0 1 1 0 0.396 5.4 7.3 0.205 1.932 ;
/* G42 */ 000000101100000000000000 0 0 0 0 0 1 0 1 0 0.398 5.0 7.1 0.222 1.793 ;
/* G43 */ 000000001010101011000000 0 0 0 0 0 0 1 0 1 0.348 5.3 6.4 0.219 1.589 ;
/* G44 */ 000000000010101011000000 0 0 0 0 0 1 0 0 1 0.364 5.3 6.9 0.212 1.717 ;
/* G46 */ 000000000010101010101010 0 0 0 0 0 0 1 1 0 0.425 5.2 7.1 0.232 1.832 ;
/* G47 */ 000000000000101010101010 0 0 0 0 0 0 1 1 0 0.382 5.5 6.9 0.227 1.683 ;
/* G48 */ 000000000000101000001100 0 0 0 0 0 1 0 1 0 0.392 5.2 6.9 0.218 1.798 ;
/* G49 */ 000000000000101100000000 0 0 0 0 0 1 0 1 0 0.371 5.3 6.6 0.219 1.694 ;
/* G50 */ 000000000000001011000000 0 0 0 0 0 0 1 1 0 0.382 5.5 6.7 0.202 1.891 ;
/* G51 */ 000000000000001010101010 0 0 0 0 0 0 1 1 0 0.428 5.1 6.9 0.242 1.769 ;
/* G52 */ 000000000000001010101010 0 0 0 0 0 0 1 0 1 0.340 4.9 7.0 0.211 1.611 ;
/* G53 */ 000000000000001010101010 0 0 0 0 0 1 0 0 1 0.345 5.0 6.6 0.208 1.659 ;
/* G54 */ 000000000000001010101010 0 0 0 0 0 1 0 1 0 0.370 5.4 7.0 0.215 1.721 ;
/* G55 */ 000000000000001011000000 0 0 0 0 0 1 0 1 0 0.361 5.6 6.8 0.211 1.711 ;
/* G56 */ 000000000000000000101100 0 0 0 0 0 0 1 1 0 0.455 5.4 7.2 0.248 1.835 ;
/* G57 */ 000000000000000000001010 0 0 0 0 0 0 1 1 0 0.485 4.7 6.9 0.218 2.225 ;
/* G59 */ 000000000000000000001010 0 0 0 0 0 1 0 1 0 0.375 4.8 6.9 0.213 1.761 ;
/* G60 */ 000000000000000000001100 0 0 0 0 0 0 1 1 0 0.513 4.9 7.2 0.232 2.211 ;
/* G61 */ 000000000000000000000010 0 0 0 0 0 1 0 0 1 0.330 5.1 6.5 0.202 1.634 ;
/* G62 */ 000000000000000000000010 0 0 0 0 0 0 1 0 1 0.265 5.1 5.9 0.185 1.432 ;
/* G63 */ 000000000000000000000010 0 0 0 0 0 0 1 0 1 0.318 5.0 6.0 0.205 1.551 ;
/* G64 */ 000000000000000000000010 0 0 0 0 0 0 1 1 0 0.360 5.1 6.7 0.196 1.837 ;
/* G65 */ 000000000000000000000010 0 0 0 0 0 0 1 0 1 0.305 5.2 6.6 0.203 1.502 ;
/* G66 */ 000000000000000000000010 0 0 0 0 0 0 1 1 0 0.495 5.3 6.6 0.232 2.134 ;
/* G67 */ 000000000000000000000010 0 0 0 0 0 0 1 0 1 0.303 4.9 5.8 0.181 1.674 ;
/* G68 */ 000000000000000000000010 0 0 0 0 0 1 0 1 0 0.404 5.3 6.7 0.217 1.862 ;
/* G70 */ 000000000000000000000010 0 0 0 0 0 1 0 0 1 0.345 5.2 6.5 0.214 1.612 ;
/* S01 */ 101010101010101010101010 0 0 0 0 1 0 0 1 0 0.570 5.3 7.1 0.222 2.568 ;
/* S02 */ 101011000000000000000000 0 0 0 0 1 0 0 1 0 0.360 4.9 5.8 0.250 1.440 ;
/* S03 */ 101010101010101010101011 0 0 0 1 0 0 0 0 1 0.242 4.6 5.7 0.177 1.367 ;
/* S04 */ 000000001011000000000000 0 0 0 0 1 0 0 0 1 0.415 5.4 7.2 0.215 1.930 ;
/* S05 */ 101011000000000000000000 0 0 0 0 1 0 0 0 1 0.279 4.4 6.4 0.200 1.395 ;
/* S07 */ 101011000000000000000000 0 0 0 0 1 0 0 1 0 0.365 5.0 6.0 0.239 1.527 ;
/* S08 */ 101010101010101000000000 0 0 0 0 1 0 0 1 0 0.320 4.8 6.2 0.222 1.441 ;
/* S10 */ 101010101010101010101010 0 0 0 1 0 0 0 1 0 0.430 5.3 6.5 0.260 1.654 ;
/* S11 */ 101010101100000000000000 0 0 0 0 1 0 0 1 0 0.500 5.8 7.0 0.279 1.792 ;
/* S12 */ 101010101100000000000000 0 0 0 1 0 0 0 1 0 0.458 5.2 6.8 0.268 1.709 ;
/* S16 */ 101010110000000000000000 0 0 0 0 1 0 0 1 0 0.450 5.1 6.9 0.258 1.744 ;
/* S20 */ 101100000000000000000000 0 0 0 1 0 0 0 1 0 0.420 4.5 6.9 0.300 1.400 ;
/* S21 */ 101010101100000000000000 0 0 0 1 0 0 0 0 1 0.250 4.3 5.5 0.215 1.163 ;
/* S22 */ 110000000000000000000000 0 0 0 1 0 0 0 0 1 0.239 4.5 5.7 0.175 1.366 ;
/* S23 */ 100000000000000000000000 0 0 0 0 1 0 0 0 1 0.260 4.4 5.8 0.178 1.461 ;
/* S24 */ 101010110000000000000000 0 0 0 0 1 0 0 0 1 0.244 4.4 4.6 0.167 1.461 ;
/* S26 */ 101010101010101100000000 0 0 0 0 1 0 0 0 1 0.260 4.7 5.4 0.173 1.503 ;
/* S28 */ 101010101010101011000000 0 0 0 0 1 0 0 1 0 0.390 5.1 6.9 0.206 1.893 ;
/* S30 */ 101010101010101010101010 0 0 0 0 1 0 0 0 1 0.370 5.4 6.8 0.205 1.805 ;
/* S35 */ 101100000000000000000000 0 0 0 1 0 0 0 0 1 0.262 4.8 6.1 0.197 1.330 ;
/* S36 */ 101011000000000000000000 0 0 0 1 0 0 0 1 0 0.493 5.2 6.5 0.200 2.465 ;
/* S37 */ 101010110000000000000000 0 0 0 0 1 0 0 1 0 0.484 5.4 6.9 0.247 1.960 ;
/* S38 */ 110000000000000000000000 0 0 0 1 0 0 0 1 0 0.362 5.3 6.5 0.195 1.856 ;
/* S42 */ 001010101010101010101010 0 0 0 0 1 0 0 1 0 0.435 5.6 7.0 0.229 1.900 ;
/* S43 */ 001010110000000000000000 0 0 0 0 1 0 0 1 0 0.472 5.3 7.6 0.240 1.967 ;
```

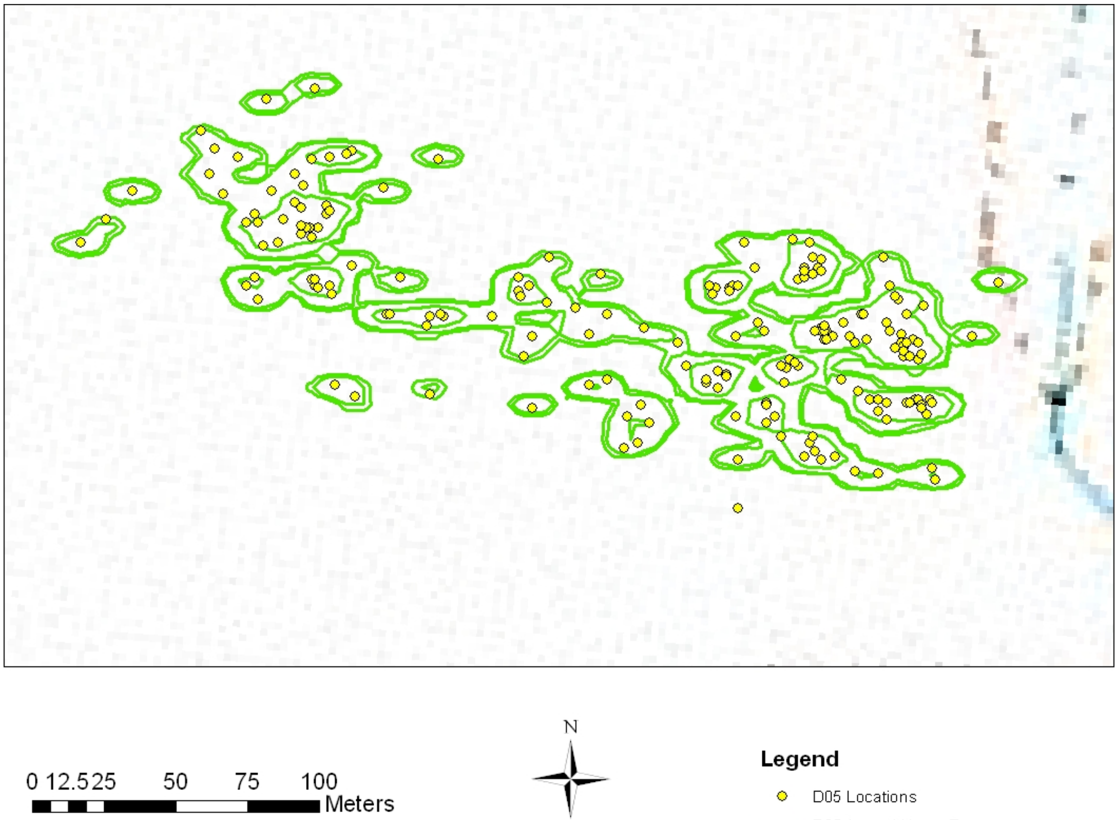
Appendix A. continued.

```
/* S44 */ 001010101010101010101010 0 0 0 0 1 0 0 0 1 0 0.405 5.5 6.9 0.232 1.746 ;
/* S45 */ 001100000000000000000000 0 0 0 0 1 0 0 0 1 0 0.455 5.4 6.9 0.231 1.970 ;
/* S46 */ 001011000000000000000000 0 0 0 0 0 1 0 0 1 0 0.471 5.5 7.4 0.252 1.869 ;
/* S47 */ 001010101010101011000000 0 0 0 0 1 0 0 0 1 0 0.420 5.5 7.2 0.211 1.991 ;
/* S48 */ 001010101010101010101010 0 0 0 0 1 0 0 0 1 0 0.452 5.3 7.2 0.236 1.915 ;
/* S49 */ 001010110000000000000000 0 0 0 0 0 1 0 0 1 0 0.384 5.2 6.8 0.221 1.738 ;
/* S50 */ 001010101011000000000000 0 0 0 0 0 1 0 0 1 0 0.426 5.2 7.0 0.238 1.790 ;
/* S51 */ 001010110000000000000000 0 0 0 0 1 0 0 0 1 0 0.391 5.5 7.0 0.222 1.761 ;
/* S55 */ 000000101100000000000000 0 0 0 0 0 1 0 0 0 1 0.379 5.3 6.9 0.211 1.796 ;
/* S56 */ 000000001100000000000000 0 0 0 0 1 0 0 0 0 1 0.353 5.0 6.9 0.206 1.714 ;
/* S57 */ 000000001010101100000000 0 0 0 0 0 1 0 0 0 1 0.357 4.9 6.6 0.203 1.759 ;
/* S58 */ 000000001100000000000000 0 0 0 0 0 1 0 0 1 0 0.406 5.2 7.3 0.226 1.796 ;
/* S59 */ 000000001010101100000000 0 0 0 0 1 0 0 0 1 0 0.419 5.2 6.9 0.210 1.995 ;
/* S60 */ 000000001010101010101010 0 0 0 0 0 1 0 0 1 0 0.390 5.0 7.2 0.218 1.789 ;
/* S61 */ 000000001010101010101010 0 0 0 0 0 1 0 0 0 1 0.339 5.1 6.7 0.202 1.678 ;
/* S62 */ 000000000010101010101010 0 0 0 0 1 0 0 0 1 0 0.395 5.4 7.1 0.215 1.837 ;
/* S63 */ 000000000010101010101010 0 0 0 0 0 1 0 0 1 0 0.435 5.4 7.5 0.228 1.908 ;
/* S64 */ 000000000010101010101100 0 0 0 0 1 0 0 0 1 0 0.432 5.3 6.8 0.211 2.047 ;
/* S65 */ 000000000010000000000000 0 0 0 0 0 1 0 0 1 0 0.415 5.3 6.7 0.220 1.886 ;
/* S66 */ 000000000010101100000000 0 0 0 0 1 0 0 0 1 0 0.452 5.7 7.0 0.229 1.974 ;
/* S67 */ 000000000011000000000000 0 0 0 0 1 0 0 0 1 0 0.454 5.4 7.1 0.244 1.861 ;
/* S68 */ 000000000010101011000000 0 0 0 0 0 1 0 0 1 0 0.436 5.6 7.0 0.239 1.824 ;
/* S69 */ 000000000010101011000000 0 0 0 0 0 1 0 0 1 0 0.470 5.4 7.3 0.225 2.089 ;
/* S70 */ 000000000010101100000000 0 0 0 0 1 0 0 0 0 1 0.366 5.7 7.0 0.211 1.735 ;
/* S71 */ 000000000010101010101010 0 0 0 0 0 1 0 0 1 0 0.419 5.5 6.9 0.223 1.879 ;
/* S72 */ 000000000010101100000000 0 0 0 0 1 0 0 0 1 0 0.385 5.1 6.4 0.212 1.816 ;
/* S73 */ 000000000000000000101100 0 0 0 0 0 1 0 0 1 0 0.432 5.2 7.0 0.218 1.982 ;
/* S74 */ 000000000000000000101010 0 0 0 0 1 0 0 0 1 0 0.388 5.2 6.9 0.223 1.740 ;
/* S75 */ 000000000000000000101010 0 0 0 0 0 1 0 0 0 1 0.382 4.7 6.9 0.205 1.863 ;
/* S76 */ 000000000000000000101010 0 0 0 0 0 1 0 0 1 0 0.522 5.1 6.9 0.240 2.175 ;
/* S77 */ 000000000000000000101000 0 0 0 0 1 0 0 0 1 0 0.330 5.1 6.6 0.218 1.514 ;
/* S78 */ 000000000000000000101010 0 0 0 0 1 0 0 0 0 1 0.265 4.8 5.8 0.190 1.395 ;
/* S79 */ 000000000000000000101010 0 0 0 0 0 1 0 0 1 0 0.535 5.1 6.9 0.253 2.115 ;
/* S80 */ 000000000000000000000011 0 0 0 0 1 0 0 0 0 1 0.255 4.5 5.9 0.192 1.328 ;
/* S81 */ 000000000000000000101010 0 0 0 0 0 1 0 0 1 0 0.429 5.2 6.8 0.211 2.033 ;
/* S82 */ 000000000000000000101010 0 0 0 0 1 0 0 0 1 0 0.360 5.1 6.2 0.229 1.572 ;
/* S83 */ 000000000000000000101100 0 0 0 0 0 1 0 0 1 0 0.540 5.0 7.4 0.245 2.204 ;
/* S84 */ 000000000000000000000010 0 0 0 0 0 1 0 0 0 1 0.250 4.5 5.8 0.176 1.420 ;
/* S85 */ 000000000000000000101100 0 0 0 0 1 0 0 0 1 0 0.408 5.3 7.0 0.225 1.813 ;
```

Appendix B. Percentage of individuals killed by coyote, avian, weasel, badger, bobcat, and unknown predators (number of individuals killed) for 265 radio-marked pygmy rabbits monitored on four study sites in southeastern Oregon and northwestern Nevada from June 2005 – April 2007.

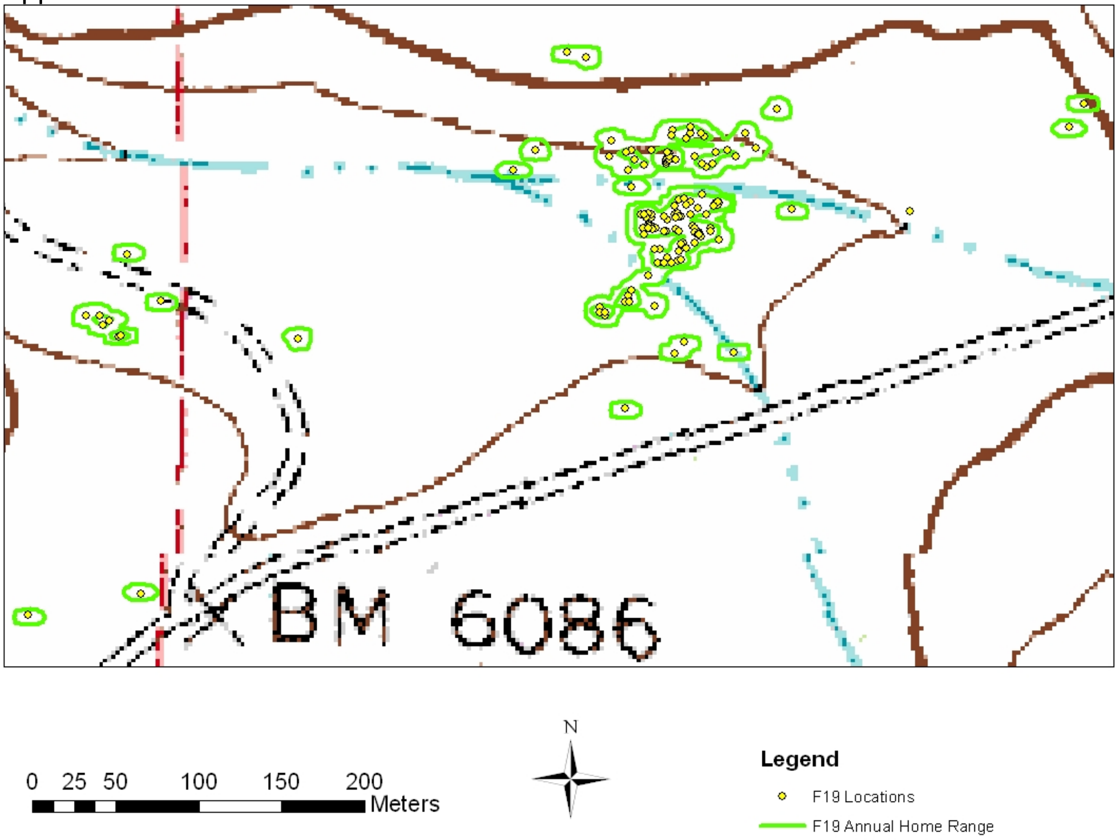
	Predator						Total
Study Site	Coyote	Avian	Weasel	Badger	Bobcat	Unknown	number
Dixon	14.3	7.8	18.2	1.3	0	58.4	77
	(11)	(6)	(14)	(1)	(0)	(45)	
Fish Creek	16.4	23.9	7.5	1.5	0	50.7	67
	(11)	(16)	(5)	(1)	(0)	(34)	
Spaulding	23.6	25.0	4.2	2.8	1.4	44.4	72
	(17)	(18)	(3)	(2)	(1)	(32)	
West Gulch	26.5	18.4	8.2	4.1	0	42.9	49
	(13)	(9)	(4)	(2)	(0)	(21)	

Appendix C. Ninety-five percent fixed kernel annual home ranges of four radio-marked individuals. Home range contours are highly fragmented, suggesting strong association with big sagebrush.



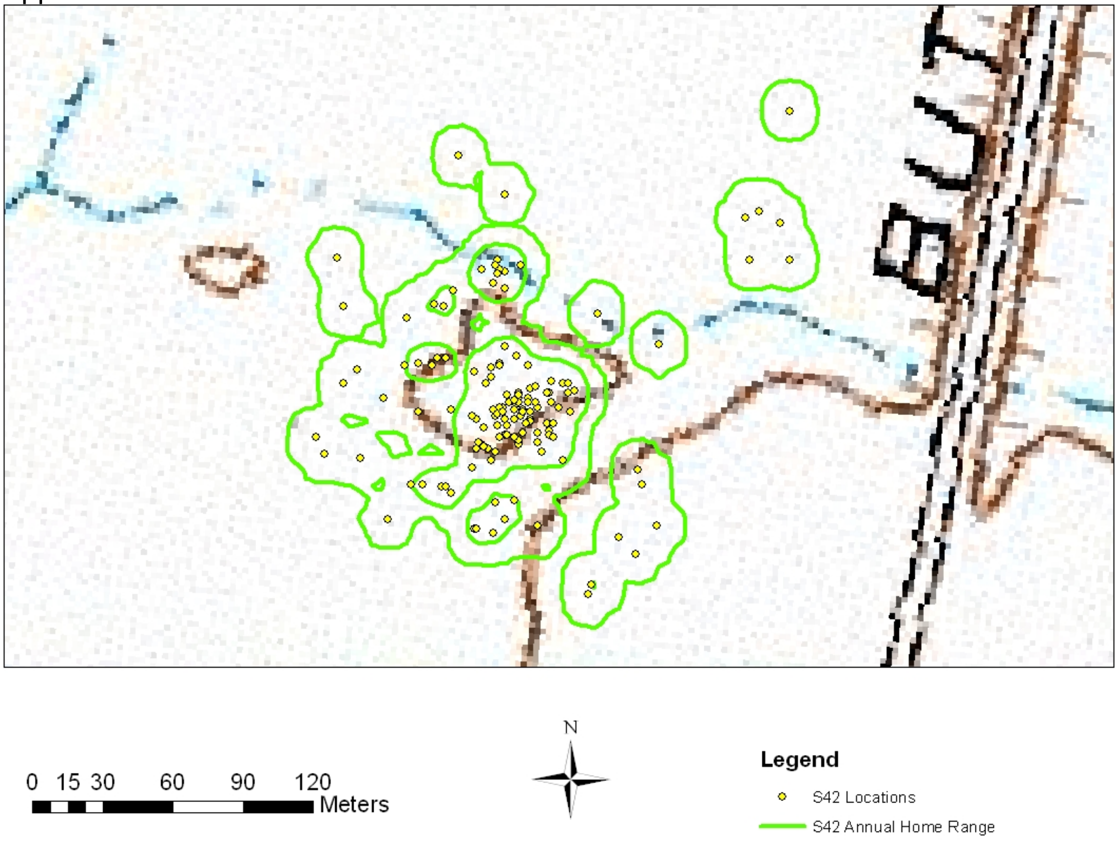
Animal D05: 95% fixed kernel annual home range (0.95 ha, *n* = 191), a female pygmy rabbit that was radio-marked from June 29, 2005 – July 12, 2006 on the Dixon study site in southeastern Oregon. Home range contours and locations are overlaid onto a Digital Orthophoto Quadrangle of the Dixon study site that shows clumps of big sagebrush.

Appendix C. continued.



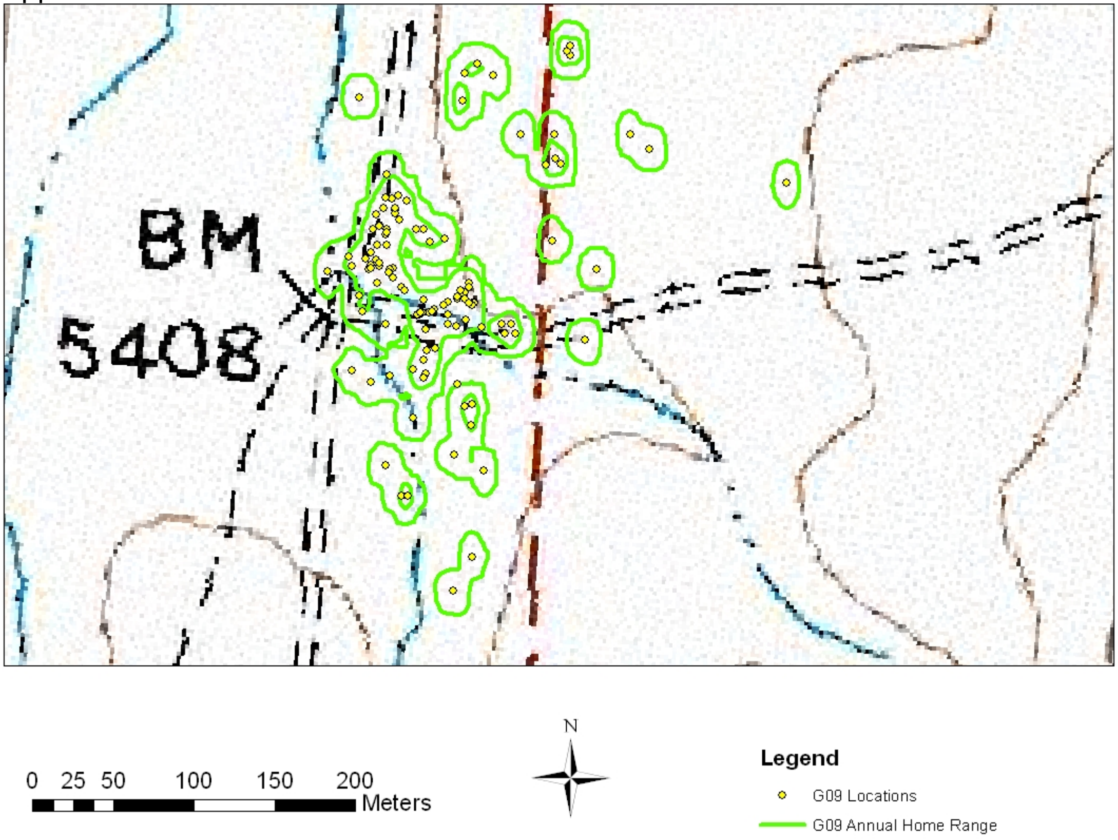
Animal F19: 95% fixed kernel annual home range (0.57 ha, *n* = 136), a male pygmy rabbit that was radio-marked from August 31, 2005 – May 14, 2006 on the Fish Creek study site in northwestern Nevada. Home range contours and locations are overlaid onto a Digital Orthophoto Quadrangle of the Fish Creek study site.

Appendix C. continued.



Animal S42: 95% fixed kernel annual home range (1.37 ha, *n* = 141), a female pygmy rabbit that was radio-marked from September 19, 2005 – October 11, 2006 on the Spaulding study site in southeastern Oregon. Home range contours and locations are overlaid onto a Digital Orthophoto Quadrangle of the Spaulding study site.

Appendix C. continued.



Animal G09 95% fixed kernel annual home range (1.47 ha, *n* = 122), a male pygmy rabbit that was radio-marked from July 25, 2005 – May 30, 2006 on the West Gulch study site in southeastern Oregon. Home range contours and locations are overlaid onto a Digital Orthophoto Quadrangle of the West Gulch study site.

Appendix D. Protocols for plot layout and vegetation sampling of pygmy rabbit habitat

Plot location and layout (Figure D-1) – Two-20 m perpendicular transects will intersect at the center point (10 m) of each transect. Upon arriving at the given UTM coordinates, the center point of the plot will be determined by randomly tossing a pencil (not more than 3 m). The position of the first transect (A) will be determined by the random direction of the pencil point. If the plot is located in a shrub island, the center point should be centered within the island. Plant measurements will be collected at quadrats located along the 20 m transects placed within the plot. Measurements along each transect will be taken along the left side (as read off the measuring tape) of each transect. All linear measurements will be taken to the nearest centimeter. Transect identification will be labeled as A (baseline transect) & B (perpendicular transect). Place and secure measuring tapes along each transect.

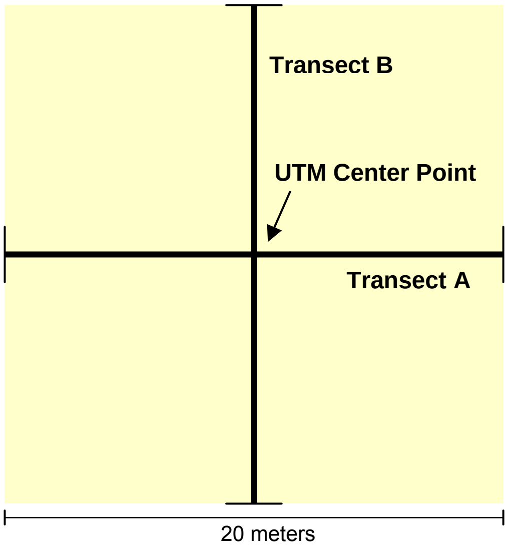


Figure D-1: Plot transect layout.

A perpendicular transect provides a potential overlapping sample area at the intersecting point of the transects. Be sure not to over sample this area. **Therefore, to eliminate the potential of over sampling, only sample the intersecting area along Transect A.**

Plots are either points randomly chosen from all habitat available to the pygmy rabbits on the entire study site or a randomly chosen location from the monitoring data.

Plot identifiers and characteristics:
For each plot we will record the study site, date, plot code, observer names, UTM center point, topographic position, slope (nearest percent, along the aspect), aspect (nearest degree), dominant and sub-dominant shrub species, and the presence of pygmy rabbit burrows (Y/N) within the plot boundaries. Topographic position for each plot will be assigned to one of four classes: Ridgetop, side-slope, terrace, and bottom-land (see Figure D-2).

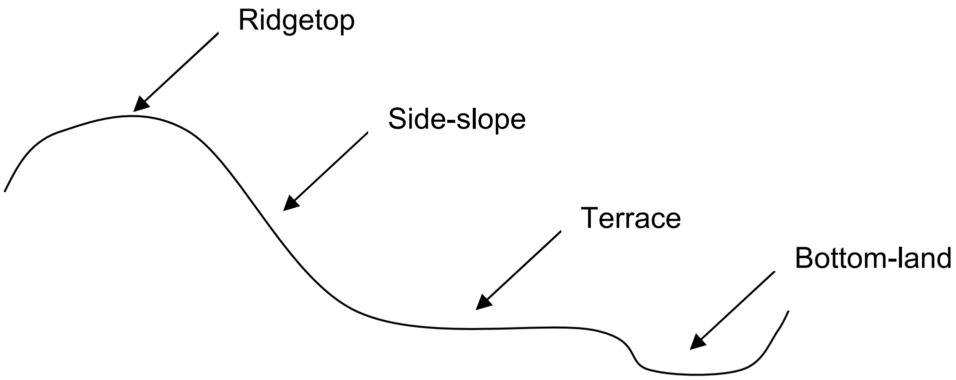


Figure D-2: Four classes of topographic positions.

Appendix D. Continued…

Overstory/Shrub sampling:
If a shrub or ant mound is measured along Transect A be sure not to resample it along Transect B. Unknown shrubs should be labeled as <u>other</u>, numbered, and collected for later identification.

<u>Density Counts:</u> Density counts of live and dead shrubs and ant mounds will be made along two–2 x 20 m rectangular belt quadrants centered along each transect (Figure D-3).

1) <u>Density of live and dead shrubs</u> – Count and identify all shrubs within the belt quadrant identifying the shrub to species, big sagebrush to subspecies, or dead shrub. Only shrubs that are *rooted* within the belt quadrant are to be counted. Use the provided guide stick to determine the quadrant boundaries. A shrub is considered alive if any part of it contains green leaves. See Table D-1 for key to plant codes.

2) <u>Density of ant mounds</u> – Count all ant mounds within the belt quadrant. Only ant mounds whose cone/mound falls within the belt quadrant are to be counted.

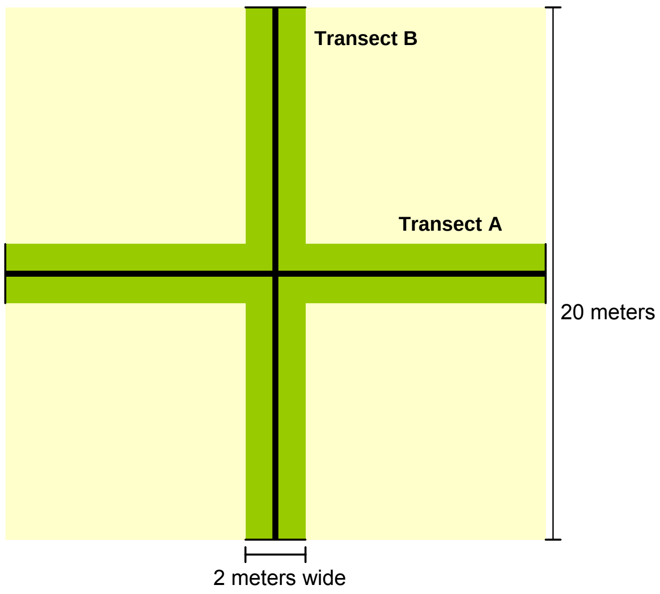


Figure D-3. Transect belt quadrant layout. Width centered along transect (1 m on either side of transect).

Appendix D. Continued…

Table D-1: Key to plant/identification codes.

Vegetation	Code
Grasses	
Perennial Native Grass	PNG
Perennial Non-Native Grass	PNOG
Annual Grass	AG
Forbs	FORB
Shrubs	
Basin Big Sagebrush	BBS
Mountain Big Sagebrush	MBS
Wyoming Big Sagebrush	WBS
Low Sage	LS
Gray Rabbitbrush	GYRB
Green Rabbitbrush	GNRB
Bitterbrush	PUTR
3 Tip Sage	3TIP
Dead Shrub	DEAD
Other	**OTHER**
Soil	S
Rock	R
Litter	LIT

Appendix D. Continued…

Intercept Measurements: Measurements to be taken on *intercepting live and dead shrubs (> 30 cm tall)* along the left side of each transect. Start sampling each transect at the start (0 m) of the tape measure and work towards the end (20 m) of the transect.

1) Identity – Identify intercepting shrubs to species and big sagebrush to subspecies. If unknown, list as other, number, and collect a sample. See Table D-1 for key to plant codes.
2) Shrub intercept distance – Measure the shrub intercept distance (cm) of all species along each transect (Figure D-4). Intercept measurements are of canopy/shrub cover. These shrubs do not necessarily need to be rooted on the transect, only provide a canopy intercept. Refer to Figure D-5 for measuring cover of shrubs that overlap each other along the transect.
3) Height of shrub – Measure the height (cm) of the intercepting shrub from the ground to the top of the shrub canopy.
4) Volume of shrub – Measure the largest canopy diameter (cm) of the intercepting shrub.
5) Frequency of shrub – Total the occurrence of each shrub species (subspecies of big sagebrush) encountered along transect.

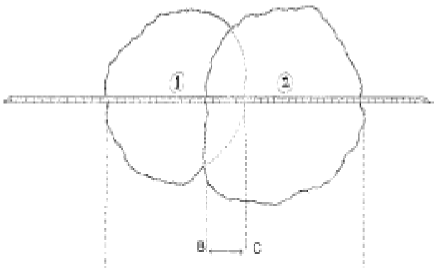


Figure D-5. Canopy overlap (points B to C) is not measured if the canopy of two or more plants of the same species overlap. For example, if shrubs 1 and 2 are the same species, then the canopy intercept is measured from points A to D. If shrubs 1 and 2 are different species, then canopy intercept is measured from points A to C for shrub species 1 and from points B to D for shrub species 2 (Elzinga, et al. 2001).

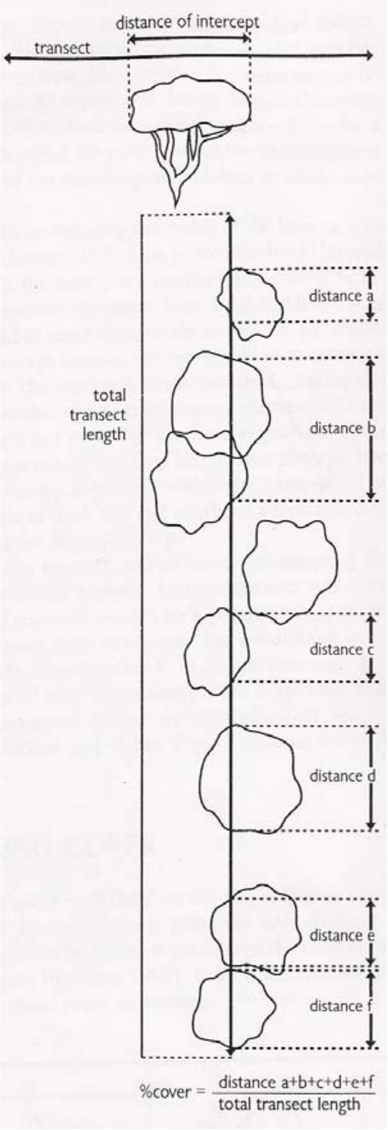


Figure D-4. Line intercept method of measuring cover for shrubs (Elzinga, et al. 2001).

Appendix D. Continued…

Understory sampling:

Rectangular quadrats (20 x 50 cm, Daubenmire frame) will be used to sample the percent cover and frequency of understory vegetation. Nine total quadrats (five along Transect A and four along Transect B) will be equidistantly spaced at 5 m intervals and placed perpendicularly to the transect (Figure D-6). Label each quadrat with the appropriate location. *Be sure not to sample the intersection of the transects twice, only sample this center plot along transect A.*

1) Percent cover – Estimate the percent cover of each understory measurement category, listed below, using the guides on the rectangular quadrat (Figure D-7). Include any vegetation whose foliage falls in the quadrat (whether or not it is rooted in the plot). See Table D-1 for key to plant/identification codes. Percent cover estimations can have a degree of personal bias to them. *It is critical that sampling be as consistent as possible.* On the data sheet, record a zero (0) under frequency and cover if the measurement category is not present in the quadrat. Cover should be estimated to the nearest 5%, or 1% if present in trace amounts. The sum of cover estimates should equal 100%.

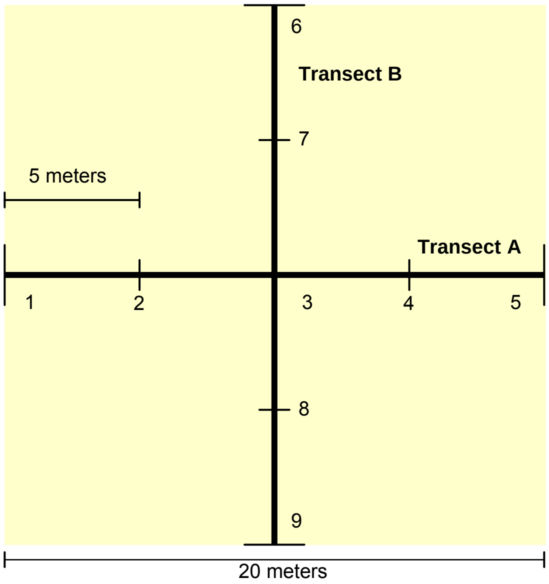


Figure D-6. Understory quadrat locations and labels

2) Frequency – Count the individual occurrence of each understory measurement category *rooted* within the rectangular quadrat. No frequency is recorded for soil, rock, or litter.

Understory measurement categories:

a. Perennial Native Grasses
b. Perennial Non-Native Grasses
c. Annual Grasses
d. Forbs - All grouped together
e. Shrub species (<30 cm)
f. Soil (< 1 cm)
g. Rock (> 1 cm)
h. Litter
i. Moss
j. Biological crust
k. Other (explain/describe)

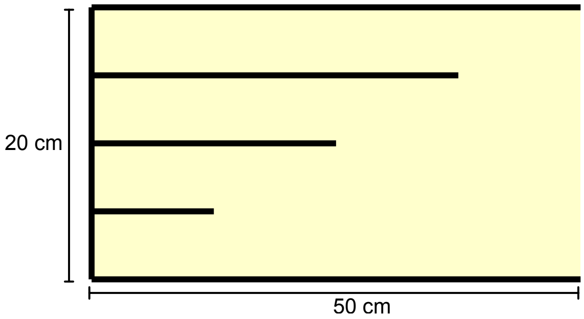


Figure D-7: Rectangular plot for understory sampling of percent cover and frequency.

Appendix E. Protocols for soil sampling of pygmy rabbit habitat

General soil sampling:

Soil sampling and measurements will be conducted at the plot center point for each 'use', 'available', and 'burrow' plot (total plots = 403). Sixteen of these plots have been randomly selected to be studied for within plot soil variation and will have four samples collected and stored separately (referred to below as 'variation' plots).

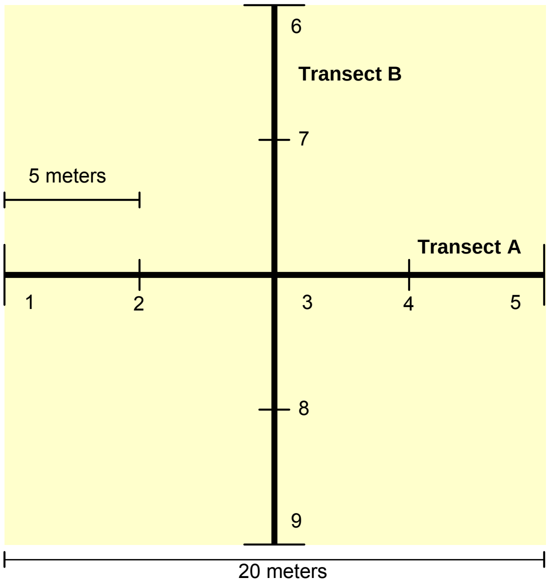


Figure E-1. Quadrat locations.

Soil Depth – One soil depth (cm) up to 1 m will be measured using a 2" diameter auger at each plot center point. The 16 'variation' plots will additionally have depth measured at 3 of the transect endpoints (total of 4 depth measurements). Ultimate depth is reached once a reasonable amount of force is applied to the auger without reasonable progress. Briefly describe anything the auger encountered, i.e. rocks.

.

Soil Texture Samples – One soil sample will be collected from each plot center point at a depth of 45 cm. If the maximal depth reached is less than 45 cm due to an obstructing restrictive layer, soil samples will then be collected at this maximal depth and noted on the data sheet and sample bag. At the 16 'variation' plots, soil depths and samples will be collected at the plot center **and 3 of the transect endpoints** (Figure E-1). All 4 soil samples collected at these 'variation' plots will be stored and labeled in **separate bags**. Please make every reasonable effort to prevent contamination of the soil sample from other soil levels. Each individual sample should weigh a *minimum of 50 grams* (roughly half a sandwich-sized resealable bag). All individual soil samples will be placed into the provided bag. ***Label each bag with the date, plot #, location in the plot (center, 1, 5, 6, or 9), and initials of collectors.*** A spade shovel could be used to reach this depth if the auger is too cumbersome. Soil samples collected from '***burrow'*** locations will be taken 1 m behind the burrow entrance.

Bulk Density – Soil bulk density will be measured at the surface using the supplied Eley Volumeter. Measurements will be taken at the plot center point and recorded on the data sheet. The 16 'variation' plots will additionally have bulk density measurements taken at 3 transect endpoints.

Appendix F. Soil parameters ($\bar{x}$, SE) collected from variation plots. Parameters were tested for differences between the plot center and plot average using a paired t-test. Differences were considered significant at α = 0.05.

	Center		Plot Average [a]			
Parameter	$\bar{x}$	SE	$\bar{x}$	SE	t	P - value
% Sand	55.19	2.08	56.19	1.20	-0.8847	0.3903
% Silt	25.87	2.20	25.26	0.92	0.3231	0.7511
% Clay	18.94	1.45	18.55	0.85	1.2251	0.2394
Maximal depth (cm)	59.31	7.33	58.90	3.64	0.1063	0.9168
Depth bulk density (g/cm^3)	1.45	0.01	1.46	0.01	2.0233	0.0612
Surface bulk density (g/cm^3)	1.22	0.05	1.20	0.02	-0.4302	0.6731

[a] Plot average is the mean parameter value from all four sampling locations within the habitat plot.

Appendix G. Parameter estimates for the best model explaining habitat selection for pygmy rabbits on the Dixon study site in southeastern Oregon, 2005 – 2007.

Parameter[a]	Estimate	SE	*P* -value	Odds[b]	95% C.I. Odds Ratio
Intercept	-18.68	7.62	0.014	NA	NA
SBDD	10.97	5.26	0.037	2.990[c]	1.069 - 8.390[c]
HD	0.03	0.01	0.006	1.035	1.010 - 1.061
CT	0.09	0.04	0.031	1.098	1.009 - 1.195

[a] CT - % Canopy cover of all live shrubs

HD - Mean height of dead shrubs

SBDD - Bulk density at maximal depth

[b] Odds ratio (e^{β}) = odds of selection increase or decrease by this factor for each unit increase in the explanatory variable.

[c] Odds ratio of selection calculated for 0.1 g/cm^3 increase in bulk density, allowing odds ratios to be reported on a smaller scale.

Appendix H. Parameter estimates for the best model explaining habitat selection for pygmy rabbits on the Fish Creek study site in northwestern Nevada, 2005 – 2007.

Parameter[a]	Estimate	SE	*P* -value	Odds[b]	95% C.I. Odds Ratio
Intercept	-4.36	1.85	0.019	NA	NA
UM	-0.30	0.10	0.003	0.737	0.603 - 0.901
DT	3.13	1.09	0.004	1.370[c]	1.105 - 1.691[c]
HBSB	0.06	0.02	0.018	1.059	1.010 - 1.111

[a] DT - Density of all live shrubs

HBSB - Mean height of big sagebrush

UM - % Cover moss

[b] Odds ratio (e^{β}) = odds of selection increase or decrease by this factor for each unit increase in the explanatory variable.

[c] Odds ratio of selection calculated for 10% increase in density, allowing odds ratios to be reported on a smaller scale.

Appendix I. Parameter estimates for the best model explaining habitat selection for pygmy rabbits on the Spaulding study site in southeastern Oregon, 2005 – 2007.

Parameter[a]	Estimate	SE	P -value	Odds[b]	95% C.I. Odds Ratio
Intercept	-11.77	3.49	0.001	NA	NA
CD	-0.48	0.20	0.015	0.616	0.418 - 0.909
CBSB	0.17	0.08	0.022	1.190	1.026 - 1.380
DT	4.97	1.73	0.004	1.640[c]	1.172 - 2.305[c]
DD	10.64	5.11	0.037	2.900[c]	1.066 - 7.880[c]
HT	0.08	0.03	0.020	1.079	1.012 - 1.151

[a] CBSB - % Canopy cover of big sagebrush

CD - % Canopy cover of all dead shrubs

DD - Density of all dead shrubs

DT - Density of all live shrubs

HT - Mean height of all live shrubs

[b] Odds ratio (e^{β}) = odds of selection increase or decrease by this factor for each unit increase in the explanatory variable.

[c] Odds ratio of selection calculated for 10% increase in density, allowing odds ratios to be reported on a smaller scale.

Appendix J. Parameter estimates for the best model explaining habitat selection for pygmy rabbits on the West Gulch study site in southeastern Oregon, 2005 – 2007.

Parameter[a]	Estimate	SE	*P* -value	Odds[b]	95% C.I. Odds Ratio
Intercept	4.60	1.77	0.009	NA	NA
UM	-0.15	0.07	0.037	0.864	0.754 - 0.991
CLAY	-0.30	0.09	0.001	0.741	0.618 - 0.890
DT	2.13	0.97	0.028	1.240[c]	1.023 – 1.495[c]

[a] CLAY - % Clay in soil

DT - Density of all live shrubs

UM - % Cover moss

[b] Odds ratio (e^{β}) = odds of selection increase or decrease by this factor for each unit increase in the explanatory variable.

[c] Odds ratio of selection calculated for 10% increase in density, allowing odds ratios to be reported on a smaller scale.

Appendix K. Model selection results for study-wide habitat categories for pygmy rabbits on four study sites in southeastern Oregon and northwestern Nevada, September 2006 – June 2007.

Habitat Category	Model[a]	Parameters removed	P - value
Shrub	DD DT DBSB CD CT CBSB HD HT HBSB	CBSB	0.9710
	DD DT DBSB CD CT HD HT HBSB	HBSB	0.9291
	DD DT DBSB CD CT HD HT	DBSB	0.6369
	DD DT CD CT HD HT	CD	0.3763
	DD DT CT HD HT	DD	0.3925
	DT CT HD HT	CT	0.2469
	DT HD HT[b]		
Understory	UAG UBC UL UPNATG UPNNG UM USHRUB UR US UF	UM	0.5886
	UAG UBC UL UPNATG UPNNG USHRUB UR US UF	USHRUB	0.4362
	UAG UBC UL UPNATG UPNNG UR US UF	UF	0.3525
	UAG UBC UL UPNATG UPNNG UR US	UPNNG	0.3658
	UAG UBC UL UPNATG UR US	UAG	0.1545
	UBC UL UPNATG UR US[b]		
Soils	CLAY SILT SAND SD SBDS SBDD	SAND	0.9765
	CLAY SILT SD SBDS SBDD	SBDD	0.5919
	CLAY SILT SD SBDS[b]		

Parameters were analyzed using logistic regression and a backward elimination procedure. Differences were considered significant at α = 0.15.

[a] CBSB - % Canopy cover of big sagebrush
CD - % Canopy cover of all dead shrubs
CLAY - % Clay
CT - % Canopy cover of all live shrubs
DBSB - Density of big sagebrush
DD - Density of all dead shrubs
DT - Density of all live shrubs
HBSB - Mean height of big sagebrush
HD - Mean height of dead shrubs
HT - Mean height of all live shrubs
SAND - % Sand
SBDD - Bulk density at subsurface
SBDS - Bulk density at surface
SD - Maximal soil depth
SILT - % Silt
UAG - % Cover annual grasses
UBC - % Cover biological crust
UF - % Cover forbs
UL - % Cover litter
UM - % Cover moss
UPNATG - % Cover perennial native grasses
UPNNG - % Cover perennial nonnative grasses
UR - % Cover rock
US - % Cover bare ground
USHRUB - % Cover shrubs <30 cm tall

[b] Top model for habitat category

Appendix L. Pearson correlation coefficients for overstory vegetative measurements collected at areas used by pygmy rabbits and areas of available habitat on four study sites in southeastern Oregon and northwestern Nevada, September 2006 – April 2007.

	DD	DT	DBSB	CD	CT	CBSB	HD	HT	HBSB
DD	1	0.457	0.534	0.645	0.162	0.118	0.432	-0.008	-0.041
DT	0.457	1	0.759	0.359	0.610	0.406	0.343	0.018	0.035
DBSB	0.534	0.759	1	0.423	0.495	0.636	0.432	0.205	0.180
CD	0.645	0.359	0.423	1	0.298	0.275	0.562	0.130	0.112
CT	0.162	0.610	0.495	0.298	1	0.797	0.290	0.391	0.375
CBSB	0.118	0.406	0.636	0.275	0.797	1	0.287	0.540	0.516
HD	0.432	0.343	0.432	0.562	0.290	0.287	1	0.237	0.215
HT	-0.008	0.018	0.205	0.130	0.391	0.540	0.237	1	0.823
HBSB	-0.041	0.035	0.180	0.112	0.375	0.516	0.215	0.823	1

Variable definitions

CBSB - % Canopy cover of big sagebrush
CD - % Canopy cover of all dead shrubs
CT - % Canopy cover of all live shrubs
DBSB - Density of big sagebrush
DD - Density of all dead shrubs
DT - Density of all live shrubs
HBSB - Max height of big sagebrush
HD - Max height of dead shrubs
HT - Max height of all live shrubs

Appendix M. Pearson correlation coefficients for understory vegetative measurements collected at areas used by pygmy rabbits and areas of available habitat on four study sites in southeastern Oregon and northwestern Nevada, September 2006 – April 2007.

	UPNATG	UPNNG	UAG	UF	US	UR	UL	USHRUB	UBC	UM
UPNATG	1	-0.004	-0.014	0.232	-0.436	0.172	-0.134	0.152	0.119	0.083
UPNNG	-0.004	1	-0.007	0.059	0.002	-0.033	0.053	-0.055	-0.021	-0.050
UAG	-0.014	-0.007	1	0.036	-0.117	-0.062	0.124	0.006	-0.104	0.137
UF	0.232	0.059	0.036	1	-0.403	0.184	0.003	0.126	0.160	0.105
US	-0.436	0.002	-0.117	-0.403	1	-0.290	-0.404	-0.381	-0.444	-0.362
UR	0.172	-0.033	-0.062	0.184	-0.290	1	-0.431	0.410	-0.090	-0.098
UL	-0.134	0.053	0.124	0.003	-0.404	-0.431	1	-0.208	-0.071	0.186
USHRUB	0.152	-0.055	0.006	0.126	-0.381	0.410	-0.208	1	0.137	-0.047
UBC	0.119	-0.021	-0.104	0.160	-0.444	-0.090	-0.071	0.137	1	-0.052
UM	0.083	-0.050	0.137	0.105	-0.362	-0.098	0.186	-0.047	-0.052	1

Variable definitions

UAG - % Cover annual grasses
UBC - % Cover biological crust
UF - % Cover forbs
UL - % Cover litter
UM - % Cover moss
UPNATG - % Cover perennial native grasses
UPNNG - % Cover perennial nonnative grasses
UR - % Cover rock
US - % Cover bare ground
USHRUB - % Cover shrubs <30 cm tall

Appendix N. Pearson correlation coefficients for soil measurements collected at areas used by pygmy rabbits and areas of available habitat on four study sites in southeastern Oregon and northwestern Nevada, June 2007.

	SD	SBDS	SAND	SILT	CLAY	SBDD
SD	1	-0.347	-0.086	0.255	-0.151	0.113
SBDS	-0.347	1	0.291	-0.277	-0.147	0.202
SAND	-0.086	0.291	1	-0.775	-0.702	0.802
SILT	0.255	-0.277	-0.775	1	0.094	-0.281
CLAY	-0.151	-0.147	-0.702	0.094	1	-0.947
SBDD	0.113	0.202	0.802	-0.281	-0.947	1

Variable definitions

CLAY - % Clay

SAND - % Sand

SILT - % Silt

SBDD - Bulk density at maximal depth

SBDS - Bulk density at surface

SD - Maximal depth

Appendix O. Vegetative and soil characteristics ($\bar{x}$ ± SE, Range) measured in areas used by pygmy rabbits and areas of available habitat on the Dixon site in southeastern Oregon, September 2006 – June 2007.

	Available (n = 25)		Used (n = 47)	
Variable	$\bar{x}$ ± SE	Range	$\bar{x}$ ± SE	Range
Density (#/m^2)				
Big sagebrush	0.31 ± 0.07	0.00 - 1.01	0.58 ± 0.06	0.00 - 1.25
Total live shrubs	0.86 ± 0.09	0.09 - 1.84	1.16 ± 0.07	0.71 - 2.26
Dead	0.09 ± 0.01	0.00 - 0.29	0.14 ± 0.01	0.01 - 0.32
Max height (cm)				
Big sagebrush	43.47 ± 7.61	0.00 - 96.56	70.56 ± 4.94	0.00 - 104.60
Total live shrubs	47.74 ± 4.18	0.00 - 82.50	64.67 ± 2.08	42.36 – 84.94
Dead	26.00 ± 6.14	0.00 - 95.5	56.22 ± 3.98	0.00 - 112.00
% Canopy cover				
Big sagebrush	0.07 ± 0.01	0.00 - 0.33	0.15 ± 0.01	0.00 - 0.38
Total live shrubs	0.14 ± 0.01	0.00 - 0.36	0.25 ± 0.01	0.11 - 0.50
Dead	0.01 ± 0.01	0.00 - 0.10	0.02 ± 0.01	0.00 - 0.07
Understory % cover				
Annual grasses	0.00 ± 0.00	0.00 - 0.00	0.01 ± 0.01	0.00 - 0.56
Biological crust	6.25 ± 2.42	0.00 - 60.55	3.86 ± 0.57	0.00 - 12.89
Forbs	1.29 ± 0.20	0.00 - 3.89	0.91 ± 0.08	0.00 - 2.89
Litter	11.48 ± 1.66	1.56 - 31.67	19.62 ± 1.76	2.44 - 46.67
Moss	0.84 ± 0.43	0.00 - 8.67	1.91 ± 0.55	0.00 - 17.78
Other (< 30 cm tall)	6.76 ± 1.48	0.00 - 22.78	2.59 ± 0.45	0.00 - 12.22
Perennial non-native grasses	0.00 ± 0.00	0.00 - 0.00	0.02 ± 0.02	0.00 - 1.11
Perennial native grasses	10.40 ± 1.06	2.78 - 30.56	7.99 ± 0.74	1.22 - 31.11
Rock	19.58 ± 3.24	1.11 - 55.00	8.73 ± 1.10	0.33 - 33.11
Soil (Bare Ground)	43.10 ± 4.62	5.44 - 79.44	55.34 ± 1.70	27.22 - 76.11
Soil characteristics				
% Clay	21.85 ± 1.20	10.90 - 33.40	16.14 ± 1.01	6.25 - 32.50
% Sand	51.30 ± 1.55	39.10 - 71.60	56.57 ± 1.31	37.50 - 80.00
% Silt	26.85 ± 1.21	10.00 - 40.00	27.29 ± 0.79	12.50 - 38.75
Maximum depth (cm)	35.88 ± 3.92	14.00 - 100.00	51.32 ± 2.59	10.00 - 90.00
Depth bulk density (g/cm^3)	1.42 ± 0.01	1.34 - 1.56	1.48 ± 0.01	1.33 - 1.65
Surface bulk density (g/cm^3)	1.22 ± 0.02	1.05 - 1.45	1.20 ± 0.02	0.90 - 1.40

Appendix P. Vegetative and soil characteristics ($\bar{x}$ ± SE, Range) measured in areas used by pygmy rabbits and areas of available habitat on the Fish Creek site in northwestern Nevada, September 2006 – June 2007.

	Available (n = 25)		Used (n = 44)	
Variable	$\bar{x}$ ± SE	Range	$\bar{x}$ ± SE	Range
Density (#/m^2)				
Big sagebrush	0.32 ± 0.04	0.00 - 0.70	0.62 ± 0.06	0.08 - 1.51
Total live shrubs	0.65 ± 0.05	0.00 - 1.32	1.06 ± 0.08	0.26 - 1.89
Dead	0.07 ± 0.01	0.00 - 0.30	0.11 ± 0.01	0.00 - 0.38
Max height (cm)				
Big sagebrush	60.58 ± 5.77	0.00 - 92.22	82.30 ± 3.39	49.50 - 115.58
Total live shrubs	57.44 ± 3.66	0.00 - 77.08	71.96 ± 2.62	40.89 - 99.72
Dead	39.15 ± 7.58	0.00 - 129.75	53.35 ± 5.25	0.00 - 99.33
% Canopy cover				
Big sagebrush	0.15 ± 0.02	0.00 - 0.36	0.31 ± 0.02	0.04 - 0.61
Total live shrubs	0.23 ± 0.03	0.00 - 0.58	0.44 ± 0.03	0.06 - 0.73
Dead	0.02 ± 0.01	0.00 - 0.12	0.03 ± 0.01	0.00 - 0.16
Understory % cover				
Annual grasses	0.12 ± 0.09	0.00 - 2.33	0.58 ± 0.43	0.00 – 18.44
Biological crust	8.12 ± 1.57	0.00 - 33.89	11.68 ± 2.35	0.00 - 60.00
Forbs	3.74 ± 0.57	0.00 - 11.33	3.29 ± 0.39	0.67 - 11.44
Litter	21.24 ± 2.25	0.00 - 50.56	31.70 ± 2.16	6.33 - 58.89
Moss	8.13 ± 1.00	0.00 - 20.67	4.35 ± 0.56	0.00 - 12.89
Other (< 30 cm tall)	3.73 ± 1.12	0.00 - 18.89	2.06 ± 0.49	0.00 - 13.33
Perennial non-native grasses	0.00 ± 0.00	0.00 - 0.00	0.00 ± 0.00	0.00 - 0.00
Perennial native grasses	10.59 ± 1.02	0.00 - 21.22	11.09 ± 0.86	0.44 - 30.00
Rock	8.00 ± 1.90	0.00 - 34.00	3.31 ± 1.10	0.00 - 41.67
Soil (Bare Ground)	37.10 ± 3.82	7.22 - 100.00	32.47 ± 3.00	1.67 - 81.11
Soil characteristics				
% Clay	19.15 ± 2.19	2.50 - 57.50	19.60 ± 1.06	8.75 - 37.50
% Sand	54.20 ± 2.34	21.25 - 72.50	55.28 ± 1.44	27.50 - 70.00
% Silt	26.65 ± 1.21	21.25 - 50.00	25.12 ± 0.72	18.40 - 40.00
Maximum depth (cm)	50.64 ± 5.73	11.00 - 100.00	60.48 ± 4.14	10.00 - 100.00
Depth bulk density (g/cm^3)	1.46 ± 0.02	1.22 - 1.77	1.45 ± 0.01	1.30 - 1.59
Surface bulk density (g/cm^3)	1.28 ± 0.04	1.03 - 1.75	1.19 ± 0.02	0.85 - 1.45

Appendix Q. Vegetative and soil characteristics ($\bar{x}$ ± SE, Range) measured in areas used by pygmy rabbits and areas of available habitat on the Spaulding site in southeastern Oregon, September 2006 – June 2007.

	Available (n = 25)		Used (n = 45)	
Variable	$\bar{x}$ ± SE	Range	$\bar{x}$ ± SE	Range
Density (#/m^2)				
Big sagebrush	0.50 ± 0.04	0.21 - 0.91	0.82 ± 0.07	0.25 - 1.80
Total live shrubs	0.60 ± 0.04	0.32 - 1.34	1.06 ± 0.09	0.26 - 1.95
Dead	0.15 ± 0.02	0.01 - 0.45	0.26 ± 0.03	0.01 - 0.99
Max height (cm)				
Big sagebrush	71.65 ± 3.26	37.38 - 94.00	68.80 ± 4.10	30.85 - 124.33
Total live shrubs	68.73 ± 2.45	47.29 - 89.00	70.10 ± 3.28	40.66 - 124.33
Dead	54.59 ± 5.07	0.00 - 112.67	60.01 ± 4.36	0.00 - 93.00
% Canopy cover				
Big sagebrush	0.15 ± 0.01	0.07 - 0.28	0.20 ± 0.01	0.04 - 0.39
Total live shrubs	0.17 ± 0.01	0.07 - 0.33	0.27 ± 0.01	0.13 - 0.43
Dead	0.04 ± 0.01	0.00 - 0.09	0.05 ± 0.01	0.00 - 0.14
Understory % cover				
Annual grasses	0.48 ± 0.19	0.00 - 5.00	0.24 ± 0.06	0.00 - 1.89
Biological crust	2.09 ± 1.32	0.00 - 32.78	3.41 ± 0.84	0.00 - 21.11
Forbs	0.82 ± 0.14	0.00 - 2.56	0.98 ± 0.21	0.00 - 9.22
Litter	21.75 ± 1.88	6.89 - 36.89	24.22 ± 1.45	6.22 - 44.44
Moss	4.30 ± 0.87	0.00 - 15.00	3.28 ± 0.62	0.00 - 16.78
Other (< 30 cm tall)	0.45 ± 0.11	0.00 - 1.67	0.55 ± 0.13	0.00 - 3.89
Perennial non-native grasses	0.08 ± 0.08	0.00 - 2.22	0.02 ± 0.02	0.00 - 1.11
Perennial native grasses	4.84 ± 0.77	0.11 - 15.56	3.76 ± 0.34	0.11 - 9.00
Rock	1.15 ± 0.21	0.00 - 4.44	1.28 ± 0.35	0.00 - 10.78
Soil (Bare Ground)	63.24 ± 2.22	45.56 - 81.11	61.91 ± 1.72	40.56 - 90.00
Soil characteristics				
% Clay	16.00 ± 1.28	6.25 - 37.50	17.81 ± 0.82	6.25 - 28.75
% Sand	62.05 ± 3.18	31.25 - 82.50	51.69 ± 2.17	27.50 - 76.25
% Silt	21.95 ± 2.51	0.00 - 48.75	30.50 ± 1.77	10.00 - 50.00
Maximum depth (cm)	56.60 ± 5.94	23.00 - 100.00	78.07 ± 4.39	14.00 - 100.00
Depth bulk density (g/cm^3)	1.49 ± 0.02	1.30 - 1.64	1.45 ± 0.01	1.33 - 1.62
Surface bulk density (g/cm^3)	1.31 ± 0.04	1.00 - 1.80	1.14 ± 0.02	0.55 - 1.50

Appendix R. Vegetative and soil characteristics ($\bar{x}$ ± SE, Range) measured in areas used by pygmy rabbits and areas of available habitat on the West Gulch site in southeastern Oregon, September 2006 – June 2007.

	Available (*n* = 25)		Used (*n* = 42)	
Variable	$\bar{x}$ ± SE	Range	$\bar{x}$ ± SE	Range
Density (#/m^2)				
Big sagebrush	0.55 ± 0.06	0.14 - 1.51	0.96 ± 0.13	0.03 - 2.79
Total live shrubs	0.80 ± 0.09	0.14 - 2.62	1.30 ± 0.13	0.43 - 3.18
Dead	0.11 ± 0.01	0.03 - 0.37	0.16 ± 0.02	0.00 - 0.92
Max height (cm)				
Big sagebrush	64.30 ± 2.23	49.60 - 90.54	66.01 ± 3.56	0.00 - 110.24
Total live shrubs	59.16 ± 2.27	43.50 - 85.13	61.69 ± 2.49	35.18 - 98.75
Dead	47.64 ± 5.17	0.00 - 101.00	64.12 ± 4.28	0.00 - 112.00
% Canopy cover				
Big sagebrush	0.20 ± 0.01	0.03 - 0.41	0.25 ± 0.02	0.00 - 0.49
Total live shrubs	0.26 ± 0.02	0.04 - 0.64	0.31 ± 0.02	0.11 - 0.62
Dead	0.02 ± 0.01	0.00 - 0.07	0.04 ± 0.01	0.00 - 0.13
Understory % cover				
Annual grasses	0.41 ± 0.26	0.00 - 5.00	0.58 ± 0.13	0.00 - 3.78
Biological crust	0.82 ± 0.24	0.00 - 3.33	0.92 ± 0.36	0.00 - 13.33
Forbs	1.57 ± 0.31	0.33 - 6.56	1.14 ± 0.16	0.11 - 4.67
Litter	22.94 ± 1.80	8.89 - 50.00	28.56 ± 1.99	12.33 - 61.11
Moss	9.24 ± 1.23	2.78 - 31.67	6.45 ± 0.89	0.00 - 26.67
Other (< 30 cm tall)	1.19 ± 0.33	0.00 - 5.00	1.18 ± 0.34	0.00 - 11.11
Perennial non-native grasses	0.00 ± 0.00	0.00 - 0.00	0.00 ± 0.00	0.00 - 0.00
Perennial native grasses	12.42 ± 1.31	0.11 - 30.00	9.77 ± 1.00	0.67 - 24.44
Rock	7.61 ± 1.51	0.00 - 24.44	5.68 ± 1.27	0.00 - 42.78
Soil (Bare Ground)	44.13 ± 2.45	25.56 - 72.22	45.44 ± 1.90	22.22 - 81.11
Soil characteristics				
% Clay	20.25 ± 1.17	12.50 - 35.00	13.35 ± 0.70	5.00 - 22.50
% Sand	55.65 ± 1.81	36.25 - 73.75	60.03 ± 0.94	46.15 - 72.50
% Silt	24.10 ± 1.09	12.50 - 32.50	26.62 ± 0.88	15.00 - 38.85
Maximum depth (cm)	40.20 ± 3.77	12.00 - 69.00	61.00 ± 4.79	17.00 - 100.00
Depth bulk density (g/cm^3)	1.44 ± 0.01	1.32 - 1.54	1.52 ± 0.01	1.42 - 1.66
Surface bulk density (g/cm^3)	1.15 ± 0.03	0.90 - 1.45	1.15 ± 0.02	0.90 - 1.50