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| Conservation Assessment for the Pygmy Rabbit (*Brachylagus idahoensis*) in Oregon and Washington |
| Jennifer Gervais  November 2016 |
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Interagency Special Status and Sensitive Species Program

USDA Forest Service Region 6, Oregon and Washington

USDI Bureau of Land Management, Oregon and Washington

Disclaimer

This Conservation Assessment was prepared to compile the published and unpublished information on the pygmy rabbit (*Brachylagus idahoensis*). If you have information that will assist in conserving this species or questions concerning this Conservation Assessment, please contact the interagency Conservation Planning Coordinator for Region 6 Forest Service, BLM OR/WA in Portland, Oregon, via the Interagency Special Status and Sensitive Species Program website at [http://www.fs.fed.us/r6/sfpnw/issssp/contactus/](http://www.fs.fed.us/r6/sfpnw/issssp/contactus/%20)

# EXECUTIVE SUMMARY

**Species**: Pygmy rabbit (*Brachylagus idahoensis*)

Taxonomic Group: Mammal

**Management Status**: The International Union for the Conservation of Nature (IUCN) lists the pygmy rabbit as “least concern” based on “the existence of several robust populations in less disturbed areas” and because “suitable habitat still exists in many areas” ([Beauvais et al. 2008](#_ENREF_5)). NatureServe (2015) ranks the pygmy rabbit as G4, “apparently secure.” The Washington population is listed as federally endangered (USFWS 2001, 2003). The Washington Natural Heritage Program ranks pygmy rabbits as “critically imperiled” or S1 ([Washington Natural Heritage Program 2014](#_ENREF_103)) and Washington Department of Fish and Wildlife ranks them as state endangered (Hays 2003). Pygmy rabbits are listed as a “sensitive species, vulnerable category” by the Oregon Department of Fish and Wildlife ([Oregon Biodiversity Information Center 2016](#_ENREF_80)). They are assigned a state rank of S2 by the Oregon Biodiversity Information Center (2016), a ranking given for either rarity or because the species is demonstrably vulnerable to extirpation in the state. In Oregon, the species is listed as Sensitive by both the Forest Service and BLM under the Interagency Special Status and Sensitive Species Program (ISSSSP 2015).

**Specific Habitat:** Pygmy rabbits are sagebrush obligates that require stands of shrubs with at least some big sagebrush (*Artemisia tridentata*), forbs and grasses in the understory, and deep, sandy or silty soils with proper texture to support burrowing.

**Threats**: The greatest threat to pygmy rabbits is habitat loss from conversion of sagebrush to non-sage-brush vegetation. Threats include conversion for agriculture, residential or energy development, and rangeland management practices that substantially reduce or remove sage brush cover. Increasing frequency and extent of fire can kill sagebrush and facilitate the invasion of cheat grass (*Bromus tectorum*) and other non-native weeds, which in turn increase fire risk. Habitat degradation resulting from overgrazing, invasive weeds, invasive pests such as the Aroga moth (*Aroga websteri*), and pinyon-juniper encroachment is also a threat and interacts to affect fire risk.

**Management Considerations**: Pygmy rabbits require a specific combination of soil characteristics and dense, tall stands of brush that include big sagebrush. Many populations are small and relatively isolated, so metapopulation dynamics may be important to regional persistence. Maintenance of suitable habitat patches that are not occupied and maintaining dispersal habitat that does not cross roads or creeks may help facilitate dispersal and lower the risk of genetic isolation and regional extinction.

**Inventory, Monitoring, and Research Opportunities**: Several sign indices have been used to monitor trends in pygmy rabbit populations. Camera surveys in particular may be very useful to determining occupancy although occupancy modeling and abundance estimation have not been applied to pygmy rabbit data. Important habitat can be broadly identified but delineating specific areas of high conservation value will require further work. Determining the extent to which metapopulation dynamics drive regional persistence and the spatial scale on which this occurs will aid in conservation efforts.

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# I. INTRODUCTION

## Goal

Pygmy rabbits (*Brachylagus idahoensis*) are patchily distributed throughout the Great Basin and intermountain region of western North America, including south-central and southwestern Oregon ([Johnson and Cassidy 1997](#_ENREF_57), [Verts and Carraway 1998](#_ENREF_102)). They are now reintroduced into central Washington ([USFWS 2012](#_ENREF_101)). Their population status varies dramatically throughout their range (see Management Status below). The range has contracted in the last century with accelerating habitat loss resulting from human activities ([Lyman 2004](#_ENREF_70)). The goal of this conservation assessment is to summarize existing knowledge across the range of the species to better inform management of pygmy rabbits and their habitats in Oregon, where they are listed as Sensitive.

## Scope

As much as possible, information gathered from Washington and Oregon was used in the writing of this conservation assessment. However, research and other sources from many parts of the pygmy rabbit’s range are also included. Although much is known about many aspects of the pygmy rabbit’s ecology and life history, this assessment should not be considered complete. Published and unpublished reports regarding occurrence, behavior, or life history are very likely to exist beyond what was found for this assessment. Although Washington populations are briefly discussed in this document, the main scope of this Conservation Assessment covers the pygmy rabbit populations in Oregon.

## Management Status

The International Union for the Conservation of Nature (IUCN) lists the pygmy rabbit as “least concern” based on “the existence of several robust populations in less disturbed areas” and because “suitable habitat still exists in many areas” ([Beauvais et al. 2008](#_ENREF_5)). This ranking was updated from previous ratings of “lower risk/near threatened” in 1996 and “vulnerable” in 1994 ([Beauvais et al. 2008](#_ENREF_5)). NatureServe ([NatureServe 2015](#_ENREF_77)) ranks the pygmy rabbit as G4, “apparently secure.” However, pygmy rabbits are considered a “species of concern” by the US Fish and Wildlife Service Region 1 ([Oregon Biodiversity Information Center 2016](#_ENREF_80)). The Washington population is considered a Distinct Population Segment and is federally endangered ([USFWS 2001](#_ENREF_99), [2003](#_ENREF_100)).

Pygmy rabbits are listed as a “sensitive species, vulnerable category” by the Oregon Department of Fish and Wildlife ([Oregon Biodiversity Information Center 2016](#_ENREF_80)). They are assigned a state rank of S2 by the Oregon Biodiversity Information Center ([Oregon Biodiversity Information Center 2016](#_ENREF_80)), a ranking given for either rarity or because the species is demonstrably vulnerable to extirpation in the state. The Washington Natural Heritage Program ranks pygmy rabbits as “critically imperiled” or S1 and Washington Department of Fish and Wildlife ranks them as state endangered (Hays 2003). Based on the Oregon ranks, they are considered Sensitive by the Forest Service and BLM in Oregon.

# II. CLASSIFICATION AND DESCRIPTION

## Systematics

The pygmy rabbit has been variously classified in the genera *Lepus*, *Sylvilagus* and *Brachylagus*, but is now considered to belong in *Brachylagus*, a classification justified by phylogenetic analysis ([Halanych and Robinson 1997](#_ENREF_50)), see the review of taxonomic history in ([Oliver 2004](#_ENREF_79)). The Washington population of the pygmy rabbit has been isolated from populations to the east and south for perhaps 10,000 years and is now genetically distinct ([USFWS 2001](#_ENREF_99)). However, there are no recognized subspecies ([Green and Flinders 1980a](#_ENREF_46)).

## Species Description

The pygmy rabbit is the smallest leporid in North America, with adults weighing an average of 400 g. The female is somewhat larger than the male ([Green and Flinders 1980a](#_ENREF_46)). It has short, relatively broad hind feet, short, rounded ears, and a small inconspicuous tail with a buffy colored underside ([Green and Flinders 1980a](#_ENREF_46), [Verts and Carraway 1998](#_ENREF_102)). The ears are heavily furred with a buffy color along the edge. The hind feet and nape are buffy cinnamon in color, although the nape is less obvious in summer than in winter (Figure 1). The general pelage color is gray, but lighter in autumn and winter than in spring and summer. Hairs are banded with blackish tips, buff-colored mid-shafts, and dark gray at the base; the width of the buffy band varies seasonally. The fur on the ventral side is slate gray with light white to buffy tips ([Verts and Carraway 1998](#_ENREF_102)).



Figure 1. Pygmy rabbit.

## Comparison with Sympatric Species

Cottontails (*Sylvilagus* species) have tails with white undersides ([Green and Flinders 1980a](#_ENREF_46), [Verts and Carraway 1998](#_ENREF_102)). Cottontails leap or bound, whereas pygmy rabbits’ gait is universally described as a scamper ([Green and Flinders 1980a](#_ENREF_46), [Verts and Carraway 1998](#_ENREF_102), [Flinders 1999](#_ENREF_31)). They also tend to circle away rather than run straight like cottontails (M. Foster, *personal communication*).

# III. BIOLOGY AND ECOLOGY

## Range, Distribution, and Abundance

The current range of the pygmy rabbit extends from southcentral and southeast Oregon (Figures 2 and 3) east through southern Idaho to the corner of southwest Montana, south through eastern Idaho to the southwest corner of Wyoming. The range extends through much of western Utah, west through northern Nevada to extreme eastern California ([Verts and Carraway 1998](#_ENREF_102)). In Washington, pygmy rabbits were found in Adams, Benton, Douglas, Franklin, Grant, and Lincoln Counties in the early part of the 20th century, but by the end of the century, there remained only a very small disjunct population of pygmy rabbits in Douglas County (Figure 4). This population dropped to roughly 30 individuals ([USFWS 2003](#_ENREF_100)) and subsequently seemed to be extirpated by 2004 ([USFWS 2012](#_ENREF_101)). The species has been successfully reintroduced in Grant County since 2011 ([USFWS 2012](#_ENREF_101)). In Oregon, it was once found in Deschutes, Klamath, Crook, Lake, Grant, Harney, Baker, and Malheur Counties, but the current range is likely smaller ([Verts and Carraway 1998](#_ENREF_102), [Hagar and Lienkaemper 2007](#_ENREF_49)). The Oregon Biodiversity Information Center (2016) also lists Jefferson, Union, Wasco, and Wheeler counties as harboring the species.

The pygmy rabbit is patchily distributed throughout its range in large part because it is restricted to a specific combination of big sagebrush (*Artemisia tridentata*) stands growing in deep soils suitable for burrowing. The species was much more broadly distributed during the Pleistocene based on fossil evidence, and declined throughout the central and northern Great Basin at the end of the Pleistocene 7,000 years before present ([Grayson 1987](#_ENREF_43)). At that time, pygmy rabbit populations persisted in cooler, moister parts of the Great Basin ([Grayson 2000](#_ENREF_44)). Changes in climate during the Holocene led to contraction in the range of sagebrush 4,000 years before present when the regional climate became wetter ([Lyman 1991](#_ENREF_69)). The disjunct population in Washington State was isolated at that time ([Lyman 1991](#_ENREF_69), [2004](#_ENREF_70)). The range further contracted following European settlement ([Lyman 2004](#_ENREF_70)). There have been some recent reports of range expansion in Utah and Wyoming ([Flinders 1999](#_ENREF_31)), but these populations were most likely just not detected previously ([Oliver 2004](#_ENREF_79)).

The elevations reported for this species range from 670 m to 2570 m (Simon and Laundré 2004). In Washington, the Columbia Plateau has a geologic history distinct from elsewhere in the pygmy rabbit’s range and hence the origin and pattern of soil deposition is also distinct. Elevations of sites occupied by pygmy rabbits in Washington are <1000 m whereas in Oregon, the elevational range of this species is >1000 m (USFWS 2001). Elevational ranges in Oregon of 1200-2400 m have been reported in Oregon (Crawford 2008 Crawford et al. 2010). The mean



Figure 2. Map of potential habitat for pygmy rabbits in Oregon. Image source: <http://oe.oregonexplorer.info/Wildlife/wildlifeviewer/?SciName=Mammalia&TaxLevel=order> This map does not reflect fine-scale soil data critical to determining habitat at a fine scale.

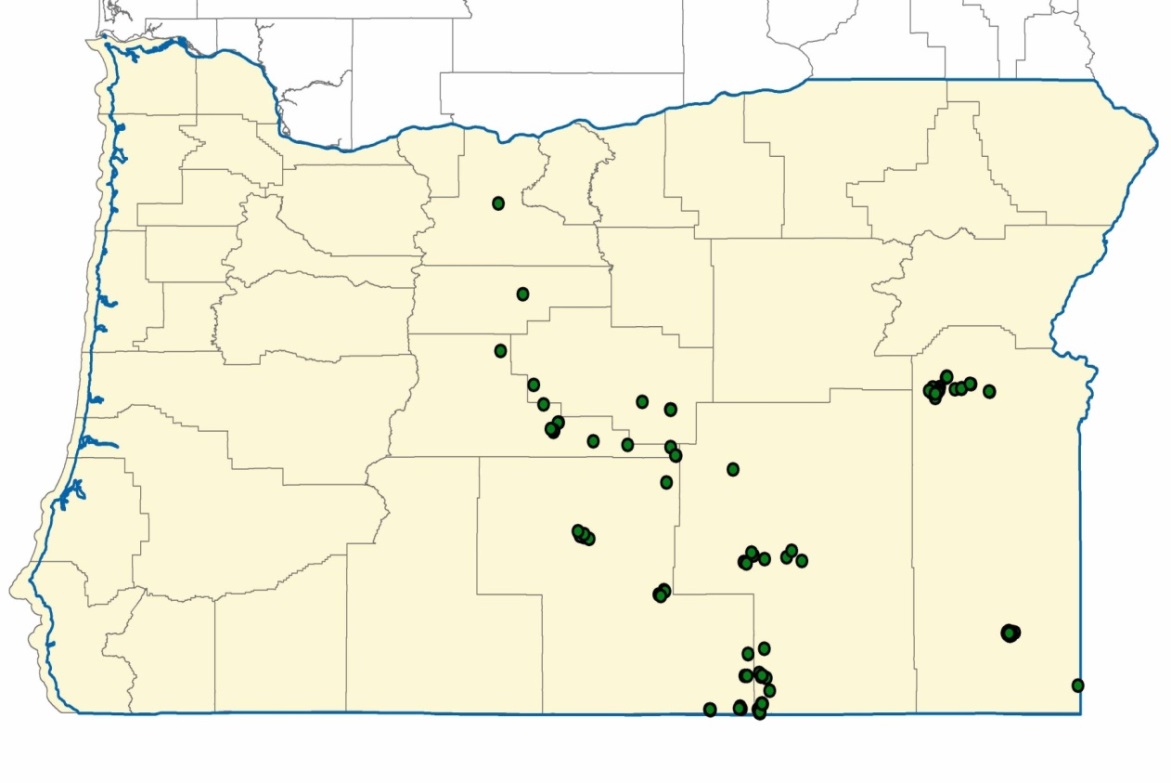


Figure 3. Map of documented locations of pygmy rabbits in Oregon as recorded in the GeoBob database. This map is known to be incomplete.

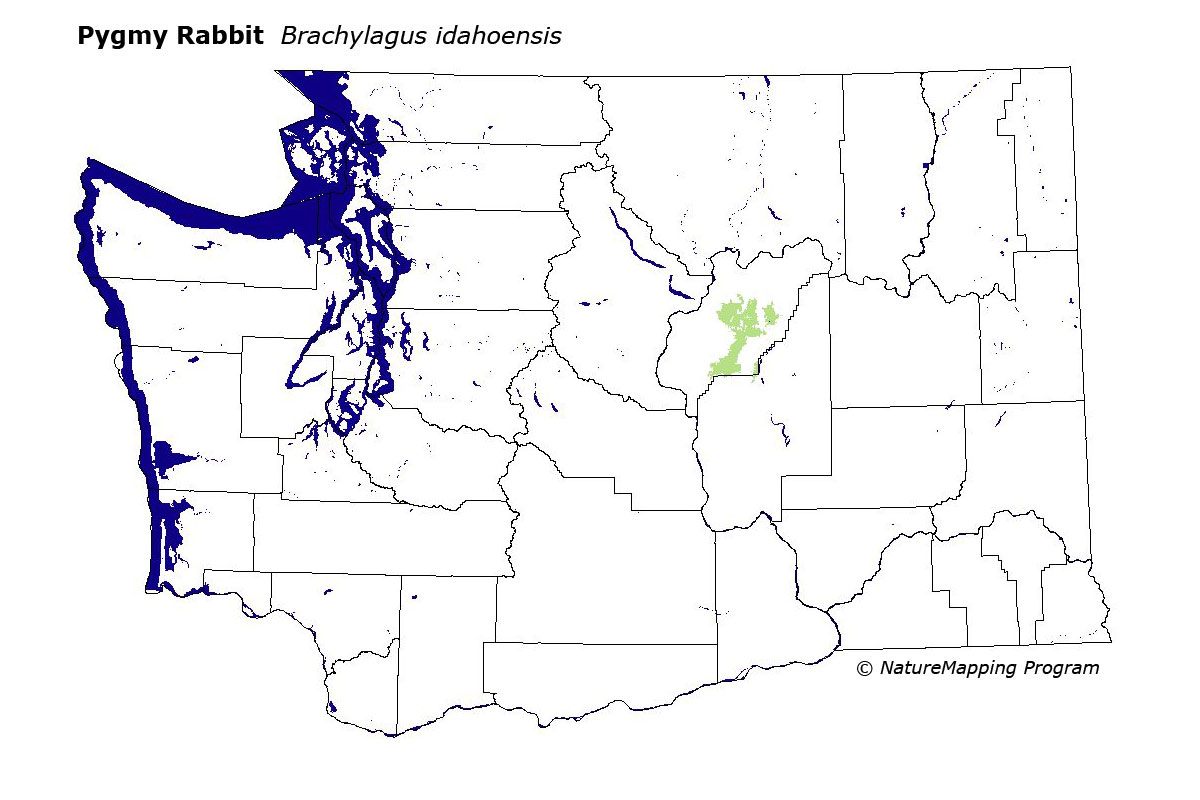


Figure 4. Map of predicted habitat for the pygmy rabbit in Washington, adapted from the Washington Gap Analysis Project. Image source: <http://naturemappingfoundation.org/natmap/facts/pygmy_rabbit_712.html>

lower elevational limit in California and Nevada has increased by about 150 m through time at historically occupied sites, likely linked to climate change and not land conversion (Larrucea and Brussard 2008a). Overall, however, sagebrush and soils distribution are the most important factors in predicting pygmy rabbit occurrence (Kenaith and McGee 2004), and suitable patches of sagebrush likely shift through time as a result of disturbance and shifts in precipitation (USFWS 2001).

Recent estimates of abundance have varied dramatically throughout time and space, in part from the use of differing techniques and from bias in those techniques. Estimates of density range up to a maximum of 45 pygmy rabbits per ha based on flush counts ([Green 1978](#_ENREF_45), [Green and Flinders 1981](#_ENREF_48)). In Utah, estimates of 0.79 rabbits per ha have been reported using strip transects ([Flinders et al. 2005](#_ENREF_32)). In Washington, estimates of 0.217-0.269 pygmy rabbits per ha were based on trapping, which may have led to an underestimation of density ([Gahr 1993](#_ENREF_40)). Mark-recapture work in Idaho led to density estimates of 0.02-0.46 pygmy rabbits per ha ([Price and Rachlow 2011](#_ENREF_84)). Other density estimates were 1.9 and 4.3 pygmy rabbits per ha in Utah and 3.0 rabbits per ha in Montana (Janson 1946 in USFWS 2005, Rauscher 1997 in USFWS 2005). Home range sizes are influenced by the prevalence of cover and the number of burrow systems that offer shelter from predation ([Sanchez 2007](#_ENREF_91)), which would in turn affect densities. Abrupt population decreases have been noted in a number of study areas throughout the pygmy rabbit’s range ([Bradfield 1975](#_ENREF_11), [Wilde 1978](#_ENREF_110), [Weiss and Verts 1984](#_ENREF_105), [Sanchez 2007](#_ENREF_91), [Crawford et al. 2010](#_ENREF_16)), although no study reported increases.

## Habitat

The pygmy rabbit lives exclusively in sagebrush habitat where stands of big sagebrush (*Artemisia tridentata*) occur over deposits of suitably textured soils that are at the very least 30 cm deep. Soil types are most commonly sandy or silty soil with low clay content but pygmy rabbits have been found in soils with greater clay content (Foster 2010, M. Foster, personal communication). Soil must have sufficient structure to support burrowing. Although shrub composition varies, big sagebrush is always present. Generally, occupied habitat has relatively more shrub cover with taller, wider shrubs than nearby unoccupied habitat, with a denser vegetation profile starting 10 cm from the ground ([Katzner et al. 1997](#_ENREF_60), [Meisel 2006](#_ENREF_72)). Specific shrub cover of occupied sites has ranged from 29% in Oregon ([Weiss 1984](#_ENREF_104)) to 43% in Wyoming ([Katzner and Parker 1997](#_ENREF_58)). In southwestern Idaho, a site supported pygmy rabbits with just 11% sagebrush cover, but other tall shrubs were present, including rabbit brush (*Ericameria nauseosus*), bitterbrush (*Purshia tridentata*), and snowberry (*Symphoricarpos oreophilus*, Burak 2006).

Big sagebrush is made up of a number of widely distributed subspecies ([Rosentreter 2004](#_ENREF_88)). Researchers concluded that the specific subspecies of big sagebrush (*Artemisia tridentata tridentata* versus *A. t. wyomingensis*) did not matter in terms of pygmy rabbit occupancy ([Weiss 1984](#_ENREF_104)). The two subspecies are found in somewhat different soil types and precipitation regimes.

*Artemisia tridentata tridentata* is found more on sandy soils while the Wyoming subspecies is found on finer-textured soils. The texture, rather than the actual sand, silt or clay content of the soil differentiates between the occurrence of the two subspecies ([Shumar and Anderson 1986](#_ENREF_96)). Mountain big sagebrush (*A. t. vaseyana*) is also used by pygmy rabbits ([White et al. 1982a](#_ENREF_108), [Burak 2006](#_ENREF_14), [Meisel 2006](#_ENREF_72)).

Other vegetative characteristics have been identified with pygmy rabbit occupancy in addition to the presence of tall, dense big sagebrush. There is often more dead shrub material in areas occupied by pygmy rabbits than in random plots ([Katzner and Parker 1997](#_ENREF_58), [Burak 2006](#_ENREF_14)) and relatively few young shrubs ([Gabler et al. 2001](#_ENREF_38)). This may be a result of the rabbits’ activity ([Dobler and Dixon 1990](#_ENREF_25), [Gabler et al. 2001](#_ENREF_38)). Although cover of perennial grasses and forbs did not differ between occupied and unoccupied sites ([Weiss and Verts 1984](#_ENREF_105), [Meisel 2006](#_ENREF_72), [Crawford et al. 2010](#_ENREF_16)), annual grasses, particularly cheat grass, which may impede pygmy rabbits’ movements or vision, seemed to be avoided ([Weiss and Verts 1984](#_ENREF_105)). Although forbs were found to have greater cover in occupied than unoccupied areas in Idaho ([Gabler et al. 2001](#_ENREF_38)), this finding was not universal ([Meisel 2006](#_ENREF_72), [Crawford 2008](#_ENREF_18)). Pygmy rabbits consume few forbs relative to grasses and sagebrush (Wilde 1978, Green and Flinders 1980b, see Diet and Foraging Behavior, below) so it seems unlikely that rabbits were selecting for forb cover per se. However, grasses and forb cover are an integral part of pygmy rabbit habitat ([Dobler and Dixon 1990](#_ENREF_25)) and grasses in particular are an important component of summer diet ([Wilde 1978](#_ENREF_110), [Green and Flinders 1980b](#_ENREF_47)).

Big sagebrush was always found to be present in sites with pygmy rabbit activity in Oregon, but the shrub composition and general habitat varied widely. Pygmy rabbits were found on playas dominated by silver sagebrush (*A. cana*), in small patches of big sagebrush surrounded by low sagebrush (*A. arbuscula*), and in big sagebrush stands with juniper (*Juniperus occidentalis*) encroachment, greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* sp.), and wild crab apple (*Peraphyllum ramosissimum*). In addition, the presence of dead sagebrush was frequently noted ([Foster 2007](#_ENREF_34)). Many shrubs in stands of sagebrush were killed by the aroga moth (*Aroga websteri*) but were still occupied by pygmy rabbits ([Foster 2007](#_ENREF_34)). A sense of overall habitat suitability can be garnered from photographs of sites known to support pygmy rabbits (Figure 5).

Deep soil deposits are necessary to support burrow networks. These networks may be up to a meter below the soil surface ([Green and Flinders 1980a](#_ENREF_46)). Such deposits have included alluvial deposits from the upper Pleistocene on lava older than 15,000 years before present, alluvial deposits of the upper Pleistocene, playa deposits, and eolian sand deposits ([Gabler et al. 2000](#_ENREF_39)). One study in Washington found that nearly all (96%) of pygmy rabbit burrows occurred in soils at least 51 cm deep (Kehne 1991 in Gabler et al. 2001). However, soil depths of at least 60 cm may be too stringent a requirement for a habitat model because of the coarseness of soil maps and the use of features such as mima mounds or alluvial fans by pygmy rabbits. These features are not captured in soil maps. An appropriate soil depth criterion for habitat modeling to identify potential habitat may be ≥ 30 cm to ensure inclusion of areas with suitable soil microsites ([Rachlow and Svancara 2006](#_ENREF_86)). Pygmy rabbit activity has been noted around rocky outcrops with shallower soils than rabbits are typically associated with ([Simons and Laundre 2004](#_ENREF_98)), but pygmy rabbits have been documented using holes in volcanic rock, stone foundations, and stone walls as well ([Green and Flinders 1980a](#_ENREF_46)). Presumably the cover provided by these features precludes the need to dig burrows.

Although pygmy rabbits are associated with deep soil deposits, populations have been found in areas with much shallower, more compacted soil. In these areas, the rabbits use burrows dug by badgers, marmots, and other fossorial mammals, or find shelter in holes in volcanic rocks or human structures such as stone walls or the foundations of abandoned buildings ([Wilde 1978](#_ENREF_110), [Green and Flinders 1980a](#_ENREF_46)). These types of features may be most important for dispersing juveniles rather than as habitat for resident populations.

Soil characteristics include higher sand and silt content rather than clay or loam ([Heady and Laundre 2005](#_ENREF_55)). Similarly in southeastern Idaho, soils supporting pygmy rabbit burrows included coarse ashy, silty, or loamy soils with less than 18% clay in one study (Kehne 1991 in Gabler et al. 2001). Soils in occupied areas had a much greater sand content of 81-87% relative to unused areas, which had only 52% sand. Clay varied from 5% in used sites to 14% in unused areas ([Gabler et al. 2001](#_ENREF_38)). In southeastern Oregon, pygmy rabbit burrows have also been located in pumice soil, volcanic ash soil, clay-loam soil and in cinder ([Foster 2010](#_ENREF_35), [2014](#_ENREF_36)).

Soils surrounding burrow sites had greater subsurface strengths than random in addition to lower clay composition, although surface strengths were both greater and less than surrounding areas ([Weiss and Verts 1984](#_ENREF_105), [Crawford 2008](#_ENREF_18)). Presumably subsurface strengths or bulk densities must be at least some minimum value in order to support the burrow systems without collapsing. That threshold in one study for bulk density as measured by a volumeter was between 1.45 g/cm3

(95% CI 1.44-1.47 g/cm3) for unoccupied sites versus 1.50 g/cm3 (95% CI 1.48-1.52 g/cm3,

Figure 5. Habitat occupied by pygmy rabbits in eastern Oregon. Photographs provided by Mary Foster.

Crawford 2008) for occupied sites. Another study reported subsurface soil horizon strengths as measured by a penetrometer of 3.8 ± 0.3 (SD) kg/cm2, which was “significantly greater” than the unreported uninhabited sites (Weiss and Verts 1984). Burrow entrances are typically placed under big sagebrush shrubs ([Wilde 1978](#_ENREF_110), [Green and Flinders 1980a](#_ENREF_46)). The root systems of sagebrush or other shrubs may help stabilize the burrow entrances in addition to the cover the branches and foliage provide. Similarly, burrows were frequently found along edges of roads, playas, cow paths and mowed strips in southeastern Oregon ([Foster 2007](#_ENREF_34)). Such features may be selected in part for either micro-topography or soil characteristics that support burrows better than surrounding soils.

Slope and aspect are two other characteristics frequently linked to pygmy rabbit habitat models ([Gabler et al. 2000](#_ENREF_39), [Simons and Laundre 2004](#_ENREF_98), [Rachlow and Svancara 2006](#_ENREF_86)). Gabler and colleagues (2000) found that on their study site in Idaho, burrows were located on slopes of less than 49%, with the mean slope of 8.6%. The mean orientation was 38.7°, a northeast aspect. In this study site, however, prevailing winds were from the SW, so the aspect was likely an artifact of where soils would have built up from wind deposition over time ([Wilde 1978](#_ENREF_110), [Gabler et al. 2000](#_ENREF_39)). Other modeling has suggested that slopes of <15% denote potential habitat ([Simons and Laundre 2004](#_ENREF_98)) and pygmy rabbits are also found on valley floors ([Wilde 1978](#_ENREF_110)), in drainages, playa edges, and adjacent to alfalfa pivots ([Foster 2006](#_ENREF_33), [2014](#_ENREF_36)).

The elevational range of the pygmy rabbit seems mostly driven by the occurrence of suitable habitat. Elevational ranges of 670-2570 m above sea level have been reported for Idaho ([Simons and Laundre 2004](#_ENREF_98)). Fire, juniper and pinyon encroachment, conversion of lower-elevation grassland to sagebrush from overgrazing, and conversely loss of sagebrush habitat as a result of rangeland improvement and development in addition to climate change are likely to alter local elevational distributions ([Larrucea and Brussard 2008a](#_ENREF_63)).

A number of modeling exercises have been conducted at large spatial scales to identify potential pygmy rabbit habitat. Characteristics were mapped at broad spatial scales to identify soil and vegetation patterns potentially suitable for pygmy rabbit occupancy. These models typically did a better job at predicting non-habitat rather than occupied habitat ([Gabler et al. 2000](#_ENREF_39), [Simons and Laundre 2004](#_ENREF_98), [Rachlow and Svancara 2006](#_ENREF_86)), largely because soil and vegetation maps were of too coarse a scale or in the case of vegetation maps, did not reflect current conditions (Simons and Laundré 2004). Failure to identify occupied habitat is likely an artifact of rarity, as suitable habitat is not expected to always be occupied even when population sizes are robust ([Hanski 1999](#_ENREF_51)).

Modeling efforts specific to Oregon include work done in 1982 over eastern Oregon used soil depth and strength, shrub height, and shrub cover to differentiate between sites occupied by pygmy rabbits and those that were not (Weiss 1984). A model developed with data collected on Hart Mountain National Wildlife Refuge identified big sagebrush height and percent of sand in the soil as the two defining features most predictive of pygmy rabbit site occupancy (Meisel 2006). This model was then used to identify potentially suitable habitat for pygmy rabbits on Hanford Reach National Monument, using GIS soil and vegetation maps followed by ground sampling of sagebrush height and soil sand content (Meisel 2006). Finally, a study of habitat selection of pygmy rabbits in southeastern Oregon and northwestern Idaho found that increased density and height of shrubs, deeper soils with lower clay content and higher silt content best explained pygmy rabbit occupancy of a site over the study area, but different sites revealed somewhat different characteristics (Crawford 2008).

## Diet and Foraging Behavior

The pygmy rabbit is known for its very high reliance on sagebrush for food, but it shifts its diet between the summer and winter seasons. In winter, it consumes almost entirely sagebrush (*Artemisia tridentata*), with sagebrush making up 90-99% of the diet ([Wilde 1978](#_ENREF_110), [Green and Flinders 1980b](#_ENREF_47)). Pygmy rabbits will climb up into the tops of sagebrush plants to reach new growth ([Dobler and Dixon 1990](#_ENREF_25), [Burak 2006](#_ENREF_14)). Grasses are consumed in summer, with the native bunchgrasses *Agropyron* and *Poa* spp. dominating early in summer and *Stipa* and *Elymus* spp. becoming prominent in late summer. Grasses made up as much as 39% ([Green and Flinders 1980b](#_ENREF_47)) or 64% of the diet ([Wilde 1978](#_ENREF_110)). Forbs were also consumed in small quantities, consisting of a maximum of 10% ([Green and Flinders 1980b](#_ENREF_47)) or 12% ([Wilde 1978](#_ENREF_110)) of the total diet. Feeding observations in Washington suggested similar proportions during the spring and summer, although grasses were observed being consumed 45% of the time and shrubs (big sagebrush and green rabbitbrush, *Chrysothamnus viscidiflorus*) 36% of the time ([Gahr 1993](#_ENREF_40)). The spring growth of grasses and forbs marked the beginning of the dietary shift ([Green and Flinders 1980b](#_ENREF_47)). Volatile compounds reach their greatest concentration in young sagebrush leaves, and are at their lowest in winter ([Rosentreter 2004](#_ENREF_88)), when the pygmy rabbits rely on sagebrush almost exclusively.

Sagebrush contains monoterpenes, compounds that can be neurotoxic and nephrotoxic. In addition, secondary compounds include camphor, coumarins, methacrolein, and flavonoids, all deterrents to potential herbivores ([Rosentreter 2004](#_ENREF_88), [Shipley et al. 2006](#_ENREF_95)). Although big sagebrush subspecies did not consistently differ in monoterpenoid content, populations of them did, and captive pygmy rabbits consistently chose to consume sagebrush harvested from some populations but not others ([Rosentreter 2004](#_ENREF_88)). Interestingly, the pygmy rabbits’ choices did not vary consistently with monoterpenoid content ([White et al. 1982a](#_ENREF_108)). Monoterpenoids may be eliminated through volatilization while being chewed. Pygmy rabbits’ stomach contents contained far less monoterpenoids than expected based on the content in the sagebrush ([White et al. 1982b](#_ENREF_109)). Selection is likely a matter of evaluating the combined content of all of the present secondary compounds rather than a single chemical group.

In captive trials, pygmy rabbits proved to be no better at digesting sagebrush than the generalist eastern cottontail rabbit, *Sylvilagus floridanus* ([Shipley et al. 2006](#_ENREF_95)). In addition, low urinary pH indicated that both species incurred a metabolic cost to eating sagebrush, although pygmy rabbits seemed to be better at detoxifying sagebrush secondary compounds than cottontails ([Shipley et al. 2006](#_ENREF_95)). Pygmy rabbits are clearly not constrained to eating sagebrush, and grasses in particular may be crucial to the successful growth and survival of young rabbits before the dying back of such vegetation requires them to rely primarily on sagebrush in the fall ([Wilde 1978](#_ENREF_110)).

## Life History and Breeding Biology

***Burrow systems***

The pygmy rabbit is one of only two species of North American rabbit that digs its own burrows. The other species, the volcano rabbit (*Romerolagus diazi*) is limited to Mexico ([USFWS 2001](#_ENREF_99)). These burrow systems are the focal points of pygmy rabbits’ activity and are likely used for protection from both weather extremes and predators. Pygmy rabbits will utilize burrows dug by other species such as badgers (*Taxidea taxus*) or marmots (*Marmota flaviventris*), as well as holes in old building foundations or in volcanic rock in areas where soils are not as suitable for them ([Green and Flinders 1980a](#_ENREF_46), [Simons and Laundre 2004](#_ENREF_98)). The home range may contain a number of burrow systems, among which an individual rabbit may shift its activity ([Sanchez and Rachlow 2008](#_ENREF_92)). The number of burrow systems used by an individual rabbit varies by site, sex, and season, but generally home range size increased with the number of burrow systems used. Numbers of burrow systems used by an individual rabbit ranged from 2 to 16, with a mean of 5.8 (SD = 2.94, n = 78, ([Sanchez 2007](#_ENREF_91)). The more burrow systems available, the more the pygmy rabbits used ([Price and Rachlow 2011](#_ENREF_84)).

Burrow entrances are typically, although not always, located under sagebrush, and often dug into minor topological features such as low-grade slopes. Tunnel systems have from 1 to 10 entrances, with most burrows having 2-3 ([Wilde 1978](#_ENREF_110), [Gahr 1993](#_ENREF_40)). Entrances tend to slope relatively gently, particularly in natal burrows (Gabler 1997, Rachlow et al. 2005). Burrow structure is typically fairly simple, consisting of tunnels without distinct chambers, and with occasional blind side tunnels. Rabbits may backfill either blind tunnels or tunnels leading to openings ([Wilde 1978](#_ENREF_110), [Gahr 1993](#_ENREF_40), [Heady 1998](#_ENREF_54)). Burrow systems may reach depths of 1 m ([Gahr 1993](#_ENREF_40)). Mean tunnel length was 177.7 cm (± 56.6 cm SD), and mean depth was 48.0 cm (± 27.1 cm SD) in Idaho ([Bradfield 1975](#_ENREF_11)). Entrances are variable in size, ranging from 10 to 35 cm in diameter. The mean diameter of 82 burrows was 19.2 cm (SD = 4.9 cm). The area covered by a single burrow system depends on the number of tunnels and entrances, but may range from 0.4 to 19.2 m2 ([Wilde 1978](#_ENREF_110), [Gahr 1993](#_ENREF_40)). Pygmy rabbits will also tunnel under snow ([Bradfield 1975](#_ENREF_11), [Wilde 1978](#_ENREF_110)) although no information was found on the extent and structure of these burrow systems.

***Activity periods***

Although pygmy rabbits are active at all times of the day, they seem to be primarily crepuscular ([Green and Flinders 1980a](#_ENREF_46), [Heady 1998](#_ENREF_54), [Larrucea and Brussard 2009](#_ENREF_65)). Pygmy rabbits show no circadian rhythms in their body temperatures, consistent with their round-the-clock activity potential ([Katzner et al. 1997](#_ENREF_60)). During most of the year, the greatest activity occurred at dawn in California and Nevada ([Larrucea and Brussard 2009](#_ENREF_65)). Activity levels generally varied by site, perhaps because of site-specific energetic demands ([Larrucea and Brussard 2009](#_ENREF_65)). In summer, substantial nocturnal activity was noted ([Heady 1998](#_ENREF_54)), as were dips in activity when temperatures rose above 25-27 °C ([Bradfield 1975](#_ENREF_11), [Heady 1998](#_ENREF_54)). Decreases in activity were noted when temperatures were < 4.5 °C ([Bradfield 1975](#_ENREF_11)). In winter, pygmy rabbits were most active in the evening, perhaps because temperatures were warmer then than in the morning (Larrucea and Brussard 2009).

Pygmy rabbits are also active throughout the year. Researchers found no evidence that pygmy rabbits depress their metabolic rate at times of stress in winter, as other lagomorphs do. They also do not store food ([Katzner et al. 1997](#_ENREF_60)). Pygmy rabbits use tunnels in the snow when the snow cover is sufficient (Katzner 1994 in Katzner et al. 1997, Larrucea and Brussard 2009), but may still spend more than 60% of winter daylight hours on the snow surface in temperatures that may drop to -26 °C (Katzner 1994 in Katzner et al. 1997). Although pygmy rabbits maintain somewhat lower body temperatures than other lagomorphs ([Katzner et al. 1997](#_ENREF_60)), this extreme thermal stress creates high energetic demands that the rabbits meet by eating almost exclusively sagebrush.

***Social behavior***

Pygmy rabbits are known to share burrow systems to some extent, and occasionally are found in pairs in burrows. This is not always in the context of mating, although pairs captured in the same burrow system at the same time were most often mixed sex in late winter and either male-female or female-female adults in summer ([Wilde 1978](#_ENREF_110), [Sanchez 2007](#_ENREF_91)). During the breeding season, most pairs of rabbits sharing burrow systems were male-female pairs, but both female pairs and male pairs were noted. Male-male pairs were the least common ([Sanchez 2007](#_ENREF_91)). More than one juvenile in the same burrow at a time was noted most frequently in June and July but burrow sharing occurred throughout the year ([Wilde 1978](#_ENREF_110)). Interestingly, there is no genetic component to adult same-sex pairs (Sanchez 2007).

Unlike any other leporid, pygmy rabbits utter an alarm call, which also supports the hypothesis that there is some social structuring in pygmy rabbit populations. The call has been variously described as a pika-like squeak ([Green 1978](#_ENREF_45)) or a series of 1-7 note squeal that most typically has 2 syllables ([Green and Flinders 1981](#_ENREF_48), [Flinders 1999](#_ENREF_31)). Both males and females emit these calls ([Green and Flinders 1981](#_ENREF_48)). These calls were emitted when captive rabbits were frightened into their burrow and continued for several seconds from within the burrow ([Green and Flinders 1981](#_ENREF_48)) and have been noted when a captured rabbit is being released into a burrow ([Wilde 1978](#_ENREF_110)). These vocalizations may well be an adaptation for a species adapted to living in an environment with low visibility ([Green and Flinders 1981](#_ENREF_48)).

***Reproduction***

Pygmy rabbits breed in their first spring at approximately 7-10 months of age and all animals attempt to breed ([Wilde 1978](#_ENREF_110)). As of this writing, it is not known whether females mate with more than one male, although it is assumed that males breed with more than one female ([Sanchez 2007](#_ENREF_91)). Males will move into new areas to obtain access to females ([Katzner and Parker 1998](#_ENREF_59), [Burak 2006](#_ENREF_14)).

Pygmy rabbits begin breeding in late winter. Day length may trigger male reproductive readiness whereas vegetative phenology may be the trigger for reproduction in females ([Wilde 1978](#_ENREF_110), [Green and Flinders 1980a](#_ENREF_46)). Males’ testes descended into the scrotal sacs in early January. Copulations between wild rabbits were observed in Idaho in March, whereas captive animals in western Washington and northwestern Oregon were first observed copulating in late February and the last observations were made in early June ([Elias et al. 2006](#_ENREF_27)). In a wild population of pygmy rabbits in Washington, lactating females were captured through September and pregnant females were also captured in July and August ([Gahr 1993](#_ENREF_40)). Gahr (1993) speculated that the milder winters on the Columbia Plateau relative to the Great Basin did not place as heavy a selective pressure on late-born young.

Female pygmy rabbits dig a natal burrow away from their core activity area before giving birth ([Burak 2006](#_ENREF_14), [Elias et al. 2006](#_ENREF_27)). This distance averaged 100 m in southwestern Idaho ([Burak 2006](#_ENREF_14)) but was >35 m from the burrow systems usually occupied by that female in south-central Idaho ([Rachlow et al. 2005](#_ENREF_85)). These natal burrows are so well hidden that the first discoveries of them in the wild only occurred in 2003, after they had been described as a result of the captive breeding program ([Rachlow et al. 2005](#_ENREF_85), [Elias et al. 2006](#_ENREF_27)). Specific details about the pygmy rabbits’ behavior during this process have only been observed in captive females. Pregnant rabbits began digging their natal burrows 12.8 days (SE= 2.8, n=8) prior to giving birth. The burrows’ entrance tunnels ranged from 16.5 to 35.5 cm to the nest chamber ([Elias et al. 2006](#_ENREF_27)). Natal burrows subsequently discovered in the wild ranged from 16 to 30 cm long, terminating in a spherical chamber ([Rachlow et al. 2005](#_ENREF_85)). Most captive females dug these burrows within one day, but some individuals took several days to finish. Some females in captivity covered the entrance to the natal burrow each time they finished a bout of digging, but others did not do so until the burrow was completed ([Elias et al. 2006](#_ENREF_27)).

In captivity, female pygmy rabbits were also observed digging a side tunnel in an existing tunnel system to use for their natal nest. This has not yet been documented in wild rabbits, and may be an artifact of the small pen, which was a 1.5 m diameter stock watering tank filled with compacted soil ([Elias et al. 2006](#_ENREF_27)). These side tunnels were also plugged with soil when not being dug. Burrows of pygmy rabbits in the wild have been found to have blind tunnels ([Bradfield 1975](#_ENREF_11), [Gahr 1993](#_ENREF_40)), but whether these were ever dug to be used as natal burrows is not currently known.

Creating the nest inside the natal burrow was a two-stage process in captive pygmy rabbits. Nests were completed 7.3 ± 2.2 days before parturition. Upon completion, females gathered the hay provided for nesting material and dragged it into the burrows. Once parturition was imminent, females added fur plucked from their undersides and backs, sides, and flanks to the nest ([Elias et al. 2006](#_ENREF_27)). Natal nests found in the wild contained shredded bark from sagebrush and fine grasses as well as hair. A number of burrows found in the wild were likely to be abandoned prior to use, which is also typical of cottontails ([Rachlow et al. 2005](#_ENREF_85)).

Remote cameras in captive pygmy rabbits’ burrows recorded 9 birth events. Gestation for these animals was 22-25 days ([Elias et al. 2006](#_ENREF_27)). Time of day for parturition was variable. Females gave birth either at the mouth of the burrow or inside. Young were cleaned by their mother and either crawled or were carried into the natal chamber. The entire process took 14.8 ± 4.5 minutes ([Elias et al. 2006](#_ENREF_27)). Females then covered the entrances with soil and often added hay or twigs as well.

Maternal care in captivity was limited to daily visits to the natal burrow to nurse. Two females nursed their litters twice a day, but six females tended their young only once per day ([Elias et al. 2006](#_ENREF_27)). Females opened the burrows and usually the young rabbits came to the surface to nurse, although sometimes the mothers were observed bringing their offspring up to nurse. The females nursed by sitting over the entrance to the burrow, covering it with their abdomen, and cleaned the young rabbits as they fed ([Elias et al. 2006](#_ENREF_27)). Nursing typically occurred in the late evening (1900-2400 h) or morning (0500-1100 h) and sessions lasted 9.8 ± 0.4 minutes for rabbits who fed their young twice a day, with session lasting slightly longer for rabbits who nursed only once per day (11.1 ± 0.3 minutes). Young were carried back inside if they did not crawl back on their own, and the entrance hidden when the session was finished ([Elias et al. 2006](#_ENREF_27)). This extremely cryptic behavior kept natal burrows from discovery until 2003 ([Rachlow et al. 2005](#_ENREF_85)), and prompted one researcher to speculate that female pygmy rabbits kept their infant young above ground and hid them scattered under sagebrush ([Wilde 1978](#_ENREF_110)). No thorough description of maternal behavior made from observations of free-living rabbits was found for this review.

The captive young pygmy rabbits became more exploratory at the end of the nursing sessions a few days before they left the natal burrow for good. This final emergence occurred at 15.4 ± 1.3 days of age ([Elias et al. 2006](#_ENREF_27)). Regular nursing sessions then ceased, occurring primarily when the mother rabbit was eating, and the young began eating rabbit pellets and vegetation. Their mothers stopped nursing two weeks after post-emergence ([Elias et al. 2006](#_ENREF_27)). In captivity, mother rabbits became aggressive toward offspring that tried to nurse after this time, so young rabbits were typically removed from the natal pen 7-14 days following emergence ([Elias et al. 2006](#_ENREF_27)). In the wild, young rabbits may remain on the natal territory for up to 10 weeks following emergence from natal burrows ([Estes-Zumpf and Rachlow 2009](#_ENREF_29)).

Three distinct cohorts of young rabbits were recognized in Idaho in the course of a single breeding season ([Wilde 1978](#_ENREF_110)). However, captive rabbits averaged less than two litters per year, although two females housed in larger, more natural pens produced four litters each ([Elias et al. 2006](#_ENREF_27)). Litter size in captive females ranged from 2-7, and averaged 4.1 ± 0.1 young per litter ([Elias et al. 2006](#_ENREF_27)). Reports of embryos found in pregnant wild pygmy rabbits ranged from 4-8 ([Green and Flinders 1980a](#_ENREF_46)).

There is no definitive information regarding timing of parturition in wild populations of pygmy rabbits, but wild females in Idaho were found to be lactating as early as late February. Timing of parturition varied annually, with the first lactating female captured as late as early April in previous years at that study site ([Wilde 1978](#_ENREF_110)). Lactation ended in early June with a few exceptions into mid-August one year. Although only three cohorts of young were recognized each year ([Wilde 1978](#_ENREF_110)), this very late date may indicate a fourth litter born to this female. Dates that each cohort of young rabbits was first observed were not reported. In Washington, lactating females were observed in September, suggesting a prolonged breeding season on the Columbia Plateau relative to the Great Basin and Intermountain regions ([Gahr 1993](#_ENREF_40)).

## Movements and Territoriality

Pygmy rabbits occupy overlapping summer home ranges. To some extent, they share burrow systems although usually only one rabbit uses a burrow system at a time ([Wilde 1978](#_ENREF_110), [Gahr 1993](#_ENREF_40), [Burak 2006](#_ENREF_14), [Sanchez 2007](#_ENREF_91)). Occasionally two rabbits were captured in the same burrow system in a single trapping event. Most of these pairs caught in the same burrow were mixed sex (82%) or juveniles in one study, suggesting that most adult sharing was likely motivated by mating activity ([Wilde 1978](#_ENREF_110)). A more thorough study of overlap found that overlap was not a function of relatedness among neighboring rabbits. Male pygmy rabbits were more likely to overlap during the spring breeding season than in summer, possibly because of shared attraction to receptive females ([Sanchez 2007](#_ENREF_91)). Overall, this species seems to show no tendency to form groups suggestive of social colonies, but it will tolerate neighbors, even unrelated neighbors of the same sex ([Sanchez 2007](#_ENREF_91)).

Pygmy rabbits typically do not stray far from their burrow systems. A home range may have several discrete burrow systems around which an individual rabbit will center its activity ([Gahr 1993](#_ENREF_40), [Katzner and Parker 1997](#_ENREF_58), [Heady and Laundre 2005](#_ENREF_55), [Sanchez and Rachlow 2008](#_ENREF_92)). Home range sizes have a strong breeding season component. Summer and annual home ranges were similar in size in study sites in southeastern Oregon and northwestern Nevada, although male pygmy rabbits have larger summer and annual home ranges than females (Crawford 2008). Non-breeding home ranges were one-half to one-third smaller and similar between the sexes (Crawford 2008).

Home range sizes are a function of site-specific conditions and thus are highly variable. Specific annual estimates of fixed-kernel home ranges for female pygmy rabbits have ranged from 0.9 ± 0.2 ha ([Crawford 2008](#_ENREF_18)) to 4.3 ± 1.4 ha ([Sanchez 2007](#_ENREF_91)). Fixed-kernel estimates of annual home ranges for male rabbits ranged from 1.7 ± 0.7 ha ([Crawford 2008](#_ENREF_18)) to 12.6 ± 2.4 ha (Sanchez 2008). Similarly, estimates of breeding-season home ranges have ranged from 0.92 ± 0.16 ha ([Crawford 2008](#_ENREF_18)) to 2.8 ± 0.8 ha ([Sanchez 2007](#_ENREF_91)) for females. Clearly the full extent of the annual home ranges is used during the breeding season, although not all studies have estimated both. Fixed-kernel home range estimates for male rabbits during the breeding season has varied from 1.67 ± 0.27 ha ([Crawford 2008](#_ENREF_18)) to 12.0 ± 1.6 ha ([Sanchez and Rachlow 2008](#_ENREF_92)). Other studies reported much larger summer home ranges with male fixed-kernel home range estimates of 24.9 ± 10.3 (SD) ha for males and 1.8 ± 1.3 (SD) ha for females in southwestern Idaho ([Burak 2006](#_ENREF_14)) and 20.2 ± 10.54 (SD) ha for males and 2.7 ± 2.36 (SD) ha for females using the 95% harmonic mean in Washington ([Gahr 1993](#_ENREF_40)). Gahr (1993) found similar estimates of home range size using the minimum convex polygon method, with 24.9 ± 12.85 (SD) ha estimated for males and 0.8 ± 0.71 (SD) ha for females. Crawford (2008) estimated non-breeding home ranges at 0.63 ± 0.11 (SD) ha for males and 0.5 ± 0.09 (SD) ha for females. Home ranges are determined in part by environmental conditions; Burak (2006) noted that home ranges in summer were considerably smaller the year that heavy precipitation fell during spring.

Daily movements of pygmy rabbits also exhibited differences between males and females. Radio-telemetry revealed that male pygmy rabbits moved greater distances than females on a daily basis in summer, an average of 220 ± 48 m compared to mean movements of 64 ± 5 m for female rabbits. Males seemed to move in response to females ([Burak 2006](#_ENREF_14), [Sanchez 2007](#_ENREF_91)), and males’ home ranges tended to overlap with a greater number of other individuals than females’ home ranges ([Sanchez 2007](#_ENREF_91)).

Both male and female juvenile pygmy rabbits disperse, beginning as young as 2.5 weeks of age. Dispersal by young pygmy rabbits was rarely prefaced with exploratory movements and once the animals began to move, they completed their dispersal relatively quickly, often within one week. Median dispersal age was 6.3-6.5 weeks old ([Estes-Zumpf and Rachlow 2009](#_ENREF_29), [Price et al. 2010](#_ENREF_83)). Total distances from natal range to settlement were up to 10.8 km straight-line distance for a young female ([Estes-Zumpf and Rachlow 2009](#_ENREF_29)). Both males and females disperse, with 90% of males and 80% of females leaving the area of the natal territory. Females traveled farther before settling, with a maximum distance of 11.9 km compared to the top two maximum distances for juvenile males, which were 6.5 and 5.6 km. Median dispersal distances did not differ, suggesting that in general the sexes traveled equivalent distances while some females exhibited long-distance movement ([Estes-Zumpf and Rachlow 2009](#_ENREF_29)). Interestingly, genetic work among a series of locations within 14 km of each other indicated that there were high levels of gene flow among them and no indication of sex bias in dispersal, but positive genetic spatial autocorrelation suggested that females dispersed farther than males ([Estes-Zumpf et al. 2010](#_ENREF_30)).

Dispersal capacity of an organism has a major impact on its ability to avoid regional extinction ([Hanski 1999](#_ENREF_51)). Researchers have questioned the dispersal capacity of this species given its reliance on specific habitat characteristics, its relatively slow speed and its general unwillingness to leave sagebrush cover ([Green and Flinders 1980a](#_ENREF_46)). Although juvenile pygmy rabbits can and do move across open areas, roads and creeks during post-natal dispersal movements ([Crawford 2008](#_ENREF_18), [Estes-Zumpf et al. 2010](#_ENREF_30), [Lawes et al. 2013](#_ENREF_68)), such barriers may still affect dispersal in some circumstances. Direction of dispersal was consistently away from these features in another study ([Estes-Zumpf and Rachlow 2009](#_ENREF_29)), and roads and perennial creeks reduced gene flow among populations that were otherwise within 1 km of each other ([Estes-Zumpf et al. 2010](#_ENREF_30)). Cover or the lack of it also influenced movement paths, although a lack of cover did not prevent dispersal ([Crawford 2008](#_ENREF_18), [Estes-Zumpf et al. 2010](#_ENREF_30)). The conditions under which roads in particular are not an absolute barrier are not clear, although presumably width and traffic volume are factors.

## Demography and Population Trends

Pygmy rabbits are prey for a wide range of predators, particularly weasels, raptors, and coyotes ([Wilde 1978](#_ENREF_110), [Crawford 2008](#_ENREF_18), [Crawford et al. 2010](#_ENREF_16)). Other potential predators include red foxes, bobcats, and badgers ([Green and Flinders 1980a](#_ENREF_46)). It is highly likely that any predatory or omnivorous animal able to kill and consume a pygmy rabbit would do so if the opportunity arose. Predation was by far the greatest cause of identified mortality in a number of studies, and far outnumbered mortality from unknown or other causes ([Sanchez 2007](#_ENREF_91), [Crawford 2008](#_ENREF_18), [Estes-Zumpf and Rachlow 2009](#_ENREF_29), [Lawes 2009](#_ENREF_66)). No information was found regarding whether altered predator distributions, community composition, or numbers may be partly responsible for the declines in some pygmy rabbit populations.

Wilde (1978) suggested that pygmy rabbits may not be able to produce additional cohorts of young to compensate for heavy predation or years of poor environmental conditions. Reproductive output between a bad year and a more favorable one was the same in his study. He speculated that population cycles should not be expected in an animal feeding on a long-lived, abundant food source such as sagebrush ([Wilde 1978](#_ENREF_110)). Population cycles have not been noted in the published literature on pygmy rabbits ([Green and Flinders 1980a](#_ENREF_46)), although several researchers have reported acute declines ([Bradfield 1975](#_ENREF_11), [Weiss and Verts 1984](#_ENREF_105), [Sanchez 2007](#_ENREF_91), [Crawford et al. 2010](#_ENREF_16)). Population declines followed by recovery have been noted in the Soup Lakes area of the Lakeview BLM district in Oregon, and the reoccupation of abandoned burrows has been noted in the Wagontire area of the Burns BLM district five years after they were first found and classified as abandoned (M. Foster, *personal communication*, Foster 2010).

Pygmy rabbits are typical of lagomorphs in their high reproductive rate, which presumably allows them to compensate for high predation rates. A number of researchers have estimated survival rates of pygmy rabbits from radio-telemetry studies and found that annual survival is low, which is in agreement with the typical life history strategy of lagomorphs. Predation is the major cause of mortality and shows seasonal variation. Annual predation rates for radio-collared rabbits were 88.6% for adults and 89.4% for juveniles over the course of a year (Crawford et al. 2010). This study found that survival varied for each sex over four sites in northwestern Nevada and southeastern Oregon, and survival rates were lowest for both sexes in November-January and April-May. Peaks in mortality were noted in March, May and August in all sites and across both years ([Sanchez 2007](#_ENREF_91)). March was also noted as a low point in pygmy rabbit survival in another study in Idaho, although the late summer and fall had some of the highest survival rates ([Wilde 1978](#_ENREF_110)). Spring mortality peaks may be a result of low food reserves prior to spring green-up (Wilde 1978).

Regardless of cause of mortality and seasonality, survival rates are generally low and the average lifespan likely very short. Sanchez (2007) estimated the average lifespan at 1.7 ± 0.5 years, with a maximum lifespan estimated as 3.3 years. Estimated survival for pygmy rabbits following natal dispersal have ranged from 0.003 (± 0.003 SE) to 0.173 (±0.066 SE) for rabbits weighing over 250 g and older than 3 months in Oregon and Nevada ([Crawford et al. 2010](#_ENREF_16)), to 0.45 (95% CI 0.24-0.66) for adult males in Idaho (Sanchez 2007). Marked variation in survival was noted across study areas in Idaho, with the low annual estimate of 0.07 (95% CI 0.00-0.21) for adult males (Sanchez 2007). Estes-Zumpf and Rachlow (2009) reported that 30.8% of marked juvenile males and 11.5% of marked juvenile females survived their first year ([Estes-Zumpf and Rachlow 2009](#_ENREF_29)). Price and colleagues (2010) estimated 22% of young rabbits survived their first year.

Juvenile survival prior to post-dispersal settlement is similarly low and variable. Wilde (1978) estimated survival from marking soon after emergence to 20 weeks as 0.23 for the first year of life and 0.44 for the next. Overall, half of the marked juvenile rabbits disappeared within five weeks of capture although some of these animals may have dispersed and not been relocated (Wilde 1978). Price and colleagues (2010) estimated juvenile survival to age 18 weeks as 0.44 for females (95% CI 0.256-0.644), and 0.35 (95% CI 0.195-0.553) for males, with the differences between sexes statistically insignificant. Similar estimates were reported in Wilde (1978). Mortality peaked during the first two months following emergence but survival did not seem to be influenced by whether the young rabbits dispersed or how far they went ([Wilde 1978](#_ENREF_110), [Estes-Zumpf and Rachlow 2009](#_ENREF_29), [Price et al. 2010](#_ENREF_83)). Overall, low survival rates support the importance of high reproductive output for this species.

Lagomorph population dynamics such as those of snowshoe hares can be famously variable. However, no evidence for cycling or even fluctuations was reported in the literature reviewed for this conservation assessment, although the potential for fluctuations arising from highly variable survival rates in space and time were noted ([Price et al. 2010](#_ENREF_83)). Likewise, although several researchers commented that populations seemed to be declining during the course of several years’ study ([Bradfield 1975](#_ENREF_11), [Wilde 1978](#_ENREF_110), [Weiss and Verts 1984](#_ENREF_105), [Sanchez 2007](#_ENREF_91), [Crawford et al. 2010](#_ENREF_16)), no estimate of population growth, either positive or negative, was found in the literature. Sharp declines in populations can be reversed through increased recruitment through either immigration or recruitment, which is a function of reproductive output and survival of young. Genetic work indicates that pygmy rabbits disperse farther and more frequently than previously thought ([Estes-Zumpf et al. 2010](#_ENREF_30)), suggesting that migration and metapopulation rescue may be occurring ([Price et al. 2010](#_ENREF_83)). Sufficient gene flow was occurring on the scale of 14 km that populations within that distance of each other were a single genetic cluster in Idaho ([Estes-Zumpf et al. 2010](#_ENREF_30)). Whether survival, dispersal and recruitment rates are great enough for population persistence in the face of habitat fragmentation is not clear.

# IV. CONSERVATION

## Ecological and Biological Considerations

The pygmy rabbit is generally considered to be tightly associated with big sagebrush communities growing on deep sandy soil. However, survey work in Oregon has located pygmy rabbits in patches of big sagebrush surrounded by low sagebrush, and in clay-loam soils, suggesting that its habitat requirements may be more flexible than previously thought. Soil may be more important than the specific shrub composition as long as big sagebrush is present (M. Foster, *unpublished reports*).

Although the social system of this species is not fully understood, pygmy rabbits readily share burrow systems ([Wilde 1978](#_ENREF_110), [Sanchez 2007](#_ENREF_91)), and give alarm calls that are separate from immediate distress calls or screams ([Green and Flinders 1981](#_ENREF_48)). Interestingly, there does not seem to be a strong component of relatedness to burrow-sharing behavior based on genetics work ([Sanchez 2007](#_ENREF_91)), nor is it limited to male/female pairs. How social dynamics may influence survival and reproductive success are unknown.

Pygmy rabbits have a number of parasites, including ticks, fleas, and bot flies ([Wilde 1978](#_ENREF_110), [Gahr 1993](#_ENREF_40)). Rabbits in general are known to act as hosts for many types of parasites, from easily observed ectoparasites to diseases such as tularemia ([Bacon et al. 1958](#_ENREF_2)). Currently, no reports were found of disease in wild populations that could explain the rapid population declines, even though in some cases research was ongoing during those declines ([Bradfield 1975](#_ENREF_11), [Weiss and Verts 1984](#_ENREF_105), [Seigal Thines et al. 2004](#_ENREF_94), [Sanchez 2007](#_ENREF_91), [Crawford et al. 2010](#_ENREF_16)). Disease has been documented in captive rabbits ([Duszynski et al. 2005](#_ENREF_26), [Bakke et al. 2006](#_ENREF_4)) but in wild rabbits, sick animals are likely either predated or die in burrows, making disease difficult to detect. Disease may be significant for some populations.

Very high predation rates on pygmy rabbits have been noted by many researchers ([Wilde 1978](#_ENREF_110), [Sanchez 2007](#_ENREF_91), [Crawford et al. 2010](#_ENREF_16)). Predation rates may be greater currently relative to historical levels as a result of altered predator community dynamics ([Kenaith and McGee 2004](#_ENREF_61)). For example, ravens and coyotes may have increased as a result of enhanced water sources ([Knight et al. 1998](#_ENREF_62), [Arjo et al. 2007](#_ENREF_1)), land-use changes such as agriculture may benefit other generalist predators such as red foxes, raccoons, and skunks ([Kenaith and McGee 2004](#_ENREF_61)), and increases in raven populations can occur with development features such as highway bridges, billboards, and powerlines that offer perches and nest sites away from traditionally used cliffs ([White and Tanner-White 1988](#_ENREF_107)). Furthermore, populations of pygmy rabbits that may have been able to compensate for heavy predation in the absence of other stressors may not be able to do so in fragmented, degraded habitat ([Kenaith and McGee 2004](#_ENREF_61)).

## Threats

Threats to pygmy rabbit persistence are primarily habitat destruction or degradation. There have been rapid and dramatic changes to western landscapes since the arrival of Europeans that have for the most part not benefitted sagebrush-obligate species. Rangeland enhancement for grazing, agriculture, and development have been responsible for the direct removal of sagebrush. Heavy grazing without removal of sagebrush can also reduce habitat quality for pygmy rabbits, although the effects of grazing on pygmy rabbits are not well understood.

Other threats include increased intensity and frequency of fire, juniper encroachment, invasive non-native plant species, and increased predation. Pygmy rabbit populations have likely always been patchy because of the unique combination of soils and vegetation that they require (Bailey 1936 in USFWS 2012). However, decreasing sagebrush habitat will lead to increasing isolation of patches of suitable habitat for pygmy rabbits and loss of genetic diversity as well as decreasing population sizes, thus increasing risk of local extirpation. Although predation has likely always been a major selective force on pygmy rabbits, habitat fragmentation and degradation may increase pygmy rabbit vulnerability and predator populations, or allow novel predators to invade pygmy rabbit habitat.

Loss of sagebrush can occur not only from fire, but from insect damage such as that caused by the native Aroga moth (*Aroga websteri* Clarke). This moth has caused extensive damage in various regions of the Great Basin, including Utah, Nevada, and Oregon ([Gates 1964](#_ENREF_41), [Bentz et al. 2008](#_ENREF_6), [Bolshakova and Evans 2014](#_ENREF_10)). Work in Utah suggested that damage is greatest in cooler, wetter microclimates that may best support sagebrush recovery. In addition, the moth’s outbreaks seem to be driven by environmental conditions ([Bolshakova and Evans 2014](#_ENREF_10)). At least three major parasitoid wasp species prey on the moth ([Bolshakova 2013](#_ENREF_9)). How future climate conditions affect its ability to infest extensive areas of sagebrush and how those conditions will affect its parasitoids is unknown.

***Grazing***

Habitat loss has occurred from range “improvement” programs meant to increase forage for livestock and big game. These programs have utilized a number of management strategies, from removing sagebrush entirely either mechanically or via herbicides followed by replanting with grass species more palatable to cattle. Land managers have also reduced sagebrush density to favor more grass and forb growth without eliminating the sagebrush entirely. When these activities occur in areas with the combination of tall, dense sagebrush and deep sandy soils, direct negative impacts to pygmy rabbit populations can be expected to result.

Cattle grazing can have multiple direct impacts on pygmy rabbit populations. Negative impacts (reviewed in Kenaith and McGee 2004) include trampling burrows ([Siegel Thines et al. 2004](#_ENREF_97)), facilitating non-native weed invasion and fire risk (see below), reduced nutritional quality of grasses and shrubs from fall through spring ([Seigal Thines et al. 2004](#_ENREF_94)), possible damage to dense, tall stands of sagebrush from trampling or browsing, and increased coyote and raven populations resulting from supplemental water sources provided for livestock ([Knight et al. 1998](#_ENREF_62), [Arjo et al. 2007](#_ENREF_1)). Cattle could compact soil enough to make it unsuitable for pygmy rabbit burrowing ([Lyman 2004](#_ENREF_70), [Seigal Thines et al. 2004](#_ENREF_94)).

Grazing may reduce habitat quality sufficiently that rabbits must increase their home ranges and movements, potentially increasing predation risk. Pygmy rabbits in Washington occupied larger home ranges and male rabbits exhibited greater movements in a grazed area in comparison to an adjacent ungrazed area within the Sagebrush Flat site in Douglas County. In addition, there were fewer burrows in the grazed area, which was grazed for 3 months each autumn ([Gahr 1993](#_ENREF_40)). Similar findings regarding burrow density were reported by Seigel Thines and others (2004), who noted that cattle grazing in late summer may lead to competition for grass prior to the fall, when pygmy rabbits switch their diet to sagebrush.

Grazing can increase sagebrush cover under some conditions, but this is often a result of overgrazing ([Ellison 1960](#_ENREF_28)) and is not necessarily beneficial to pygmy rabbits. For example, sagebrush productivity and overall cover increased following heavy grazing, but grasses and forbs were reduced ([Ellison 1960](#_ENREF_28), [Pearson 1965](#_ENREF_82)). Similarly, although grazing and dropping water tables have allowed former grassy valley floors to be invaded by sagebrush that becomes the new climax vegetation ([Miller and Rose 1999](#_ENREF_75)), this has to occur in areas with deep, sandy soils in order to be considered as new habitat for pygmy rabbits.

However, it is possible that in some cases grazing may be a tool to help reduce risk of fire in or adjacent to pygmy rabbit habitat, if that habitat is already degraded by cheatgrass. Researchers examined the effects of grazing cheatgrass-infested plots in May when the grass was at the boot stage followed by burning in October. They found that grazing could reduce the potential for catastrophic fire because flame lengths were much less than compared to control plots (Diamond et al. 2009). Whether such grazing management offers benefits that offset potential burrow trampling, soil compaction, and other negative impacts will likely be site-specific. Increasing fire intensity and return interval is a major threat to sagebrush ecosystems (see *Fire* below).

***Invasive plant species***

Habitat degradation has occurred from grazing, invasive plants, and altered fire regimes, which have allowed the invasion of pinyon and juniper into areas once dominated by sagebrush. In south central Oregon, tree ring data indicated that juniper expansion began 1875-1885. Wetter climatic conditions between 1870 and 1915, combined with reduced fire frequency and grazing, created favorable conditions that led to a peak in juniper expansion in the region between 1905 and 1925 ([Miller and Rose 1999](#_ENREF_75)). Of 15 sites in Nevada and California invaded by pinyon-juniper woodlands that were previously known to have supported pygmy rabbits prior to 1950, only one was still occupied in 2003-2006 ([Larrucea and Brussard 2008a](#_ENREF_63)). Pinyon-juniper invasion has occurred primarily in the foothills, shifting pygmy rabbit habitat to lower elevations. As climatic shifts occur, warmer temperatures may make these lower-elevation sites less suitable, but the pinyon-juniper invasion may prevent the pygmy rabbit populations from compensating by moving to higher elevations ([Larrucea and Brussard 2008a](#_ENREF_63)).

***Fire***

Fire has been listed as a contributing cause of population disappearances in Washington ([Hayes 2003](#_ENREF_53)). In Idaho, recent fire was found to be a negative predictor of pygmy rabbit occurrence. Sites that did not support rabbits frequently showed evidence of fire within the previous 15 years ([Rachlow and Svancara 2006](#_ENREF_86)). Fire has been considered a major threat to populations ([McCallister 1995](#_ENREF_71), [Larrucea and Brussard 2008a](#_ENREF_63)). Although fire is a natural process in the intermountain west, fire regimes have changed substantially and have a much greater potential for negative impacts, particularly given the fragmented, remnant nature of existing pygmy rabbit habitat.

Fire return intervals prior to European settlement were variable, from 12-25 years on productive sites with mountain big sagebrush to over 200 years in xeric habitats with sandy soil and dominated by big sagebrush and needle grass ([Miller and Rose 1999](#_ENREF_75), [Crawford et al. 2004](#_ENREF_17)). These intervals were sufficient to remove encroaching juniper and pinyon ([Crawford et al. 2004](#_ENREF_17)), and long enough for big sagebrush to recover via seed dispersal. Seed dispersal was facilitated by the patchiness of burns which left stands of living sagebrush in among burned areas ([Crawford et al. 2004](#_ENREF_17), [Baker 2006](#_ENREF_3)). These historic patterns could inform restoration of the sagebrush community.

Historically, fire regimes have changed dramatically following the invasion of species such as cheatgrass (*Bromus tectorum*). Both fire frequency and the extent of burns have increased ([Brooks et al. 2004](#_ENREF_13)). In the case of cheatgrass in particular, fire frequencies have increased such that native vegetation cannot recover in the interlude between fires ([Brooks et al. 2004](#_ENREF_13)). Other invasive plants that decrease fire return intervals include knapweed (*Centuarea* spp.), rush skeletonweed (*Chondrilla juncea*), and bur buttercup (*Ceratocephala testiculata*). The invasion of fine fuels into native vegetative communities also increases the potential for very large fires ([Crawford et al. 2004](#_ENREF_17)).

Microsite characteristics dictate the extent to which fire may be a risk, with Wyoming big sagebrush (*A. t. wyomingensis*) being most resistant to fire, basin big sagebrush (*A. t. tridentata*) intermediate and mountain big sagebrush (*A. t. vaseyana*) the most prone to burning; wetter microclimates and deeper soil support more fuel ([Britton and Clark 1984](#_ENREF_12)). However, they also support the tall, thick sagebrush required by the pygmy rabbit.

Sagebrush ecosystems can be particularly vulnerable to fire. Unlike some species of sagebrush, big sagebrush does not re-sprout following a fire, but must re-establish from seed ([Blaisdell 1953](#_ENREF_8)). Its seeds do not typically travel far from the parent plant or last for extended periods in the soil ([Whisenant 1990](#_ENREF_106), [Meyer 1994](#_ENREF_73)). Therefore, regeneration after a fire requires a nearby seed source. Further, big sagebrush does not produce seed until at least 4-6 years following establishment ([Whisenant 1990](#_ENREF_106)), and may not set seed every year ([Meyer 1994](#_ENREF_73)). These characteristics affect recovery of big sagebrush in burned areas.

***Development***

Suburban development has occurred on sites that once supported pygmy rabbits ([Larrucea and Brussard 2008a](#_ENREF_63)). Energy development may have had an even greater impact because in addition to the loss of habitat to ground disturbance for installations and supporting infrastructure, roads may inhibit dispersal movements ([Estes-Zumpf and Rachlow 2009](#_ENREF_29), [Estes-Zumpf et al. 2010](#_ENREF_30)) and increase predation risk when rabbits disperse through areas without suitable cover. Coyotes may increase with increasing availability of surface water ([Arjo et al. 2007](#_ENREF_1)), raptors may use power poles and lines as hunting perches, and ravens may increase their presence ([Knight et al. 1998](#_ENREF_62)), although the predation risk posed by ravens is unknown. In addition, roads can facilitate the spread of invasive plants that establish on the disturbed soil of roadsides. Agricultural development has often occurred on the deep, sandy and silty soils needed by the pygmy rabbits ([Beauvais et al. 2008](#_ENREF_5), [Larrucea and Brussard 2008a](#_ENREF_63)).

***Population fragmentation and loss of genetic diversity***

Dispersing juvenile pygmy rabbits are now known to cover distances of up to at least 10 km and at least occasionally move across open habitat, including minor roads and creeks. Habitat loss and degradation may reduce connectivity among populations by reducing cover needed for dispersing juveniles. Although pygmy rabbits will cross open ground or roads and perennial creeks, movement across those barriers is reduced relative to movements across landscapes without them ([Lawes 2009](#_ENREF_66), [Estes-Zumpf et al. 2010](#_ENREF_30)). Reduced connectivity can result in disrupted population dynamics, such that immigration is not available to bolster populations that have declined, or to establish new populations to compensate for those that have disappeared ([Hanski 1999](#_ENREF_51)).

Ultimately, low connectivity among populations leads to reduced gene flow. This has been demonstrated in pygmy rabbit populations separated by only a short distance, but also a small road and perennial creek. A population 30 km from others demonstrated genetic isolation ([Estes-Zumpf et al. 2010](#_ENREF_30)). Although Estes-Zumpf and colleagues (2010) concluded that the genetic patterns within the study populations likely had been a result of both spatial and temporal variability in patterns of connectivity, isolation of a population genetically can lead to genetic drift and fixation of deleterious traits, even if the population is large enough that it is self-sustaining in the immediate future ([Frankham et al. 2002](#_ENREF_37)).

## Management Considerations

The formerly great extent of complex sagebrush communities allowed coexistence and persistence of species requiring different habitat characteristics. There are several sagebrush obligate species of considerable management concern, including the greater sage grouse (*Centrocercus urophasianus*), sage sparrow (*Amphispiza belli*), Brewer’s sparrow (*Spizella breweri*), and sage thrasher (*Oreoscoptes montanus*). However, management actions that benefit one species may conflict with the habitat requirements of another ([Beauvais et al. 2008](#_ENREF_5)). For example, management recommendations for sagebrush used for greater sage-grouse nesting included canopy cover of 15-25% ([Connelly et al. 2000](#_ENREF_15)), whereas pygmy rabbits typically utilize much greater shrub cover of 28% to >40% ([Green and Flinders 1980a](#_ENREF_46), [Weiss and Verts 1984](#_ENREF_105), [Katzner et al. 1997](#_ENREF_60), [Hagar and Lienkaemper 2007](#_ENREF_49)). Management actions will need to consider geographic factors such as location of lekking sites and deep sandy soil deposits to maximize the benefits of interventions across all sagebrush species.

Sagebrush steppe has been dramatically reduced since European settlement, with an estimated loss of 59% of this habitat type in Washington alone ([Dobbler et al. 1996](#_ENREF_24)). Further, remaining sagebrush steppe has been fragmented and altered from development and range improvement practices. The interplay between habitat fragmentation, overgrazing and increased fire frequency and extent following the spread of invasive annual forbs and grasses continue to reduce pygmy rabbit habitat. These forces are interrelated and a comprehensive management approach will be needed.

***Grazing***

The intensity and timing of grazing may be the keys to its impact. Although overgrazing has been identified as a major factor in the initial invasion of cheatgrass ([D'Antonio and Vitousek 1992](#_ENREF_20)), invasion can occur without grazing ([Davies et al. 2011](#_ENREF_21)). Appropriately managed grazing may be a part of the solution to breaking the fire cycle (Diamond et al. 2009). Grazing cheat grass during its boot stage, when the inflorescence was emerging from the leaf sheath, had maximum effects on its growth. When controlled burns were initiated in October, there was reduced flame length and rate of spread. A second year of grazing in May reduced the cheat grass enough so that fires did not carry ([Diamond et al. 2009](#_ENREF_23)). This may not be a suitable treatment where native understory plants persist, but it could be applied in strip form to create a fire break (Diamond et al. 2009). The timing of grazing will also depend on the vegetative composition of the sagebrush understory ([Paige and Ritter 1999](#_ENREF_81)). The potential benefits of grazing will need to be balanced against the potential for cattle to crush burrows and compact soil (Lyman 2004, Siegel Thines et al. 2004).

Research evaluating the interaction of grazing and burning in sagebrush with native understory found that litter accumulation was much greater in ungrazed plots, and subsequent fire reduced bunchgrass densities by nearly half ([Davies et al. 2009](#_ENREF_22)). Bunchgrass was not reduced by fire when moderate grazing removed 30-40% of available forage ([Davies et al. 2009](#_ENREF_22)). Native bunchgrasses are a major dietary item for pygmy rabbits during the late spring through summer, and pygmy rabbits may compete with cattle for this resource during this time (Green 1978).

***Invasive Species and Fire***

Fire and invasive weeds are inextricably linked problems for managers. Larger and more severe fire is facilitated by invasive annuals, and post-fire conditions are often conducive for further establishment of invasive annual plants ([Whisenant 1990](#_ENREF_106), [Brooks et al. 2004](#_ENREF_13)). Although fire has historically been a force shaping vegetation patterns in the intermountain west, big sagebrush is not adapted to frequent fire. Big sagebrush is easily killed by fire and requires a minimum of 30 years to recover ([Blaisdell 1953](#_ENREF_8), [Harniss and Murray 1973](#_ENREF_52)). It also requires a seed source to re-establish, because it does not re-sprout following fire (Wright et al. 1979 in Braun 1998). Large-scale fires pose an even greater time lag on sagebrush recovery because big sagebrush seed does not persist in the seedbank and does not disperse far from the parent plant ([Whisenant 1990](#_ENREF_106), [Meyer 1994](#_ENREF_73)). Restoration efforts can be further hampered by spatial and temporal changes in the soil’s nutrient profile in burned areas, and by the potentially large seed bank of invasive plants ([Brooks et al. 2004](#_ENREF_13)). These factors may also reduce the re-establishment of big sagebrush.

Fire will control juniper and pinyon in areas where they have encroached, and the mean fire return interval to do so has been estimated as once every 50-100 years ([Crawford et al. 2004](#_ENREF_17)). Fire may not be an appropriate management tool if the understory is dominated by annuals because of increased severity and extent of burns in those conditions ([Crawford et al. 2004](#_ENREF_17)). Grazing management may help alleviate fire risk, if grazing is of moderate pressure and is applied at the appropriate phenological stage ([Diamond et al. 2009](#_ENREF_23)). If invasive annual vegetation is present, mechanical removal of conifers may pose less risk to big sagebrush habitat. Whether managers will have control over mean fire return interval is an open question, given the increased severity and extent of fires in the intermountain west in recent decades.

Some specific projections regarding the impacts of climate change on eastern Washington and Oregon suggest that under a range of scenarios, dry sagebrush steppe is likely to decrease and mesic shrub-steppe increase, potentially with further expansion of juniper (*Juniperus occidentalis*). Summers are projected to become hotter and drier. Winters will be warmer and rainfall is projected to increase in the non-summer months ([Michalak et al. 2014](#_ENREF_74), [Mote et al. 2014](#_ENREF_76), [Creutzburg et al. 2015](#_ENREF_19)). These changes may dramatically affect the distribution of suitable habitat for pygmy rabbits and the risks of invasive annuals and fire by altering vegetative communities.

***Development***

Protection of remaining suitable habitat from development, including additional road building, should greatly aid in the conservation of this species. Habitat that has not yet been degraded by invasive species or rangeland management for grazing should be prioritized. Thought should also be given to habitat at higher elevations, which may be crucial to both sagebrush and sagebrush-obligate species as the regional climate changes.

Development pressure arises from urban and exurban sprawl, but also from energy development and agriculture. Energy development has the potential to severely fragment sagebrush habitat particularly in conjunction with ranching and farming activities ([Naugle et al. 2011](#_ENREF_78)) and can facilitate the invasion and spread of invasive annual grasses and forbs ([Bergquist et al. 2007](#_ENREF_7)). Lands suitable for agriculture have largely been converted to that use, as the peak of that activity occurred at the turn of the 20th century ([Dobbler et al. 1996](#_ENREF_24)). However, 6% of 105 sites known to support pygmy rabbits prior to 1950 were converted to agriculture by the first decade of the 21st century ([Larrucea and Brussard 2008a](#_ENREF_63)). Remaining sagebrush occurring on deep, sandy or loamy soils should be a priority for conservation from further development.

***Population fragmentation and loss of genetic diversity***

Pygmy rabbit populations were likely always patchy as a function of their specific habitat requirements. However, increasing isolation from development or alteration of habitat in the intervening matrix habitat may have substantially reduced long-distance dispersal with consequences for metapopulation persistence and gene flow ([Estes-Zumpf et al. 2010](#_ENREF_30)). Finally, genetic diversity may be disrupted as populations become isolated by changing climate conditions and subsequent habitat shifts ([Razgour et al. 2013](#_ENREF_87)).

Although pygmy rabbits will disperse across open space lacking overhead cover ([Lawes et al. 2013](#_ENREF_68)), such areas can act as isolating barriers even in the short term as rabbits avoid them ([Crawford 2008](#_ENREF_18), [Estes-Zumpf et al. 2010](#_ENREF_30)). Movement may be facilitated by maintaining sagebrush along fence lines, streams, and even borrow ditches next to roadways ([Oliver 2004](#_ENREF_79)). Roads may be attractive nuisances in that road crowns lead to water drainage along road edges, and therefore may support thicker, taller sagebrush stands ([Lawes et al. 2012](#_ENREF_67)). However, roads may serve as travel corridors for predators such as coyotes, raising predation risk ([Lawes et al. 2012](#_ENREF_67)). In addition, associated structures such as billboards or utility poles and wires may increase the presence of avian predators. Fence lines may also serve as movement corridors or perches for predators, although the cumulative effects of better dispersal cover combined with potential predator concentration are unknown, as is the extent to which such habitat corridors will be used. The relevance of these questions may be magnified by energy development, which can severely fragment landscapes with roads and infrastructure ([Naugle et al. 2011](#_ENREF_78)).

***Recreation***

The two forms of recreation most likely to pose a risk to pygmy rabbit populations are off-road vehicles and hunting. Areas known to support pygmy rabbits may need to be protected from off-road vehicle access, to avoid loss of sagebrush, understory grasses and forbs, and collapse of burrows under vehicle tires. Road closures and removal may be necessary in some areas, or signage may be sufficient in others. Pygmy rabbits are not legally hunted in the state of Oregon (OARS, Division 044, 635-044-0000), but Nuttall’s cottontail (*Sylvilagus nuttallii*) is considered a game species (ODFW 2014, <http://www.dfw.state.or.us/resources/hunting/small_game/>). Outreach efforts to hunters to educate them in differentiating between cottontails and pygmy rabbits may reduce the possibility of accidental shooting.

***Maintenance and restoration of habitat***

* Identify and inventory high-quality habitat composed of dense, tall stands of big sagebrush on deep deposits of suitable soils.
* Develop management plans or guidelines for these areas.
* Evaluate potential connectivity among populations of pygmy rabbits and if necessary develop management plans to facilitate connectivity by creating and maintaining habitat corridors or patches to facilitate movement and preventing fragmentation of such corridors.
* Develop fire and weed control plans for areas with high-quality habitat.
* Reclaim disturbed areas as soon as possible after disturbance to minimize recovery time and minimize the amount of degraded habitat at any given time.
* Prioritize reseeding efforts focused on native vegetation and locally sourced seed. Mixtures should reflect shrubs, forbs, and grasses found on undisturbed sites.
* Deal with conifer encroachment using mechanical control rather than fire. A number of sites in Oregon that are occupied by pygmy rabbits have juniper encroachment (e.g., Foster 2006).
* Grazing may be an important part of habitat management. Monitor and utilize at optimal times and rates, such as during the boot stage of cheatgrass and at 40% forage utilization.
* Avoid management actions that fragment tall, dense patches of deep sagebrush suitable for pygmy rabbits.
* Minimize use of broad leaf herbicides in management, which have the potential to harm vegetation critical to pygmy rabbits.
* Remove unnecessary structures that could be used as nesting or perching sites by avian predators, such as old buildings or fences in pygmy rabbit habitat. Structures that cannot be removed may be altered to reduce their attractiveness to raptors.
* Remove or prevent development in core areas that may enhance mammalian predator populations, such as campgrounds and wildlife-accessible water sources.

# V. INVENTORY, MONITORING, AND RESEARCH OPPORTUNITIES

## Data and Information Gaps

Metapopulation dynamics may be critical to the long-term survival of this species. Research has demonstrated that pygmy rabbits can and will disperse across unfavorable habitat (Lawes 2009, Lawes et al. 2013), but understanding the scale of habitat patches necessary to function as “stepping stones” across unfavorable habitat and the minimum effective size of dispersal corridors will aid in management planning for protection and restoration of habitat. To date, only preliminary genetic work has evaluated rates and scale of movements (Estes-Zumpf et al. 2010). Determining the extent to which metapopulation dynamics influence individual site occupancy and recolonization will aid in conservation planning. For example, effects of oil and gas development (road and other infrastructure as barriers to movement) have not been evaluated although they have potential to further fragment pygmy rabbit habitat ([Naugle et al. 2011](#_ENREF_78)).

## Inventory and Monitoring

A number of studies have demonstrated that habitat models can be used to delineate suitable habitat for pygmy rabbits ([Gabler et al. 2000](#_ENREF_39), [Gabler et al. 2001](#_ENREF_38), [Simons and Laundre 2004](#_ENREF_98), [Meisel 2006](#_ENREF_72), [Rachlow and Svancara 2006](#_ENREF_86), [Himes and Drohan 2007](#_ENREF_56), [Germaine et al. 2014](#_ENREF_42)). These models have utilized vegetation maps and soils data to define broadly suitable habitat for pygmy rabbits. Models for habitat are probably best used to identify areas for future survey work ([Kenaith and McGee 2004](#_ENREF_61)) or to identify areas to consider for further conservation or restoration work.

Researchers have developed protocols for sign indices to establish occupancy status and estimate abundance ([Hagar and Lienkaemper 2007](#_ENREF_49), [Larrucea and Brussard 2008b](#_ENREF_64), [Sanchez et al. 2009](#_ENREF_93), [Price and Rachlow 2011](#_ENREF_84)). This work has been motivated by the many drawbacks presented by trapping, including risks to the animals ([USFWS 2012](#_ENREF_101)), expense, time, and necessary sample sizes ([Sanchez et al. 2009](#_ENREF_93), [Price and Rachlow 2011](#_ENREF_84)). The indices have relied on pellet counts or burrow inventories as well as attempts to classify the age of pellets and burrows, with varying degrees of success. Burrows that appear inactive in combination with old, dried pellets have been used as indications that a site is not currently occupied ([Sanchez et al. 2009](#_ENREF_93)). However, pellet and burrow persistence and appearance are affected by many environmental factors ([Sanchez et al. 2009](#_ENREF_93)). These issues may easily lead to either an inability to classify a site’s activity status, or incorrectly classifying it.

More recently, researchers have explored burrow counts as a method of estimating abundance, testing the method in populations of marked pygmy rabbits ([Price and Rachlow 2011](#_ENREF_84)). The relationship between densities of burrows and numbers of rabbits was not linear, because when burrow densities increased, individual rabbits used more of them. This made the index less reliable at higher burrow densities. Further, abundance of rabbits may change more rapidly than the number of burrows, which in this particular case were classified as active even when they may not have been used for nearly a year ([Price and Rachlow 2011](#_ENREF_84)). However, if the method is calibrated to local conditions, it may offer an inexpensive method of monitoring broad population trends ([Price and Rachlow 2011](#_ENREF_84)). If the goal of monitoring is to identify when managers should intervene to maintain populations, indices need to be carefully evaluated prior to use to ensure the results do not misinform management.

Work comparing remote cameras, pellet counts, burrow counts, visual surveys and road transects found that cameras were the superior method for detecting site occupancy by pygmy rabbits ([Larrucea and Brussard 2008b](#_ENREF_64)). Of twenty sites known to support pygmy rabbits, one week of camera work detected rabbits in 95% of sites, whereas observer identification of active burrows occurred at 55%, and observations of rabbits or discovery of fresh pellets occurred at only 30% of the sites ([Larrucea and Brussard 2008b](#_ENREF_64)). Whether remote camera data could be used for abundance estimation as well has not been explored, although such methods exist ([Royle and Nichols 2003](#_ENREF_90), [Royle and Dorazio 2008](#_ENREF_89)).

Suitable but temporarily unoccupied habitat should be identified and protected. Development of a monitoring framework that may incorporate a mix of methods in order to efficiently determine site occupancy, extinction, and recolonization may be a first step in describing metapopulation dynamics in pygmy rabbits. It would also lead to the identification of sites that are suitable for pygmy rabbits but that are not currently occupied. Protection of such sites will be necessary for regional persistence.

Research

Understanding metapopulation dynamics will be necessary to determine whether the loss of populations is balanced by the establishment of new populations, perhaps in sites not previously known to support them. Ultimately, connectivity maintains genetic diversity, a critical piece of long-term conservation. Genetic work in turn can help in the evaluation of connectivity across a range of spatial and temporal scales. This knowledge will help evaluate the negative impacts of habitat loss or degradation of specific areas on the species’ regional persistence, and aid conservation planning in identifying the appropriate scale at which multiple populations must be maintained. In addition, evaluating management actions aimed at increasing connectivity such as planting big sagebrush along fencerows or roadsides is needed.

Mapping of remaining potential habitat in Oregon will aid in conservation and management efforts. For example, the mapping of remnant potential habitat in agricultural regions such as the Malheur Basin around Burns, Goose Lake near Lakeview, and Treasure Valley near Vale may aid in evaluating connectivity among remnant patches in these areas, which may be prone to further agricultural development. Identifying areas that may most benefit from conservation efforts to maintain connectivity or large habitat patch size will allow prioritization of efforts and funding.

Based on the survival estimates in the work reported in this assessment (e.g., Crawford 2008 in Oregon), pygmy rabbits have very low survival rates, such that population stability seems unlikely. Understanding factors that enhance population persistence including metapopulation dynamics will be critical to maintaining viable pygmy rabbit populations. Understanding whether survival estimates are low because they are simply poorly estimated (as might be the case with very small sample sizes) or because of researcher effects will aid in determining appropriate management actions.

Grazing may have the potential to enhance pygmy rabbit habitat in some already degraded areas. Specific research to better understand the risks and benefits of different grazing regimes and identifying optimal timing and intensity will aid managers in determining whether and how grazing may benefit pygmy rabbits at specific sites.

Estimates of mortality from predation have been high for pygmy rabbits (Wilde 1978, Sanchez 2007, Crawford et al. 2010). Although Kenaith and McGee (2004) have suggested that predation pressure may have increased with habitat alteration from human activities, data to evaluate this possibility is lacking. Determining whether habitat fragmentation or development such as roads, powerlines, and fences have either enhanced predator populations, led to the expansion of predator species’ ranges into pygmy rabbit habitat, or increased pygmy rabbits’ vulnerability will be extremely helpful in determining appropriate management actions to safeguard small, isolated populations in particular.

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