Appendix A.4

Habitat Connectivity for White-tailed Jackrabbit (*Lepus townsendii*) in the Columbia Plateau Ecoregion

Prepared by Howard L. Ferguson (WDFW) and Michael Atamian (WDFW)

Modeling and GIS analysis by Brian Cosentino (WDFW), Brian Hall (WDFW), Darren Kavanagh (TNC), Brad McRae (TNC), and Andrew Shirk (UW)

Introduction

White-tailed jackrabbit, photo by Doug Backlund.

This account describes components of white-tailed jackrabbit (*Lepus townsendii*) life history that are relevant to an analysis of habitat sensitivity and connectivity in the Columbia Plateau Ecoregion. This effort started with the *Washington Connected Landscapes Project: Statewide Analysis* (WHCWG 2010) which modeled connectivity for 16 focal species within Washington. This statewide analysis incorporated data layers such as land cover/land use, elevation, slope, housing density, and roads at a 100-meter scale of resolution. Because of the generality of the layers and the relatively coarse scale of the statewide analysis, the next step was to conduct a connectivity assessment of the Columbia Plateau Ecoregion. This ecoregion is an arid eastside portion of the state that has an extensive human footprint while also having several habitats—e.g., shrubsteppe and scabland—and many species that are declining in both distribution and abundance. This ecoregion is very important since less than 50% of the historical shrubsteppe remains in Washington and what is left is contained in the Columbia Plateau (Schroeder & Vander Haegen 2011).

To better define key wildlife corridors and crucial wildlife habitats in the Columbia Plateau Ecoregion analysis we used additional data layers, better defined habitat variables, and a finer scale of resolution (30-meter scale of resolution rather than 100-meter), to examine connectivity issues for 11 focal species, including the white-tailed jackrabbit. The white-tailed jackrabbit was selected as a focal species to represent the grass-dominated habitats in the Columbia Plateau Ecoregion—grass dominated shrubsteppe, grass dominated scabland, and grass dominated dune vegetation classes. The black-tailed jackrabbit (*L. californicus*) was also selected as a focal species for this analysis and is addressed in its own species account (See Appendix A.3).

Justification for Selection

The white-tailed jackrabbit was selected as a focal species because it is a good representative of wildlife habitat and connectivity needs within the shrubsteppe vegetation type. White-tailed jackrabbits are closely associated with this habitat in Washington and throughout their range with the exception of occupying ecologically equivalent alpine regions in Colorado (Braun &

Streeter 1968). Specific habitats that were classified as prime habitat for white-tailed jackrabbits were Grassland Basin and Scabland; secondary habitats were Shrubsteppe, Shrubland Basin, and Dunes.

White-tailed jackrabbits are vulnerable to loss of habitat connectivity from all major connectivity threats: clearing and vegetation removal, development, roads and traffic, fire, climate change, energy development, irrigation and its infrastructure, and the presence of people and domestic animals. From many of these same factors jackrabbits also face increased mortality e.g., persecution from farmers, harassment by pets—especially domestic dogs—and increased predation by both native and non-native predators.

For jackrabbits, population monitoring is a challenge as no reliable census method exists; however, individual monitoring is now fairly easy when using radio telemetry. Techniques that have been used to determine density include road counts, pellet counts, drive counts and transects. White-tailed jackrabbit movement scale is appropriate for this ecoregional modeling effort.

Jackrabbits have been reported causing considerable damage to agricultural crops including lawn and pasture grasses, ornamental shrubs, orchards, grape vines, alfalfa (*Medicago sativa*), wheat (*Triticum* spp.), and potato plants (Lim 1987; Best 1996). As a result jackrabbit populations were harvested heavily in the early 1900s. They were hunted throughout the year, in rabbit drives, organized hunts, trapping, snaring, and poisoning (Bailey 1936). Hunters were paid bounties (Best 1996). Poisons were used particularly in the 70s and 80s. Tiemeier (1965) reported that humans with motorized vehicles, spotlights, and guns probably caused the greatest mortality. Jackrabbits are vulnerable to high mortality on roads. The number of carcasses found on highways range from <1/km to 130/km in Idaho (Williams & Nelson 1939; Best 1996).

Although jackrabbit populations are known to oscillate greatly in different years and in different habitats with density estimates varying from 2.2 to 45/km^2 (Lim 1987), it appears that the jackrabbit population in Washington has been on a decreasing trend for at least the past 20 years. The most likely reason for this decline is loss of habitat. Historically, most of the land in the Columbia Plateau supported shrubsteppe vegetation communities (Daubenmire 1970). Large-scale clearing of land for agriculture began in the late 1800s and expanded when irrigation became widespread after damming of the Columbia River in the 1930s (National Research Council 1995). Using historical and current land cover maps from the Interior Columbia Basin Ecosystem Management Project (Quigley & Arbelbide 1997), McDonald and Reese (1998) estimated that the mean patch size of sagebrush (*Artemisia* spp.) in Washington decreased from 13,420 ha circa 1900s to 3418 ha in the 1990s, and the number of patches increased from 267 to 370 becoming smaller and more fragmented.

A considerable portion of the Columbia Plateau currently is farmed, with wheat being the main crop in higher rainfall zones, irrigated orchards, vineyards, and row crops prevail at lower elevations. Grazing by livestock began in the region in the late 1800s and has continued to varying degrees. There is also the additional stressor on the landscape of increased fire frequency that converts shrubsteppe to annual grasslands (Knick et al. 2003). The synergistic effect of livestock grazing, introduced plant species, and altered fire regimes have resulted in large scale alterations to the landscape including shifts in the composition of plant communities, loss of topsoil, and altered hydrology (West 1999). Once established, cheatgrass (*Bromus tectorum*), an introduced annual grass, provides a continuous fuel that results in larger, more frequent, and more complete burns, that in many cases preclude reestablishment of big sagebrush (*A. tridentata;* Whisenant 1990; West 1999). West (1999) estimated that 25% of the shrubsteppe region has been converted to exotic annual grasslands, and an additional 25% is at risk of transitioning. All of this has likely contributed to the widely observed decrease of the white-tailed jackrabbit population.

Outside of Washington, the white-tailed jackrabbit is experiencing similar declines. Berger (2008) reported that the white-tailed jackrabbit has disappeared from Yellowstone and Grand Teton national parks in Wyoming but other reports have refuted this (Gunther et al. 2009). In California, evidence suggests that populations of white-tailed jackrabbits have also declined drastically. Competition with domestic livestock has been reported as a principal factor in the drastic population declines occurring throughout its range (Dalquest 1948; Mossman 1979). Loss of habitat to cultivation and other developments are probably also important factors in the decline. Hunting could be a factor, but is probably less important than habitat loss. Williams (1986) commented that white-tailed jackrabbits are extinct over the greater part of their historical range in the Columbia Plateau.

The white-tailed jackrabbit is considered a Priority Species by the Washington Department of Fish and Wildlife (WDFW) Priority Habitats and Species Program (WDFW 2008), a Species of Recreational, Commercial, and/or Tribal Importance, and is listed as a Washington State Candidate Species. In Washington State a species is given Candidate Species status “When populations are in danger of failing, declining, or are vulnerable, due to factors including, but not restricted to, limited numbers, disease, predation, exploitation, or habitat loss or change" (WDFW 2008). Due to these same factors they are also listed as a Species of Greatest Conservation Need in Washington (WDFW 2005). The Bureau of Land Management (BLM) also lists the lists the white-tailed jackrabbit as Sensitive (BLM 2008).

In Canada, the white-tailed jackrabbit is presumed to be extinct and is listed on the provincial Red List (B.C. Conservation Data Centre 2011). It is given the second highest ranking in their Conservation Priority Framework—the conservation priority assigned to each species. NatureServe (2011) ranking status of the white-tailed jackrabbit for U.S. and Canada indicates that they are of conservation concern throughout their range (Table A.4.1).

The plight of the white-tailed jackrabbit may have been foreseen even in 1948, when Dalquest noted that “The early explorers and settlers found the white-tailed jack rabbits abundant in eastern Washington. With the invasion of the black-tailed jackrabbit, and the reduction of native bunchgrasses through overgrazing by livestock, the whitetail has become rare. In several years of field work on the Columbian Plateau, I saw none. Near Wallula, the type locality, residents had not seen whitetails for years” (Dalquest 1948).

Table A.4.1. NatureServe (2011) status of the white-tailed jackrabbit in the U.S. and Canada.

	*NatureServe U.S. and Canada state/province status**
U.S.	California (S3?), Colorado (S4), Idaho (S5), Illinois (SX), Iowa (S3), Kansas (SX), Minnesota (SNR), Missouri (SX), Montana (S4), Nebraska (S4), Nevada (S5), New Mexico (S2), North Dakota (SNR), Oregon (S4?), South Dakota (S4), Utah (S3S4), Washington (S2S3), Wisconsin (SNA), Wyoming (S4)
Canada	Alberta (S5), British Columbia (SH), Manitoba (S4), Ontario (S1), Saskatchewan (S4)

**S1= critically imperiled; S2 = imperiled; S3 = vulnerable; S4 = apparently secure; S5 = secure; SNR or SNA = not ranked or not applicable; SX= possibly extirpated; SH= possibly extirpated; historically present but not enough data to presume extirpation.*

Distribution

The white-tailed jackrabbit is distributed across west-central North America from the prairies of southern Saskatchewan and Alberta to the Rocky Mountains of northern New Mexico, and from Lake Michigan in Wisconsin to east of the Cascade Mountains of Washington and the Sierra Nevada Mountains of California (Wilson & Ruff 1999). Historically, the distribution of this species spread as far east as Wisconsin, Iowa and Missouri in areas of cleared forest. However, when its prairie habitat became more and more cultivated, the range of the species contracted, and it became extinct in Kansas and southern Nebraska (Chapman & Flux 1990).

In Washington, the white-tailed jackrabbit is an eastside species, with distribution throughout the Columbia Plateau shrubsteppe habitat from British Columbia to Oregon. However, there is concern for this species in Washington because of their shrinking range which may be a result of multiple land-use changes including agricultural conversion, development, and overgrazing combined with competition from the black-tailed jackrabbit. Larrison in 1976, expressed his concern for the decline of the white-tailed jackrabbit when he wrote, "The white-tailed jackrabbit was once common in the sagebrush-bunch grass habitat of Central and Eastern Washington, but at the present time it is restricted and scarce in that state except in the Okanogan Valley… the splendid large white-tailed jackrabbit may well disappear from Washington, and even large parts of the remainder of the Northwest."

In parts of its historical range, where cultivation, drought or overgrazing have affected the habitat, white-tailed jackrabbits have been replaced by black-tailed jackrabbits (Armstrong 1972). In the Washington Gap Analysis (GAP; Johnson & Cassidy 1997), it was noted that the white-tailed jackrabbit was once more abundant and that its reduction was due to agriculture, overgrazing, and perhaps competition by the black-tailed jackrabbit. They went on to say that the white-tailed jackrabbit was formerly present and is now absent from the dryland wheat farming belt from southern Spokane to northern Garfield and Asotin counties with overgrazing throughout the Columbia Plateau resulting in replacement of its preferred bunchgrass with sagebrush.

There are some indications that black-tailed jackrabbits are recent colonizers of Washington State (Couch 1927; Larrison 1976). Larrison (1976) mentions, "…in the years preceding their sweep into Eastern Oregon and Washington…" This colonization may have diminished the white-tailed population since the literature reports that the black-tailed jackrabbit outcompetes

(Lim 1987) the white-tailed and also because the white-tailed jackrabbit seems less tolerant of human development.

Habitat Associations

General

White-tailed jackrabbits feed primarily on succulent grasses and forbs, eating some shrubs in winter if they are the only food item available. They tend to consume grasses and forbs that are young and have not yet produced seed. When feeding on shrubs, woody stems are eaten more frequently than leaves or young shoots (Lim 1987). They are known to feed on alfalfa when available. In Colorado, diet items in summer consisted of 70% forbs, 19% grasses, and 7% shrubs. The four most commonly ingested plants were clover (*Trifolium* spp.), dandelion (*Taraxacum officinale*), dryland sedge (*Carex obtusata*), and Indian paintbrush (*Castilleja integra*). In autumn, white-tailed jackrabbit diet consisted of 43% grasses, 34% forbs, and 14% shrubs. In winter, diet items consisted of 76% shrubs and 12% forbs (Bear & Hansen 1966). Although there are no studies for the white-tailed jackrabbit, a black-tailed jackrabbit pellet analysis on the Hanford Site (Uresk et al. 1975) reported that no cheatgrass was found in the pellets, indicating this non-native plant has little or no forage value for jackrabbits.

Washington Gap (Johnson & Cassidy 1997) reported that white-tailed jackrabbits inhabit areas with bunchgrass and rabbitbrush (*Chrysothamnus viscidiflorus*) and are less frequently found in open, low sagebrush. They noted that in Washington, the white-tailed jackrabbit tends to occur at higher elevations (on grassy hills and plateaus) than the black-tailed jackrabbit, and its distribution extends farther north (up the Okanogan drainage into British Columbia) than the black-tailed jackrabbit. Bunchgrasses in the Columbia Plateau include bluebunch wheatgrass (*Pseudreogneria spicata*), Sandberg's bluegrass (*Poa secunda*), Idaho fescue (*Festuca idahoensis*), and needle-and-thread grass (*Hesperostipa comata*). Common forbs include balsam root *(Balsamorhiza* spp.), lupine (*Lupinus* spp.), and phlox (*Phlox* spp.).

Throughout the Columbia Plateau habitat quality for white-tailed jackrabbits has declined as livestock grazing has resulted in replacement of bunchgrass with sagebrush or cheatgrass. The two species of jackrabbits use different habitats with black-tailed jackrabbits occurring primarily in sagebrush with open grass, while white-tailed jackrabbits are most common in bunchgrass habitats with less open cover (Anthony 1913; Couch 1927). In eastern Washington, Dalquest (1948) found white-tailed jackrabbits on arid, hilly bunchgrass sites during the summer and in lower sagebrush valleys during winter. Dalquest (1948) also noted the gradual disappearance of bunchgrass as the result of overgrazing speculating that this caused the reduction of numbers and confinement of the white-tailed jackrabbit to arid grasslands in the Okanogan Valley.

Agriculture

In Washington, large-scale clearing of land for agriculture began in the late 1800s and expanded when irrigation became widespread after the damming of the Columbia River in the 1930s (National Research Council 1995). Approximately 43% of the Columbia Plateau is farmland. Dryland wheat is the main crop in higher rainfall zones, whereas irrigated orchards, vineyards, and row crops prevail at lower elevations. Grazing by livestock began in the "basin" part of the ecoregion in the late 1800s and has continued to varying degrees (Quigley & Arbelbide 1997).

Sagebrush habitats are among the most imperiled ecosystems in North America as a result of conversion to agriculture, removal of sagebrush and planting of introduced grasses to improve livestock forage, widespread energy development, and increasing fire frequency that converts shrubsteppe to annual grasslands (Knick et al. 2003). Changes in shrubsteppe communities have been particularly severe in Washington State, where half of the area historically in shrubsteppe has been converted to agriculture, resulting in high fragmentation of extant habitat and a disproportionate loss of deep-soil communities (Jacobson & Snyder 2000; Vander Haegen et al. 2000).

We generally lack an understanding of how dispersal costs and animal movements vary among different crops in agroecosystems (Cosentino et al. 2011). Because of the lack of data specific for white-tailed jackrabbits, much of the literature cited in this section is from black-tailed jackrabbit studies. When dealing with habitat, including agricultural environments, both jackrabbits appear to display the same behavior and use of agricultural crops. The primary difference to be considered is likely the native vegetation adjacent to the agricultural fields—white-tailed jackrabbit preferring the more open grass-dominated habitats. Both species of jackrabbits may frequent agricultural land where they can become a pest of crops and fruit trees (Lechleitner 1958).

Flinders and Hansen (1972) reported that agricultural crops used as food for jackrabbits included alfalfa and winter wheat. Research by Longland (1991) showed significantly less use of palatable feed by jackrabbits when distance from cover was only 5–10 m. However, in other studies black-tailed jackrabbits typically forage within a 300 m band adjacent to protective cover (Westoby & Wagner 1973; Roundy et al. 1985; McAdoo et al. 1987; Ganskopp et al. 1993).

In agricultural fields, especially those that have sparse cover, vulnerability increases for jackrabbits; however, plant cover increases through the growing season, resulting in the potential for more and/or longer forays by rabbits into agricultural crops. Marin et al. (2003) demonstrated that jackrabbits integrate both resource level and predation risk in their selection of habitats. Thus, as predicted by optimal foraging theory, jackrabbits are balancing foraging gains (resource levels) and costs (predation risk).

This may explain why jackrabbits have been observed using Conservation Reserve Program (CRP) fields more than other croplands (Schroeder & Vander Haegen 2006). The CRP is a voluntary program administered by the United States Department of Agriculture that pays farmers to take agricultural lands out of production to achieve specific conservation objectives, one of which is improved wildlife habitat. Some of the habitat loss due to agriculture may be mitigated through conversion of cultivated agricultural lands to CRP. The vast majority of CRP land in Washington occurs on land that was historically shrubsteppe. There are currently ~599,180 ha of CRP in eastern Washington, which is roughly 10% of the region's total agricultural lands (USDA 2011). In general, the "usefulness" of CRP for wildlife is influenced by maturity of the planting, species planted, presence of sagebrush, and juxtaposition to native habitat (Schroeder & Vander Haegen 2011). Lands enrolled in the CRP program in Washington can reduce resistance to movement in the landscape for jackrabbits by providing suitable habitat.

Sensitivity to Development

Housing and other forms of development either destroy or fragment the preferred habitat of shrubland and shrubsteppe. Again, the primary impact of development is the loss of habitat, but it also carries the associated impacts of other infrastructure—roads, transmission lines, etc., and increased predation and harassment by pets, particularly dogs. Unlike the black-tailed jackrabbit, the white-tailed is not often observed in and around developed areas and overall seems more sensitive to development and human occupancy.

Over much of the shrubsteppe landscape in the West, the native habitat that remains is further impacted by linear and point features such as roads, power lines, irrigation ditches, well sites, and related infrastructure (Knick et al. 2003; Connelly et al. 2004).

Sensitivity to Roads and Traffic

Vehicles collide with wildlife more than 1.5 million times each year in the U.S. and the annual number of collisions has increased by more than 50% in the last 15 years (Hedlund et al. 2003). The number of jackrabbit carcasses on highways reported in 1939 by Williams and Nelson, ranged from <1/km to 130/km in Idaho (Best 1996). It is evident that roads are a source of injury and mortality for jackrabbits. The relatively high dispersal capacity of the jackrabbit also increases the likelihood that they will encounter roads during dispersal through landscapes with high road densities. However, there is little specific information available defining the relative resistance of different types of roads and different levels of traffic volume for the jackrabbit. Potential impacts other than direct mortality may be increased predation due to lack of cover, additional perches for raptors, and an increase of both noise and light.

White-tailed jackrabbits are known to use undeveloped roads for movement between habitat areas and will cross all roads, including major highways if encountered. It is on these high-speed high-volume roads that white-tailed jackrabbits are at high risk to mortality associated with vehicles.

Sensitivity to Energy Development

WIND ENERGY DEVELOPMENT

Although no studies are available evaluating the impact of wind energy development on jackrabbits, it is probably not severe. The amount of habitat destroyed by wind energy projects is relatively small and therefore only minimal impacts might be expected from direct habitat loss. Other impacts include general habitat fragmentation, increased road traffic, potential increase of fire frequency, weed introduction, increased light, and increased predation. These factors may be relatively minor for a single project, but need to be looked at on a cumulative landscape level to determine their impact. These effects, however, have not yet been documented. When considering dispersal, energy development probably has little effect on the jackrabbit.

TRANSMISSION LINES

Transmissions lines can potentially increase jackrabbit mortality by providing perch sites for raptors in habitat that is generally more open than the surrounding native habitat. This same feature could also make jackrabbits more vulnerable to coyote predation. In addition, the vegetation under the transmission lines is often mowed or cleared on a regular basis eliminating cover for jackrabbits, again making them more vulnerable to predators.

Sensitivity to Climate Change

Global climate change models predict more variable and severe weather events, higher temperatures, drier summer soil conditions, and wetter winter seasons (Miller et al. 2011). Projected climate change and associated consequences are recognized as potentially interacting with the stressors, mentioned in earlier sections of this document, that are already impacting jackrabbits (Miller et al. 2011). The current distribution of sagebrush is predicted to decrease 12% for each degree of temperature increase (Neilson et al. 2005). Climate change may potentially impact jackrabbits by amplifying effects of parasites and disease, e.g., *Pasteurella tularensis* and *Pasteurella pestis* (Bacon & Drake 1958).

The impact of climate change is speculative, but if it leads to increased atmospheric CO^2, introduced and exotic species such as cheatgrass may be favored, become more dominant and put more of the grassland and shrubsteppe ecosystems at risk to increased fire—frequency, extent, and intensity—reducing the native forage of white-tailed jackrabbits.

Dispersal

Due to lack of published studies on the white-tailed jackrabbit life history, we relied on data from black-tailed jackrabbit studies for dispersal. The data that have been reported for the white-tailed jackrabbit appears to closely parallel that of the black-tailed jackrabbit. Similar to the black-tailed jackrabbit, movement by the white-tailed jackrabbit appears to be quite variable, some individuals showing little mobility while many others appear highly mobile (Table A.4.2).

Table A.4.2. Summary of spatial data available for white-tailed jackrabbits.

Home range (km^2)	*Radius (m)*	*Density (hare/ha)*	*Location*	*Telemetry used (yes/no)*	*Citation*
2.8–4.3	1000–1500			no	Jackson (1961)
		<0.1–0.7	IO	no	Kline (1963)
		<.1	CO	no	Flinders & Hansen (1973)
		0.1	WY	no	Rogowitz & Wolfe (1991)
		0.1–0.4	MI	no	Mohr & Mohr (1936)
2.6	906	<.1–0.1	CO	no	Donoho (1971)

The home range of the white-tailed jackrabbit has been reported as 2.6–4.3 km in diameter (Table A.4.2); however, research on movement and other aspects of this species is scant. The densities reported for white-tail jackrabbits (<0.1–0.7 hares/ha) appear to be lower than those reported for the black-tailed (0.1–2.8 hares/ha; Table A.4.2; Table A.4.3).

There are no maximum movement distances reported for the white-tailed jackrabbit, the only movement is a daily maximum dispersal distance of approximately 1.0 km/hr reported by Rogowitz (1997). Because of this lack of information, white-tailed dispersal distances were assumed to be the same as those of the black-tailed jackrabbit (Table A.4.4).

Table A.4.3. Summary of spatial data available for black-tailed jackrabbits.

Home range (km^2)	*Radius (m)*	*Density (hare/ha)*	*Location*	*Telemetry used (yes/no)*	*Citation*
0.2	236	2.7	CA	no	Lechleitner 1958
0.2	227		ID	no	French et al. 1965
2.6	906	0.1–0.3	CO	no	Donoho 1971
0.3			ID	no	Grant 1987
0.2	252		CA	no	Chapman & Flux 1990
1.0–3.0	977		UT	yes	Smith 1990
0.8	501	0.4–2.8	WA	yes	Major 1993
		0.1–1.0	UT	no	Gross et al. 1974
		1.2	AZ	no	Vorhies & Taylor 1933
		0.2	NV	no	Hayden 1966
		0.9	UT	no	Woodbury 1955
		0.2–1.1	NM	no	Daniel et al. 1993
			UT	yes	Nelson & Wagner 1973
		0.3–1.0	NM	no	Lightfoot et al. 2010

Table A.4.4. Dispersal distances reported for black-tailed jackrabbits.

Maximum dispersal distance (km)	*Mean dispersal distance (km)*	*Location*	*Telemetry used (yes/no)*	*Citation*
1.6		CA	no	Lechleitner 1958
	12.0	UT	no	Porth 1995
45.0		ID	no	French et al. 1965
57.3	16.2	ID	yes	Grant 1987
35.0	11.0	UT	yes	Smith et al. 2002
17.0		UT	no	Rusch 1965
17.0	4.4	CO	no	Donoho 1971
8.0		WA	yes	Major 1993

Conceptual Basis for Columbia Plateau Model Development

Overview

White-tailed jackrabbits prefer grasses and forbs for browse. Washington Gap analysis (Johnson & Cassidy 1997) noted that white-tailed jackrabbits are commonly distributed in bunchgrass and rabbitbrush habitats, and sparsely distributed in open, low sagebrush—generally more open habitat than the black-tailed jackrabbit. Washington Gap modeled all steppe zones within the Columbia Plateau as core area for white-tailed jackrabbit except for the Central Arid Steppe which was considered peripheral. They noted that white-tailed jackrabbits prefer higher elevation habitat where grass is the dominant vegetation (grassy hills and plateaus) and their distribution extends farther north than black-tailed jackrabbits (Johnson & Cassidy 1997). Although slope is a component of suitable jackrabbit habitat it is not likely to be a factor impeding movement or dispersal.

Because land enrolled in the CRP program can reduce resistance to movement in the landscape for jackrabbits, we assigned the Pasture Hay agriculture class, which included CRP fields (See Appendix D), less resistance to movement than Non-irrigated Cropland, Irrigated Cropland, and Highly Structured Agriculture.

White-tailed jackrabbits are at risk from the conversion of native shrubsteppe and grassland habitats for development and the other risks associated with development—road, railroads, powerlines, campgrounds, rest stops, landfills, irrigation canals, water and oil-gas wells, and human-induced fires; they are especially sensitive to a housing density greater than 20 acres/dwelling unit.

White-tailed jackrabbits are known to use undeveloped roads for movement between habitat areas and will cross all roads, including major highways if encountered. However, white-tailed jackrabbits are at risk from roads due to injury and mortality associated with vehicles. Road size and traffic volume are key factors influencing risk associated with roads. On high-speed and high-volume roads, white-tailed jackrabbits are at high risk due to mortality associated with vehicles; therefore we assumed that Freeway and Major Highway were the primary road classes contributing to resistance to movement for jackrabbits in the landscape. Local roads and secondary highways were assumed to have minimal impact.

With this background in mind, we began modeling the habitat for rabbits using the vegetation layer obtained from the National Land Cover Gap Analysis Project (Appendix D). LandSAT imagery base data used in developing the layer was circa 2000.

Habitat Concentration Areas

Habitat concentrations areas (HCAs) are core habitat areas that are expected or known to be important habitat for focal species. These areas are used as the focus locations for running dispersal models that identify connectivity pathways. A more technical definition of HCAs is that they are aggregations of habitat grid cells that are connected to each other by a species-specific home range diameter or short range dispersal distance. These aggregations must also meet a minimum size requirement designed to select only those areas that are capable of supporting multiple individuals.

Due to a lack of sufficient local studies and occurrence points that were not on a road, the core habitat for white-tailed jackrabbits in Washington is not well defined. Because of this, models were developed to define the core habitat areas. Our modeling effort for the jackrabbits consisted of defining the resistance and habitat values for different landscape features (Table A.4.5) as well as movement capabilities and habitat patch size requirements. These were then used to model jackrabbit habitat and generate HCAs. In order to ensure that the HCA areas developed were prime habitat for white-tailed jackrabbits, a minimum habitat value of 0.8 was applied and a conservative estimate of 500 m was used for home-range radius. Additionally, to ensure that HCAs would be of sufficient size to be relevant at the scale of our analysis, a minimum HCA size of 25 km^2 was used.

Table A.4.5. Landscape features and resistance values used to model habitat connectivity for the white-tailed jackrabbit.

Spatial data layers and included factors	*Resistance value*	*Habitat value*
Landcover/Landuse		
Grassland_Basin	0	1.0
Grassland_Mountain	2	0.6
Shrubsteppe	0	0.8
Dunes	4	0.8
Shrubland_Basin	1	0.8
Shrubland_Mountain	4	0.4
Scabland	0	1.0
Introduced upland vegetation_Annual grassland	2	0.6
Cliffs_Rocks_Barren	10	0.2
Meadow	5	0.4
Herbaceous wetland	2	0.4
Riparian	10	0.4
Introduced riparian and wetland vegetation	12	0.2
Water	50	0.2
Aspen	8	0.6
Woodland	15	0.2
Forest	100	0.0
Disturbed	100	0.0
Cultivated cropland from RegapNLCD	4	0.2
Pasture Hay from CDL	2	0.8
Nonirrigated cropland from CDL	4	0.6
Irrigated cropland from CDL	4	0.4
Highly structured agriculture from CDL	10	0.2
Irrigated/Not Irrigated/Cultivated Crop Ag Buffer 0 – 250m from native habitat	0	0.6
Irrigated/Not Irrigated/Cultivated Crop Ag Buffer 250 – 500m from native habitat	4	0.6
Pasture Hay Ag Buffer 0 – 250m from native habitat	0	1.0
Pasture Hay Ag Buffer 250 – 500m from native habitat	2	0.8
Elevation (meters)		
0 – 250m	2	0.6
250 – 500m	1	0.8
500 – 750m	0	1.0
750 – 1000m	0	1.0
1000 – 1250m	0	1.0
1250 – 1500m	2	0.8
1500 – 2000m	10	0.6
2000 – 2500m	50	0.4
2500 – 3300m	500	0.2
Slope (degrees)		
Gentle slope Less than or equal 20 deg	0	1.0
Moderate slope Greater than 20 less than equal to 40 deg	2	0.8
Steep slope Greater than 40 deg	10	0.0
Ruggedness		
Very gentle terrain (or surface water)	0	1.0
Gentle terrain	0	1.0
Moderate terrain	0	1.0
Rough terrain	0	1.0
Very rough terrain or escarpment	500	0.4
Housing Density Census 2000		
Greater than 80 ac per du	0	1.0
Greater than 40 and less than or equal 80 ac per du	0	1.0
Greater than 20 and less than or equal 40 ac per du	5	0.4
Greater than 10 and less than or equal 20 ac per du	15	0.2

Spatial data layers and included factors	*Resistance value*	*Habitat value*
Less than or equal 10 ac per du	500	0.0
Roads		
Freeway Centerline	200	0.0
Freeway Inner buffer 0 – 500m	3	0.6
Freeway Outer buffer 500 – 1000m	0	1.0
Major Highway Centerline	50	0.0
Major Highway Inner buffer 0 – 500m	2	0.8
Major Highway Outer buffer 500 – 1000m	0	1.0
Secondary Highway Centerline	10	0.4
Secondary Highway Inner buffer 0 – 500m	1	0.8
Secondary Highway Outer buffer 500 – 1000m	0	1.0
Local Roads Centerline	3	0.6
Local Roads Inner buffer 0 – 500m	0	1.0
Local Roads Outer buffer 500 – 1000m	0	1.0
Railroads Active		
Railroads Active Centerline	5	0.4
Railroads Active Inner buffer 0 – 500m	0	1.0
Railroads Active Outer buffer 500 – 1000m	0	1.0
Railroads Inactive		
Railroads Inactive Centerline	0	0.8
Railroads Inactive Inner buffer 0 – 500m	0	1.0
Railroads Inactive Outer buffer 500 – 1000m	0	1.0
Transmission Lines		
LessThan 230KV One Line Centerline	3	0.4
LessThan 230KV One Line Inner buffer 0– 500m	1	1.0
LessThan 230KV One Line Outer buffer 500 – 1000m	0	1.0
LessThan 230KV Two or More Lines Centerline	5	0.4
LessThan 230KV Two or More Lines Inner buffer 0 – 500m	2	1.0
LessThan 230KV Two or More Lines Outer buffer 500 – 1000m	1	1.0
Greater Than or Equal 230KV One Line Centerline	3	0.4
Greater Than or Equal 230KV One Line Inner buffer 0 – 500m	2	1.0
Greater Than or Equal 230KV One Line Outer buffer 500 – 1000m	1	1.0
Greater Than or Equal 230KV Two Lines Centerline	5	0.4
Greater Than or Equal 230KV Two Lines Inner buffer 0 – 500m	3	1.0
Greater Than or Equal 230KV Two Lines Outer buffer 500 – 1000m	1	1.0
Wind Turbine		
Wind turbine pnt buffer 45m radius	16	0.2
Buffer zone beyond pnt buffer 0 – 500m	1	0.8
Buffer zone beyond pnt buffer 500 – 1000m	0	1.0
Irrigation Infrastructure		
Irrigation canals	60	0.0

During HCA development several questions consistently arose, are HCAs core habitat areas or core population areas, is an area an HCA even if there have been no rabbit observations in the area and experts agree that there are no rabbits in the area, what if rabbits have been observed in the HCA in the past but not currently? For the final model it was decided to remove those HCAs that were not currently occupied and did not have the necessary habitat to support colonization. These removals were based on local biologists' knowledge and familiarity with the areas in question.

The modeling process for white-tailed jackrabbit HCA identification involved the following steps:

1) A continuous habitat value map was generated by multiplying together all the landscape feature habitat values for an individual grid cell (30 m).
2) A continuous average habitat value map was then generated using a circular moving window with a radius of 500 m, an area equal to a home range size of 1 km^2.
3) Areas in the habitat model falling below the habitat quality threshold of 0.8 in the circular moving window were masked out, and the remaining areas were converted into a binary habitat/non-habitat map based on a threshold of 0.8.
4) All cells within the home range movement (500 m) of a binary habitat cell were joined together to form HCAs. This was done using the resistance model and expanding designated habitat cells outwards up to a total cost-weighted distance of 500 m. This had the effect of joining nearby habitat cells together if the intervening landscape supports within-home-range movements.
5) Habitat concentration areas smaller than a 25 km^2 were then eliminated.

Movement Distance

The central objective of this ecoregional analysis was to explore connectivity opportunities across the Columbia Plateau. In this context, we selected 50 km as the maximum Euclidean distance between HCAs to model habitat linkages. This choice implies that an exchange of individuals could occur between populations separated by up to 50 km. This distance is just short of the maximum 57.3 km dispersal distance recorded in the literature for a black-tailed jackrabbit (Table A.4.4). Our rationale for using the near maximum is based on the fact that the final HCA model selected included: (1) only the best habitat patches in the landscape—many patches of suitable habitat were excluded that can serve as stepping stones between HCAs; and (2) the capacity of jackrabbits to find and opportunistically inhabit stepping stone habitats—a mechanism that if spread across years or even generations affords long-distance movements between habitat concentration areas. This is an important reason to protect these travel corridors since if not protected or restored these stepping stone habitats would be lost further isolating the core HCA areas.

Resistance and Habitat Values for Landscape Features

For many of the landscape features used in the modeling, specific information was not available in the literature regarding resistance to movement by the white-tailed jackrabbit. Therefore, the assignment of habitat values was based on the professional judgment of local experts with extensive field experience who helped review and refine these values. For both resistance values and habitat quality values several iterations of assignment, implementation, and then review were made before the resulting ecoregional maps conformed reasonably well to expert opinion about the distribution of white-tailed jackrabbit populations and the resistance each feature contributes to jackrabbit movement. We also used a database of known white-tailed jackrabbit observations as an appraisal of accuracy of our habitat value assignments.

***Land cover and land use*—**For the white-tailed jackrabbit prime habitats are grasslands and grass-dominated scabland so these classes were assigned a habitat value of 1 (core habitat) and no resistance (0). Secondary habitats white-tailed jackrabbits prefer are grass-dominated shrubsteppe, grass-dominated basin shrubland, and grass-dominated dunes, so these habitats were assigned habitat values of 0.8 (adequate habitat) and resistance values of 1 and 2 (Table A.4.5). All other habitat types were scored as marginal (<0.6) or non-habitat (0). Resistance values were all relative to ideal or prime habitat types. For example, introduced annual grasslands and mountain grassland were given a resistance of 3 reflecting jackrabbit avoidance of cheatgrass dominated habitats. Cliffs Rocks Barren habitats were assigned a resistance value of 10 indicating general avoidance of these areas—a 10 would equate to a jackrabbit travelling an extra 300 m to avoid these habitats compared to prime habitats. The highest resistances were assigned to Water (50) and Forest (100). Although jackrabbits are able to swim when forced to by predators, they normally avoid water. Forest habitats, except the early transition zones, are normally not occupied or used for dispersal.

Although a significant amount of jackrabbit habitat has been lost due to agriculture, certain agricultural crops provide forage for jackrabbits, such as alfalfa. As mentioned in previous sections, the black-tailed jackrabbit will typically forage within a 300 m band into cropland that is adjacent to protective cover (Westoby & Wagner 1973; Roundy et al. 1985; McAdoo et al. 1987; Ganskopp et al. 1993) which includes not only native habitat but CRP as well. Schroeder and Vander Haegen (2006) conducted a pellet study on shrubsteppe associated wildlife and found significantly higher number of jackrabbit pellet groups in CRP fields than non-CRP fields, and higher pellet counts in younger CRP than older CRP. The younger CRP fields were often planted with more native plants which may include one or more shrubby species. Because of this, we included the GIS generated agricultural buffer classes—irrigated/non-irrigated and pasture-hay, into our modeling process. The pasture-hay class was considered to approximate CRP lands. In addition, two different buffer distances were used; 0–250 m and 250–500 m. This allowed different resistance and habitat values to be modeled for the use of croplands adjacent to preferred jackrabbit habitat (Table A.4.5).

Elevation—Elevation became a major variable in the modeling of the white-tailed jackrabbit. After several iterations of the model and attempted manipulations of the different vegetation classes it became apparent the classes within the land cover/land use layer was not fine enough resolution to differentiate between black-tailed jackrabbit and white-tailed jackrabbit habitat. The main differentiating features from the literature and from field observations appear to be: (1) shrub density or percent shrub cover, (2) percent grass cover, and (3) shrub and grass height.

Realizing this shortcoming, many modeling runs were done using different combinations of the resistance and habitat values for all of the other classes in the available layers (Appendix D). The elevation layer when used in combination with the land cover/land use layer produced the best fit of "good" white-tailed jackrabbit habitat and "good" black-tailed jackrabbit habitat. The use of the elevation classes to distinguish between these species and the "fit" of the HCAs produced were reviewed by local biologists and assessed with observation data.

Elevation is referred to indirectly if not directly in several jackrabbit citations (Lim 1987; Rickard & Poole 1989; Fitzner & Gray 1991; Best 1996; Knick & Dyer 1997; Kansas State University 2001). For example, black-tailed jackrabbits have been reported as relatively common at the Hanford Site in areas where a dense overstory of sagebrush is present particularly in the lower valleys, whereas observations of white-tailed jackrabbits have been rare and restricted to the higher elevations of Rattlesnake Mountain (Rickard & Poole 1989; Fitzner & Gray 1991; H. Newsome, personal communication). Severaid (1950) observed white-tailed jackrabbits more frequently on higher slopes and ridges, and black-tailed more frequently on valley floors (Lim 1987). A habitat model in Kansas noted that white-tailed jackrabbits prefer higher elevation areas than the black-tailed jackrabbit, where grass is the dominant canopy cover, rather than shrubs and less grazed grasslands used by the black-tailed jackrabbit (Kansas State University 2001). The Washington Gap analysis (Johnson & Cassidy 1997) noted that in California and Montana, the white-tailed jackrabbit ranges higher in elevation than the black-tailed jackrabbit, but may be sympatric in the higher valleys. In Washington they note that the white-tailed jackrabbit tends to occur a little higher (on grassy hills and plateaus) than the black-tailed jackrabbit (more often in valleys), and goes farther north.

Using elevation as a correlate for vegetation is not a perfect solution, but does provide a reasonable differentiation of habitat for the two jackrabbit species. The preferred elevation range for black-tailed jackrabbits was 0–500 m, with a higher resistance and lower habitat value assigned to elevations above 500 m (Table A.4.5). In contrast, the preferred elevation range for white-tailed jackrabbits was 500–1250 m which were assigned no (0) resistance and a core habitat value of 1, with higher resistance and lower habitat values assigned to elevations below 500 m and above 1250 m (Table A.4.5).

Slope—A slope of less than 20 degrees was considered to have no impact on either prime habitat or on dispersal movements, thus it was given a habitat value of 1 and a resistance of 0 (Table A.4.5). Though it may seem counter intuitive to give slopes of less than 20 degrees a habitat value of 1, because the habitat model is based on multiplying the habitat values together, a value of 1 imparts no impact on a cell's final habitat value. Moderate slopes and ridges were evaluated to have about 2 times the resistance of flat ground but still would not eliminate prime habitat from being HCAs. Steep slopes of greater than 40 degrees were considered relatively difficult for jackrabbits to cross and also were not considered as habitat.

Ruggedness—Only one class of the ruggedness layer was used for modeling jackrabbits and that was the most extreme—very rough terrain and escarpment, which was used as an analog for the very steep cliffs and slopes found throughout the channeled scablands and basaltic canyons. This class was implemented as a complete barrier for jackrabbits and was assigned a very high resistance value of 500 and a marginal habitat value of 0.4 (Table A.4.5).

Housing density—We considered the resistance of areas with lower housing densities (>40 acres per dwelling unit) to be dominated by other features, such as cover type, and were thus given a resistance value of 0 and a habitat value of 1. A high resistance value of 500 and a habitat value of 0 were assigned to housing density of less than 10 ac per dwelling unit, which included industrial, suburban, urban developments.

Roads—White-tailed jackrabbits are known to cross all roads, including freeways and major highways if encountered. It is on these high-speed and high-volume roads that white-tailed jackrabbits are at high risk of collision. For this reason a high resistance of 200 was assigned to the centerline of freeways and a resistance of 50 was assigned to the centerline of major highways (Table A.4.5). The increased resistance assigned to Freeway and Major Highway buffers is due to the associated increase in structures making it more attractive to predators of the jackrabbit, especially raptors. The Local Road and Secondary Highway classes were assumed to have minimal impact and were given relatively low resistance values. While centerlines of roads, particularly freeways, are assigned the highest resistance values, jackrabbit movement is not prohibited by the presence of roads.

Railroads—Railroads were considered as significantly lower resistance features than freeways and major highways due to the much lower frequency of potential collisions and also due to the lack of infrastructure of railways when compared to freeways and major highways (Table A.4.5). Aside from the Railroads Active Centerline, the remaining classes were considered to have no resistance to jackrabbit movement or effect on habitat value. All classes within the Inactive Railroads layer were considered to have no effect on resistance or habitat value for jackrabbits.

Transmission lines—Transmission lines likely increase jackrabbit mortality by providing perch sites for raptors similar to that found for Greater Sage-Grouse (*Centrocercus urophasianus*) (Steenhof et al. 1993; Connelly et al. 2004; Beck et al. 2006). Increased predation may also occur due to the regular maintenance of many of these lines—mowing, clipping or herbicide applications—that eliminate protective cover. Other impacts would be related to general habitat fragmentation, increased road traffic, fire frequency, and weed introduction. Impact of the development phase is greater, but assuming contractors are sensitive to general wildlife needs, jackrabbits are minimally impacted (Table A.4.5).

Wind turbine—The impact of wind turbines is more than the towers themselves; it includes the associated access roads, vehicular traffic, and maintenance activities. Considering these additional factors, a resistance value of 16 and a habitat value of 0.2 were assigned to the wind turbine and immediate 45 m around it, values that would prevent an HCA forming on top of a turbine and reduce the likelihood of a linkage developing through a wind turbine (Table A.4.5). Buffer zones were considered of little impact for both dispersal movements and creation of HCAs.

Irrigation infrastructure—We lacked specific information about the resistance of major irrigation canals. We feel that overall resistance of these canals is a combination of effects from the canal itself, seasonal usage, access roads, and maintenance activities that could include herbicide applications. Most large canals have adjacent, native-surface access roads and canal crossings at least every 13 km or so—an effort is being made to reduce this distance to approximately 6 km. These roads typically have very low traffic volumes, suggesting that the resistance of the access road component is probably lower than that of typical local roads. Considering the canals themselves, during the irrigation season (approximately April to September), high water velocity in these canals increases landscape resistance due to harm from the water diversion infrastructure itself, the inability of jackrabbits to extract themselves from the canal, and the displacement to locations where potentially low habitat values could reduce survival. Because of the additional increases in potential injury and mortality, irrigation canals were given a higher resistance of 60 compared to 50 for water (Table A.4.5).

Modeling Results

Resistance Modeling

Resistance surface maps show the relative difficulty of movement across the varying landscape of the study area and are integral in the production of HCA, cost-weighted distance (CWD), and linkage maps. If a cell has a resistance value of 1 the cost to cross this cell is equal to that of the real world distance (30 m); if the cell has a value of 5 the cost to cross is 5 times as much. All resistance values for white-tailed jackrabbits are relative to the cost to move through a one cell of ideal habitat (i.e., basin grassland).

The resistance surface for movement of white-tailed jackrabbits in the Columbia Plateau (Fig. A.4.1) shows a landscape extensively fragmented by development, roads, powerlines, irrigation canals, and agriculture. Although the majority of the area would appear to have relatively low resistance with values less than 10, the cumulative cost of moving through it can quickly become very expensive for a jackrabbit whose average home range is 1 km^2 (a value equaling 1111 grid cells). Many of the agricultural lands in eastern Washington exhibit a "checkered" pattern of small patches of low resistance habitat set in a matrix of higher resistance. The areas of low resistance are essentially "islands" of jackrabbit habitat bordered by resistant features of the landscape. Additionally long linear features (e.g., roads, powerlines, etc.) do not present alternative paths for crossing—either the rabbits must cross the feature and absorb the cost or remain isolated.

The areas that appear to have the lowest resistance for white-tailed jackrabbits in the north are the Upper Crab Creek drainage in Lincoln County, the glacial moraine in eastern Douglas County, Moses Coulee in Grant County, and the Okanogan Valley—Okanogan to Oroville. Movement potential between the large areas of low resistance in Douglas County and central Lincoln County is reduced in part by extensive areas of cropland, roads, water, and high voltage powerline corridors that extend from Grand Coulee Dam, near to Coulee City and down to Soap Lake.

In the southwest, areas of low resistance appear to be centered on and in the large public land holdings, e.g., Yakima Training Center (YTC), WDFW Colockum Wildlife Area, as well as tribal lands on the Yakama Reservation. There is a narrow, highly constrained east–west band of low resistance that extends along Ahtanum Ridge south and west of Yakima, crosses I-82 (at Union Gap, just south of Yakima), and connects to the Rattlesnake Hills east of Yakima. Potential for movement along this east-west band of low resistance is again intersected by development, I-82, and the Yakima River which essentially isolates the low resistance habitats on the Yakama Reservation from areas west and north.

Given the resistance to movement created by features such as urbanization and roads we anticipate that connectivity of jackrabbit populations will be negatively impacted by future development.

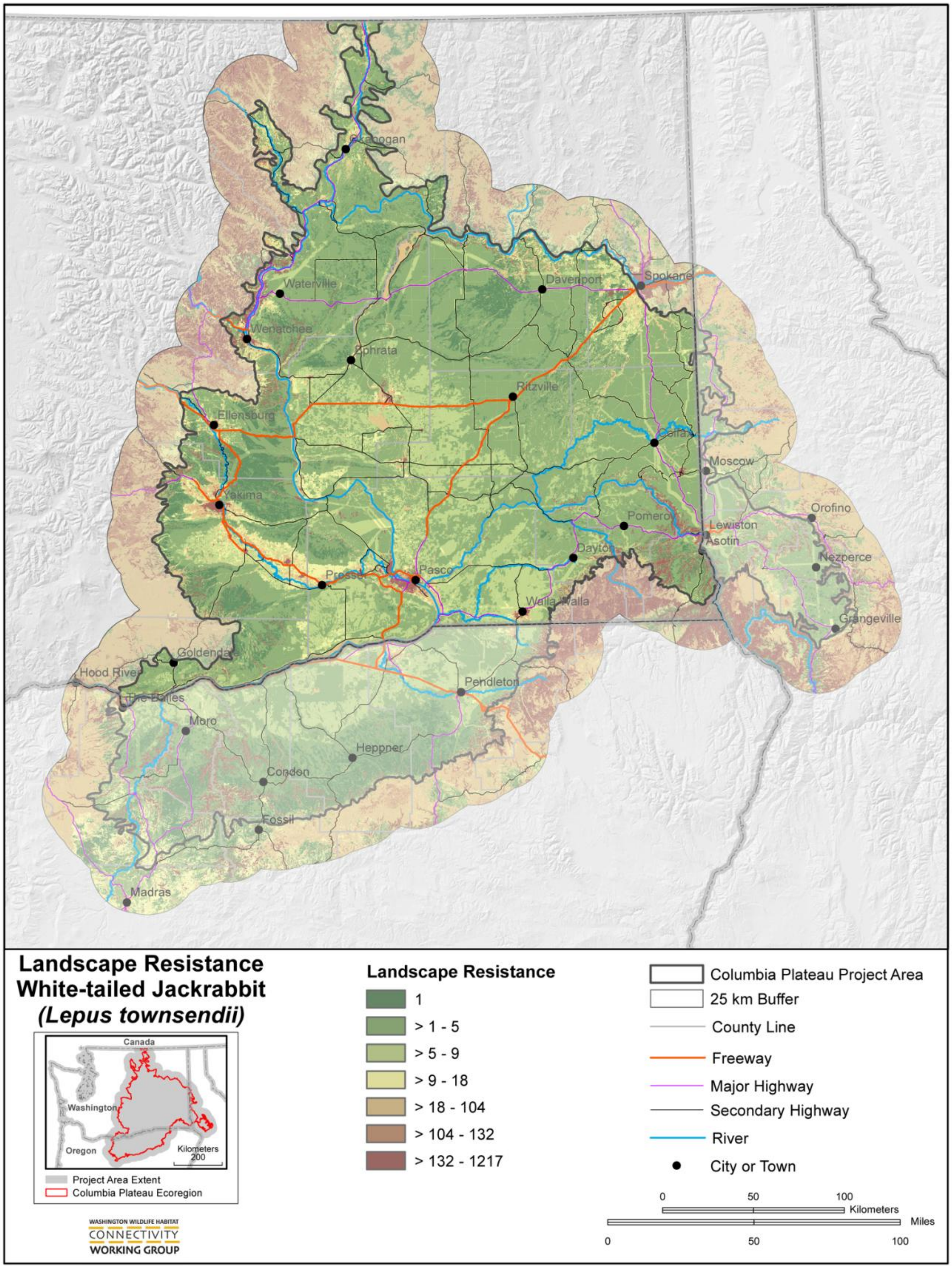

Figure A.4.1. Resistance map for white-tailed jackrabbit in the Columbia Plateau Ecoregion.

Habitat Modeling and Habitat Concentration Areas

With little published literature and limited unbiased occurrence data, core habitat for white-tailed jackrabbit in Washington is not well defined. Having insufficient data, habitat concentration areas were modeled on habitat suitability (see Habitat Concentration Area section above).

During the modeling process, HCAs were formed using a combination of different parameters on many different runs. The HCA model produced using a minimum average habitat value (MAHV) of 0.8 (Fig. A.4.2) was selected as a base map and, although it was the considered the best model by expert review and fit with known data points, it still produced several HCAs that were undesirable and failed to create some that were. Undesirable HCAs were those either outside the known range of white-tailed jackrabbit or occurring within the historical range but in an area where habitat no longer exists (Table A.4.6). The HCAs the model failed to create were few, but some were missing in areas of known white-tailed jackrabbit concentrations and/or areas that were judged to have excellent jackrabbit habitat. These missing HCAs were mapped when a MAHV of 0.75 was used (Fig. A.4.3; Table A.4.6), however at the 0.75 level many more undesirable and extensive HCAs were created. Thus it was decided to use the 0.8 MAHV model as the base, and then “manually” remove undesirable HCAs and manually add missing HCAs to create the final HCA map (Fig. A.4.4).

The final HCA model was a conservative or lean model of HCAs (a total of 90) that were believed to have high quality habitat (most at 0.80 MAHV; see also Fig. A.4.5) and in most cases an existing population of white-tailed jackrabbits. All HCA removals and additions were based on known jackrabbit populations, jackrabbit expert review, and local biologists’ knowledge of current habitat conditions and occurrence.

Table A.4.6. Additions and deletions of white-tailed jackrabbit HCAs to produce the final HCA map.

	HCA ID	*MAHV*	*Map*
HCAs removed	91, 92, 93, 94	0.80	Fig. A.4.2
HCAs added	88, 89	0.75	Fig. A.4.3

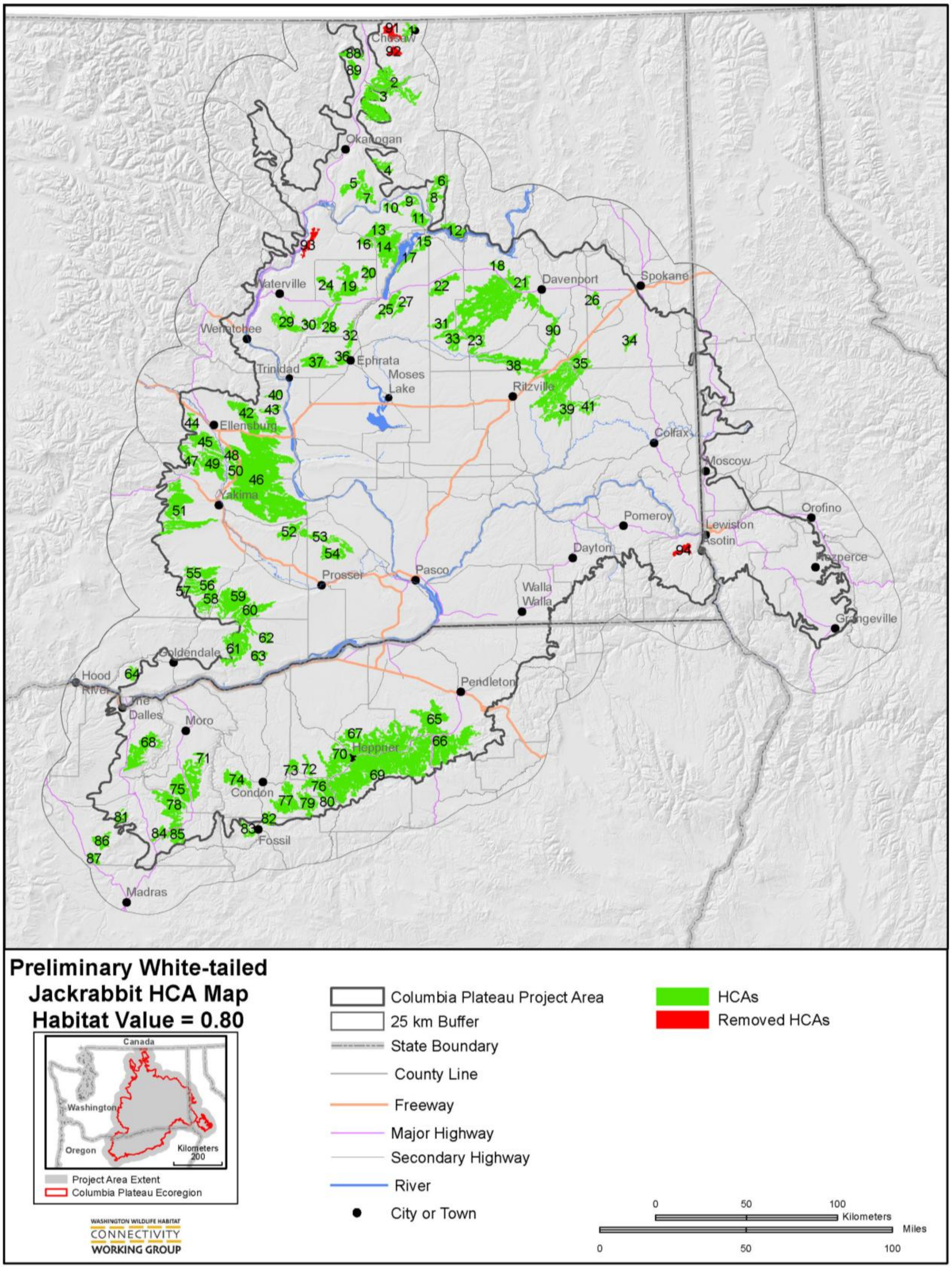

Figure A.4.2. Preliminary white-tailed jackrabbit HCA map using a habitat value of 0.80. Habitat concentration areas in red were removed to make the final HCA map based on local biologists' knowledge of the habitat and lack of jackrabbit occupancy.

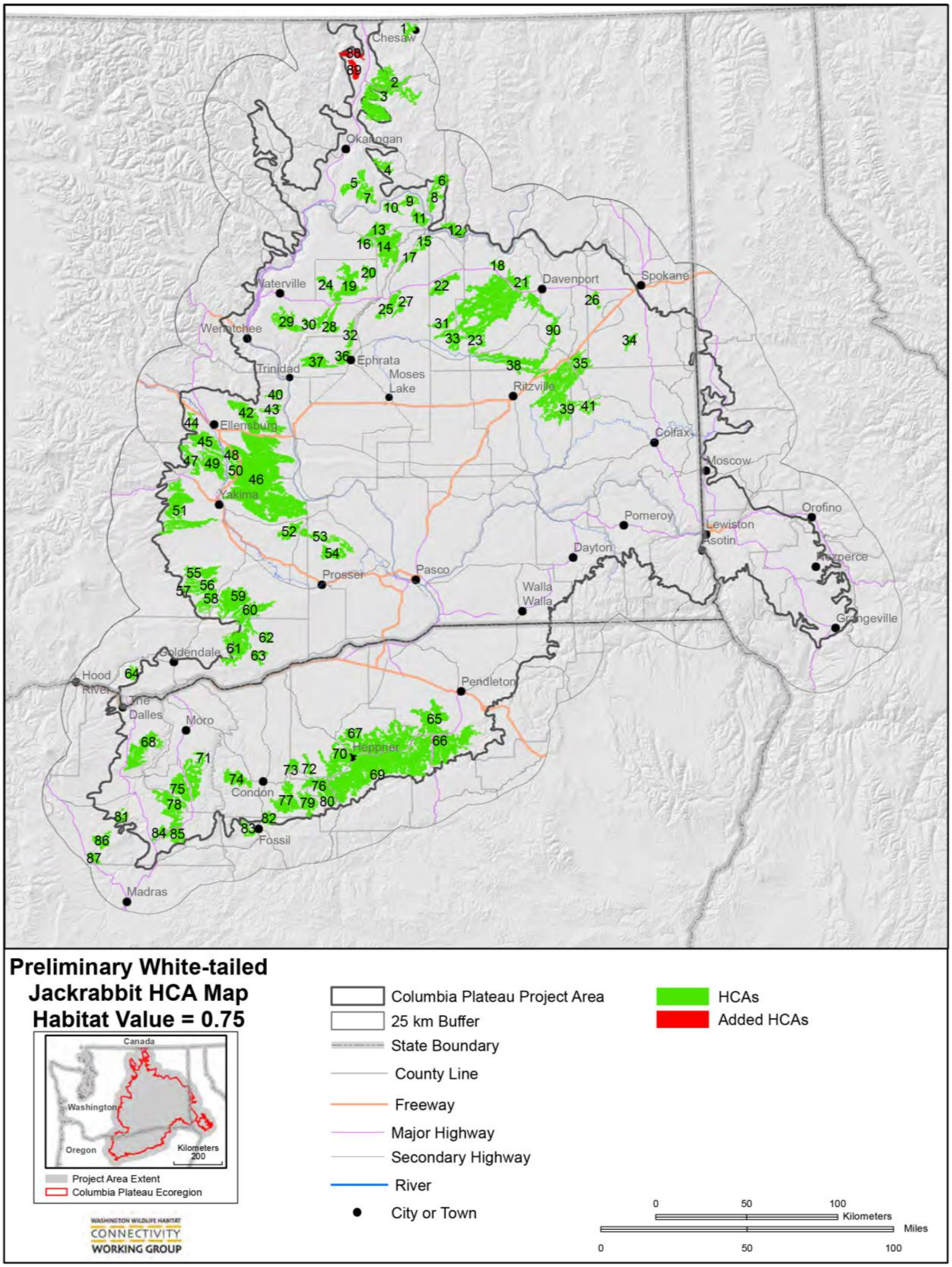

Figure A.4.3. Preliminary white-tailed jackrabbit HCA map using a habitat value of 0.75. Habitat concentration areas in red were those added to the final HCA map based on local biologists' knowledge of habitat and jackrabbit populations.

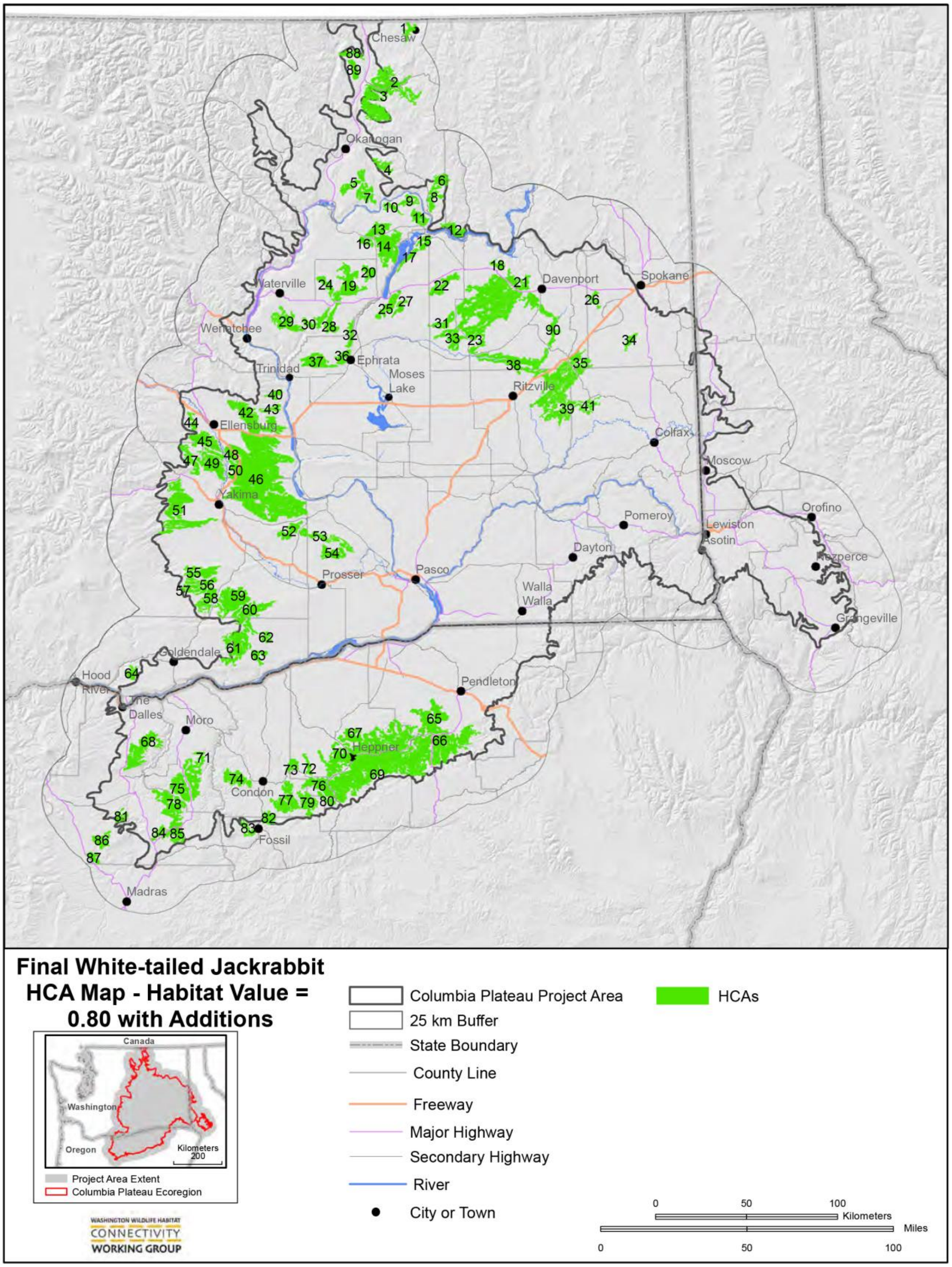

Figure A.4.4. Final white-tailed jackrabbit HCA map after additions and deletions.

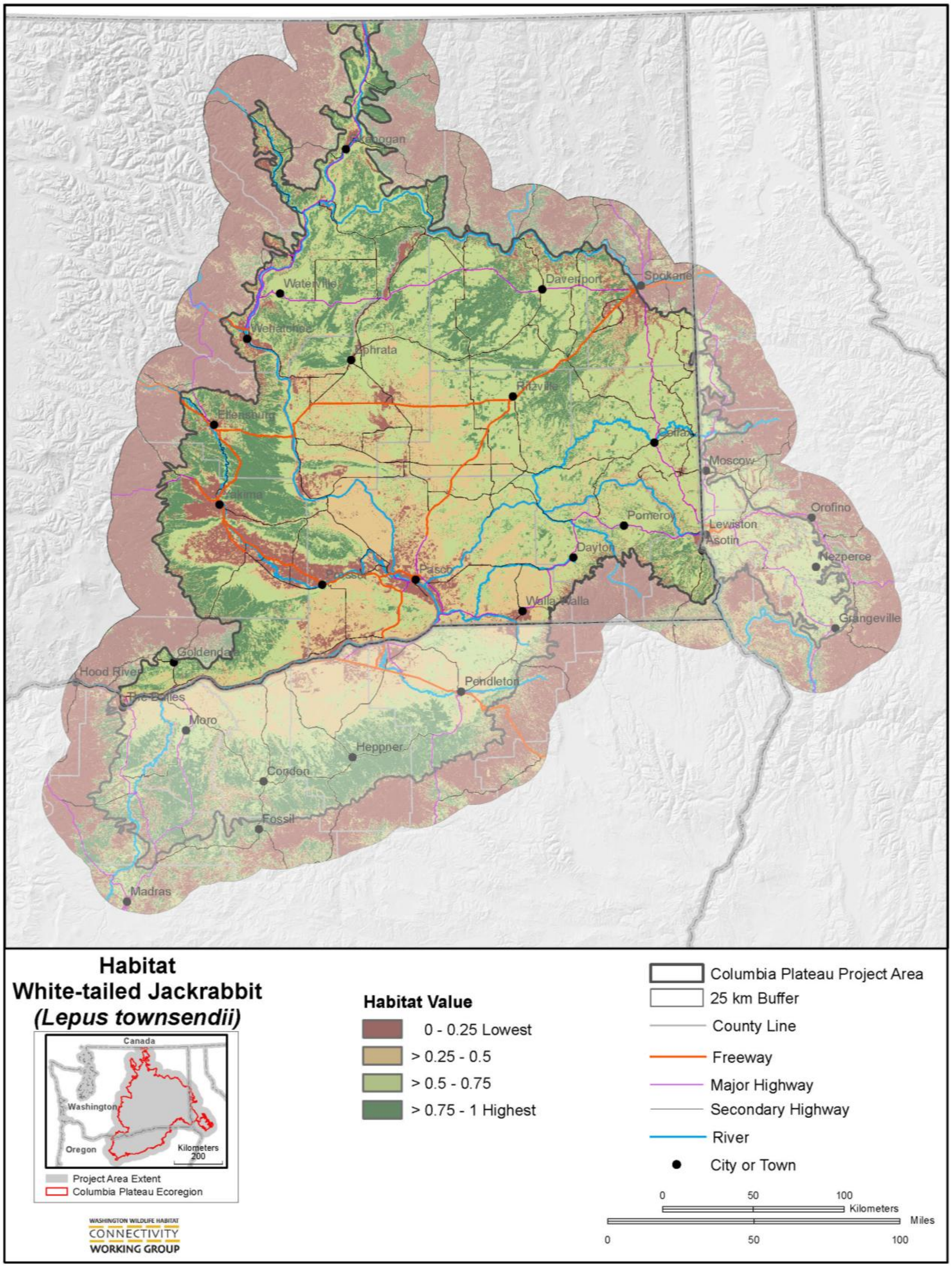

Figure A.4.5. Habitat map for white-tailed jackrabbit in the Columbia Plateau Ecoregion.

In the final HCA map (Fig. A.4.4), the 90 white-tailed jackrabbit HCAs, totaling 996,327.8 ha are located throughout the Columbia Plateau grassland and shrubsteppe habitat. White-tailed jackrabbits tend to occur at higher elevations than black-tailed jackrabbits, and their distribution extends up the Okanogan Valley into B.C. The most sizeable HCAs are located on the Yakama Reservation, YTC, and around the combined BLM Lake Creek Drainage Area and WDFW Swanson Lakes Wildlife Area in Lincoln County. Four HCAs – 4, 12, 86 and 87, occur outside the Columbia Plateau Ecoregion boundary but within the buffer area. Two other HCAs straddle the boundary – HCAs 2 and 6.

The final HCA map is a good representation of the distribution of remnant grassland-dominated habitat in the Columbia Plateau. Many of the areas left out are low-quality habitat, most often expansive areas of irrigated agriculture such as that in northern Adams County, south-central Douglas County around the Waterville Plateau, and the Yakima Valley in east-central Yakima County. A large "hole" with no HCAs exists in the Yakima Valley area due to high resistance caused by a combination of development, I-82, the Yakima River, and little remnant habitat.

The HCAs for the white-tailed jackrabbit are small and dispersed except for two large HCAs, one found in Lincoln County (HCA 23) and the other straddling the YTC (HCA 46). Unlike the black-tailed jackrabbit, the white-tailed occupies habitat north of the Columbia River and into the Okanagan Valley. This area has good potential for north–south movement.

Some of the HCAs are quite small, for example, the two HCAs in Spokane County (26, 34) and the three HCAs – one in Yakima County and two in Benton County (52, 53, and 54). These small HCAs are important because they are likely the last remnants of habitat in the area, and in the case of HCAs 52, 53 and 54, may provide the only link between other HCAs. Protection of these areas may be of high priority especially if they provide critical links in maintaining connectivity.

When comparing our final HCA map with the 1997 Washington Gap analysis (Johnson & Cassidy 1997) white-tailed jackrabbit range map (Fig. A.4.6) two features standout. First, much of the core range area in the southeast Columbia Plateau identified by the 1997 Gap project is now not considered white-tailed habitat. Our model produced no HCAs in the southeast portion of the Columbia Plateau (Walla Walla and Franklin counties).

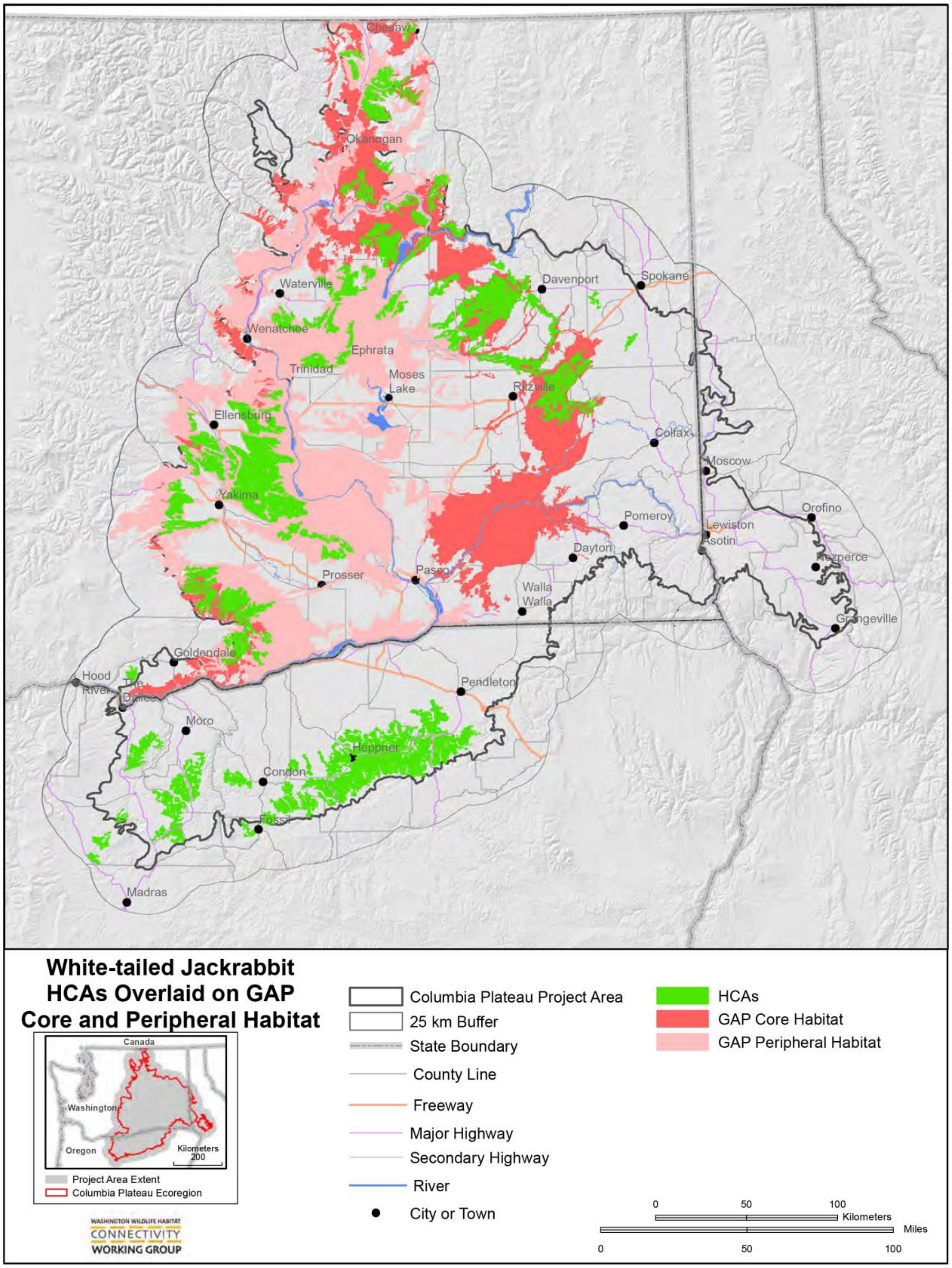

Figure A.4.6. White-tailed jackrabbit HCAs (green polygons) overlaid on Gap core habitat (dark pink areas) and peripheral habitat (light pink areas) in the Columbia Plateau Ecoregion.

This is due largely to the loss of habitat, but also to the use of elevation to separate the jackrabbit species. Second, our final map shows HCAs along the western edge of the Columbia Plateau (eastern edge of the Cascade Range) which the Gap project considered peripheral range.

Shortcomings of the use of elevations showed up in a number of conditions such as:

- changes in environmental conditions due to changes in latitude;
- micro-climate conditions caused by a number of environmental factors such as soil, slope, aspect, and precipitation; and,
- human causal factors such as grazing, irrigation, irrigated crops, human landscaping.

Despite these shortcomings, the use of the elevation classes in our modeling effort to distinguish the habitat of the two jackrabbit species resulted in a good fit of the known jackrabbit range and also the field observations that are available.

Cost-Weighted Distance Modeling

The cost-weighted distance (CWD) map (Fig. A.4.7) provides an estimate of the relative cost of movement across the landscape—the cumulative effect of features that impede the movement of the jackrabbit for any route taken from an HCA—illustrating patterns for potential movement of white-tailed jackrabbit in the Columbia Plateau. This map is particularly useful for identifying barrier effects and broad areas that contribute to connectivity.

Connectivity to the west, northwest, east and southeast of the Upper Crab Creek HCAs (Lincoln County) appears good with poor connectivity to the north and south mostly due to extensive agricultural areas and development. A “hole” is apparent in this HCA complex, surrounding the town of Harrington (Fig. A.4.8) which is due to an extensive area of cropland with little or no native habitat left in the area.

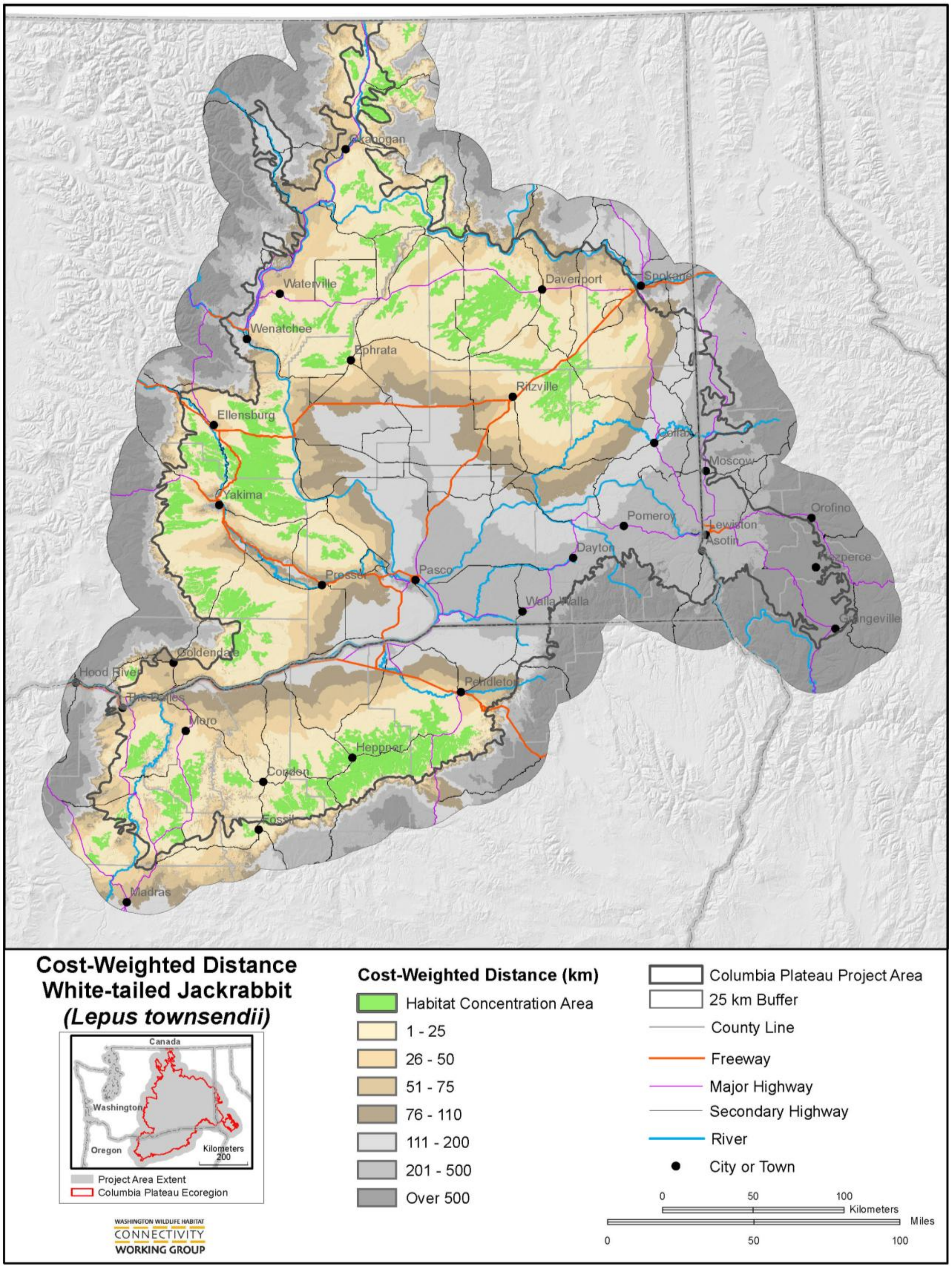

Figure A.4.7. Cost-weighted distance map for white-tailed jackrabbit in the Columbia Plateau Ecoregion.

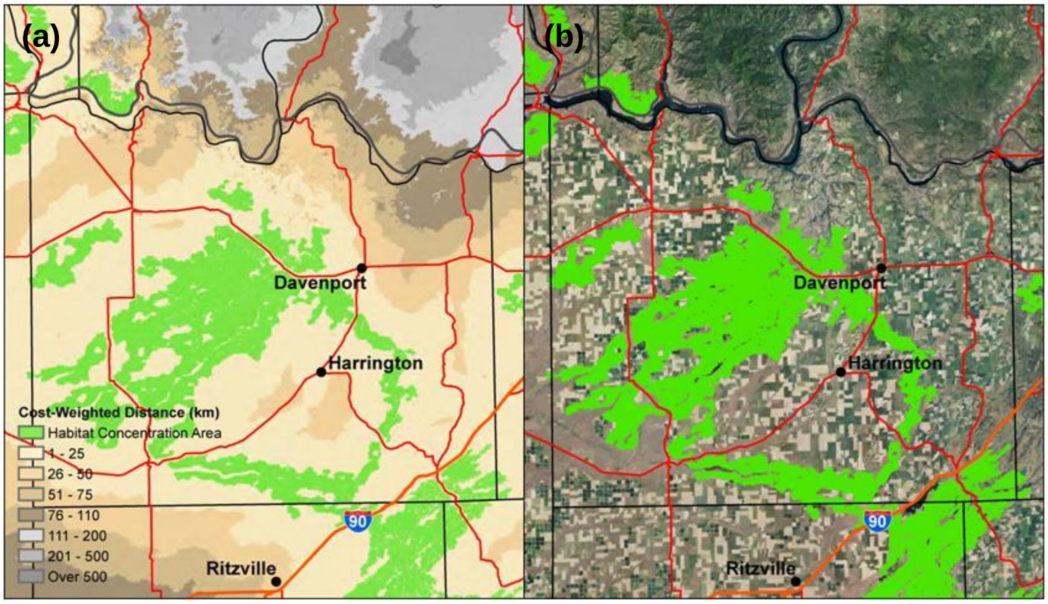

Figure A.4.8. Close up of HCAs in the vicinity of Harrington in Lincoln County. Panel "a" shows the CWD map and Panel "b" is an aerial image of the same area showing a "hole" caused by an aggregate of agricultural fields creating areas of high resistance and poor habitat.

From the Upper Crab Creek area, movement potential is highest to the west reflecting low resistance through the native habitat of the channeled scablands. In contrast, the area south of Ephrata near Moses Lake is high resistance to white-tailed jackrabbits (Fig. A.4.9; Fig. A.4.10) so all potential movement is north of the area. This funneling creates a major pinch-point for north–south movement where Chelan, Douglas, Grant, and Kittitas counties meet at the Columbia River (Fig. A.4.11; Fig. A.4.12). At this pinch-point not only does the Columbia River pose a barrier but there is also I-90 and wind power development further impeding connectivity to the south (Fig. A.4.12).

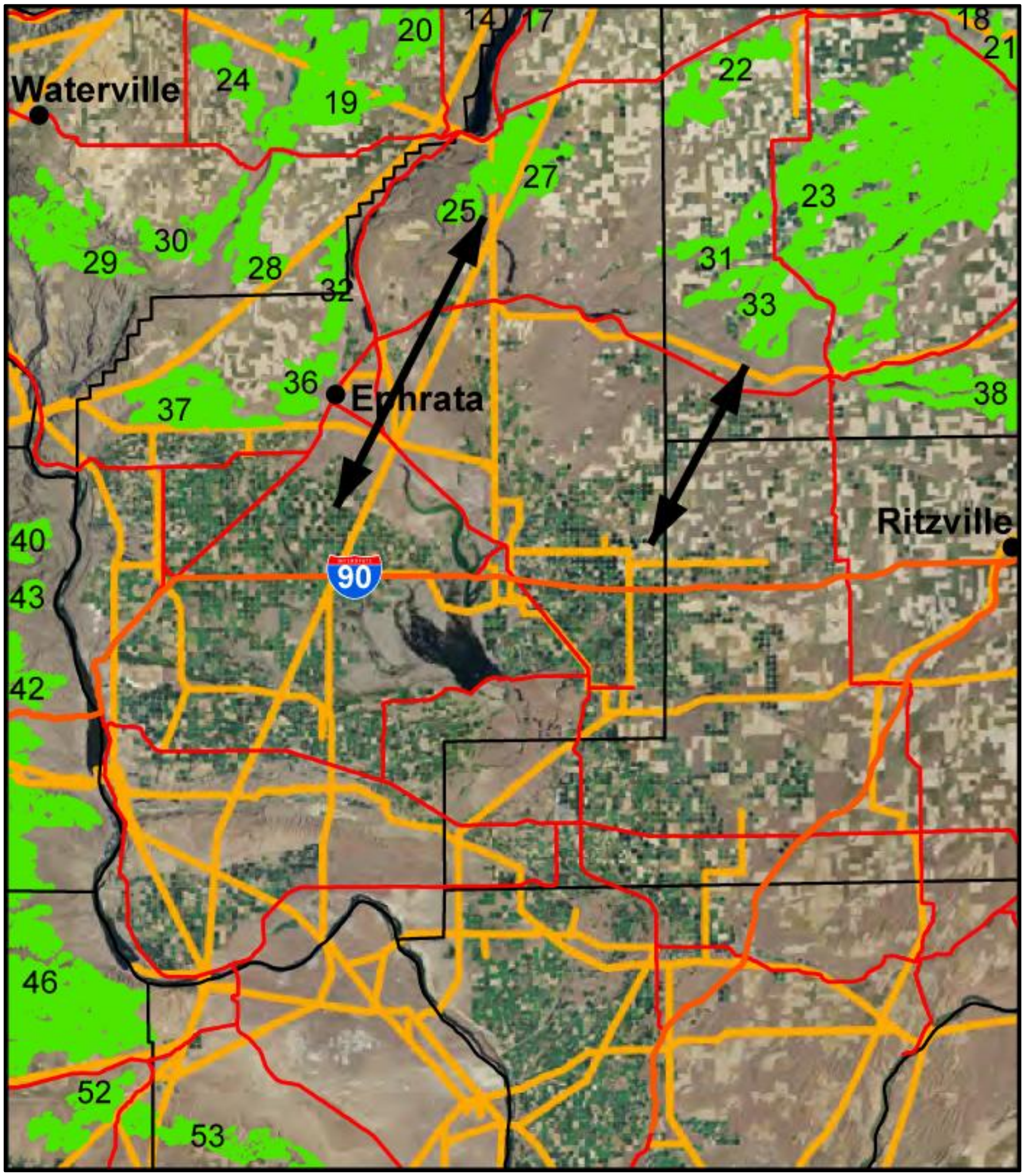

Figure A.4.9. Close up of Moses Lake area south of Ephrata showing resistance features impeding north–south dispersal along potential paths (arrows) from Lincoln and Douglas counties.

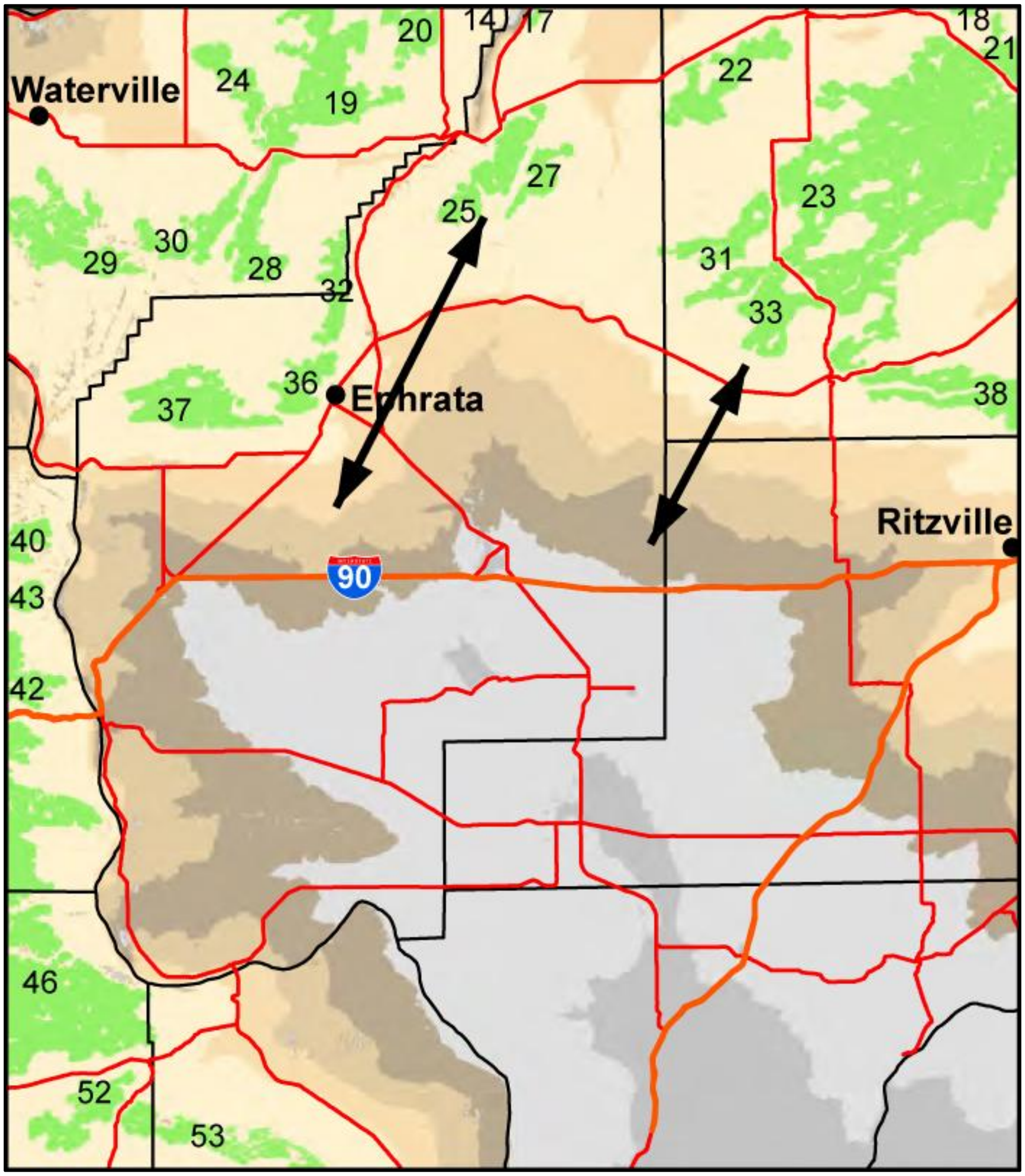

Figure A.4.10. Close up of Moses Lake area south of Ephrata showing high CWD along potential paths (arrows) due to high resistance features impeding north–south dispersal from Lincoln and Douglas counties.

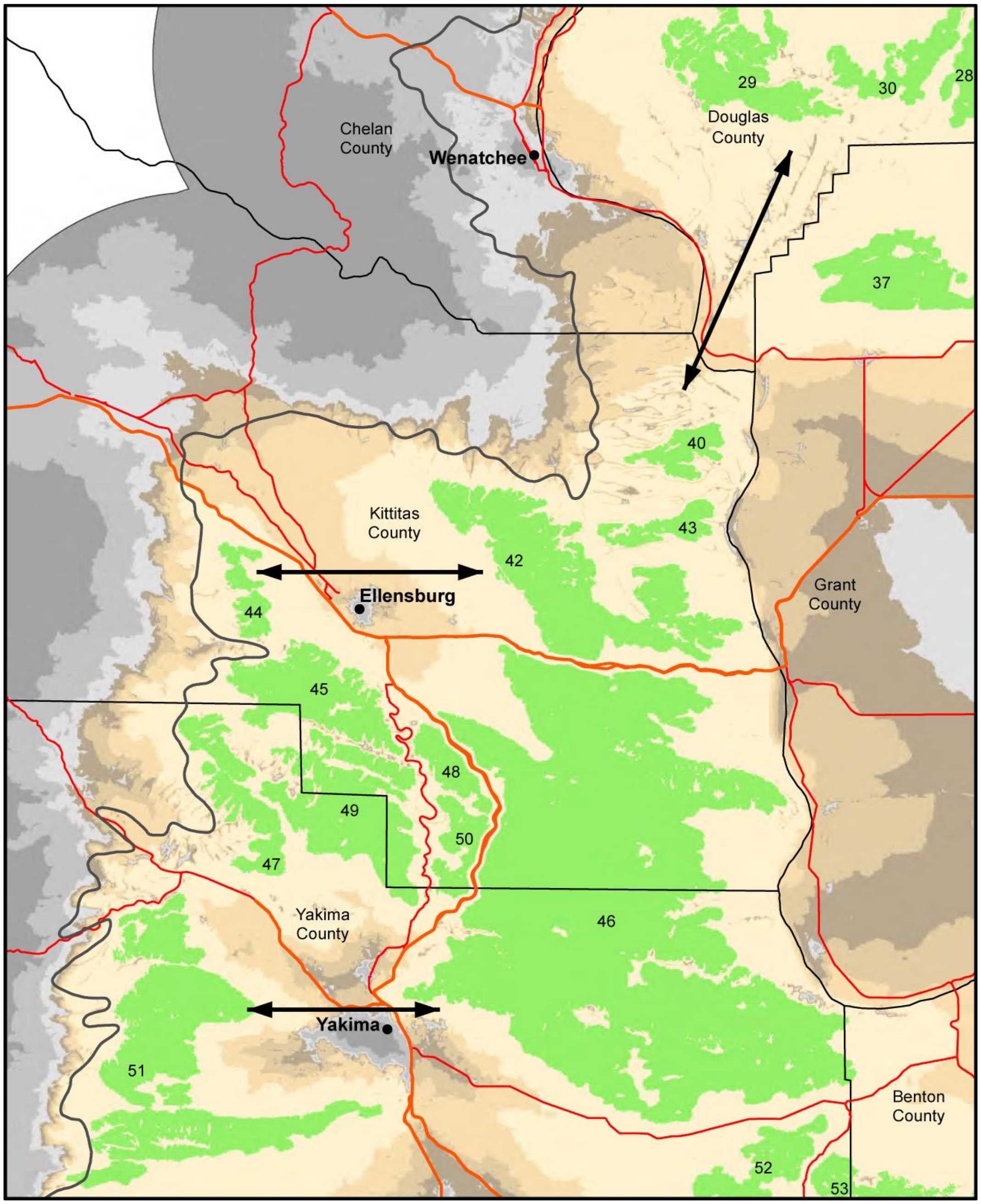

Figure A.4.11. Close up of area near Ellensburg showing resistance features causing high CWD values impeding north–south dispersal from Lincoln and Douglas counties and east–west dispersal around Ellensburg and Yakima.

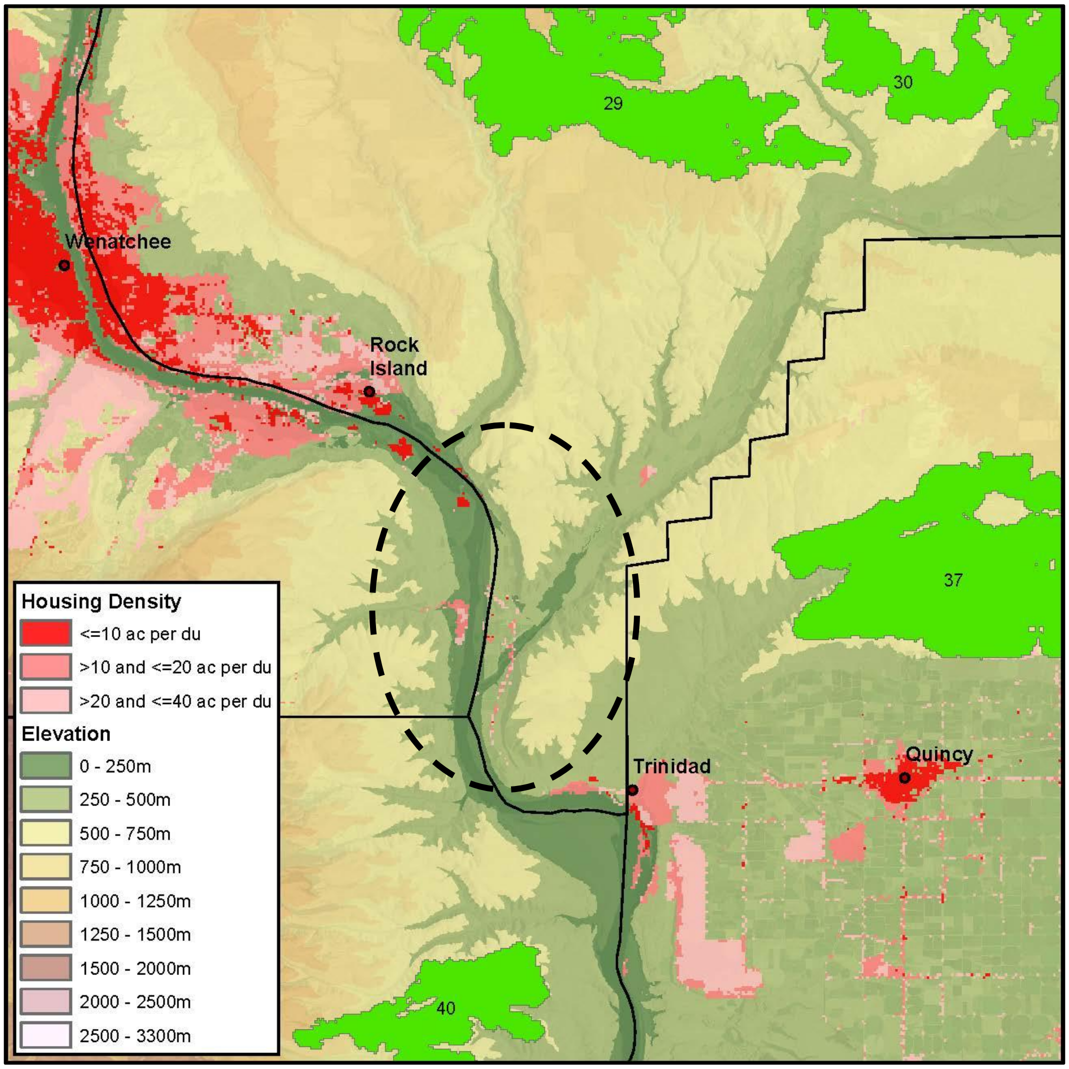

Figure A.4.12. Primary pinch-point (dashed oval) for white-tailed jackrabbit north–south connection near Quincy, Grant County.

In the southern HCAs, connectivity north to south (from HCAs 42 to 46 and from 47 to 51) and east to west (from HCAs 46 to 49) is hampered by interstate highways (I-90 and I-82), the Yakima River, development, and agriculture (Fig. A.4.11) creating multiple pinch-points.

As mentioned earlier, the white-tailed jackrabbit occupies area north of the Columbia River, unlike the black-tailed jackrabbit, and at one time extended all the way into Canada. It is believed that jackrabbits are currently extirpated from British Columbia. The CWD map indicates there is good north–south movement potential and that good habitat exists in the Okanogan Valley (Fig. A.4.5; Fig. A.4.13). This is another important area to protect to conserve the northern extent of the population in Washington (Fig. A.4.4). Connectivity of the Okanogan area with Douglas County to the south is hampered a little by higher resistances around Omak.

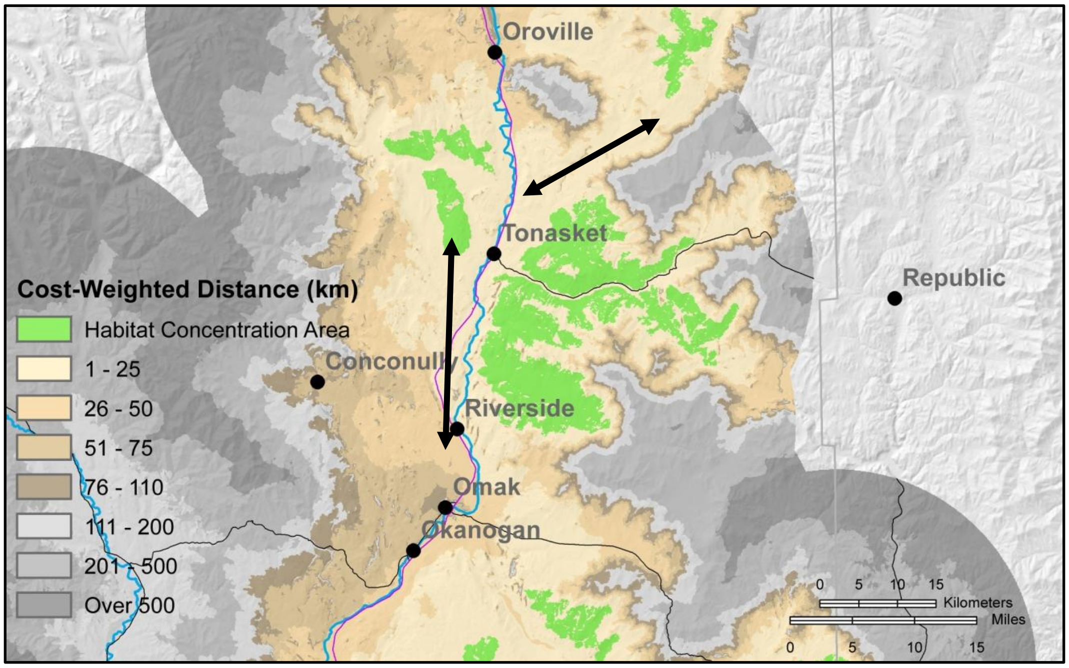

Figure A.4.13. Okanogan Valley shows good potential north-south dispersal (low CWD values) from Canada border south to Riverside area. When reaching the area around Omak, resistance increases impeding movement.

Linkage Modeling

One of the primary goals of this project was to determine and map connectivity across the Columbia Plateau Ecoregion for white-tailed jackrabbits (Fig. A.4.14; see Fig. A.4.15 for HCA identification). Cost-weighted distance methods were used to map least-cost corridors, identifying continuous swaths of land expected to encompass the best routes for species to travel between HCAs. Least-cost corridor links depict the path taken that provided the lowest resistance value in providing connectivity between an HCA pair. This technique allows users to identify which routes encounter more or fewer features that facilitate or impede movement while moving between two HCAs.

The final white-tailed jackrabbit HCA model was conservative. Therefore, between the final HCAs, there are many areas with good habitat and likely small populations of jackrabbits. During the modeling process these were often referred to as "stepping stones". This is an important concept, especially for linkage mapping. With smaller and fewer HCAs across the landscape, as might be expected linkage lengths are quite high, often exceeding dispersal distances reported in the literature. However, the maximum dispersal distance reported in the literature for the black-tailed jackrabbit (used because there is a lack of information for white-tailed jackrabbits) is 57 km (Grant 1987) clearly within the range of the 50 km limit used in our modeling. This approach resulted in the desired effect of producing a maximum number of corridors across the landscape (i.e., all HCAs are connected to at least one other HCA). To verify some these assumptions, we compared these "sparse" HCAs and their associated linkages to the more liberal mapping of HCAs as seen in Fig. A.4.3, most if not all of the linkages fall across or near HCAs that were eliminated when higher quality habitat limits were used (0.8 rather than 0.75). This assumption is further validated when considering that other smaller areas of good quality habitat were also eliminated in the HCA formation when we imposed a 25 km^2 minimum HCA size on the landscape.

Linkages for the white-tailed jackrabbit were modeled between 90 HCAs and resulted in 164 discrete links, 120 of which are contained within or partially within Washington. There were no HCA islands—all HCAs are linked to at least one other. Least-cost distances between all 164 linkages ranged from <1 to 82 km (<1 to 49 km Euclidean distance). The cost-weighted distance to Euclidean distance ratio (CWD:EUC) ranged from <1 to 55 (Appendix B). This ratio is an indication of how favorable or unfavorable a path might be. A low ratio (closer to 1) indicates favorable conditions, while larger ratios indicate less favorable and more high cost features—areas of high resistance and/or poor habitat. Most of the 10 highest CWD:EUC ratios are for linkages that cross major highways or freeways. Others cross high slopes and areas with extreme ruggedness, or combinations of all these factors.

Linkages running from the Crab Creek HCAs (18, 22) to HCAs in the northwest (12, 15) have some of the highest CWD values. Other links with high CWD values are in western Douglas County connecting HCAs 5 and 24, the north–south link between Douglas County and Kittitas County (HCA 29 to 40), and the linkages on the south end of the Yakima Valley crossing Benton County (HCAs 54 to 60 and 62). All of these involve crossing the Columbia River, except for the linkage between HCAs 54 to 60 and 62 which crosses the Yakima River. All require crossing of highways, agriculture, and other development.

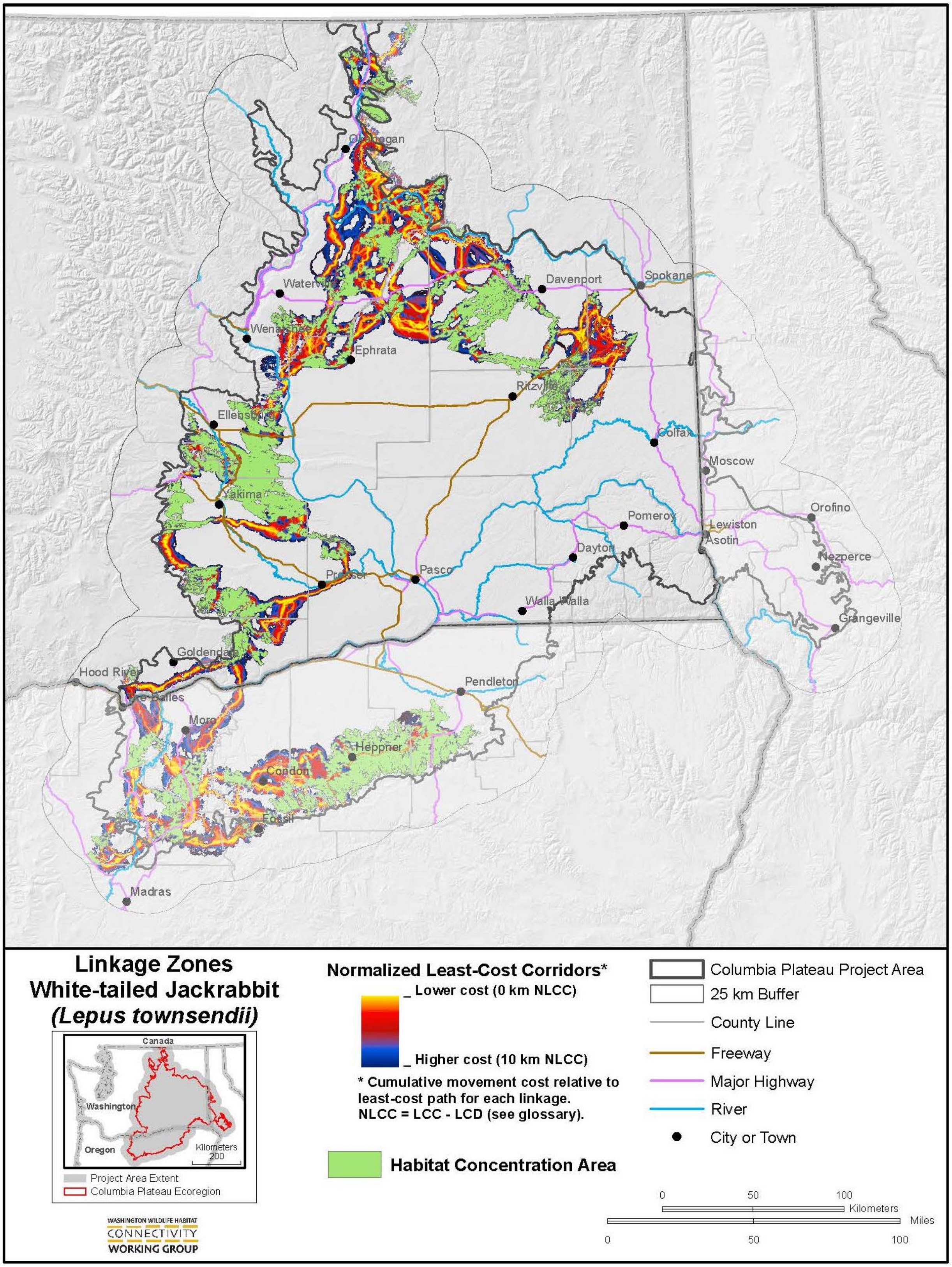

Figure A.4.14. Linkage map for white-tailed jackrabbit in the Columbia Plateau Ecoregion.

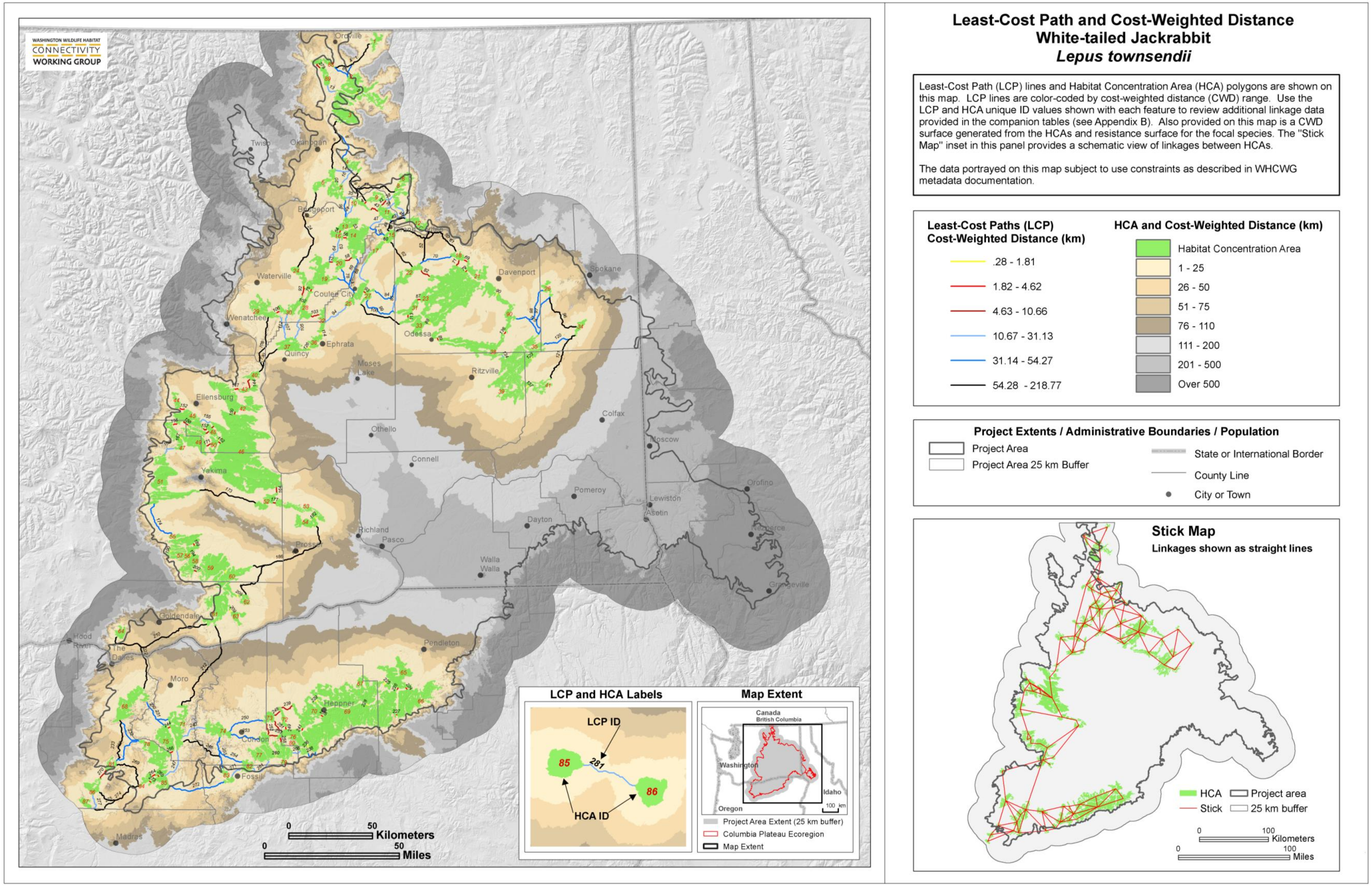

Figure A.4.15. Cost-weighted distance map with numbered HCAs (green polygons labeled with red numerals) and least-cost paths (lines labeled with black numerals) for white-tailed jackrabbit. Linkage modeling statistics given in Appendix B.

There are no HCAs without linkages; all have some path under the 50 km cutoff. There are 3 HCAs connected by only 1 linkage: (1) HCA 6 in Ferry and Okanogan counties, (2) HCA 44 in Kittitas County, and (3) HCA 63 in Klickitat County. All appear as outliers and, if lost, would eliminate jackrabbit movement to these regions thereby isolating these small populations further endangering their existence.

One major concern is the potential separation of the population into 2 subpopulations—a north and south population. According to this model all connectivity between HCAs to the north and east of the Columbia River and those to the south and west, occurs in just one area—where Chelan, Douglas, Grant, and Kittitas counties meet along the Columbia River (Fig. A.4.4; Fig. A.4.15). As well as the river, connectivity between these two areas must transverse Hwy 28, transmission lines, irrigation canals, agricultural fields, wind power development, and rugged slopes. In addition, both the cities of Quincy and East Wenatchee are expanding into this dispersal linkage. All these factors create a severe pinch-point. This is another important area requiring immediate conservation efforts and land use planning to try and preserve this potential corridor.

Another area of concern is around Yakima and along the Yakima Valley, Yakima River, and I-82 corridor. If the linkages are lost between HCAs 51 and 55 this would create more “islands” of unconnected habitat to the south of Yakima, further exacerbating jackrabbit isolation.

Comparative Insights between the Statewide and Ecoregional Connectivity Analyses

In the statewide analysis, a larger home range radius (2 km) and minimum HCA size (50 km2) was used than in the ecoregion analysis, 500 m and 25 km2 respectively. This resulted in larger and fewer HCAs, 68 in the statewide analysis versus 90 in the ecoregional (Fig. A.4.16). For the statewide analysis there was a greater interest in mapping all potential habitat whether currently or even historically occupied and with lower quality of habitat. Additionally, in the ecoregional analysis, elevation was used to better distinguish between the black-tailed and white-tailed jackrabbit core ranges resulting in the absence of HCAs in Idaho, east-central and south Grant County, southeast Adams County, Franklin County, and Whitman County when compared to the statewide analysis.

The elevation constraints, smaller home range, and improved landscape layers tended to reduce the size of the HCAs, especially those on the edge of the white-tailed jackrabbit range, and most notably the HCAs along the foothills of the Cascades and the on Yakama Nation lands. On the other hand, there were a few cases where the improved landscape layers expanded the HCAs, most notably the HCA in Lincoln County and the HCAs in and around the Yakima Training Center. The addition of agricultural buffers also likely contributed to the expansion of some HCAs. Overall, the larger HCAs from the ecoregional analysis match up closely with those from statewide analysis. However, several smaller HCAs appear in the ecoregional analysis that were not mapped in the statewide analysis.

In the statewide analysis the white-tailed jackrabbit was considered to be a linkage dweller. If suitable habitat was available between defined HCAs, it was assumed jackrabbits would use it for feeding, cover, movement, and reproduction. For this reason, no maximum dispersal distance was assigned and all HCAs were connected during linkage modeling. In the ecoregional analysis, the jackrabbit was not considered a corridor dweller, but given the high potential for patches of habitat along linkage pathways that, although not suitable or large enough to be considered an HCA but would be suitable for feeding and reproduction, we felt comfortable using 50 km (close to the largest 57 km dispersal observed in any study) for the maximum dispersal distance. The 50 km cut off allowed for all HCAs to be connected.

Comparing the least-cost pathways (LCP) identified in the two analyses is difficult given the differences in HCAs, all of which determine where LCPs are formed. Comparing the total links for each project, there were 131 for the statewide and 164 in this ecoregional project. Least-cost paths differed in that the two longest least-cost paths for the statewide were 106 km and 109 km (when limited to Washington links only, not British Columbia or Oregon), while in the ecoregional they were much smaller at 69 km and 82 km. This is likely due to the fact that the final ecoregional model was based on higher quality data and therefore does not have as many isolated HCAs as the statewide, e.g., HCAs in Asotin County and southern Grant County. One key similarity in linkages between the two analyses is the identification of the area around where Chelan, Douglas, Grant, and Kittitas Counties meet along the Columbia River as a key point of connectivity between the north and south. Although the statewide analyses did produce two other links, both of these are farther south and depended on HCAs of questionable existence for white-tailed jackrabbits.

To summarize, the comparison between the statewide and the ecoregion analysis for the white-tailed jackrabbit, the Least Cost Pathways network of the statewide project formed basically a large reverse “Q”, whereas the ecoregional study is more of a “C” with a small tail extending west into Klickitat County. The most notable links that are missing entirely from the ecoregional analysis are those in Franklin, southeast Adams, southwestern Whitman, and Asotin Counties. Given the resolution of the ecoregion analysis and the incorporation of better data one may assume that the LCPs from this analysis would be more precise. However, it will require field surveys and field validation to truly determine the best LCPs that are required to maintain connectivity for white-tailed jackrabbits.

Key Patterns and Insights

Key patterns and insights for connectivity modeling of white-tailed jackrabbits in the Columbia Plateau Ecoregion include:

- There appears to be four major zones or concentration areas for the white-tailed jackrabbit in Washington—Okanogan, Lincoln-Douglas down to Malaga, Kittitas-Yakima centered on the Yakima Training Center, and south Yakima centered on the Yakama Reservation. Connectivity within these zones appear to be good, however connectivity between the zones is of concern. The areas of concern are Omak, Malaga to Crescent Bar, and Yakima Valley—from Yakima all the way to Benton City.
- A major pinch-point occurs in the area between Malaga, Rock Island, and Crescent Bar and any increased resistance would negatively impact dispersal potential for the white-tailed jackrabbit and potentially split the population into two isolated north and south zones.

- The I-82/Yakima River corridor between Yakima and the Tri-Cities is a barrier to north-south movement. Further development and expansion in this area either to the north or south will further widen this gap.
- There are four small HCAs in Spokane County (HCAs 26, 34), one in Yakima County (HCA 52), and two in Benton County (HCAs 53 and 54) that are important because they are likely the last remnants of habitat in the area, and in the case of HCAs 52, 53 and 54, may provide the only link between other HCAs. Protection of these areas may be of high priority for maintaining connectivity.
- Areas of low resistance are constrained by development, freeways and major highways, rivers, and agriculture. Roads and agriculture seem to impart the biggest impact on jackrabbit habitat and dispersal.
- Some of the HCAs are small and isolated and if they and associated links are lost, the range of the white-tailed would be further decreased.
- Overall the white-tailed jackrabbit range appears to be shrinking when comparing the results of this study to the 1997 Gap project.
- When reviewing the HCA maps and occurrence data there are relatively few observations of white-tailed jackrabbits in the Yakima County HCAs (Fig. A.4.17). If indeed white-tailed jackrabbits do not occupy these HCAs and if their absence is due to a lack of habitat (i.e. our model incorrectly predicted this area to have jackrabbit habitat), the connectivity between Benton and Kittitas County HCAs is severely limited and the available habitat for the southern Washington population of white-tailed jackrabbits is vastly diminished.

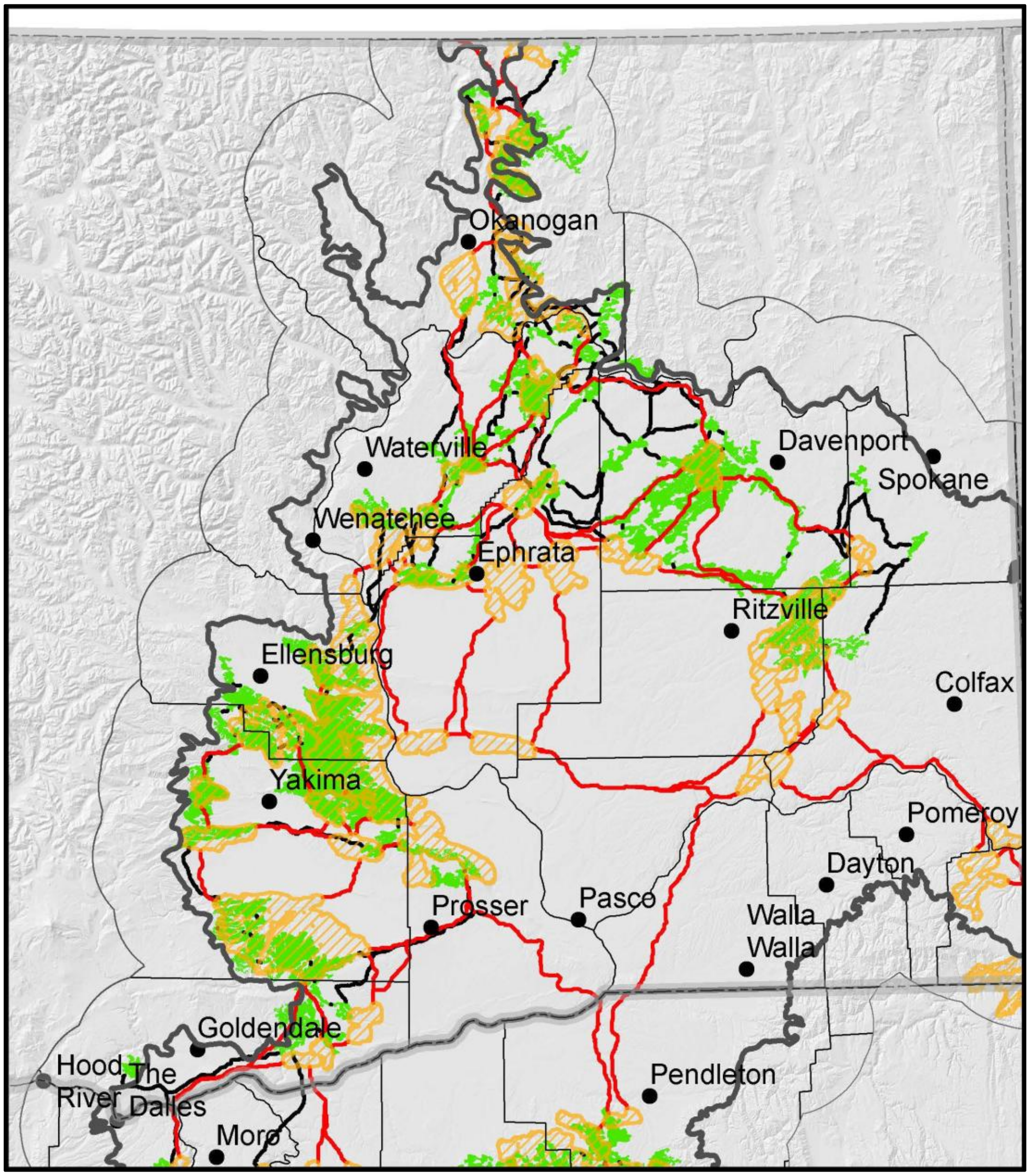

Figure A.4.16. Statewide HCAs (orange hashed areas) and LCPs (red lines) overlaid on the ecoregional HCAs (green polygons) and LCPs (black lines).

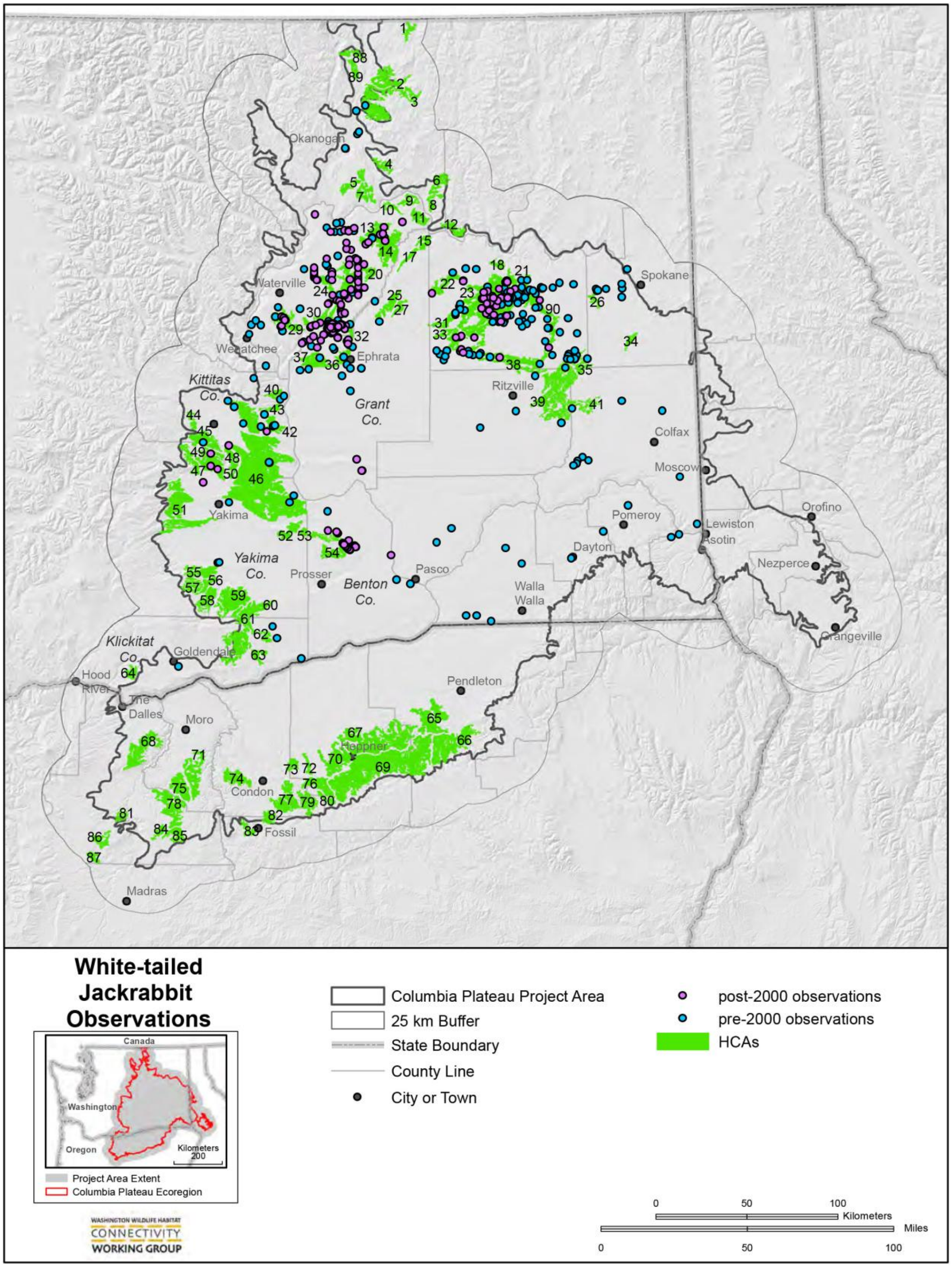

Figure A.4.17. HCAs showing both post-2000 (purple) and pre-2000 (blue) white-tailed jackrabbit observations.

Considerations and Needs for Future Modeling

Due to these two projects it has become more obvious than ever that there is a tremendous lack of studies and occurrence data for the white-tailed jackrabbit both in Washington and range-wide, especially when the "pest" or damage studies are excluded. The field data available for the white-tailed jackrabbit is limited and biased as many of the observations are along roadways. These are some of the biggest gaps in information identified by this project. There are also few, if any, scientific studies available to help and determine the impacts of many of the threats—e.g., land conversion, agriculture, roads, transmission lines, or wind power. Most of the impacts for these analyses were determined by gauging the direct habitat destruction that would take place, while the less direct impacts were evaluated using expert opinion.

As mentioned in the text, some of the shortcomings of the modeling were due to the detail of the vegetation classes. To more accurately map the distribution of the two jackrabbit species, a layer with vegetation classes that could distinguish shrub vs. grass cover, density and height would be needed.

We need to better understand the relationship between Euclidean and cost-weighted distances. What is the cost-weighted distance that a jackrabbit will move and how do they make their decisions about moving forward, turning back, or seeking alternate pathways? These questions are extremely important for helping to understand characteristics of a functional corridor and informing connectivity conservation efforts.

With these points in mind, future modeling should:

- Collect more location data and population information to improve delineation of HCAs.
- Conduct research prior to modeling to estimate jackrabbit movement capabilities and response to feature classes of interest.
- Use more current and finer-scale vegetation data.

Opportunities for Model Validation

There are numerous opportunities to evaluate the assumptions and interpretations of the connectivity models developed. These include:

- The radio-marking of individuals to gain insight into movement capability of the jackrabbits with respect to landscape resistance.
- GPS transmitter marking of individuals would allow detailed information on movement pathways, distances traveled in different habitats, use of croplands, CRP, etc.
- Genetics could be used to evaluate movement across landscapes and between HCAs.
- Black-tailed jackrabbits are reported to outcompete white-tailed jackrabbits, but is there an upper limit of elevation, shrub cover, and/or other parameters that reverses this trend?

Acknowledgements

Brian Cosentino (WDFW), Leslie Robb (Independent Researcher), Andrew Shirk (UW), Jason Lowe (BLM), Chris Sato (WDFW), Mike Livingston (WDFW), Kelly McAllister (WSDOT), Joanne Schuett-Hames (WDFW), Peter Singleton (USFS-PNW), Brad McRae (TNC), Albert Perez (WSDOT), Heidi Newsome (USFWS), Mike Schroeder (WDFW), Jeff Bernatowicz (WDFW) Kevin White (YTC), Jeffrey Heinlen (WDFW), Jon Gallie (WDFW), Paul Wik (WDFW), Brock Hoenes (WDFW), Rich Finger (WDFW), Scott Fitkin (WDFW), Jeffery Bernatowicz (WDFW).

Literature Cited

Anthony, H. E. 1913. Mammals of northern Malheur County, Oregon. Bulletin of the American Museum of Natural History 32:1–27.

Armstrong, D. M. 1972. Distribution of mammals in Colorado. Monograph, University of Kansas Museum of Natural History 3:1–415.

B.C. Conservation Data Centre. 2011. B.C. species and ecosystems explorer. B.C. Ministry of Environment, Victoria, B.C. Available from http://a100.gov.bc.ca/pub/eswp/ (accessed December 2011).

Bacon, M., and C. H. Drake. 1958. Bacterial infections in wild rabbits of eastern and central Washington. Northwest Science 32:124–131.

Bailey, V. 1936. The mammals and life zones of Oregon. North American Fauna 55:1–416.

Bear, G. D., and R. M. Hansen 1966. Food habits, growth and reproduction of white-tailed jackrabbits in southern Colorado. Technical Bulletin Agricultural Experimental Station, Colorado State University 90:1–59.

Beck, J. L., K. P. Reese, J. W. Connelly, and M. B. Lucia. 2006. Movements and survival of juvenile greater sage-grouse in southeastern Idaho. Wildlife Society Bulletin 34:1070–1078.

Berger, J. 2008. Undetected species losses, food webs, and ecological baselines: a cautionary tale from the Greater Yellowstone Ecosystem, USA. Oryx 42:139.

Best, T. L. 1996. *Lepus californicus*. Mammalian Species 530:1–10.

Braun, C. E., and R. G. Streeter. 1968. Observations on the occurrence of white-tailed jackrabbits in the alpine zone. Journal of Mammalogy 49:160–161.

Chapman, J. A., and J. E. C. Flux. 1990. Rabbits, hares and pikas. Status survey and conservation action plan. IUCN, Gland, Switzerland.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of Greater Sage-Grouse and sagebrush habitats. Unpublished report. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming.

Cosentino, B. J., R. L. Schooley, and C. A. Phillips. 2011. Connectivity of agroecosystems: dispersal costs can vary among crops. Landscape Ecology 26:371–379.

Couch, L. K. 1927. Migrations of the Washington black-tailed jackrabbit. Journal of Mammalogy 8:313–314.

Dalquest, W. W. 1948. Mammals of Washington. University of Kansas Publication, Museum of Natural History 2:1–444.

Daniel, A., J. Holechek, P. Valdez, A. Tembo, L. Saiwana, M. Fusco, and M. Cardenas. 1993. Jackrabbit densities on fair and good condition Chihuahuan desert range. Journal of Range Management 46:524–528.

Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agricultural Experiment Station Technical Bulletin 62:1–131.

Donoho, H. S. 1971. Dispersion and dispersal of white-tailed and black-tailed jackrabbits, Pawnee National Grasslands. U.S. International Biological Program.

Fitzner, R. E., and R. H. Gray. 1991. The status, distribution and ecology of wildlife on the U.S. DOE Hanford Site: A historical overview of research activities. Environmental Monitoring and Assessment 18:173–202.

Flinders, J. T., and R. M. Hansen. 1972. Diets and habitats of jackrabbits in northeastern Colorado (Science Series 12). Range Science Department, Colorado State University, Colorado.

French, N. R., R. McBride, and J. Detmer. 1965. Fertility and population density of the black-tailed jackrabbit. Journal of Wildlife Management 29:14–26.

Ganskopp, D., B. Myers, and S. Lambert. 1993. Black-tailed jackrabbit preferences for eight forages used for reclamation of Great Basin Rangelands. Northwest Science 67:246–250.

Grant, J. C. 1987. Ecology of the black-tailed jackrabbit near a solid radioactive waste disposal site in southeastern Idaho. Master's thesis. University of Montana, Missoula, Montana.

Gross, J. E., L. C. Stoddart, and F. H. Wagner. 1974. Demographic analysis of a northern Utah jackrabbit population. Wildlife Monographs N-40, The Wildlife Society.

Gunther, K. A., R. A. Renkin, J. C. Halfpenny, S. M. Gunther, T. Davis, P. Schullery, and L. Whittlesey. 2009. Presence and distribution of white-tailed jackrabbits in Yellowstone National Park. Yellowstone Science 17: 24–32.

Hayden, P. 1966. Seasonal occurrence of jackrabbits on Jackass Flat, Nevada. Journal of Wildlife Management 30:835–838.

Hedlund, J. H., P. D. Curtis, G. Curtis, and A. F. Williams. 2003. Methods to reduce traffic crashing involving deer: what works and what does not. Insurance Institute for Highway Safety, Arlington, Virginia.

Jackson, H. H. T. 1961. Mammals of Wisconsin. University of Wisconsin Press, Madison.

Jacobson, J. E., and M. C. Snyder. 2000. Shrubsteppe mapping of eastern Washington using Landsat Satellite Thematic Mapper data. Washington Department of Fish and Wildlife, Olympia, Washington.

Johnson, R. E., and K. M. Cassidy. 1997. Terrestrial mammals of Washington State: location data and predicted distributions. Vol. 3 in K. M. Cassidy, C. E. Grue, M. R. Smith, and K. M. Dvornich, editors. Washington State Gap Analysis – Final Report, Washington Cooperative Fish and Wildlife Research Unit, University of Washington, Seattle.

Kansas State University (KSU). 2001. Habitat model for black-tailed jackrabbit. Kansas Gap State Project Available from http://www.k-state.edu/kansasgap/KS-GAPPhase1/index.html (accessed December 2011).

Kline, P. D. 1963. Notes on the biology of the jackrabbit in Iowa. Proceedings of the Iowa Academy of Science 70:196-204.

Knick, S. T., and D. L. Dyer. 1997. Distribution of black-tailed jackrabbit habitat determined by GIS in southwestern Idaho. Journal of Wildlife Management 61:75–85.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. van Riper, III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. Condor 105:611–634.

Larrison, E. J. 1976. Mammals of the Northwest. Seattle Audubon Society. Seattle, Washington.

Lechleitner, R. R. 1958. Certain aspects of behavior of the black-tailed jackrabbit. American Midland Naturalist 60:145–155.

Lightfoot, D. C., A. D. Davidson, C. M. McGlone, and D. G. Parker. 2010. Rabbit abundance relative to rainfall and plant production in northern Chihuahuan Desert grassland and shrubland habitats. Western North American Naturalist 70:490–499.

Lim, B. K. 1987. *Lepus townsendii*. Mammalian Species 288:1–6.

Longland, W. S. 1991. Risk of predation and food consumption by black-tailed jackrabbits. Journal of Range Management 44:447–450.

Major, D. J. 1993. Movement patterns and habitat use of the black-tailed jackrabbit in south-central Washington. Master's thesis. Washington State University, Pullman, Washington.

Marın, A. I., L. Hernandez, and J. W. Laundre. 2003. Predation risk and food quantity in the selection of habitat by black-tailed jackrabbit (*Lepus californicus*): an optimal foraging approach. Journal of Arid Environments 55:101–110.

McAdoo, J. K., W. S. Longland, G. J. Cluff, and D. A. Klebenow. 1987. Use of new rangeland seedings by black-tailed jackrabbits. Journal of Range Management 40:520–524.

McDonald, M. W, and K. P. Reese. 1998. Landscape changes within the historical distribution of Columbian sharp-tailed grouse in eastern Washington: Is there hope? Northwest Science 72:34–41.

Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of Sagebrush Habitats and Limitations to Long-Term Conservation. Pages 145–184 in S. T. Knick and J. W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology Series (vol. 38), University of California Press, Berkeley, California.

Mohr, W. P., and C. O. Mohr. 1936. Recent jackrabbit populations at Rapidan, Minnesota. Journal of Mammalogy 17:112–114.

Mossman, A. 1979. Mammal narratives, in California Wildlife/Habitat Relationships Program. North Coast/Cascade Zone. Volume 3. USDA Forest Service, Pacific Southwest Forest and Range Experimental Station, Berkeley, California.

National Research Council. 1995. Upstream: Salmon and Society in the Pacific Northwest. Washington, D. C. National Academy Press.

NatureServe. 2011. NatureServe Explorer: An online encyclopedia of life. Version 7.1. NatureServe, Arlington, Virginia. Available from http://www.natureserve.org/explorer (accessed December 2011).

Neilson, R. P., J. M. Lenihan, D. Bachelet, and R. J. Drapek. 2005. Climate change implications for sagebrush ecosystems. Transactions of the 70th North American Wildlife and Natural Resources Conference 70:145–159.

Nelson, L. Jr., and F. H. Wagner. 1973. Effects of sublethal, cerebral x-irradiation on movement, activity and home-range patterns of black-tailed jackrabbits. Health Physics 25:507–514.

Porth, A. T. 1995. Movements of black-tailed jackrabbits (*Lepus californicus*) and effects of high population densities on the nitrogen budget of sage-brush steppe. Master's thesis. Idaho State University, Pocatello, Idaho.

Quigley, T. M, and S. J. Arbelbide (technical editors). 1997. An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, Vol. 1–4. General Technical Report PNW-GTR-405. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Rickard, W. H., and L. D. Poole. 1989. Terrestrial wildlife of the Hanford Site: Past and future. Northwest Science 63:183–193.

Rogowitz, G. L. 1997. Locomotor and foraging activity of the white-tailed jackrabbit (*Lepus townsendii).* Journal of Mammalogy 78:1172–1181.

Rogowitz, G. L., and M. L. Wolfe. 1991. Intraspecific variation on life-history traits of the white-tailed jackrabbit (*Lepus townsendii).* Journal of Mammalogy 72:796–806.

Roundy, B. A., G. J. Cluff, J. K. McAdoo, and R. A. Evans. 1985. Effects of jackrabbit grazing, clipping, and drought on crested wheatgrass seedlings. Journal of Range Management 38:551–555.

Rusch, D. H. 1965. Some movements of black-tailed jackrabbits in northern Utah. Master's thesis. Utah State University, Logan, Utah.

Schroeder, M. A., and W. M. Vander Haegen. 2006. Use of Conservation Reserve Program fields by greater sage-grouse and other shrubsteppe-associated wildlife in Washington state. Technical report prepared for U.S. Department of Agriculture Farm Service Agency. Washington Department of Fish and Wildlife, Olympia, Washington.

Schroeder, M. A., and W. M. Vander Haegen. 2011. Response of greater sage-grouse to the Conservation Reserve Program in Washington State. Pages 517–529 in S. T. Knick and J. W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology Series (vol. 38), University of California Press, Berkeley, California.

Severaid, J. H. 1950. The pygmy rabbit (*Sylvilagus idahoensis*) in Mono County, California. Journal of Mammalogy 31:1–4.

Smith, G. W. 1990. Home range and activity patterns of black-tailed jackrabbits. Great Basin Naturalist 50:249–256.

Smith, G. W., L. C. Stoddart, and F. F. Knowlton. 2002. Long-distance movements of black-tailed jackrabbits. Journal of Wildlife Management 66:463–469.

Steenhof, K., M. N. Kochert, and J. A. Roppe. 1993. Nesting by raptors and common ravens on electrical transmission line towers. Journal of Wildlife Management 57:271–281.

Tiemeier, O. W. 1965. Study area, reproduction, growth and development, age distribution, life span, censusing, live trapping and tagging, crop damage, predation and habits. Pages 5–39 in The black-tailed jackrabbit in Kansas. Kansas State University Agricultural Experimental Station Technical Bulletin 140:1–75.

Uresk, D. W., J. F. Cline, and W. H. Rickard. 1975. Diets of the Black-tailed Hares on the Hanford Reservation. Battelle, Pacific Northwest Lab, Richland, Washington.

USDA (United States Department of Agriculture). 2011. Summary of active and expiring CRP cropland acres by county. December report for 2011.

Vander Haegen, W. M., F. C. Dobler, and D. J. Pierce. 2000. Shrubsteppe bird response to habitat and landscape variables in eastern Washington, USA. Conservation Biology 14:1145–1160.

Vorhies, C. I., and W. P. Taylor. 1933. The life histories and ecology of the jackrabbits *Lepus alleni* and *Lepus californicus* in relation to grazing in Arizona. University of Arizona Agricultural Experimental Station Technical Bulletin 49:1–117.

WDFW (Washington Department of Fish and Wildlife). 2005. Washington's Comprehensive Wildlife Conservation Strategy - Final Draft. Olympia, Washington.

WDFW (Washington Department of Fish and Wildlife). 2008. Priority Habitat and Species List. Olympia, Washington.

West, N. E. 1999. Accounting for rangeland resources over entire landscapes. Pages 726–736 in D. Eldridge and D. Freundenberger, editors. People and rangelands: Building the future. Proceedings, VI. International Rangeland Congress, Vol. 2.

Westoby, M., and F. H. Wagner. 1973. Use of a crested wheatgrass seeding by black-tailed jackrabbits. Journal of Range Management 26:349–352.

WHCWG (Washington Wildlife Habitat Connectivity Working Group). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, Washington.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Pages 4–10 in E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, editors. Proceedings – symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. United States Department of Agriculture Forest Service, General Technical Report INT-276.

Williams, C. S., and M. C. Nelson. 1939. Highway mortality of rabbits in Idaho. Journal of Mammalogy 20:380–382.

Williams, D. F. 1986. Mammalian Species of Special Concern in California. Prepared for the State of California, Department of Fish and Game, Sacramento, California.

Wilson, D. E., and S. Ruff, editors. 1999. The Smithsonian Book of North American Mammals. Smithsonian Institution Press, Washington D.C.

Woodbury, A. M. 1955. Ecology of the Great Salt Lake Desert. Ecology 36:353–356.

Personal Communication

Heidi Newsome
U.S. Fish and Wildlife Service