LINKING HABITAT FOR LARGE CARNIVORES BETWEEN THE CASCADES AND THE ROCKY MOUNTAINS: THE OKANOGAN VALLEY OF WASHINGTON STATE AS A CASE STUDY

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A Thesis
Submitted in partial fulfillment
of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
June, 2019

This Thesis for the Master of Environmental Studies Degree

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ABSTRACT

Linking Habitat for Large Carnivores Between the Cascades and the Rocky Mountains: the Okanogan Valley of Washington State as a Case Study

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The Okanogan-Kettle subregion represents a transborder, physiographic ecoregion between the Cascades and the Rocky Mountains in northeast Washington State and southern British Columbia. Canada lynx (*Lynx canadensis)*, wolverines (*Gulo gulo)*, grizzly bears (*Ursus arctos)* and gray wolves *(Canus lupis)* currently occupy the east Cascades and the Okanogan Highlands in small, geographically isolated subpopulations. It is important to ensure that viable and connective habitat exists across the region in order to: A) facilitate gene flow between subpopulations, B) maintain sustainable population densities and C) provide long-term, generational demographic exchange between the Cascades and the Rocky Mountains across the Okanogan-Kettle subregion. Resource extraction like mining and clearcutting reduces and degrades existing, suitable habitat for wide-ranging large carnivores. Land conversion for development, infrastructure and to a lesser extent, ranching and agriculture isolates subpopulations, thus preventing gene flow across landscapes. All of these compounding factors result in disconnected and shrinking patches of habitat separated by increasing matrices of human activity. The case study area of interest for this thesis study examines known fracture zone, the Okanogan River Valley and US Highway 97 in Washington State. Infrastructure and development cut off a lateral dispersal opportunity for large carnivores as well as ungulates between the North Cascades and the Kettle Mountains, east of the Okanogan Valley. By constructing fine-grained, small-scale, least-cost corridor models for focal large carnivores: Canada lynx, grizzly bears and gray wolves, this thesis study provides solutions to fragmentation within the fracture zone. Additionally, private lands receive permeability rankings based on levels of residential housing density. This methodology provides a snapshot of the current permeability of private lands for wide-ranging large carnivores and statistical tools to assess the impacts of development on landscape permeability for these focal species over time.

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Acknowledgements

I would like to thank my fiancé, Amy Cooper for her support through this process of acquiring a Master of Environmental Studies degree. It has not been an easy journey and she stood by me through all of the peaks and valleys. I would like to thank both of our families, especially Marguerite Cooper for always being willing to edit my work. I would like to thank all of my dear friends for all of their support. I want to thank Tyrus Smith, my thesis reader, for advising me and editing my work and keeping everything in perspective. I would also like to thank my cohort, my peer review group, all of the core MES faculty and Mike Ruth, my GIS professor for three quarters. Additionally, I would like to thank (in no particular order) the following individuals, for providing me with data, resources and advice: Jay Kehne and Laurel Baum from Conservation Northwest, Kelly McAllister from Washington State Department of Transportation, Peter H. Singleton, PhD from the Forest Service Pacific Northwest Research Station, Benjamin A. Serr from the Washington State Department of Commerce, Allisa Carlson from the Okanogan Land Trust, Jerry DeBacker from the Okanogan Conservation District and Bill Gaines, PhD from the Washington Conservation Science Institute.

INTRODUCTION

Open spaces, towering mountain ranges and large, wide-ranging mammals characterize the North American West. In reality this landscape encompasses a patch-work of roads, agriculturally developed valleys, managed forests and towns. Despite the influence of anthropogenic activity, small populations of large carnivores persist. Grizzly bears (*Ursus arctos horribilis)*, gray wolves (*Canis lupus*), Canada lynx (*Lynx canadensis*) and wolverines (*Gulo gulo)* still roam these lands. However, the viability of these iconic species becomes increasingly threatened as development claims more of their habitat. Large carnivores are disappearing, along with their ranges and habitats across the world (Table 1.) (Wolf & Ripple, 2018). Habitats that could once accommodate the large territories of these predators have been reduced to small patches, fragmented and isolated as anthropogenic activities continue to expand and surround them (Diamond, 1975; 1976; Laurance et al., 2000; Soule et al., 1999).

The theory of island biogeography helps explain habitat destruction and fragmentation (MacArthur & Wilson, 1967). Insularity is an inherent factor of island biogeography. Surrounded on all sides by impassable waters, islands represent isolated places of finite resources. Barred from dispersal by limited terrestrial habitat, many island taxa speciate, each new species occupying a different ecological niche. Taxa achieve survival by maximizing the potential of finite resources (Quammen, 2004). Conversely, many species go extinct due to the finite resource availability of island ecosystems (MacArthur & Wilson, 1967). When the rates of speciation and immigration of new

family	scientific name	common name	category	trend	range lost (%)	reintroduced?
Canidae	*Canis rufus*	red wolf	CR	increasing	>99	yes [1]
Canidae	*Canis simensis*	Ethiopian wolf	EN	decreasing	99	no
Felidae	*Panthera tigris*	tiger	EN	decreasing	95	no
Felidae	*Panthera leo*	lion	VU	decreasing	94	yes [2]
Canidae	*Lycaon pictus*	African wild dog	EN	decreasing	93	yes [2]
Felidae	*Acinonyx jubatus*	cheetah	VU	decreasing	92	yes [2]
Canidae	*Cuon alpinus*	dhole	EN	decreasing	82	no
Felidae	*Panthera pardus*	leopard	VU	decreasing	79	yes [2]
Felidae	*Panthera uncia*	snow leopard	EN	decreasing	78	yes [3]
Ursidae	*Tremarctos ornatus*	Andean black bear	VU	decreasing	75	yes [4]
Ursidae	*Ursus thibetanus*	Asiatic black bear	VU	decreasing	64	yes [5]
Felidae	*Neofelis nebulosa*	clouded leopard	VU	decreasing	64	no
Felidae	*Neofelis diardi*	Sunda clouded leopard	VU	decreasing	51	no
Felidae	*Panthera onca*	jaguar	noT	decreasing	50	no
Ursidae	*Helarctos malayanus*	sun bear	VU	decreasing	50	no
Ursidae	*Ursus arctos*	brown bear	LC	stable	42	yes [1]
Ursidae	*Ursus americanus*	American black bear	LC	increasing	39	yes [3]
Ursidae	*Melursus ursinus*	sloth bear	VU	decreasing	39	no
Felidae	*Puma concolor*	puma	LC	decreasing	32	yes [1]
Hyaenidae	*Hyaena brunnea*	brown hyaena	noT	decreasing	27	yes [2]
Canidae	*Canis lupus*	gray wolf	LC	stable	26	yes [6]
Hyaenidae	*Crocuta crocuta*	spotted hyaena	LC	decreasing	24	yes [2]
Hyaenidae	*Hyaena hyaena*	striped hyaena	noT	decreasing	15	no
Felidae	*Lynx lynx*	Eurasian lynx	LC	stable	12	yes [3]
Canidae	*Canis dingo*	dingo	VU	decreasing	12	no

Table 1. Worldwide carnivore decline. This table shows the following variables: family name, species name, common name, conservation category, (LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered; CR, critically endangered), which direction the population is trending. The percentage of range habitat loss and the status of documented reintroduction. Source: Wolf, C., & Ripple, W. J. (2018). Rewilding the world's large carnivores. Open Science, 5(3), 172235.

species equal that of local extinctions, ecological equilibrium is achieved. This observed phenomenon became known as equilibrium theory (MacArthur & Wilson, 1967).

This method of measuring the number of species that a certain area could support can be applied to terrestrial ecosystems via a large-scale, landscape framework (Diamond, 1975; D. S. Simberloff & Abele, 1976). Indeed, MacArthur and Wilson themselves exhorted the potential use of the theory of island biogeography to explain habitat fragmentation of continental landscapes, “Many of the principles graphically displayed in the Galápagos Islands and other remote archipelagos apply in lesser or greater degree to all natural habitats.” And they go on to say, “The same principles apply, and will apply to an accelerating extent in the future, to formerly continuous natural habitats now being broken up by the encroachment of civilization…” (MacArthur & Wilson, 1967). This led to studies of viable populations of species on a landscape scale (Shaffer, 1983). Biota in places like Western North America have become surrounded and isolated by a sea of human activity. Immigration/emigration of biota becomes impeded under these conditions. Thus, the rate of extinctions exceeds that of immigration, effectively preventing equilibrium and reducing populations below the minimum numbers necessary for the viability of their species (Buechner, 1987; Diamond, 1975; Laurance et al., 2000; Soule et al., 1999). The issue of habitat area reduction is particularly problematic for large mammals whose existence is predicated on the need for vast, well connected territories for migration and/or dispersal. For wide-ranging species like large carnivores, life on these terrestrial islands of limited, isolated habitat has become untenable.

The effects of climate change for western North America further complicate matters. As the climate warms, summers become hotter and dryer in the western United States, accelerating fire regimes across the landscapes of Western North America (Heller & Zavaleta, 2009; Hessburg et al., 2015; Krosby et al., 2010). Additionally, warmer winters result in less alpine snow-pack, thereby reducing summer water reserves for use by both anthropogenic communities and wildlife (Heller & Zavaleta, 2009; Krosby et al., 2010). These factors are changing the landscape and forcing biota to either adapt to these changes or move on to more habitable ground. However, in most cases the presence of road infrastructure, development and to a lesser extent agriculture, prevent wildlife from leaving highly disturbed and altered land for more suitable habitat (Blanton & Marcus, 2009; Laurance et al., 2000). Additionally, these factors prevent wildlife from extending their ranges in search of potential mates.

Large carnivores provide essential ecosystem functions where populations still persist. They can affect every trophic level below them when they exist in adequate densities (Winnie & Creel, 2017). Ecosystem functions that occur due to the presence of large carnivores result in ecosystem services (Figure 1.) (Millennium Ecosystem Assessment (Program), 2005). The following are examples of trophic cascades that occur due to the presence of large carnivores and the ensuing ecosystem services that these functions produce. **Regulating**: through predation, gray wolves prevent large herds of ungulates from overgrazing plant communities. Fear of predation keeps these herds alert and on the move, thereby benefiting the establishment of plant communities (Ripple, Beschta, & Painter, 2015). **Provisioning**: carcasses left by gray wolves and grizzly bears provide food for scavenging mesopredators like foxes *(Vulpes)*, martens *(Martes)*, fishers

(Pekania pennanti) and bobcats *(Lynx rufus)* (Consitble, Sandro, & Lee, 2008). **Supporting**: carrion remains contribute to nutrient cycling, thus fueling increased primary production. Grizzly bears drag salmon to the river banks, consume the meat and leave the remains. **Supporting**: the carcasses decay, adding nutrients to riparian vegetation communities (Wilson, Gende, & Marston, 1998). **Supporting/regulating**: bears consume berries depositing the seeds across the landscape via scat. In this way, the browsing habits and mobility of grizzly and black bears *(Ursus americanus)* contribute to the diversity of plant communities.

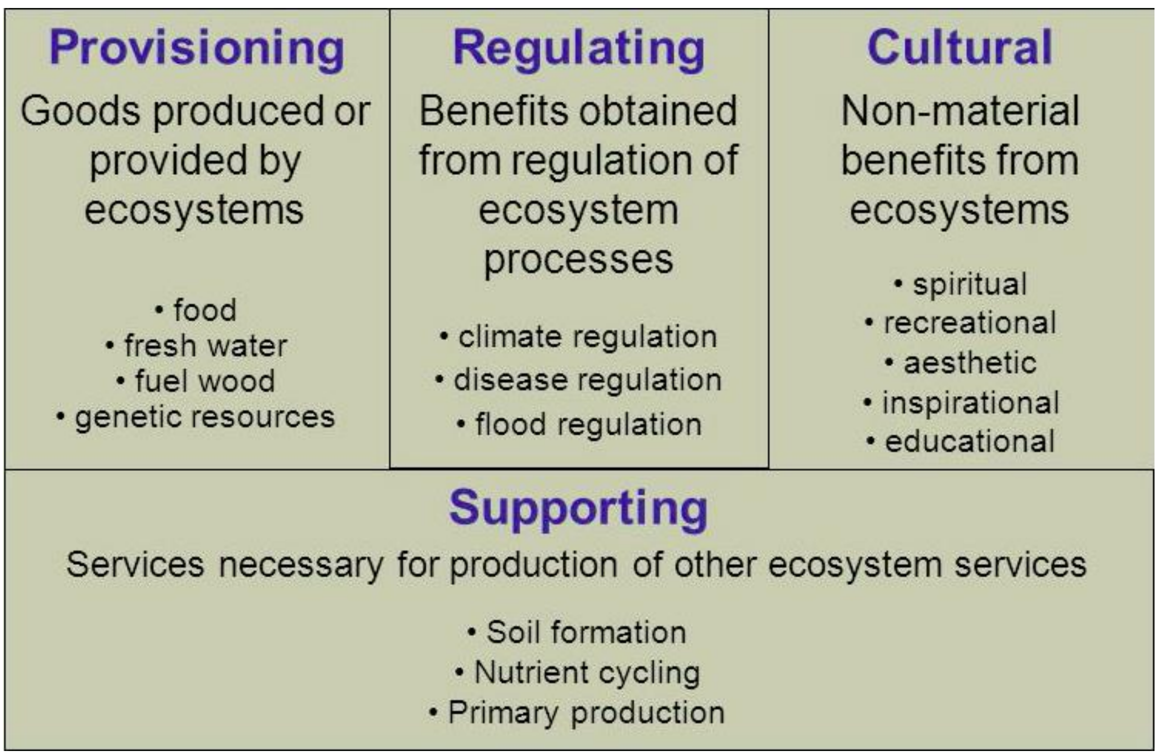


Figure 1. This figure depicts the four categories of ecosystem services derived from the Millennium Ecosystem Assessment (2005) and breaks them down into individual attributes by service. Source: Millennium Ecosystem Assessment. (2005). Retrieved from Millennium Ecosystem Assessment website: https://www.millenniumassessment.org/en/index.html

Intact forest habitat structures provide natural breaks in forest canopy cover within different seral stages of forests and edge ecotones. Each of these seral stages represents a microhabitat that fosters different biotic communities. The movements of species between microhabitats ensues in species flux and influx between these communities, resulting in dynamic equilibrium (Hessburg et al., 2015). One example of this process is the ecological relationship between Canada lynx and snowshoe hares *(Lepus americanus*) within subalpine forest ecosystems. Canada lynx occupy an ecological niche within boreal forests of Canada and subalpine forests of the southern extent of their range which includes northern Washington State. Multiple factors play into the dynamic ecological cycles between Canada lynx and snowshoe hares. Snowshoe hares are the primary food source for Canada lynx across their range in North America (Ruggiero, 2000). By consuming hares, lynx manage the numbers of hares. In addition to population control, the presence of lynx establishes a predation risk factor which keeps hares from staying in one place long enough to over-browse vegetation (Beschta & Ripple, 2009; Ford & Goheen, 2015). The risk of predation effects the fitness of hares as well. In a study by Boonstra et al. (1998), increasing stress hormones led to lower fitness levels and a
to lower fitness levels and a 25-30% reduction per capita birth rate of hares (Boonstra et al., 1998; Peckarsky et al., 2008). Vegetation communities increase as hares decline. In turn, lynx population numbers fall with the lower fertility rate in snowshoe hares. Snowshoe hare numbers rebound as predation risk lessens and the dynamic cycle continues (Peckarsky et al., 2008). Fear of predation forces hares to move seasonally between the forest understory and gaps between forest stands. Hares occupying various

parts of heterogeneous landscapes at different times of the season prevents over-browsing of the vegetation of a single microhabitat (Ford & Goheen, 2015; Hodson et al., 2010).

Large-bodied mammals require extensive habitat in order to prevent the depletion of resources necessary for their survival. At the top of the food chain, large carnivores track, stalk and hunt ungulates across vast, territories. One trophic level below carnivores, ungulates need large territories in order to escape predation and ensure that vegetation communities remain available and do not become over-browsed. At the top of the food chain, large carnivores track, stalk and hunt ungulates across vast territories. Freedom of movement for both ungulates and carnivores represents an essential ecological necessity for the survival of species at both trophic levels. Moreover, as previously stated, the movement of large bodied mammals across landscapes produces regulating, provisioning and supporting ecosystem services (Figure 1.)(Millennium Ecosystem Assessment (Program), 2005).

Interspecies competition represents another factor in the wide distribution and habitat preferences of large carnivores. For instance, where the distribution of Canada lynx and mountain lions *(Puma concolor)* overlaps, lynx avoid interspecific competition by occupying subalpine forests throughout the year. Lynx thrive in year-round subalpine ecotypes whereas, mountain lions avoid high elevations and snowpack (Gary M. Koehler et al., 2008). This drives down interspecies competition for the same resources, which is particularly important in winter, when prey availability is low (Koehler et al., 2008; Ruggiero, 2000).

As wide-ranging habitat generalists, gray wolves and grizzly bears provide a basis for conservation of ecotone, edge habitats. The Okanogan-Kettle subregion physiography characteristically changes in elevation. Subalpine forests give way montane forests and montane forests to shrub steppe lowlands. Habitat conservation of ecotones where these habitats transition provides wildlife with important access points to these different habitats and ecotypes. Additionally, due to the merging of biota from different habitat types, ecotypes represent places with high levels of biodiversity (Myster, 2012).

In addition to connecting different habitats at changing elevation gradients, conservation of a permeable, braiding surface of the Okanogan River valley protects an important floodplain ecosystem. Conservation of connective riparian and floodplain habitat preserves heterogeneous landforms that support high levels of biodiversity. Floodplains and river valleys provide important crossings between mountain ranges for large mammals. High levels of primary production in these ecosystems attract ungulate species, thus providing a hot spot for carnivore and prey species interactions (Hauer et al., 2016; Proctor et al., 2012). As previously stated, salmonid and ungulate carrion, left behind as a result of predation, contributes to nutrient cycling. High levels of primary production in riparian ecosystems stabilizes stream banks by promoting tree growth (Bump, Peterson, & Vucetich, 2009; Helfield & Naiman, 2006).

Regional Context

The Okanogan Highlands of Washington State and southern British Columbia represent a physiographic subregion characterized by shrub steppe in lower elevations and subalpine conifer forest in the mid to high elevations (Transboundary Connectivity Group, 2016). Mid-elevation peaks of the Kettle and Selkirk mountains provide an important north to south range for Canada lynx and wolverines (Inman et al., 2013;

Murray et al., 2008; Singleton et al., 2002). The Okanogan Valley lies to the west of the Kettle range, between the Kettles and the east Cascades. This shrub steppe ecoregion provides an important habitat linkage for habitat generalists like gray wolves and grizzly bears to cross, east to the Kettles and west to the Cascades (Carroll et al., 2006; Proctor et al., 2012; Singleton et al., 2002) (Figure 2.). Residential development and road infrastructure represent the primary habitat connectivity barriers within the Okanogan valley of Washington state (National Fish and Wildlife Foundation, 2017; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). Across the border in Southern British Columbia, the Okanogan highlands retain a semi-arid climate making the region an emerging vacation destination with a chain of large reservoirs and towns built up around them (Brando, 2009; Transboundary Connectivity Group, 2016).

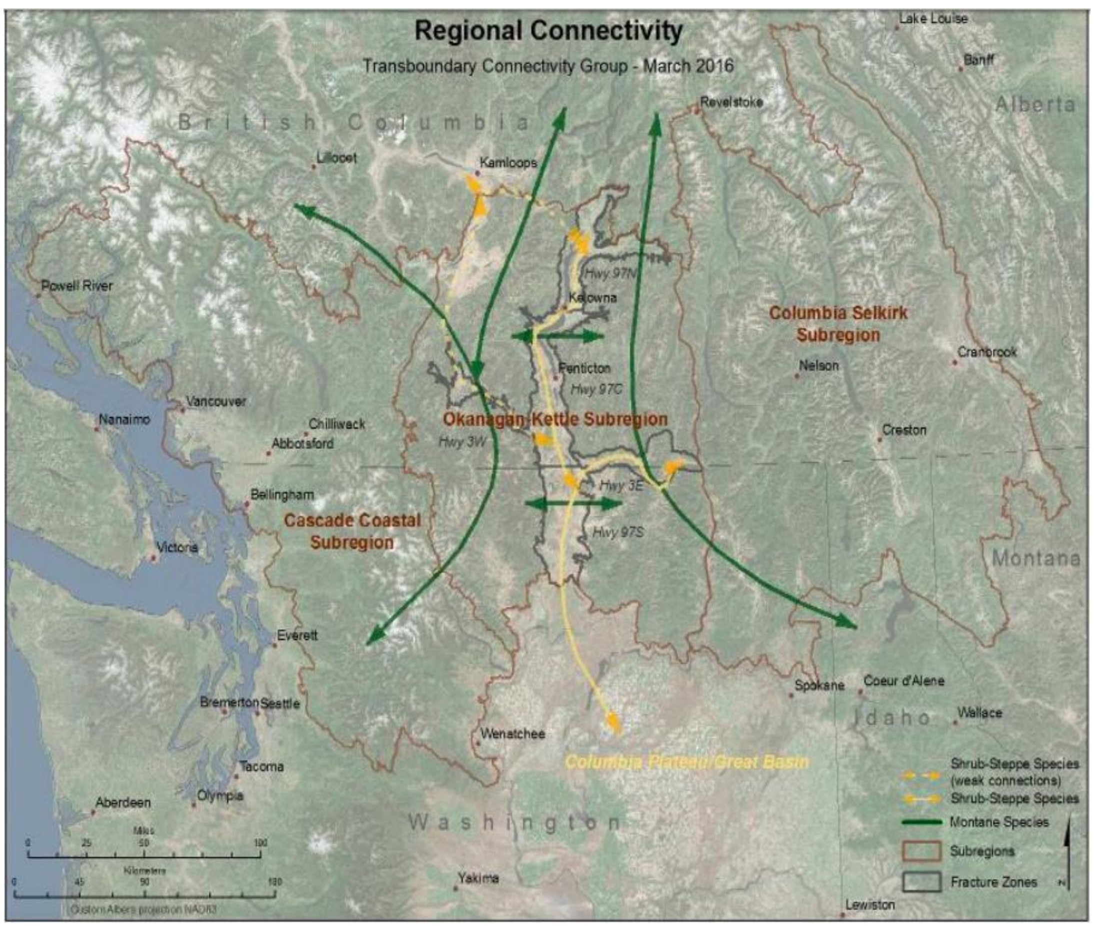


Figure 2. Green arrows indicate landscape scale movements of montane species like Canada lynx, grizzly and black bears and the yellow lines indicate wide-spread movement of shrub-steppe species like American badger. Source: Transboundary Connectivity Group. (2016). *Providing a Regional Connectivity Perspective to Local Connectivity Conservation Decisions in the British Columbia–Washington Transboundary Region: Okanagan-Kettle Subregion Connectivity Assessment*. Retrieved from https://waconnected.org/wp-content/uploads/2016/03/Okanagan-Kettle-Connectivity-Assessment_2016_FINAL.pdf

East of the Kettle Range, the Columbia River runs north to Canada and south to the Columbia Plateau in Washington State. Beyond the Columbia river, the Selkirk mountains extend north into the Columbia mountains in British Columbia. Like the Kettles to the West, the Selkirks consist of subalpine/alpine ecoregions providing north to south movement routes for Canada Lynx and Wolverines (Gaines et al., 2017; Inman et al., 2012; Ruggiero, 2000). In Washington State the area remains remote, mostly encompassed by the Colville National Forest and the Tribal lands of the Colville Federated Tribes. The montane habitat and distance from human population centers make both the Kettles and the Selkirk mountains very important to all large carnivores of the region.

Overall, this thesis highlights the importance of the Okanogan Highlands as a subregion that currently retains small densities of large carnivores of concern (Endangered Species Act listed) (Department of the Interior & U.S. Fish and Wildlife Service, 1973). In particular, it sheds light on whether or not the current state of conservation implementation throughout the region reflects the ecological value that this land retains, especially for large carnivores of concern. This thesis study will contribute to the spatial analysis of habitat connectivity for species of concern across the vast, dynamic landscapes of the Inland Northwest. The methodology employs a fine-scale spatial analysis to determine the retention of habitat suitability, connectivity and landscape permeability on the ground. This research will provide regional insight into the viability of species of concern in the transborder region between the Cascades and the Rocky Mountains. Moreover, by employing a unique methodology of tracking development this thesis has the potential to provide a critical framework for evaluating land use in currently unprotected areas. Landscape conservation within the Okanogan-Kettle subregion has broader implications for the trajectory of focal species over generations and across vast landscapes of the Inland Northwest and across western North America.

Local context: case study area of interest

Between Riverside, WA and Tonasket, WA in Okanogan County lies a twelve-mile wide, approximately 25 mile long area of quality, high integrity habitat that stretches laterally across the Okanogan Valley to high elevation, subalpine forested areas in the northeast Cascades and across the valley, east to montane forest within the Okanogan National Forest. As stated previously, this area of interest has been identified by prior habitat assessments as an important east-west linkage for montane species and north-south habitat for shrub steppe species (Arid Lands Initiative & U.S. Fish and Wildlife Service National Wildlife Refuge System, 2014; National Fish and Wildlife Foundation, 2017; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). The list of departments and organizations that have contributed to the ecological knowledge base for this area of interest includes, but is not limited to: the Great Northern Conservation Cooperative, the North Pacific Landscape Cooperative, Conservation

Northwest, the Washington Habitat Connectivity Working Group, the National Fish and Wildlife Foundation, the Nature Conservancy, the Okanogan Conservation District, the Washington Department of Fish and Wildlife, the Washington Department of Natural Resources, the USDA Forest Service, the Bureau of Land Management and the Washington Department of Transportation. Environmental assessments of this regional area of interest include larger scale, course-grained landscape conservation analyses (Krosby et al., 2015; Singleton et al., 2002; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). The results of these assessments provide land managers and property owners with land use recommendations to foster biodiversity, ecosystem functions and habitat connectivity on their lands (Reed et al., 2014; Selman, 1993; Washington Department of Fish and Wildlife, 2009).

While the results of least cost path analyses for the Okanogan Highlands have identified this thesis area of interest (AOI) as a priority habitat linkage, that does not mean that existing, high-integrity habitat within this linkage will persist into the future. Current levels of development in this area of the Okanogan Valley encroach upon habitat, compromising the permeability of the region for wildlife and the capacity for a key wildlife linkage to remain intact (Craig et al., 2010). Additionally, changing climate regimes contribute to landscape change across this area of interest. As fire regimes become more frequent and destructive, they drive the conversion of shrub steppe to arid grasslands while pushing shrub steppe and forest ecotones to higher elevations, causing arid lands to expand and forested ecosystems to recede across the Columbia Plateau and into the Okanogan Highlands and the East Cascades (Haugo et al., 2010).

This thesis case study focuses on a lateral linkage that could accommodate large carnivore movement while preserving ecosystem functions and biodiversity through the ancillary benefit of conserving umbrella habitat. Large carnivores require relatively ecologically intact, open spaces with low human impact (Noss et al., 1996). Thus habitat conservation for large carnivores engenders the greatest amount of biodiversity conserved within their habitat requirements and spatial parameters (Noss et al., 1996). The potential for conservation of large, undisturbed riparian habitat on the banks of the Okanogan River remains a distant possibility due to the degree to which most of the riverbank has been cultivated for active agricultural lands. That said, large carnivore, umbrella habitat conservation retains the possibility of conserving existing pockets of connected, riparian habitat. Increasing the potential in those areas for large carnivore dispersal would in turn, provide more undisturbed habitat for ecological functions and conservation of biodiversity (Lambeck, 1997).

The selection of this area of study follows the recommendations of multiple habitat assessments, reports and modeling of a lateral linkage for connectivity across the Okanogan Valley in Washington State. Development for agriculture and infrastructure spans most of the Okanogan River Valley imposing challenges to permeability for large carnivores throughout the length of the valley. The selected location represents an area of least-cost corridor and low resistance values, according to multiple large-scale landscape permeability assessments for large carnivores (National Fish and Wildlife Foundation, 2017; Singleton et al., 2002; Transboundary Connectivity Group, 2016). Additionally, this geographic area retains critical umbrella habitat for multiple taxa as outlined by WDFW, Priority Habitat and Species[1].

This thesis addresses the extent to which conservation of crucial habitat is being carried out on the ground within the case study area of interest. The first phase of this study involved identifying an area of interest that represents many of the challenges inherent in conserving and connecting habitat between core reserves across the Western United States. The Highway 97 fracture zone represents the greatest challenge to permeability in the Okanogan Valley. Population growth in the Okanogan Valley drives the conversion of agricultural land use and open shrub steppe/forested lands to residential development (American Farmland Trust, 2007). Forest management practices also threaten the integrity of forest habitats across the Okanogan Highlands (Gaines et al., 2017; Haugo et al., 2010).

The next phase included constructing spatial representations in ArcGIS Pro (ESRI) of species occurrence data within Okanogan County and the AOI for this case study. USGS GAP designated protected areas[2] and PHS (Priority Habitat and Species) data were represented in order to demonstrate what has been protected and to identify unprotected areas that have been designated as important PHS areas within the AOI.

The third phase of the methodology used for this thesis study included evaluating suitable habitat for conservation of focal, umbrella species: gray wolves, grizzly bears

[1] WDFW. (n.d.). Priority Habitats and Species (PHS) Interactive Mapping | Washington Department of Fish & Wildlife [Interactive mapping]. Retrieved from PHS on the Web: https://wdfw.wa.gov/mapping/phs/

[2] Protected areas for this case study were derived from GIS layer packages provided by the USGS Gap Analysis Project (GAP). Retrieved from: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap

and Canada lynx within the case study AOI. This phase of the methodology involved building models in ArcGIS Pro (ESRI) in order to produce raster surfaces that spatially represent A) habitat suitability for all three focal species, B) habitat core areas and C) species corridors connecting habitat core areas, west to east across the fracture zone of highway 97 and the Okanogan River Valley. These maps chart the least-cost paths, or paths of least resistance for each species across the fracture zone of highway 97 and the Okanogan Valley. Additionally, the methodology includes an evaluation of the permeability of private lands across the area of interest (AOI). For this analysis, residential development density was determined, categorized and ranked using permeability performance indices: Optimal, Acceptable and Poor. The performance standards indicate the permeability of a given area of private land within the AOI.

The selected AOI for this thesis provides the physiography for a case study wherein quality, heterogeneous habitat currently exists to support wildlife passage and dispersal between mountain ranges. Additionally, this AOI represents cultural landscapes that characterize land use practices across the Inland Northwest. The mosaic of different public and private landowners within the AOI exemplifies the struggle to reconcile habitat connectivity with land use practices that change, parcel by parcel. This thesis study uses a fine-scale approach to magnify a challenging area for wildlife permeability. By weighting development against conserved habitat and land cover with high conservation value, an assessment can be made as to the extent to which the AOI supports habitat connectivity for large carnivores of concern. This approach differs from previous course-grained, large-scale landscape conservation assessments of the area. Focusing on a challenge area for landscape permeability, like the Okanogan Valley fracture zone, and magnifying the scale and scope of a project allows for localized, detailed results, products and recommendations. Conservation working groups, land managers and organizations can then directly adapt the products and result of this study, such as habitat corridor designs, to their respective conservation projects and efforts on the ground within the AOI.

For the study, housing density performance indices were used to assess the current state of habitat permeability of private lands within the AOI. This study of housing density in relationship to landscape permeability required the development of a unique methodology. For this methodology an adaptation of conservation metrics for wide-ranging species, sensitive to fragmentation from a WDFW PHS guidance document, Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas (2009) was applied. These metrics were used to categorize census block groups into performance indices based on the amount of residential development on each block group. The results of this study produced recommendations for habitat conservation based on the path trajectories of species habitat corridors and the current state of conservation and development on the ground. Due to the identification of this AOI as a key lateral linkage for montane, large carnivore species, the results of this study could have broader implications for the dispersal of large carnivores of concern between the Cascades and the Rockies.

LITERATURE REVIEW

Introduction

Ample scholarly work and research exists to: A) address the habitat conditions needed for the survival of large carnivores, B) provide a foundation for environmental assessments, and C) provide good science and best practices with which to inform policy and land use. This research has contributed to the conservation of vast tracts of land within the Cascades and Rocky Mountain ranges by providing a scientific basis for conservation policies and by informing land use practices of land owners and land managers. This literature review draws from the founding principles of conservation biology in order to explain habitat fragmentation and justify conservation of connective habitat. The ecological assessments and reports reviewed throughout this thesis study provide analyses of entire ecoregions at landscape-scales (Soule & Terborgh, 1999). Furthermore, landscape conservation studies of mountain west ecoregions like the Greater Yellowstone Ecosystem and the Northern Rocky Mountain Ecosystem have implications for current and future conservation projects in the Okanogan Highlands. The Northern Rockies Ecoregion encompasses all of the subregions between the Cascades and the Rockies within the contiguous USA[3]. Therefore, individual case studies for the conservation of focal, umbrella species in a subregion of the intermountain west apply across much of the inland northwest as a whole.

Long term demographic relationships and gene flow between populations of large carnivores of the Cascades and the Rockies will be achieved by conservation of montane,

[3] Level 3 Ecoregions of the USA map available through the Environmental Protection Agency: Retrieved from EPA website: https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

subalpine, connective habitat that lies between these great mountain ranges (Gaines et al., 2000; Transboundary Connectivity Group, 2016; Lyons et al., 2016). Without suitable habitats that extend beyond major north/south mountain chains, especially considering additional fragmentation and other stressors within mountain ranges, large carnivores will not be able to sustain population densities and dispersal rates necessary for their survival (Inman et al., 2012; Proctor et al., 2012; Singleton et al., 2004). Concerns over habitat loss and fragmentation led to the formation of broad conservation partnerships like the Yellowstone to Yukon Initiative and Continental Conservation Cooperative Networks (Chester, 2015; Mattson et al., 2011; Soule et al., 1999). This literature review evaluates individual, regional applications of landscape conservation that build upon a vision for continental-scale conservation.

The literature focuses on conservation of areas essential to expanding the range and dispersal of large carnivores. These areas include spatially challenging features like highway infrastructure and human populated river valleys. The literature addresses political challenges that arise when human communities are confronted with the realities of living alongside large carnivores. Therefore, this review features scholarship that goes beyond scientific assessments to address the hard work and struggle that goes into navigating wildlife through cultural and political landscapes.

The first section below will address the influences of habitat fragmentation and climate change on large carnivores throughout the broader Okanogan-Kettle subregion. This section will explore the literature on the implications of habitat fragmentation for wildlife in landscapes undergoing transformations under current climate regimes. This section will include literature on climate projections in the context of planning habitat corridors. Additionally, the subject of large carnivores as indicator species of landscape change will be covered in this section. The section that follows will explain the importance of focal, umbrella species as a conservation strategy. This section includes literature on case studies regarding focal large carnivore conservation throughout the intermountain west. The primary literature on habitat corridors and connectivity provides insight into regional conservation efforts throughout the Okanogan and Columbia highlands. Finally, I will analyze the literature which speaks to the practical applications of conservation strategies. This section evaluates the steps taken after the completion of ecological research and environmental assessments. This section will highlight the difficulties of getting all of the stakeholders in a region on board with conservation efforts. Ecological management will be evaluated as a means of achieving habitat connectivity and ecosystem functions across landscapes while acknowledging cultural landscapes and engaging regional stakeholders in the process. Discontinuity of ecological policies will be explored in the context of environmental federalism vs national, unifying conservation policies. Finally, this section will explore the literature on attitudes towards controversial species like wolves and grizzly bears and how these effect the long-term conservation of the focal species of this thesis study.

Habitat Fragmentation and Climate change

The continuous territories of wide-ranging species become disconnected and degraded as a result of fragmented habitat (Diamond et al., 1976; Finch, 2000; Koehler et al., 2008; Laurance et al., 2000). Several factors contribute to the fragmentation of different types of important habitat, including roads and railways which often take the paths of least resistance through mountainous terrain. Roads often occupy the lowest possible elevation points, in locations with the least severe slope on adjoining lands (Blanton & Marcus, 2009). Streams in montane environments tend to converge at the lowest elevation point, creating alluvial plains. Floodplain ecosystems represent dynamic mosaics of streams braiding around riparian forested shoals. Water pushes laterally across the level ground, settling into wetland habitats rich in biodiversity (Blanton & Marcus, 2009; Hauer et al., 2016). Heterogeneous systems of streams, pools and woody debris provide salmonid spawning habitat (Hauer et al., 2016). Salmon, a keystone species, provide food for apex predators like grizzly and black bear *(Ursus americanus)* (Helfield & Naiman, 2006).

The construction of levies for road and railway infrastructure prevents the spread of alluvial stream braiding across level valley bottoms. This infrastructure also reduces, or eliminates the ecological functions of flood plains and fragments habitat (Blanton & Marcus, 2009). According to Blanton and Marcus (2009), the highest degree of lateral floodplain habitat disconnection occurs in regions with montane physiography like the Pacific Northwest (Blanton & Marcus, 2009). According to their research on lateral floodplain habitat disconnection, Blanton and Marcus found a strong correlation between "water resource areas" (rivers, lakes, floodplains, wetland etc.) and rugged terrain (Spearman's ρ $r_S = 0.83$) (Blanton & Marcus, 2009).

Roads often impose barriers to wildlife passage across the landscape. These barriers prove especially disruptive when habitat becomes degraded by anthropogenic activities that often accompany road-building, like logging and mining (Finch, 2000). Road infrastructure prevents migration for wildlife seeking viable habitat with available resources, territory and potential mates. Under the conditions of a changing climate, water sources will become increasingly scarce and forests subject to accelerated fire regimes over longer and dryer summers (Heller & Zavaleta, 2009; Hessburg et al., 2015; Krosby et al., 2010; Rasmussen, Hibbard, & Lynn, 2007). As habitats become unsuitable for wildlife, species must migrate, yet infrastructure can prevent wildlife movement across landscapes.

While roads and railways present significant barriers to wildlife movement across the landscape, other factors prove detrimental to ecological functions and wildlife migration. In montane environments, deforestation and mineral extraction disrupt contiguous habitat and reduce habitable environments to small, disconnected patches separated by quarries, mines, logging roads and clear-cuts (Buechner, 1987; Diamond, 1975; Soule et al., 1999). Recreational land poses problems as well. Wolverines and Canada lynx avoid snowmobile and all-terrain vehicle paths and to a lesser extent, mountain biking and hiking trails (Gaines et al., 2003). Recreation routes can create paths for generalist predators through lynx and wolverine habitat, leading to interspecies competition (Gaines et al., 2003). Recreational ski areas can lead to fragmentation of north to south wildlife passage across the mountain chains of the Cascades and the Rockies (Apps et al., 2016; Inman et al., 2013; Koehler et al., 2008).

Lynx and wolverines seek habitat where snowpack is present throughout most of the year. Both species are especially adapted to high elevation conditions. These taxa reduce interspecific competition by occupying areas for which most other carnivores are not well suited (Lyons et al., 2016; Mckelvey et al., 2014). Climate change threatens to remove this competitive advantage by changing vegetation communities over time. As subalpine forest gives way to lower elevation montane forest, generalist predators will migrate into the habitat niches of wolverines and Canada lynx, increasing competition for prey and territory (A. Lyons et al., 2016; Washington Wildlife Habitat Connectivity Working Group, 2013).

Wolverines act as an indicator species of the effects of climate change. Reclusive, rare and understudied carnivores, wolverine attributes include unyielding fierceness and endurance in harsh conditions and terrain (Chadwick, 2011). Wolverines hunt and scavenge for ungulates and smaller herbivores alike (Inman et al., 2012). They occupy an extremely wide range of territory. Inman et al. (2012) conducted a study on wolverines that found their average home range to be 303 km^2 for females and 797 km^2 for males. Within that range, wolverines prefer montane alpine environments that remain snow-bound for most of the year (Aubry, McKelvey, & Copeland, 2007; Inman et al., 2012). Historically (1827-1960), wolverines preferred subalpine forest, 50% in the Cascades, 81% in the Rockies (Aubry et al., 2007). Snowpack reduction due to climate change forces wolverines to migrate to higher ground for suitable habitat. Aubry et al. (2007) suggested that current wolverine ranges are limited to alpine habitat in the North Cascades and the Northern Rockies with a 25-50% probability of retaining spring snow cover (Aubry et al., 2007). Wolverines require snow pack that lingers into late May. Wolverines preserve food caches in snow pack proximal to their dens (Inman et al., 2012). Additionally, wolverines birth and nurse their young between February and April at which time both the mother and her young require abundant, high calorie food sources provided by snow caching as well as the protection of deep snow dens (Inman et al., 2012). As alpine habitat with lingering snowpack becomes more scarce in places like the

North Cascades, wolverines will have to migrate north in search of year-round snowpack (Krosby et al., 2010).

With viable habitat compromised by anthropogenic activities and landscapes transformed by a changing climate, wildlife populations increasingly will be on the move. In the next section, methodologies that facilitate wildlife migration and help restore and conserve quality habitat will be discussed for wide-ranging, large mammals, particularly top predators of concern.

Umbrella Species and Habitat Connectivity

The Columbia Plateau bottlenecks in north-central Washington at the Okanogan Valley. Elevation gains rapidly on either side of the valley giving way initially to shrub steppe and to montane habitat shortly thereafter (Figure 3.). This narrow bottleneck of arid land provides a short distance (< 5 miles in some places) that wide-ranging montane species have to travel to reach suitable climatic and habitat conditions. The Columbia Plateau widens considerably south of Okanogan County shifting from primarily mid-high elevation conifer forests to scabland prairie desert. South of the Columbia Plateau in central Washington State and north-central Oregon, the Basin and Range Desert accounts for much of the area that separates the south Cascades and the Sierra Nevada Mountains from the Rockies. The Basin and Range Desert contains few subalpine oases surrounded by desolate and mostly uninhabitable desert (Diamond, 1975; Wells, 1983). During the late-Pleistocene, much of this area consisted of subalpine forest. After the Holocene warming, these forests became restricted to high elevations only (Wells, 1983). According to the equilibrium theory, posited by MacArthur & Wilson (1967), large and small mammals in these subalpine islands are unable to move between habitat patches, subjecting them to demographic stochasticity over time (Diamond et al., 1976; MacArthur & Wilson, 1967). Therefore, natural landforms, distance and extreme climatic gradients prevent lateral passage and dispersal for large carnivores, across this region (Wells, 1983). North of the Basin and Range Desert and the Columbia Plateau in Central Washington State, the physiography becomes montane and rugged again across the transborder region between Canada and Washington State. Thus, given the unique physiographic location of the Okanogan Valley of Washington State, the area provides a wildlife linkage for montane species, between the Cascades and the Rockies in the contiguous United States.

Linking habitat for large carnivores between the North Cascades and the

Figure 3. Columbia Plateau narrowing near WA/BC border. Source: Hall, S. A. (2018). *Conservation Northwest's Sagelands Heritage Program: Where to go and what to do: Synthesis of partner input and existing connectvity science* (p. 30). Wenatchee, WA, USA: SAH Ecologia LLC.

Kettle River Range to the east not only facilitates dispersal for these taxa with spatially extensive habitat requirements, but it increases access to quality habitat for taxa across the Okanogan-Kettle subregion (Apps et al., 2016; 2007; Brown & Nicoletto, 1991; Buechner, 1987). Wildlife linkages allow species of concern, like the focal species of this thesis study, to disperse widely across the landscape, thereby improving gene flow, demographic relationships (Gilbert-Norton et al., 2010). Thus, corridors and linkages for species dispersal should be a central concern for land management. Conservation biologists take a landscape approach to identifying suitable habitat, including land outside of major mountain chains (Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). Additionally, they use population viability analysis, a systematic approach developed by Gilpin and Soulé (1987), to evaluate the potential risks to target populations across landscapes (Shaffer, 1990; Soulé, 1987). The Okanogan Highlands presently supports small densities of large carnivore populations. Anthropogenic development in low elevation areas like the Okanogan Valley imposes barriers to metapopulation and demographic exchange (Michael F. Proctor et al., 2012; Singleton et al., 2002). Thus, species dispersal across the Highlands is not assured and the viability of large, wide-ranging carnivores remains in question. Habitat corridors that circumnavigate challenging landscapes like developed valleys can facilitate dispersal for focal large carnivores across the Okanogan-Kettle subregion and beyond.

Although habitat suitability assessments exist for the Okanogan-Kettle subregion, regions with more recreational and iconic value, such as the Greater Yellowstone Ecosystem and the Cascades, receive the lion’s share of the attention (Knibb, 2008). Nonetheless, the subalpine, montane and shrub-steppe ecotypes of the Okanogan

Highlands provide habitat continuity between the Northern Rocky Mountain and Cascades ecoregions. Protecting large carnivores of concern within the Okanogan Highlands supports the dispersal, gene-flow and long-term demographic relationships of these species across the inland Northwest. Thus, this thesis study stresses the importance of conservation of connective habitat within the Okanogan-Kettle subregion.

Keystone species represent a key element in an ecosystem, the removal of which produces positive feedback loops that affect ecosystems at every trophic level (Mills & Soule, 1993). Gray wolves regulate ungulate populations which promotes the growth of vegetation communities. Separate studies of gray wolves by Ripple et al. (2015) in the Greater Yellowstone Ecosystem and McLaren & Peterson (1994) in Isle Royale National Park in Michigan establish a basis for the status of gray wolves as a keystone species (McLaren & Peterson, 1994; Ripple et al., 2015). These studies demonstrate that the presence and absence of gray wolves resulted in trophic cascades across these ecoregions (McLaren & Peterson, 1994; Ripple et al., 2015).

The status of large carnivores as keystone species continues to be the subject of some debate within ecological literature (Ford & Goheen, 2015; Mills & Soule, 1993; Peckarsky et al., 2008). Ripple et al. (2015) argue that wolves and lynx effect every species below them in the food web, whereas Mills and Soule (1993) argue that the keystone species term has been applied too broadly across a range of species. For the purposes of this thesis study, the focal, umbrella status of large carnivore conservation provides the most relevant arguments (Noss et al. 1996). Umbrella species represent species whose range, or territory can encompass that of several other species in their range and ecological guild (Lambeck, 1997; D. Simberloff & Dayan, 1991). Grizzly bears, Canada lynx, gray wolves and wolverines represent taxa that require extensive, well linked habitat to accommodate their respective, extensive territories and home ranges. In addition to this spatial component, the viability of habitat specialists like wolverines and Canada lynx depends on conservation of specific ecotypes. Canada lynx for instance, tend to occur in a subalpine ecotype and elevation band. They prefer mature forests for ease of movement with adequate cover and denning habitat (Gaines et al., 2000; Lyons et al., 2016; Ruggiero, 2000). Meso-predators, like martens (*Martes americana*) favor the same habitat, elevation band, seral stage and forest type (Wasserman, 2008; Zielinski et al., 2017). One trophic level lower, snowshoe hares occupy the same forest ecotype and are the primary prey of Canada lynx (Ruggiero, 2000). Snowshoe hares are considered keystone species due to their importance in shaping vegetation communities in subalpine forests and the ecological niche they occupy with Canada Lynx, as mentioned above (Mills & Soule, 1993; Winnie & Creel, 2017). Thus, conservation of lynx, umbrella habitat protects complex interactions between species which in turn, shapes vegetation communities.

By protecting contiguous habitat, or restoring habitat linkages, habitat connectivity efforts provide models for the prevention of fragmentation (Laurance et al., 2000; Soule et al., 1999). These models offer permeability for species across developed, or disturbed land. West of the Okanogan Valley, the Pasayten Wilderness stretches nearly a hundred miles across the northeast Cascades along the border with Canada. This vast area adjoins the EC Manning and Cathedral Provincial Parks in Canada. Grizzly bear and gray wolf populations have migrated to the North Cascades Ecosystem from the north in British Columbia (Carroll et al., 2006; Gaines et al., 2000; Lyons et al., 2018; Singleton et al., 2002). For these species to succeed in Washington State, they must be able to expand their range both north to south and west to east. Development of farms, towns, ranches and infrastructure in the Okanogan Valley presents several significant barriers to east/west migration.

Unlike the comparatively sparsely populated farming community of Okanogan County in North Central Washington State, the Okanogan Highlands in British Columbia represents a quickly developing vacation hub. The region encompasses a series of vast reservoirs with towns and suburbs built around the lakeshores and the upland hills (Schwann, 2018). Both sides of the international border present challenges to permeability for large mammals. Dense human populations result in more heavily trafficked and wider roads, worsening landscape fragmentation for wildlife movements (Kintsch & Cramer, 2011). Human encounters with large carnivores presents a potential danger to both parties, though large carnivores experience greater risk of injury and mortality. Large carnivores are particularly endangered while attempting to pass safely through densely populated suburbs, or rural farming/ranching communities. Okanogan County residents who participated in a survey study by Dietsch, Teel & Manfredo (2016) demonstrated a 13.6-20.6% willingness to coexist with gray wolves. Habitat corridors can provide for wildlife passage in the area of human population centers. Indeed, wildlife like large carnivores require habitat corridors in order to provide permeability across landscapes in addition to avoidance of wildlife/human conflicts.

Habitat corridors provide the means to connect reserve patches across otherwise disturbed landscapes. The concept seems simple, yet in reality it is more nuanced and complex. The planning of habitat corridors includes multiple factors. Wildlife behaviors like: mating, foraging, denning, hunting and child-rearing can help to determine habitat type and overall conditions needed to provide a suitable corridor (Apps et al., 2016; Carroll et al., 2006; Chetkiewicz et al., 2006). Sympatry (tolerance of overlapping territories with similar species) among large carnivores exists, though allopatric (seeking habitat that does not overlap with similar species) interactions occur more frequently. For example, Canada lynx avoid interspecific competition with mountain lions *(Puma concolor)* by occupying higher elevations and colder climates than those preferred by mountain lions (Murray et al., 2008; Ruggiero et al., 2000). These behaviors indicate interspecific competition between large predators. Taking this information into account, heterogeneous habitat types need to be included in a single corridor, or multiple corridors representing different habitats need to be established.

Wildlife corridors composed of existing habitat have a higher frequency of use by fauna than experimental, constructed corridors (Figure 4.) (Gilbert-Norton et al., 2010). Thus, conservation of existing habitat proves essential to the movement of species

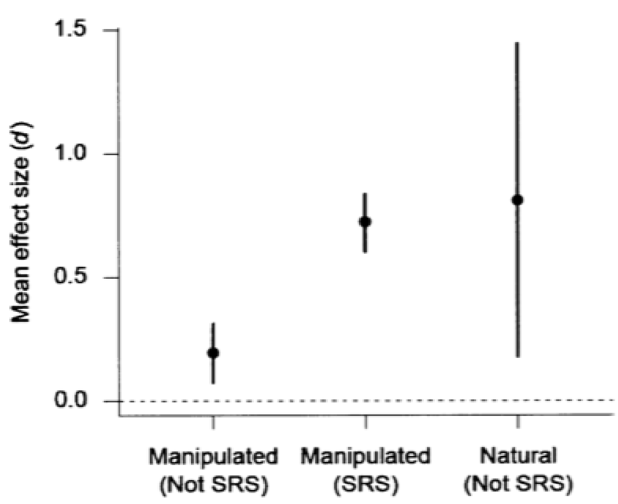


Figure 4. Mean effect size (SE 1) experiments (not at Savannah River Site) (n=35) manipulated (at Savannah River Site) (n=31) and natural (not manipulated, conducted at Savannah River Site) (n=12). Source: Gilbert-Norton, L., Wilson, R., Stevens, J. R., &

Beard, K. H. (2010). A Meta-Analytic Review of Corridor Effectiveness. Conservation Biology, 24(3), 660–668.

across the landscape. Regionally, Krosby et al. (2015) found a significant positive relationship between movement of large mammals and high quality, existing habitat corridor networks of Washington State ($n = 16$, $r^2 = 0.31$, $F = 10.60$, $p = 0.024$).

High quality, diverse habitat exists across the remote watersheds of the Selkirk and Kettle Mountains of eastern Washington State. Unfortunately, viable habitat decline is a factor in this region due to development for housing and infrastructure (David G. Knibb, 2008; Gaines et al., 2017). Wolverines represent a focal species that is similar to grizzly bears and gray wolves in regard to risks from human development and infrastructure (Suring et al., 2011). According to the Terrestrial Species Viability Assessments for National Forests in Northeastern Washington (2017), 54% of historically viable watersheds remain for wolverines and only 14% of watersheds retain high quality denning habitat for wolverines (Gaines et al., 2017). These lands currently contain high quality habitat comprised of alpine (in the east Cascades), subalpine forest, montane forest, shrub steppe and ecotones where these ecotypes meet. Roads, recreation routes and residential development represent the most significant fragmentation factors for large carnivores, between core habitat within northeastern Washington State (Gaines et al., 2003, 2017; Suring et al., 2011).

Existing habitat may be optimal for species of concern, but restoration of connective habitat should not be discounted as an effective conservation strategy. Some connectivity projects have to be constructed out of nothing. Wildlife underpasses and overpasses provide passage across roadways, a primary barrier to wildlife movement (Kintsch & Cramer, 2011; Sullivan & Danberg, 2009). These structures can be adapted by widening culverts, removing invasive species, replanting native vegetation and adding habitat structures that mirror those found in existing habitats (Bissonette & Cramer, 2006; Clevenger & Huijser, 2009; Kintsch & Cramer, 2011). According to a report for WSDOT by Wang et al. (2010), the stretch of highway 97 within the Okanogan Valley of Washington State represented some of the highest rates of reported wildlife/vehicle collisions from 2002-2006 (127-325 VWCs). Wildlife overpasses and underpasses can minimize wildlife road mortalities by preventing wildlife/vehicle collisions. Moreover, these structures facilitate the movement of taxa, thereby improving gene -flow and demographic exchange between populations of fauna across landscapes (Finch, 2000; Sullivan & Danberg, 2009).

Ecological restoration of disturbed land forms a building block for reestablishing broken habitat linkages. Restoration of habitat connectivity between patches provides passage for wildlife through anthropogenically disturbed areas. Additionally, conservation and restoration of key locations can facilitate permeability across human-occupied spaces. In order for wide-ranging mammals to successfully populate the landscape, they have to be able to move across land that has been converted for anthropogenic uses (Chetkiewicz et al., 2006; Michael et al., 2012). Simply preserving habitat or greenspace near an urban, suburban or exurban area will not achieve passage for large carnivores (Chetkiewicz et al., 2006). Connective habitat corridors proximal to urban population centers must be predicated on the movement patterns of species (Chetkiewicz & Boyce, 2009; Simberloff et al., 1992). Unlike wolverines and Canada lynx, gray wolves represent a generalist species that can inhabit most ecotypes successfully (O'Neil et al., 2017; Williams et al., 2002). Road infrastructure, human encounters, proximity to livestock and residential development present the greatest danger to gray wolves (Hanley et al., 2018; Mazur & Asah, 2013). Therefore, large carnivore species sensitive to anthropogenic development and fragmentation need corridors to allow them to circumvent converted land and divert them from potential conflicts.

Land managers cannot simply preserve some habitat patches in a populated area in the hope that they will be utilized by species of concern. In order to be successful, habitat conservation has to be based on the behaviors of the target species. The Bow River Watershed, located in Banff National Park, encompasses the towns of Canmore, Lake Louise, Banff and others. Originally, land managers had reserved existing corridors for wildlife passage near these developed areas, thinking that they would be used by large mammals of the region. The habitat corridors comprise parcels of undeveloped land that remained after the development of the towns and roads (Chetkiewicz et al., 2006). The corridors included duel uses: a wildlife corridor and a municipal nature park with hiking/running trails through the corridors. Grizzly bears among other wildlife, keep their distance from the corridors during seasons and times of high recreational use in order to minimize contact with people (Chetkiewicz & Boyce, 2009; Gibeau et al., 2002). This underscores the need for habitat corridor locations and uses to correspond to the behaviors of target focal species. Otherwise, the target species may seek more suitable habitat elsewhere (Gibeau et al., 2002). For large carnivores, straying from corridors near populated areas puts them in physical danger of human contact. If wildlife corridors are dually used for human recreation, this will all but assure that target species will avoid them. Human encounters with grizzly bears and gray wolves near population centers can foment panic in local residents, thereby straining the potential for coexistence. This can result in a higher risk of carnivore mortality in the short term to assuage people's fears or concerns, however, the long term erosion of favorability towards large carnivores can eventually translate to wildlife management policies harmful to the long-term viability of large carnivores of concern (Dietsch et al., 2016; Linnell et al., 2001; Packer et al., 2009).

Anthropogenic activities increasingly convert vast tracts of quality habitat into ranches, farms, towns, roads, mines, clear-cuts and housing developments (Arneth et al., 2017). All the while, large carnivores of concern walk a tightrope between recovery and regional extirpation in the western United States. If land use practices continue to favor development over conservation, habitat patches will become smaller and more isolated (Laurance et al., 2000). Under such conditions, widespread densities of large carnivores will not become an ecological reality in places like the Okanogan Highlands (Singleton et al., 2004; Suring et al., 2011). Furthermore, climatic shifts make conservation planning all the more confounding. Climatic trends do not guarantee certainty, though we can predict that phenological patterns will alter and weather regimes will become more extreme for the inland Northwest (Haugo et al., 2010; Hessburg et al., 2015). This phenomenon will likely find taxa leaving degraded and altered habitat and dispersing long distances in search of quality habitat somewhere new. Therefore, conservation biologists must factor climate change into every habitat corridor they plan to conserve. How will the landscape change and what will that mean for fauna moving through it in the coming generations? These questions represent the challenges that conservation biologists now incorporate into models and designs for habitat corridors and new protected areas.

Biologists and ecologists in Washington State have been researching similar questions and have developed spatial analyses that can predict landscape changes and how they will affect conservation efforts (Transboundary Connectivity Group, 2016; Krosby et al., 2015, 2010; Nuñez et al., 2013). Biophysical processes will have different outcomes on landscapes depending on the physiographic make-up of the region (Theobald et al., 2015). The Okanogan-Kettle subregion includes: shrub steppe, subalpine forest and some alpine tundra bog in higher elevations (Gaines et al., 2017; Holt et al., 2016). For biota to move through shrub steppe ecotypes, they need access to reliable water sources. Conservation of habitat corridors along rivers and streams, shaded by riparian and upland forest canopies provide important resources, likely to endure future climatic changes (Heller & Zavaleta, 2009; Nuñez et al., 2013; Theobald et al., 2015). In arid valleys like the Okanogan, riparian ecosystems provide the backbone of ecosystem functions for the greater biotic community as well as ecosystem services for agricultural communities like those of Okanogan County. Thus, it is absolutely crucial that riparian ecosystems be conserved and restored in order to remain resilient to intensifying climatic shifts in places like the Okanogan Valley.

In montane environments, preserving existing mature forests, as well as a mosaic of seral stages in subalpine forest will provide habitat for the focal species of this study while preserving umbrella habitat for biodiversity and ecosystem functions (Koehler et al., 2008; Quade et al., 2006). Wide, (<20 km with a buffer of 500 m on each side) (Proctor et al., 2015) intact habitat corridors provide immigration/emigration routes for wildlife to travel between reserve patches (Gilbert-Norton et al., 2010; Krosby et al., 2015; Proctor et al., 2015). These corridors facilitate demographic exchange and gene-flow for subpopulations of large carnivores throughout montane and subalpine forest ecotypes of the Okanogan-Kettle subregion (Transboundary Connectivity Group, 2016; Lyons et al., 2016; Singleton et al., 2004). In addition, corridors offer an escape from habitat that becomes uninhabitable due to disturbance from climatic events (Heller & Zavaleta, 2009; Vanbianchi et al., 2017; Zielinski et al., 2017).

Recovery of species of concern requires conservation of quality habitat and restoration of disturbed habitats. Reserves established before we had extensive knowledge of the effects of climate change stand to experience landscape alterations as a result of climatic factors (Theobald et al., 2015). Therefore, as part of climate adaptation, new conservation reserves may need to be established and connectivity to all reserves assured (Heller & Zavaleta, 2009). Furthermore, any new reserves should account for climate change predictions as they pertain to projected landscape change.

Conservation on the ground: from recommendations to implementation

Thus far, several recommendations have been presented for conservation of crucial habitat. The literature demonstrates spatial and strategic suggestions that enable land managers to accommodate habitat conservation for species of concern. However, this body of literature often lacks examples of successful implementation of conservation strategies, on the ground. Considering the many challenges that ecological reports and assessments face before they can be incorporated into land use practices, lack of implementation of these recommendations comes as no surprise. After completion of the scientific research for a habitat corridor to facilitate the migrations of pronghorns (*Antilocapra americana*) meridianally from Wyoming to New Mexico, Berger and Cain (2014) documented the process that led to the ultimate implementation of the project (Berger & Cain, 2014). Their team was tasked with convincing local state and federal governments of the value of this project. In order to do this, they had to win the support of constituencies across three states. Participants exhibited widely varying degrees of understanding of the project and political will to allow such a project to be undertaken in their backyards (Berger & Cain, 2014).

Habitat conservation across a vast region can be achieved by coordinating cooperation between disparate groups. This is done by: A) gathering information on public concerns and opinions and B) responding to citizen concerns with accurate ecological information to assuage fears and encourage understanding (Morgan et al., 2004). It takes a concerted effort to galvanize different stakeholders from multiple localities and backgrounds to agree to common conservation goals. Even though conservationists and natural scientists agree on the ecological benefits of top predator recovery, the return of gray wolves, for instance, may be perceived as a threat to ranching and agricultural communities (Browne-Nuñez et al., 2015; Clarke, 1999; Vaske et al., 2013) Currently, gray wolves are recovering their historical range in eastern Washington State, a primarily conservative region with a mere 20.6-28.6% willingness to coexist with wolves (Dietsch et al., 2016). On the surface, this would indicate general public antipathy towards wolf recovery in the region. However, a survey analysis by Mazur & Asah (2013) of attitudes towards wolves in eastern Washington revealed that, of 56 wolf-related issues presented to respondents, 14 of them yielded consensus, the vast majority showed some common ground and only 5 garnered polarizing disagreement (Mazur & Asah, 2013). People demonstrate an inclination to align publicly with the views and attitudes expressed by the social and political groups with which they claim membership (Vaske et al., 2013). However, this research indicates that, even in rural, conservative counties of Washington State, the nuances of attitudes toward large carnivore recovery ultimately display more common overlap than disagreement.

Getting conservation to happen on the ground requires the support of communities proximal to existing, or potential conservation areas. Land within range of critical habitat represents a mosaic of different ownership designations. Connecting reserves with habitat corridors requires conservation of these lands under various ownership classifications, parcel by parcel (Chester, 2015; Sayer et al., 2013; 2015; Soule et al., 1999;). In 2005, a plan was approved to expand fifteen miles of highway and in the process, build a wildlife overpass and several wildlife underpasses east of Snoqualmie Pass in the Central Cascades of Washington State (Sullivan & Danberg, 2009). This project required buy-in from the public; the project funding came primarily from a voter-approved gas tax (+9.5 cents per gallon). Additionally, the project took ten years of partnering with private and public land owners as well as an extensive public outreach campaign to address questions and concerns of citizens (Sullivan & Danberg, 2009). This project marks a significant success of both conservation recommendations, planning and implementation. For crucial habitats to be preserved there must be buy-in from individual landowners to state agencies and most everyone else in between (Berger & Cain, 2014; Browne-Nuñez et al., 2015; Shafer, 2015;).

Landscape conservation biology conceives of processes on a continental scale and executes them on a local level (Chester, 2006, 2015; Morgan et al., 2004; Soulé & Terborgh, 1999). Networking and organizing locally helps communities achieve this larger goal of conservation on a landscape scale, since the communities dot a vast swathe of territory that spans states, provinces and international borders (Chester, 2015; Gailus, 2001; Mattson et al., 2011).

Two countries -or two municipalities, for that matter- can have vastly different policies, but ecological agencies and conservation organizations tend to share goals driven by conservation science (Pahre, 2009; Stefanick, 2009). That being said, interagency cooperation renders much greater efficiency when conducted domestically, as legal discrepancies occurring between neighboring states prove difficult to reconcile (Ostrow, 2012). The policies that govern two countries can be extremely challenging to navigate. Even so, interagency cooperation across the international border proves necessary in an effort to ensure habitat connectivity in a transborder region like the Okanogan-Kettle subregion (Stefanick, 2009).

The broad, sweeping scope of landscape conservation uses the principles of ecosystem management to visualize ecological functions on a grand scale. Ecosystem management prioritizes ecological functions and the sustainability of ecosystems as the primary goals of land management (Christensen et al., 1996). Ecosystem management recognizes the land as a living world or ecosystem of which humanity is a member (Christensen et al., 1996; Grumbine, 1994). Established in the mid-1990's, this management system has since been adopted by conservation districts and organizations across North America (Shafer, 2015). The concepts of ecosystem management have been incorporated into the guiding principles of federal resource agencies like the National Forest Service and the Bureau of Land Management (Szaro, Sexton, & Malone, 1998). Historically, attempts to enshrine ecosystem management as the law of the land have been stymied by special interests representing resource extraction companies (Clarke, 1999). Still, the importance of ecosystem management as a universal practice of federal resource agencies cannot be overstated. For example, the USDA Forest Service, National Parks and the USDI Bureau of Land Management and other federal agencies cumulatively own and manage 76% of the Greater Yellowstone Ecosystem (Shafer, 2015). Each of these agencies relies on a different set of land use protocols. With a consistent approach of ecosystem management, it could be feasible to coordinate landscape scale conservation between these different ownership classes (Szaro et al., 1998).

Coordination between various federal, state, local and private landowners with differing land use strategies becomes nearly impossible without a clear guiding set of ecological principles (Christensen et al., 1996). Regional conservation groups push local, state and federal governments for conservation legislation, since it provides a blanket, protectionary mandate by which all landowners must abide (Shafer, 2015). Of course, conservation organizations must galvanize enough public support for such legislation to be formally proposed, let alone passed.

Ecosystem management has long been an adopted principle of most conservation organizations and land trusts (N. J. Mitchell & Diamant, 1998; Platt, 2000). This local/ regional form of conservation, governed by municipal laws, can vary by town and by county (Ostrow, 2012). Discontinuity of local government support for conservation manifests itself in small and fragmented conserved parcels. Lack of consolidated geographic cooperation in regard to habitat connectivity leads to further fragmentation from a landscape conservation perspective (MacMynowski, 2007; Michael F. Proctor et al., 2004; Stefanick, 2009). Ecosystem management practices might be consistent across conservation districts, but the degree to which habitat conservation has been incorporated into local, state and federal policies becomes inconsistent across landscapes (Christensen et al., 1996; Ostrow, 2012). Building public support, locally and regionally can increase participation and civic activity, thereby broadening the base of advocacy for habitat conservation (Mitchell & Diamant, 1998; Reed et al., 2014). Grassroots organizing, networked across communities in regions that contain critical habitat has the potential to link social will in neighboring regions with habitat conservation between those localities.

Cultivating support for habitat conservation and large carnivore recovery entails a rigorous effort on the part of conservation organizations, biologists, the local citizenry and government officials. Large carnivores of concern have been rare to absent across their historical ranges in the United States for decades (Miller et al., 2013). Canadians have more recent, extensive and ongoing experience with large carnivore and human coexistence (MacMynowski, 2007; Wolf & Ripple, 2018). Canadian Provincial parks, National and resource management departments have used fencing and wildlife overpasses in areas of high densities of large mammals to avoid road mortalities and improve permeability across the landscape (Sawaya, Clevenger, & Kalinowski, 2013). Hiking trails and portions of reserves close seasonally to protect wildlife activities like migration, natal denning, foraging and hunting (Gibeau et al., 2002; Linnell et al., 2001; Schwann, 2018). In order to minimize human encounters with large carnivores, parks staff inform hikers of recent sightings in the area of their proposed routes. It should be noted that these precautionary measures are taken in national parks in the United States, with relatively high densities of large carnivores, i.e. Glacier and Yellowstone National Parks. Canadian wildlife management practices go a step further; in forests managed for timber, logging roads close when large carnivores of concern are spotted in the area (Proctor et al., 2004). These represent some of the practical strategies that Washington State will have to develop in the coming years in order to ensure the successful return and recovery of large carnivores of concern across the transborder region of the Okanogan-Kettle subregion.

Pragmatic approaches that provide spatial awareness of wildlife locations and ways of avoiding human contact with large carnivores represent an important facet of the conservation of these species. Grizzly bear and gray wolf recovery remain particularly vulnerable to the attitudes of the public. The public perception and fear of these species represents one of the most challenging barriers for the conservation of large carnivores (Dietsch et al., 2016; Hauf, 2016; Linnell et al., 2001). These taxa have not occupied the U.S. regions of the Okanogan-Kettle subregion in, even moderate numbers, for generations. Inexperience living alongside large carnivores fosters misunderstandings about them. Lack of information about large carnivore behavior and ecology becomes exacerbated by sensationalized media accounts of predator human encounters and cattle depredation (David G. Knibb, 2008; Haber, 2013) The reality of what it will be like when large carnivores recover across their historical range becomes distorted by preconceptions (Clarke, 1999; Vaske et al., 2013). For large carnivores of concern to thrive across the Okanogan Highlands, outreach and education about these species, what they mean to the ecosystem and how we can foster coexistence, must be a conservation priority (Morgan et al., 2004). Additionally, efforts to educate the public about large carnivores within their regional ecosystems should, if possible, preempt the expansion of these species' territories. Citizen science programs provide an interactive way for the public to get involved in conservation and learn about the target species and their habitats. Additionally, programs beneficial to predator/human relations include K-12 curricula that teach the connection of recovering predators with cultural and ecological landscapes. Consitble et al., (2008) designed a high school biology exercise that allowed students to read about trophic cascades in Yellowstone and provide mathematical models demonstrating that top predators make ecosystems more resilient to climate change by providing carrion for mesopredators and scavengers. The modeling indicated that, warmer winters in the Greater Yellowstone Ecosystem (GYE) brought a reduction of carrion for scavengers and mesopredators in the absence of gray wolves (Consitble et al., 2008). Historically harsh winters in the GYE brought on a steady mortality rate in ungulates which provided for scavengers and mesopreditors in the absence of gray wolves. The reintroduction of wolves to the GYE mitigated the effects of climate change on scavengers and mesopredators by renewing a source of winter carrion (Consitble et al., 2008). The reaction of the public to large carnivores is extremely variable, but with greater knowledge of these species and their current and historical interactions with cultural landscapes, we will be better prepared to coexist as they expand their ranges across the Okanogan-Kettle subregion and the North American West.

Conclusion

Large carnivores are species with small population densities scattered widely across vast landscapes. Many large carnivores play integral roles in food web dynamics. As top predators, the behaviors of these species have a cascading effect throughout all other trophic levels of ecosystems. Due to their wide range of habitat, they represent focal, umbrella species. Conservation of the habitat that they occupy will additionally encompass that of myriad species within multiple species guilds (D. Simberloff, 1998; D. Simberloff & Dayan, 1991).

Matrices of anthropogenic activity, development and infrastructure now predominate across most landscapes across the world. Thus, large carnivore populations suffer world-wide decline and many species have become threatened with extinction (Wolf & Ripple, 2018). Additionally, climate change alters the landscape, forcing large carnivores to adapt or migrate in search of suitable conditions. Reserves become isolated, fragmented and separated by impermeable urban/suburban/exurban development and infrastructure. Thus, large mammals become isolated as well, and subject to stochastic pressures that jeopardize the viability of these species**.** Large carnivores are acutely impacted by this geographic isolation due to the wide range of territory that they occupy.

Western North America retains enough quality habitat in key areas to support viable densities of large mammals, including carnivores. Biodiversity in western North America can be protected by preserving heterogeneous habitat and conserving quality corridors to connect systems of large *and* small reserves. By conserving and restoring habitat in the Okanogan-Kettle subregion of northeast Washington State and southern British Columbia, large carnivores of concern can continue to disperse through a vast landscape that connects to the Columbia Mountains, the Rockies and the Cascades. Assessments of crucial habitat in the region have identified several key areas for conservation. However, in a recent assessment of the region it was discovered that conservation goals have not been met and the viability of species of concern remains in question (Gaines et al., 2017). Thus, it becomes necessary to target areas that remain particularly challenging to landscape permeability for focal large carnivores across the Okanogan-Kettle Subregion. The Okanogan Valley of Washington State represents a fracture zone where US-Highway 97 runs north to south across the Canadian border and the Okanogan River parallels the highway (for the most part). Low densities of farms and residential development line the banks of the Okanogan River and the highway; agricultural and residential density remains very low just outside of the river valley and the Highway 97 fracture zone. The area as a whole retains a high potential for permeability between the northeast Cascades and the Kettle River Range. Establishing a lateral wildlife corridor system between protected areas across the Okanogan Valley of Washington State has the potential to facilitate dispersal for wide-ranging large carnivores between the north Cascades to the Kettle River Range and beyond, across the Okanogan-Kettle Subregion (National Fish and Wildlife Foundation, 2017; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010).

METHODS

The methodology for this thesis is comprised of three phases. The first phase required the selection of an area of interest (AOI) to serve as the study areas for this case study. Phase 2: generate least-cost distance maps for each focal species. These maps determine habitat suitability and connect core areas across the Okanogan Valley with a network of habitat corridors based on the path of least resistance (least-cost path) for each species. Phase 3: use two decades of census data (3 census years: 1990, 2000 and 2010) to analyze the rate of residential development over time. This analysis provides insight into the ways that development on private property affects habitat suitability and permeability for large carnivores sensitive to fragmentation and human impact. Additionally, using the most recent census data provides a snapshot of development across the AOI. This data can then be used to analyze the degree to which private lands retain quality, connective habitat for large carnivores within the AOI.

Determining the area of interest for a case study

The area of interest for this case study must exemplify the broad implications of habitat fragmentation across the greater inland Northwest. The overarching themes of this thesis can be described as: A) the impacts of anthropogenic land use activities between the Cascades and Rocky Mountains and B) the challenges these activities pose to wildlife movement, dispersal and gene flow. Therefore, the AOI for this case study had to include at least some of the following anthropogenic activities indicative of working lands throughout the inland Northwest: infrastructure development, exurban development, logging, mining, ranching and agriculture. Much like the majority of land between the

Cascades and Rocky Mountain chains, this study area has not been afforded strict federal protections such as Wilderness or National Park designations. Conversely, it represents a multiple use mosaic of public and private ownership classes (Figure 5.) (National Fish and Wildlife Foundation, 2017).

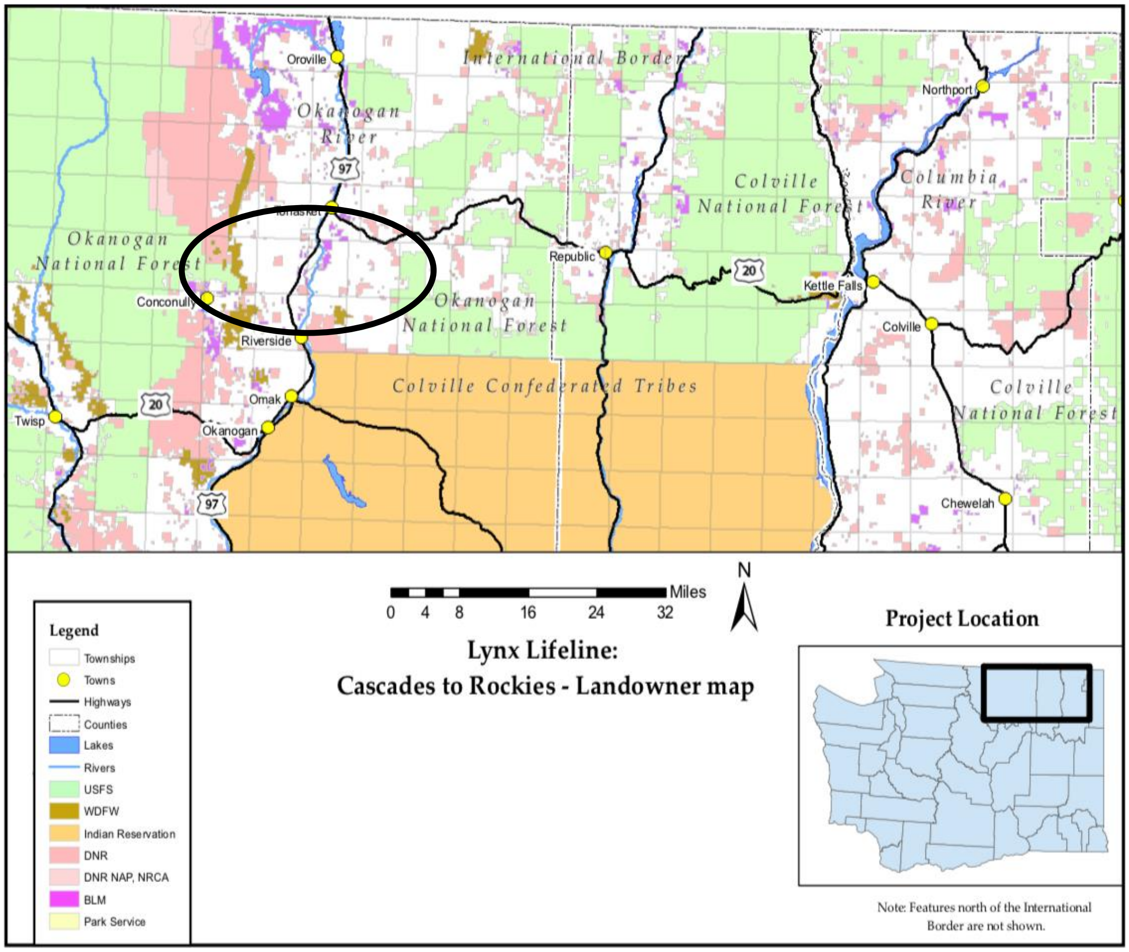


Figure 5. Map displays public and private land ownership between the northeast Cascades and the Kettle River Range. The oval indicates the AOI for this case study. The map is part of the Working for Wildlife Initiatives effort to link habitat for Canada lynx between the east Cascades and the Kettle River Range. Source: National Fish and Wildlife Foundation. (2017, May). Working for Wildlife: Maintaining Okanogan's working lands and wildlife heritage. A National Fish and Wildlife Foundation plan to conserve a crucial linkage for lynx and other wide-ranging species. National Fish and Wildlife Foundation.

The arid subregion of the Columbia Plateau bottlenecks narrowly in north central Washington State. The Okanogan Valley is flanked to the east and west by the montane habitat of the Okanogan Highlands, the Kettle mountains and the Cascades. The AOI of this thesis study covers a well-established east/west, twelve-mile-wide habitat linkage in Okanogan County, WA, between the towns of Riverside and Tonasket (Figure 6.) (National Fish and Wildlife Foundation, 2017; Singleton et al., 2002). The length of this habitat linkage is intended to traverse both the fracture zone of Highway 97, which runs north to south, and the Okanogan River Valley. Passage between core, montane habitat in the Okanogan Highlands and the northeast Cascades can be achieved by linking habitat across this narrow stretch of the Okanogan Valley and connecting habitat east and

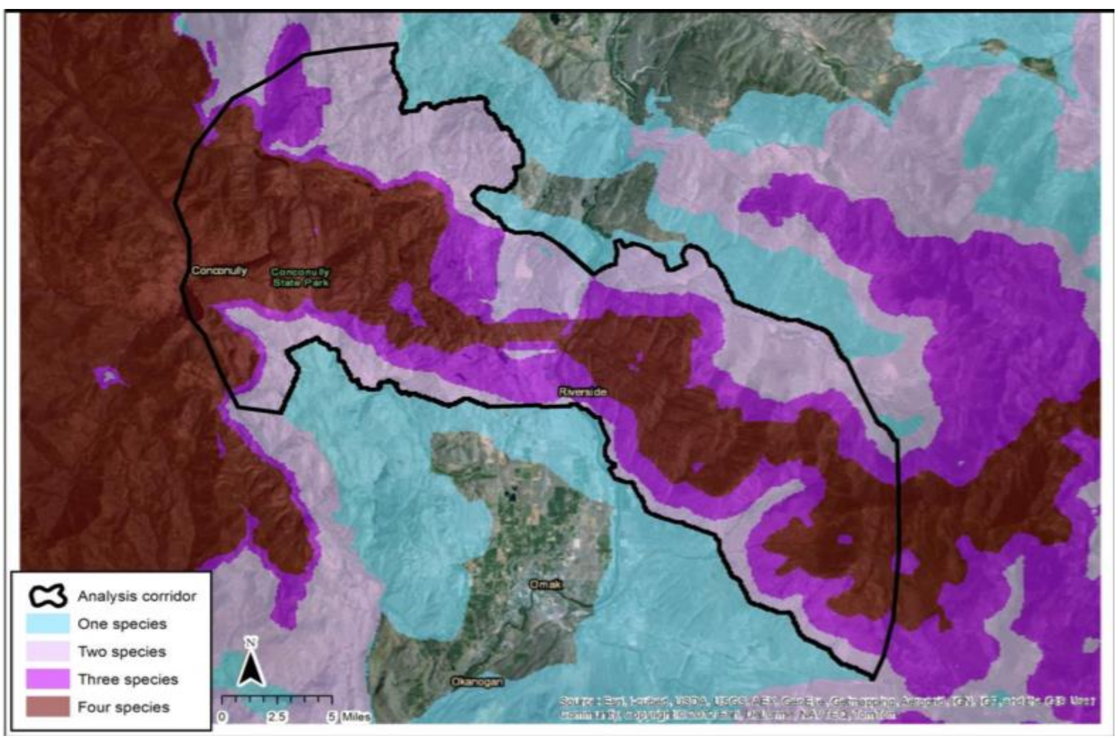


Figure 6. This map appears in the Working for Wildlife Initiative Business Plan (2017), Source: National Fish and Wildlife Foundation. (2017, May). Working for Wildlife: Maintaining Okanogan's working lands and wildlife heritage. A National Fish and Wildlife Foundation plan to conserve a crucial linkage for lynx and other wide-ranging species. National Fish and Wildlife Foundation. The black border represents a proposed

habitat corridor. The colors symbolize focal species: grizzly bear, wolverine, gray wolf and Canada lynx. The color symbology comes from the original map source: Singleton, P. H., Gaines, W. L., & Lehmkuhl, J. F. (2002). Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment (Research Paper RMRS No. 549; pp. 1–89). Retrieved from USDA Forest Service - Research Papers RMRS website:http://allianceprimo.hosted.exlibrisgroup.com/primo_library/libweb/action/dlDisplay.do?vid=EVSC&afterPDS=true&docId=CP71166054460001451.

west of the valley (Hall, 2015; National Fish and Wildlife Foundation, 2017; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). However, development on both sides of Highway 97 and the Okanogan River continue to reduce linkages to habitat cores in the Kettle mountains and the northeast Cascades (Transboundary Connectivity Group, 2016).

This case study area includes a lateral habitat linkage that spans shrub steppe, montane forest and subalpine forest ecotones as well as a lower elevation, floodplain and /or riparian ecosystems. The AOI of this study covers a wide range of elevations, from 1,000 ft at the valley bottom to ≥ 7,000 at the western extent of the study AOI. These varying elevation gradients result in multiple ecological zones. As previously stated, ecotones between ecotypes at changing elevation gradients harbor high degrees of biodiversity. Conservation across these ecological zones protects critical habitat while providing connectivity for movement and dispersal of wildlife across different ecotypes (Myster, 2012). Additionally, conservation of lowland river valleys protects important physiographic features that strengthen ecological resilience to climate change (Theobald et al., 2015). Landforms that retain quality habitat into the future will become essential for the migration patterns of ecological communities affected by intensifying climate regimes.

Climate projections for the greater inland Northwest indicate that increased summer temperatures and decreased precipitation will lead to intensified and extended fire regimes (Haugo et al., 2010; Krosby et al., 2010; Nuñez et al., 2013). Arid grasslands of the Columbia Plateau will expand and dry forests on the edge of the transition zone will give way to shrub steppe as they become unable to withstand the higher intensity and frequency of fires (Haugo et al., 2010). Conservation of climate refugia east of the Cascades is essential in light of climate regimes driving this pattern of landscape change (Comer et al., 2015; Zielinski et al., 2017). The Okanogan River Valley in north central Washington State represents a link to habitats in the Cascades and the Kettle mountains, both areas are projected to remain resilient to future climate regimes (Figure 7.) (Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2011). Hence, conserving a habitat corridor across this AOI will benefit current patterns of wildlife movements as well as future adaptability to landscape change.

Climate projections for the North Cascades and the Kettle mountains display a northward retraction of alpine habitat and spring snowpack (Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2011). The highest elevations that fall within the AOI of this case study will be subject to loss of alpine habitat and spring snowpack. In light of these climatic trends across the North Cascades and the Kettle ecosystems, wolverines were excluded from this case study analysis of a habitat linkage between these ecosystems. Additionally, the climate gradient between the extant alpine habitat within the AOI and the Okanogan Valley render this wildlife linkage particularly unsuitable for wolverine dispersal. According to the WWHCG (2010), the wolverine linkage map shows the suggested least-cost path moving across the Okanogan Valley, north of the AOI for this case study and at a much narrower point of the Okanogan Valley backbone (Figure 8.). Moreover, this map avoids the Kettle region

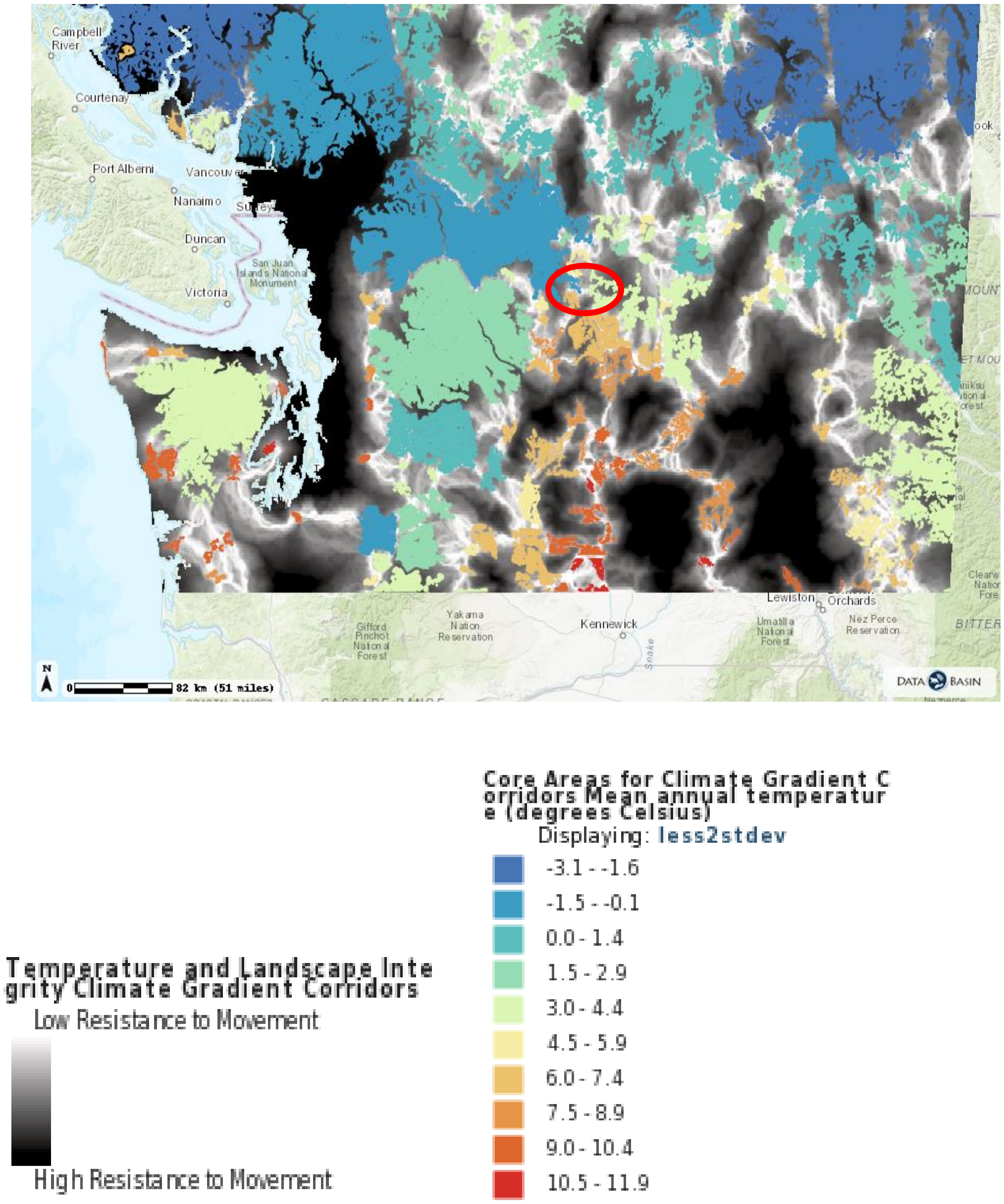
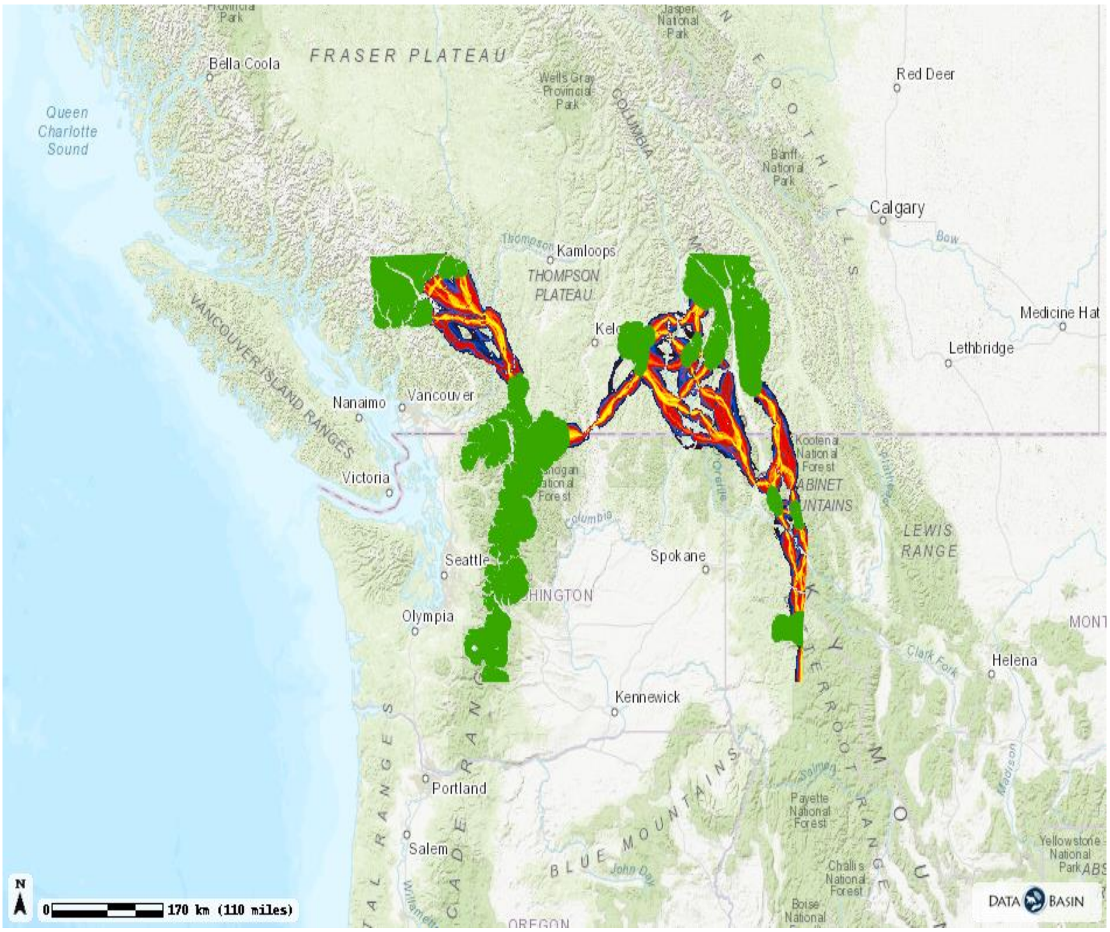


Figure 7. This map shows the mean temperature gradients along with climate gradient corridors for the transboundary area between WA and BC, Canada. The red oval outlines the AOI of this case study. Source: Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2011). Washington Connected Landscapes Project: Climate-Gradient Corridors Report [Climate-Gradient Corridors Report]. Olympia, WA, USA: Washington Departments of Fish and Wildlife, and Transportation.

altogether and instead indicates that dispersal will occur between core areas in the North Cascades and the Kettle region altogether and instead indicates that dispersal will occur between core areas in the North Cascades and the Columbia Mountains in British Columbia (Washington Wildlife Habitat Connectivity Working Group, 2010).

The AOI identified for this thesis contains populations of focal, umbrella species like Canada lynx, gray wolves and a small subpopulation of grizzly bears (<20 individuals, mostly confined to the Cascades in BC, Canada) (Gaines et al., 2017; Andrea L. Lyons et al., 2018). The suite of focal species varies based on the ecoregion being assessed for conservation. For instance, the Columbia Plateau is an arid grassland and shrub steppe landscape. Thus, the focal species identified by environmental reports from the Arid Lands Initiative (ALI, 2014) and the Analysis of the Columbia Plateau Ecoregion (WHCWG, 2012), belong to ecological guilds representative of different ecosystems within this arid landscape. Shrub steppe and arid grasslands include black-tailed jackrabbit *(Lepus californicus),* western rattlesnake *(Crotalus oreganus),* Townsend's ground squirrel *(Urocitellus townsendii),* white-tailed jackrabbit *(Lepus townsendii),* sharp-tailed grouse *(Tympanuchus phasianellus),* Washington ground squirrel *(Urocitellus washingtoni), least chipmunk (Tamias minimus),* greater-sage grouse *(Centrocercus urophasianus)* and mule deer *(Odocoileus hemionus).* Whereas, representative focal species in riverine systems within this ecoregion include tiger salamander *(Ambystoma tigrinum),* and beaver *(Castor canadensis)* (Washington Wildlife Habitat Connectivity Working Group, 2012). The Okanogan-Kettle subregion includes subalpine forest, shrub steppe as well as grassland ecotypes. Therefore, the AOI for this case study features focal species from montane, shrub steppe, riverine as well as generalist species guilds (Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010).



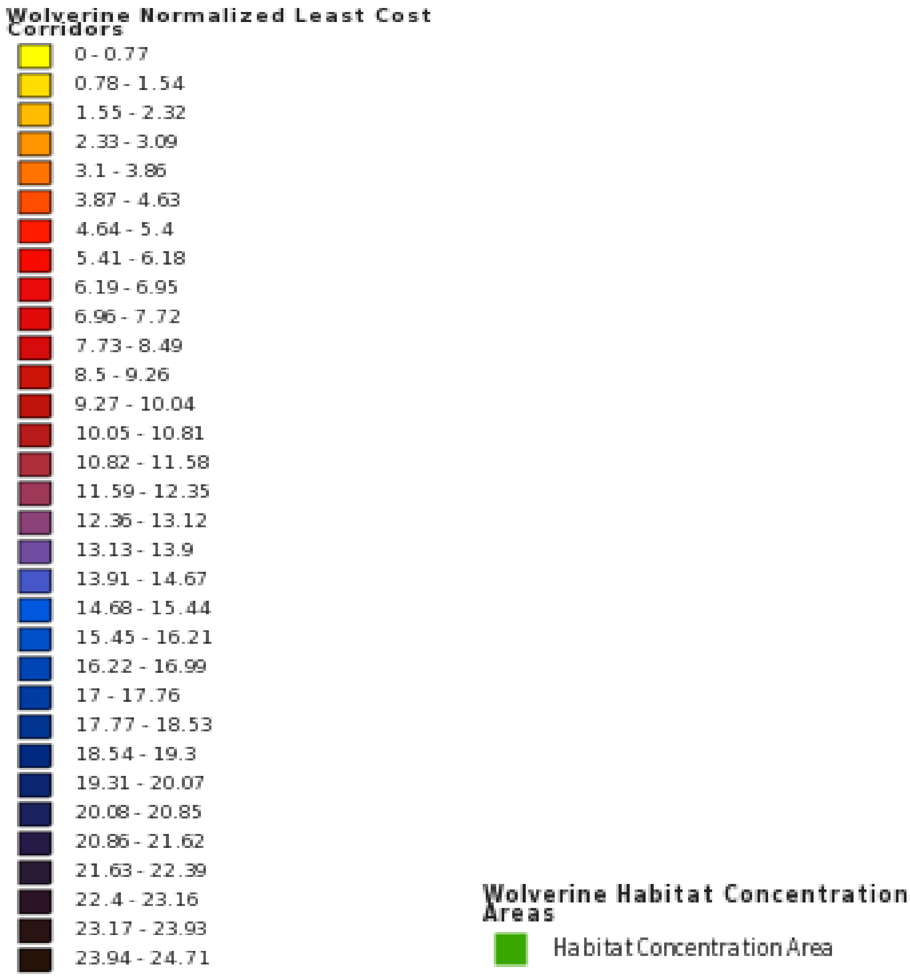


Figure 8. Wolverine least-cost corridor map showing linkage values between Habitat Concentration Areas in the North Cascades and The Columbia Mountains in BC, Canada. Source: Washington Wildlife Habitat Connectivity Working Group (WHCWG). (2010). Washington Connected Landscapes Project: Statewide Analysis. (p. 209). Olympia, WA: Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

The AOI for this thesis study includes a lateral habitat corridor that supports the dispersal of montane focal species, Canada lynx as well as habitat generalist focal species, gray wolves and grizzly bears. As previously stated, these species represent the large carnivore guild which is characterized by large home ranges and wide-range movement and dispersal. Conservation of existing, connective habitat for this suite of focal species in turn preserves the terrestrial habitat for the focal species guilds of arid lands across the Okanogan Valley (Lambeck, 1997). Within the Working for Wildlife Initiative, Canada lynx represent the focal species for the broader carnivore guild that includes gray wolves, and grizzly bears (National Fish and Wildlife Foundation, 2017).

Canada lynx tend to be cover obligates of subalpine forests in Washington State (Hoving et al., 2005). Though primarily cover obligates, lynx disperse widely across a range of ecological zones when habitat conditions and prey availability become unsuitable within their home range (Lyons et al., 2016). Accelerated fire regimes within the subalpine forests of the Okanogan portion of the LMZ (Lynx Management Zone) have caused the Canada lynx population to retract northward where suitable elevation and habitat conditions persist presently (Lewis, 2016). Stochastic pressures brought on by receding spring snowpack, reductions in prey availability and accelerated fire regimes continue within the Lynx Management Zone (LMZ) of the Northeast Cascades (Vanbianchi et al., 2017). Due to the compounding factors affecting Canada lynx in the Okanogan block of the LMZ, conserving connective habitat across the Okanogan Valley provides a path for metapopulation dispersal between the Okanogan block of the LMZ and the Kettle Mountains (Stinson, 2001). Research and monitoring of lynx in the Kettle region of the LMZ has not yet established a stable population in that area (Lewis, 2016). Although lynx observation data is lacking in the Kettle ecosystem, subalpine forest persists along the north/south Kettle Crest which provides lynx with core habitat (Lyons et al., 2016).

This thesis study differs from other focal species analyses of wildlife linkages between the northeast Cascades and the Kettle mountains in so far as gray wolves and grizzly bears are included as focal species in addition to Canada lynx. This thesis study includes focal, large carnivore, habitat generalist species gray wolves and grizzly bears due to the varying habitat types at different elevation gradients that can be conserved under the umbrella habitat requirements attributed to these species (Haber & Holleman, 2013; Knibb, 2008). Additionally, gray wolves have dispersed and formed packs on the west and east sides of the Okanogan Valley (Washington Department of Fish and Wildlife et al., 2018). Thus, a wildlife linkage would facilitate metapopulation dispersal across the valley to the packs west and east of Highway 97 and the Okanogan River. Grizzly bears persist in the northeast cascades in such small numbers (<20) that grizzly reintroduction to the North Cascades Grizzly Recovery Zone has been recommended by WDFW (Washington Department of Fish and Wildlife) and the IGBC (Interagency Grizzly Bear Committee) as the only way to stave off local extinction (Lewis, 2018). The Environmental Impact Statement for grizzly bear reintroduction to the North Cascades Ecosystem remains ongoing. In the event of an approval for reintroduction, as widely dispersing habitat generalists, grizzly bears, especially males exhibit the potential for wide dispersal from the confines of the alpine slopes of the Cascades to the Okanogan Valley (Singleton et al., 2004). In order to preclude conflict across working lands, they will need targeted, conserved habitat and connective habitat corridors comprising a wildlife linkage between the larger habitat cores within the North Cascades and Kettle Ecosystems.

Analysis of variables within the AOI

The next phase of the methodology for the case study entailed developing a set of tools and strategies for a small-scale, fine-grained analysis of habitat connectivity across the AOI. The vast majority of the wildlife linkage analyses reviewed for this thesis study provide broad, landscape scale models. This case study, however, was designed to magnify the scale of a fracture zone and the surrounding area in order to evaluate the factors that both prevent permeability and provide potential for connectivity across public and private lands.

The first stage of data collection entailed finding Shape files from WDFW[4] and Okanogan County[5] on species observation data for Okanogan county. The Okanogan County Planning Department's FTP site provided additional layer files for roads, parcels and Priority Habitat Species (PHS) data from WDFW. This data included historical observation records of the three focal species of this study within the AOI as well as wolverine data outside of the AOI but within Okanogan County. USGS GAP analysis data includes protected areas layer[6]. These layers depict the locations and designations of protected areas and land cover types within the AOI. The collection of GAP analysis data became essential to the task of representing the degree of connectivity between public lands appeared within the AOI. Additionally, this study required delineations between

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[4]WDFW. (n.d.). Priority Habitats and Species (PHS) Interactive Mapping | Washington Department of Fish & Wildlife [Interactive mapping]. Retrieved from PHS on the Web website: https://wdfw.wa.gov/mapping/phs/

[5] Okanogan County Planning Department GIS layers. Retrieved from Okanogan County FTP site: ftp://47.25.168.198/

[6] USGS Gap Analysis Program GIS layer packages for landcover and protected areas. Retrieved from: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap

public and private land in order to analyze protected areas vs private lands with conservation potential and areas that contribute to habitat fragmentation within the AOI.

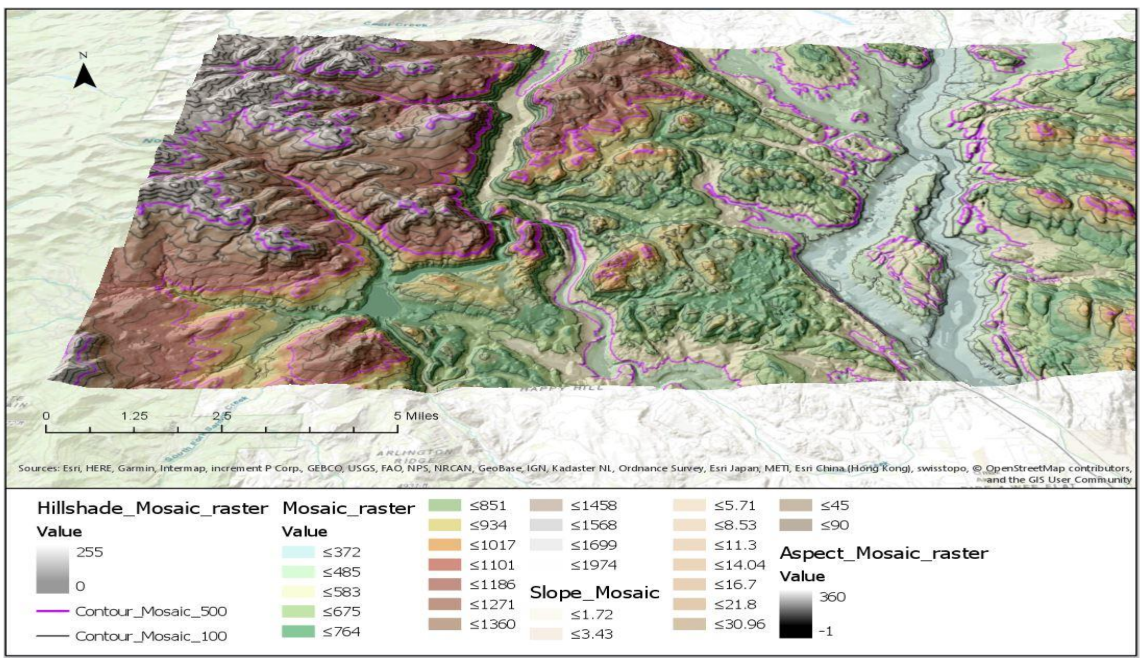
The primary literature for this thesis includes state-wide, least-cost distance analyses that feature the area of interest as well as the four focal species of this case study (Transboundary Connectivity Group, 2016; Singleton et al. 2002; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). However, these analyses were conducted on much larger scales than this thesis study and most of the mapping for these studies had been conducted nearly twenty years prior to this thesis study. Therefore, the methodology for this study provides current least-cost distance corridor mapping for focal species: gray wolves, grizzly bears and Canada lynx across the case study AOI. Additionally, this thesis study uses a fine-grained approach in order to increase the level of detail across the AOI. Magnifying the scale of the spatial analysis provides conservation districts and other local conservation organizations with specific target areas for on-the-ground implementation of conservation efforts.

Least-cost distance mapping for focal species across AOI

Spatial Analyst (ESRI), 3D Analyst (ESRI) Modelbuilder (ESRI) and a full suite of Geoprocessing applications were employed in ArcGIS Pro (ESRI) to represent the variables: elevation, slope, land cover, protected areas and road density. Each of these variables required considerable data management in order to represent them accurately. In addition, once loaded into a Geodatabase in ArcGIS Pro, multiple Geoprocessing tools were employed to: A) clip each feature and/or raster layer to the spatial parameters of the

AOI and B) transform them to the geographical coordinates of the target Digital Elevation Model (DEM) source layer.

The source files for elevation data included 30 x 30m Digital Elevation Models (DEM) retrieved from Washington State Department of Natural Resources[7]. The DNR source files consisted of fourteen Tile Image File Format (TIFF) files. These files were imported into ArcGIS Pro using the Mosaic Raster Geoprocessing Tool (ESRI) which merges individual raster image files into a single layer. The mosaic raster DEM provided the basis for a 3D elevation map of the AOI (Figure 9.)(Figure 10.). An additional 30 x 30m DEM from USGS Earth Explorer[8] provided the foundational raster DEM layer by which elevation, slope or hillshade raster functions (ESRI) were derived in each of the least-cost distance maps to follow.



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[7] These DEM files in TIFF format,were retrieved from the Washington State Department of Natural Resources FTP site: ftp://dnrftp.dnr.ne.gov/pub/data/dems/

[8] Single DEM source file retrieved from USGS Earth Explorer: https://earthexplorer.usgs.gov/

Figure 9. 3D, Digital Elevation Map of western extent of the AOI and fracture zone. This map uses hillshade, contours, slope and a 3D extrusion to depict dimension, elevation, and ruggedness of the terrain. The symbology for elevation symbolizes raster values by elevation gain. The gradient begins at the lowest elevation extent (green = ≤1,000 ft) and ends at the highest extent (white = ≤7,000 ft).

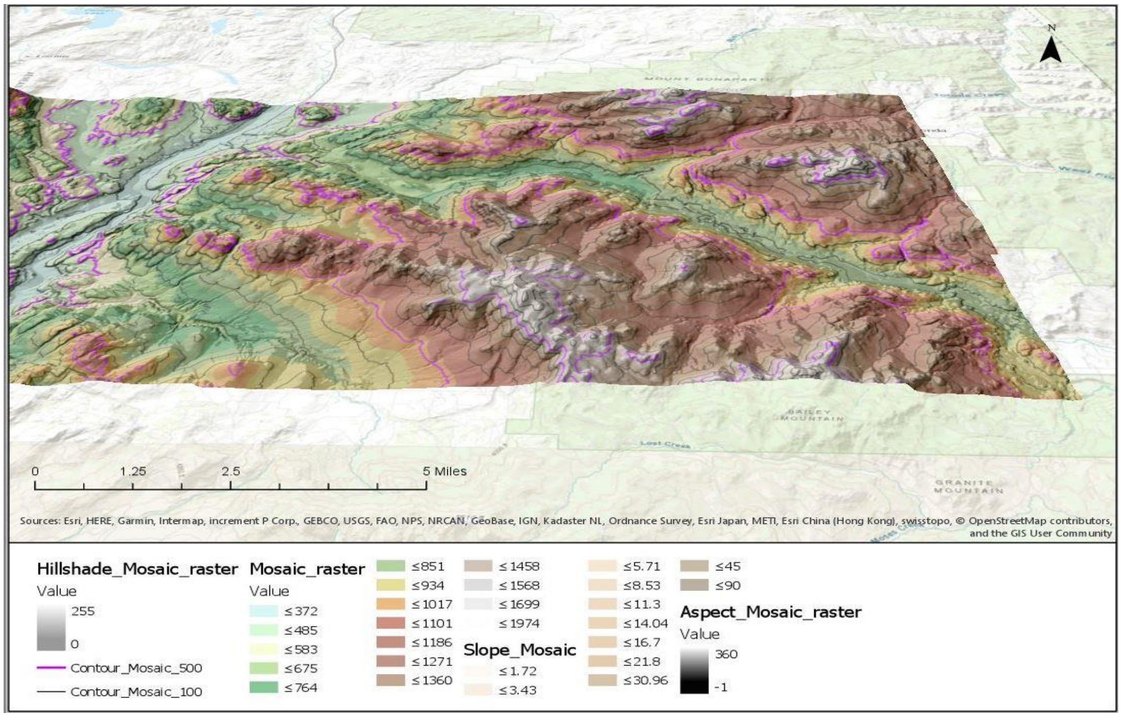

Figure 10. 3D, Digital Elevation Map of eastern extent of the AOI and the northern half of the fracture zone. This map employs the use of slope, hillshade and contours.

For this study, a Tile Image File Format (TIFF) file from the National Land Cover Database (NLCD) was retrieved through the USGS Gap Analysis Program in order to represent land cover/land use in ArcGIS Pro (ESRI) (Figure 11.). When clipped to the AOI, the land cover classes become reduced to those contained within the parameters of the AOI, omitting all extraneous land cover data outside of the study area. The raster becomes represented spatially as cells. In the case of land cover, higher cell value assignments belong to the predominant types of land cover within the AOI. Evergreen forest and shrub steppe land cover types represent the majority of cell value "counts" for the land cover raster layer (Figure 12.).

The source files for GAP analysis protected areas were provided by USGS and, originally imported into the project Geodatabase in ArcGIS Pro as a feature class. The

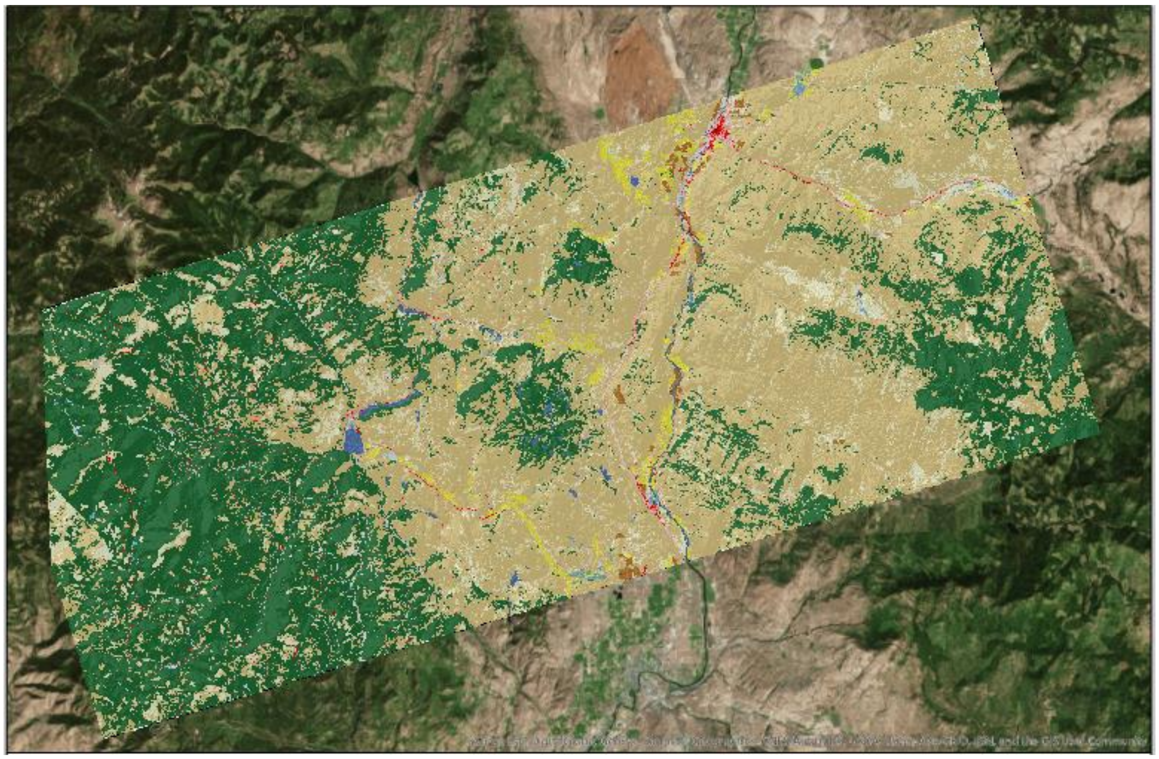

Figure 11. USGS GAP Analysis land cover/land use map. Green = forest/beige = shrub steppe/yellow = agriculture and red = development (housing not roads).

Field: Add Delete Calculate Selection: Zoom To Switch Clear De

OBJECTID	Value	Count	Red	Green	Blue	NLCD_2011	Opacity
1	11	5953	0.278431	0.419608	0.627451	Open Water	1
2	21	11583	0.866667	0.788235	0.788235	Developed, Open Sp...	1
3	22	14431	0.847059	0.576471	0.509804	Developed, Low Inte...	1
4	23	3015	0.929412	0	0	Developed, Medium...	1
5	24	477	0.666667	0	0	Developed, High Inte...	1
6	31	774	0.698039	0.678431	0.639216	Barren Land	1
7	41	2197	0.407843	0.666667	0.388235	Deciduous Forest	1
8	42	414817	0.109804	0.388235	0.188235	Evergreen Forest	1
9	43	368	0.709804	0.788235	0.556863	Mixed Forest	1
10	52	580989	0.8	0.729412	0.486275	Shrub/Scrub	1
11	71	88734	0.886275	0.886275	0.756863	Herbaceuous	1
12	81	17560	0.858824	0.847059	0.239216	Hay/Pasture	1
13	82	4726	0.666667	0.439216	0.156863	Cultivated Crops	1
14	90	4604	0.729412	0.847059	0.917647	Woody Wetlands	1
15	95	3885	0.439216	0.639216	0.729412	Emergent Herbaceuo...	1

Figure 12. Image of table for Land cover raster layer within ArcGIS Pro. The Value column assigns a number to each landcover type. The “Count” refers to the number of raster cells that a land cover type occupies on the map. The NLCD_2011 (National Landcover Database) refers to land cover type.

layer provides multiple designation options for protected areas including landowner type, conservation designation type and a gradient of protection status. For the PHS maps of the AOI the multiple conservation designation types for Protected Areas (federal, state, county, private) provided a diverse field of conserved areas for visual representation. For the least-cost distance mapping, The Protected Areas layer required resymbolization to a simple GAP designation of four conservation classes: 1) Land trust, or easement designated for biodiversity, 2) public, state or federal land designated for biodiversity, 3) Public land designated for multiple uses: extractive, recreation and conservation and 4) no known designation for conservation. In order to represent this layer as a variable in

Modelbuilder (ESRI) for least-cost distance mapping, the layer was converted to a raster using the Geoprocessing tool, Convert Feature Class to Raster.

The source roads layer used for this case study comes from the Okanogan County Planning Department FTP site[9]. The layer was imported into the project Geodatabase in ArcGIS Pro (ESRI) as a line feature class. This roads layer did not include seasonally or rarely used logging roads on public lands. Federal and State lands within the AOI have developed guidelines for the management of listed species (all of the focal species of this thesis study are Endangered Species Act listed) as required by the (ESA) (Department of the Interior & U.S. Fish and Wildlife Service, 1973). These plans include species monitoring that informs habitat protection and connectivity within the bounds of public lands. Though the efficacy of these management plans on public lands can be argued, the lack of oversight on private lands undesignated for conservation proves particularly germane to this thesis study. Thus, the roads layer used in this study focuses primarily on road density outside of large blocks of contiguous, National Forest, DNR, WDFW, BLM, or other public lands. That being said, the roads layer used in this study includes highways and other main roads that run through public lands/protected areas.

After preparing each of these data layers to be analyzed in ModelBuilder (ESRI), the time came to begin loading them into models for analysis. ModelBuilder (ESRI) allows the user to build a tool that can be run for various spatial analysis scenarios. The models constructed for this case study included: A) habitat suitability models for each least-cost distance, focal species map and B) corresponding least-cost path corridor

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[9] Okanogan County Planning Department GIS layers. Retrieved from Okanogan County FTP site: ftp://47.25.168.198/

models for each focal species map. The habitat suitability model takes the input variables: elevation, slope, road density, protected areas and land cover and consolidates the data of these layers through a series of Geoprocessing mechanisms. The Focal Statistics Geoprocessing Tool (ESRI) was applied to the slope and elevation variables. This tool calculates output raster values based on the input values within neighboring raster cells. The statistical functionality of the tool provides output calculation options: average, range, or sum of all values within a neighborhood of cells. For the purposes of the model, the range option provided a scale of raster values that could depict change in elevation and slope.

In order to produce a raster output for the roads layer, the roads layer was added to the model and connected to the Line Density Geoprocessing tool (ESRI). The Line Density tool uses the input line feature class to calculate the density of lines within each raster cell (see the following equation). L1 and L2 = the lines within a circle of

$$\text{Density} = ((L1 * V1) + (L2 * V2))/(\text{area of circle})$$

neighboring raster cells. V1 and V2 = the cell values within the area of the circle. The output for this tool was set to calculate for square kilometers. The tool produces a raster, line-density layer with a highest to lowest scale of raster values. It should be noted that an initial least-cost distance map for wolves was generated using the Euclidean Distance Geoprocessing tool (ESRI) for the roads layer instead of the Line Density tool. The methodology for this thesis study uses a road density metric as a proxy for development when generating least-cost distance maps. Additionally, all of the least-cost path maps

Gray wolf (*Canis lupus)*		
Variable	Behavioral/ecological metrics	Source
Land cover	Forest/mixed forest/shrub steppe	(WDFW, 2008)
Elevation	318-2,857 m	(Spence & Wielgus, 2017)
Slope	25°	(Singleton et al., 2002)
Distance from roads	Gravel road = 500 m Main Road = 2500 m	(Taylor, 2010) (Zimmerman et al., 2014)
Road Density	0.72 mi/mi^2	(Wiles et al., 2011)
Housing unit density	≤1 hu (housing unit)/≥ 80 acres = optimal ≤1 hu 40-80 acres = acceptable	(WDFW, 2009)
Dispersal	≤ 1500 km	(Carroll et al., 2006)
Home Range	504 km^2	(Carroll et al., 2006)

Table 2. Gray wolf ecological and behavioral information pertinent to the reclassification of variables for the habitat suitability model and least-cost corridor model. The last column refers to the source for the spatial parameters of each variable.

Grizzly Bear (*Ursus arctos*)		
Variable	Behavioral/ecological metrics	Source
Land cover	Alpine, riparian, avalanche, forest edge, shrub steppe, grasslands, dry interior forests, wet coastal forests	(Lewis, 2018)
Elevation	271-3,732m	(Proctor et al., 2015)
Distance from roads	2198 m	(Gibeau et al., 2002)
Road Density	0.6 km/km^2	(Lewis, 2018)
Housing unit density	≤1 hu (housing unit)/≥ 80 acres	(WDFW, 2009)
Dispersal	Females, ≤ 655 km^2 Males: ≤ 1,088 km^2	(Lewis, 2018)
Home Range	Min.: 100 km^2 Median: 280 km^2 Max.: 440 km^2	(Lyons et al., 2018)

Table 3. Grizzly bear ecological and behavioral information pertinent to the reclassification of variables for the habitat suitability model and least-cost corridor model. The last column refers to the source for the spatial parameters of each variable.

Canada Lynx *(Lynx canadensis)*		
Variable	Behavioral / ecological metrics	Source
Land cover	Boreal forest, subalpine forest, early, mid and late seral forest mosaic	(Squires et al., 2010)
Elevation	1000-2250 m	(Singleton et al., 2002)
Slope	Low slope: < 25°	(Quade et al., 2006)
Road density	1 km/km^2	(Hoving et al., 2005)
Housing unit density	≤ 1 hu (housing unit)/≥ 80 acres = optimal ≤ 1 hu 40-80 acres = Acceptable	(WDFW, 2009)
Home Range	15-25 km^2	(WDFW, 2008)

Table 4. Canada lynx ecological and behavioral information pertinent to the reclassification of variables for the habitat suitability model and least-cost corridor model. The last column refers to the source for the spatial parameters of each variable.

referenced in this study used the roads density metric. Therefore, the model and the map using Euclidean Distance has been excluded from this thesis study, though it can be found in the Appendix.

Land cover and the converted protected areas raster layer represent the final two layers added to the habitat suitability model. The Reclassify Geoprocessing Spatial Analyst tool (ESRI) was then added to each variable of the model. The focal statistics outputs for slope and elevation connected to the Reclassify tool as well as the output for the road density and the landcover and protected areas layers. The Reclassify tool allows the user to customize the range of values symbolized in the map. It also allows the user to choose the number of classes to represent and provides the option to assign a value to each class. At this point, in order to reclassify each variable accurately, it became necessary to refer to the behaviors and ecology of each focal species. For instance, Slope can be an important predictor of what landforms certain species will avoid, or favor while moving across a landscape. For instance, both gray wolves and Canada lynx prefer low slope gradients for movement (≤ 25°) (Quade et al., 2006; Singleton et al., 2002). Therefore, low degree slopes get a value of 1, medium slope angles 2, and the steep slope values received the lowest value of 3. The following tables display all of the focal species and the associated metrics for behaviors and ecology accounted for when reclassifying the variables for the habitat suitability and least-cost corridor models (table 2.) (Table. 3) (Table 4.).

With each variable reclassified according to the ecology and behavioral data for each focal species, the next step entailed the use of the Weighted Sum Geoprocessing Spatial Analyst tool (ESRI). This tool allows the user to assign a value, or "weight" of 1. Five variables can be assigned values from 0-1 adding up to a cumulative total of 1. For example: slope = .1, elevation = .1, roads = .3, land cover = .3, protected areas = .2. Again, this step represents an opportunity to assign weighted values to each variable based on the overall importance of that variable to the target focal species. Therefore, behavioral and ecological attributes of each species determined the weights assigned to each variable (Tables 2, 3 & 4.). Running the Weighted Sum tool produces a raster image which indicates suitable habitat based on highest (optimal) to lowest (poor) habitat values symbolized by a color band. For this study, the color band was resymbolized and assigned 9 classes between a value gradient of 1 (optimal) and 3 (poor) habitat.

The next phase of the model-building required the establishment of habitat core areas for each species. The behavioral/ecological metrics that provided the basis for locations of each species core area within the AOI included: A) a 2,500 m buffer from roads (Tables) (Gibeau et al., 2002; Taylor, 2010; Zimmermann et al., 2014), B) areas with the highest suitability values from the results of the species suitability surface maps, C) areas that were either contiguous with currently protected polygons, or contained within protected area polygons and D) areas that exceeded 450 acres[10] or were connected to protected area polygons. The results from the habitat suitability model indicated the best locations for core areas based on optimal conditions of all five variables: slope, elevation, road density, protected areas and land cover. Distance from infrastructure and development represents the common factor across all taxa within the large carnivore guild (Wolf & Ripple, 2018). Tolerance of roads, housing units and human population centers differ across the individual focal species of this study. Due to the rural landscape make-up of the AOI in general, the most conservative metric for distance to roads could be applied (≥ 2500 m) (Proctor et al., 2015; Taylor, 2010). The size of core areas required a minimum of 500 acres (WDFW, 2009) in order to support the highest degree of biodiversity, unless the core area connected directly to contiguous protected habitat outside of the AOI.

With core areas established, this core areas layer could be added to the model. The Spatial Analyst Geoprocessing tool (ESRI), Cost Connectivity was then added to the

[10] The metric for acres of patch size was adapted from a WDFW metric for large mammals with the highest possible umbrella habitat / biodiversity conservation potential: Washington Department of Fish and Wildlife. (2009). *Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas: A Priority Habitat and Species Guidance Document*. WDFW. 88 pp. + APD, Olympia, WA

model. The core areas and the suitability surface generated connected to the Cost Connectivity tool. Running this tool produced two corridor outputs for each least-cost path species map. The first corridor output was intended to select the path of least resistance across the suitability surface to connect all core areas to one another. The second output retained the original corridor network and added additional corridors linking the outer core areas to one another. Together, the two models (Suitability Model and Corridor Model) were used to create least-cost path corridor maps for each of the focal species of this study. The corridors themselves were assigned a 1000 ft width (WDFW, 2009) buffer in order to satisfy the focal species requirements and preserve umbrella habitat for the greatest number of additional species possible. The following figure provides an example one of three least-cost path models built for each species (Figure 13.).

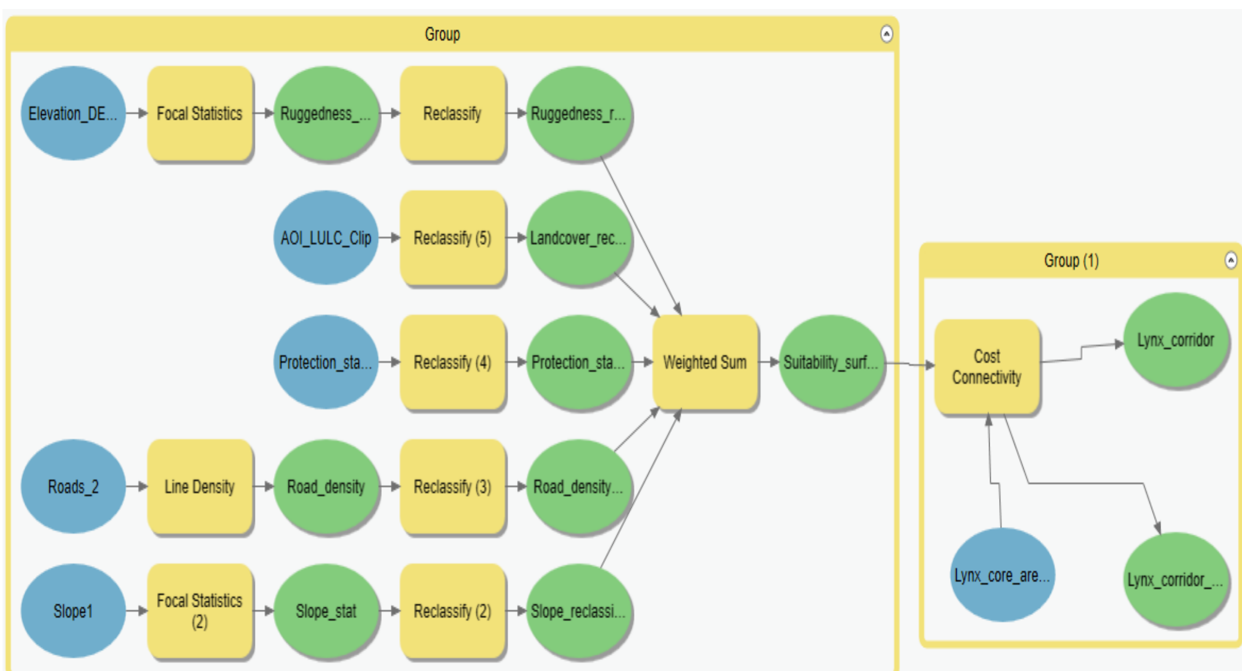

Figure 13. The build-out in Modelbuilder (ESRI) of the two-part, habitat suitability and corridor tool constructed for to assess the habitat suitability and least-cost corridor path for Canada lynx.

Using census data to determine permeability and conservation potential of private lands

As previously stated, anthropogenic development represents a growing obstacle to habitat connectivity across the study area and on a landscape scale between the Cascades and the Rocky Mountains (Suring et al., 2011; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). Though public lands "Protected Areas" had been incorporated into the least-cost distance maps, private lands were assigned a "no conservation" designation classification by default for the least-cost distance analyses. Housing unit density could serve as the variable by which to assess conservation potential retained by private lands. Therefore, the final variable selected for analysis consisted of three years of census data provided by the USDA Forest Service Northern Research Station for the express intent of aiding research regarding development of the urban wildland interface[11]. The census worksheets contained population and housing information for the 1990, 2000 and 2010 census. The statistical analysis for this variable was conducted in both ArcGIS Pro (ESRI) and Microsoft Excel. Representational charts and graphs of housing unit data results were generated in Microsoft Excel, Word and ArcGIS Pro (ESRI).

WDFW (2009) provides a recommended distance from housing units for species with a high sensitivity to development (Table 5.). This metric became the basis for a set of performance standards by which each individual census block group within the AOI

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[11] Radeloff, Volker C.; Helmers, David P.; Kramer, H. Anu; Mockrin, Miranda H.; Alexandre, Patricia M.; Bar Massada, Avi; Butsic, Van; Hawbaker, Todd J.; Martinuzzi, Sebastián; Syphard, Alexandra D.; Stewart, Susan I. 2017. The 1990-2010 wildland-urban interface of the conterminous United States - geospatial data. 2nd Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2015-0012-2

could be ranked. For this analysis, the census block group represented the independent variable, as block groups will be tested to determine their permeability values for the suite of focal large carnivores of this study. Acres and housing units represented the dependent variables, as the number of housing units and acres per block group were calculated to determine how a block group would perform. The metric weighed the performance of individual block groups based on: A) landscape permeability for large carnivores and B) habitat quality/suitability on those block groups which depended on the number of houses per block group and whether or not the block group contained undeveloped lands (Table 6.). Because this exercise was designed to evaluate suitable habitat on private land, block groups with ≥ 95% area contained within the boundaries of a protected area where no housing units were present were excluded from the study of housing units/acres/block group. Block groups entirely encompassing open water were excluded from the study, as these surfaces proved inapplicable to both housing unit development as well as terrestrial species habitat.

The statistical analysis for this study was performed in Excel, then visually confirmed by examining each block group with a satellite imagery basemap in ArcGIS

Development response group	Undeveloped	Rural/ Resource/ Conservation
Large mammals with extensive movement, moderately fragmentation tolerant	0 hu/0 ac	1hu/40ac to 1hu/80ac
Wide-ranging mammals, fragmentation intolerant	0 hu/0 ac	≤ 1hu/≥ 80ac

Table 5. The above table demonstrates the development tolerance of the focal species of the large carnivore guild. Modified from: WDFW. (2009). Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas: A Priority Habitat and Species Guidance Document. *WDFW. 88 pp. + APD, Olympia, WA*

Performance Standards	Performance Metric
1 (optimal)	≤1 hu/≥ 80 + acres
2 (acceptable)	≤1 hu/40-80 acres
3 (poor)	>1 hu/≤ 40 acres

Table 6. Performance standards indicating habitat quality and level landscape permeability for focal species and accompanying metrics that define the parameters of performance standards. Adapted from: WDFW. (2009). *Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas: A Priority Habitat and Species Guidance Document*. WDFW. 88 pp. + APD, Olympia, WA

Pro (ESRI). All small acre block groups (<40 acres) containing no housing units were absorbed by their nearest neighboring block group and the performance standard designation assigned to that neighboring block group. For instance, a block group containing 0 hu (housing units)/2 acres proximal to a block group with a performance standard 3 receives a performance standard 3 ranking. Each block group designation required visual confirmation due to land use practices within the block group area. For instance, a block group was identified within the data as optimal (performance standard 1); upon further examination on the imagery basemap in ArcGIS Pro (ESRI), the block group contained no housing units due to the fact that the entire area represented an off-road vehicle recreation track. Therefore, each block group required visual confirmation before a final performance standard ranking could be assigned to the area. Finally, upon completion of this system of ranking by block group across the entire AOI, a map could be generated. This map depicted 1 (optimally), 2 (acceptably) and 3 (poorly) performing block groups symbolized by different colored polygons. Additionally, this map showed protected area polygons in order to depict the permeability of private property in relationship to currently conserved areas.

Finally, a statistical analysis of housing unit data was conducted in order to determine the housing unit growth rate from 1990-2010 within the AOI. For this analysis block groups had already been ranked, so the block group categorized by its performance rank represented the independent variable. Time, acres and housing units represented the dependent variables to be measured. The mean housing unit increase on optimally (1), acceptably (2) and poorly (3) performing census block groups was then be calculated for each census year (1990, 2000 and 2010). Using ArcGIS Pro Statistics tools (ESRI), mean housing unit increase was represented on the Y axis and the block groups separated by performance standards on the X axis. The mean housing unit increases for each census year was then compared using, either a stacked color-coded bar graph, or side by side for 3 columns on the X axis representing: optimally (1), acceptably (2) and poorly (3) performing block groups. For the second part of this study of change over time, the equation (A-B)/B=P was employed in order to find out the percent change in housing unit density between 1990 and 2010 where *A* = the total number of housing units in 2010 and *B* = the total number of housing units in 1990 and *P* = the percent change over time.

The statistical analysis of housing density change was used to produce the percentages of optimally (1), acceptably (2) and poorly (3) performing block groups within the AOI. The result the first phase of analysis provided a snapshot of landscape permeability based on 2010 housing unit census data within the AOI. Whereas, the second phase, calculating the rate of change in development over three census years (1990, 2000, 2010), was employed in order to demonstrate how housing unit density changed over time. Moreover, this change over time analysis demonstrates how development has been trending in order to prescribed conservation actions that can have a positive effect for the future of landscape permeability and overall biodiversity across the AOI.

RESULTS & DISCUSSION

Priority Habitat and Species areas, focal species occurrence data and climatic factors

Okanogan county represents a highly important area for conservation of Priority Habitat and Species of Washington State, as delineated by WDFW (Washington Department of Fish and Wildlife, 2008). The North Cascades ecosystem contains the highest number of focal species occurrences in the county (Figure 16). The North Cascades National Park gives way to the Pasayten Wilderness, east of the Pacific Crest Trail. These federally protected areas prevent most anthropogenic disturbance outside of certain limited recreational activities like hiking, horse-packing and backcountry camping. Thus, these lands provide refugia to the focal large carnivores of this case study. Occurrence data within the AOI confirms the strong presence of Canada lynx within the Okanogan LMZ as well as occasional gray wolf and grizzly bear occurrences (Figure 17.).

The Loup Loup gray wolf pack resides west of the Okanogan River Valley partially within the western half of this case study AOI (Washington Department of Fish and Wildlife et al., 2018) (Figure 14.). The Loup Loup pack, comprised of two known members (Washington Department of Fish and Wildlife et al., 2018), likely accounts for the few gray wolf occurrences within the AOI.

Highly credible, confirmed grizzly occurrence data put the number of grizzly bears in the Cascades of Washington State at ≤ 20 individual bears by the 1990s (Knibb, 2008). Over the past 25-30 years, due to stochastic pressures, that number may have declined as much as 100% with only five unconfirmed grizzly bear sightings occurring between 2010 and 2015 across the entire NCRZ (North Cascades Recovery Zone), all within the British Columbia portion of the Cascades (Lewis, 2018) (Figure 15.).

The map representing Canada lynx occurrence data across the Okanogan portion of the LMZ presents a rosier picture than may be the case on the ground (Figure 16.). Successive fires across the Okanogan LMZ from 2000-2015 contributed to a 36-68% reduction of the female lynx population (Lyons et al., 2016). Additional large fires in the Kettle LMZ reduced the female lynx population by 30-52% (Lyons et al., 2016). According to climate projections, the entire LMZ within Washington State could experience ≤ 25 additional days of high fire risk per year (Abatzoglou, 2013). Additionally, according to high emissions scenario projections from the IGPCC (Inter-governmental Panel on Climate Change), Canada lynx could experience a near complete range contraction east of the Cascades in Washington State (Shafer et al., 2015).

Though suitable habitat and therefore, home range changes appear to be sweeping for Canada lynx under high emissions projections between the Cascades and the Rocky Mountains, pockets of lynx habitat may remain stable in the North Cascades and the Kettle River Range (Shafer et al., 2015) (Figure 18.). With historical Canada lynx habitat changing across Washington State, the need for a wildlife linkage between resilient subalpine habitat patches in the North Cascades and the Kettle River Range becomes imperative to the recovery of Washington's Canada lynx populations (National Fish and Wildlife Foundation, 2017).

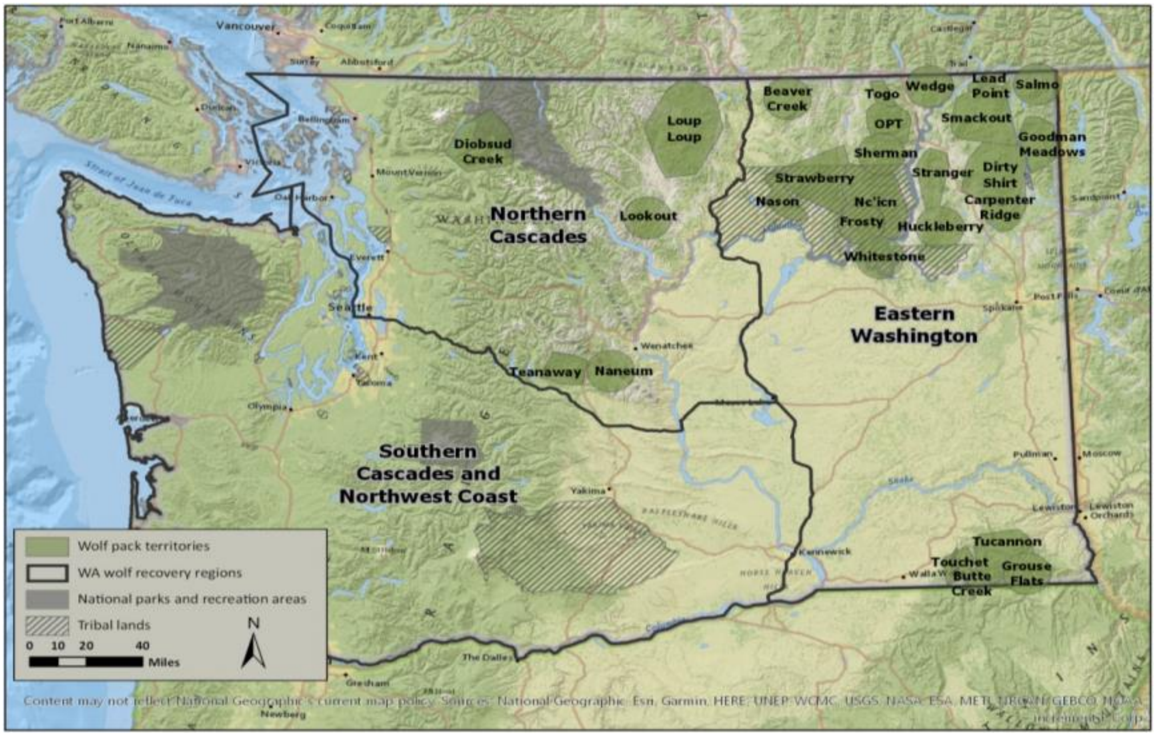

Figure 14. Map of known gray wolf packs including names and their home ranges within Washington State. Source: Washington Department of Fish and Wildlife, Confederated Colville Tribes, Spokane Tribe of Indians, USDA-APHIS Wildlife Services, & U.S. Fish and Wildlife Service. (2018). *Washington Gray Wolf Conservation and Management 2017 Annual Report* [Annual Report]. Wenatchee, WA, USA: Washington Department of Fish and Wildlife.

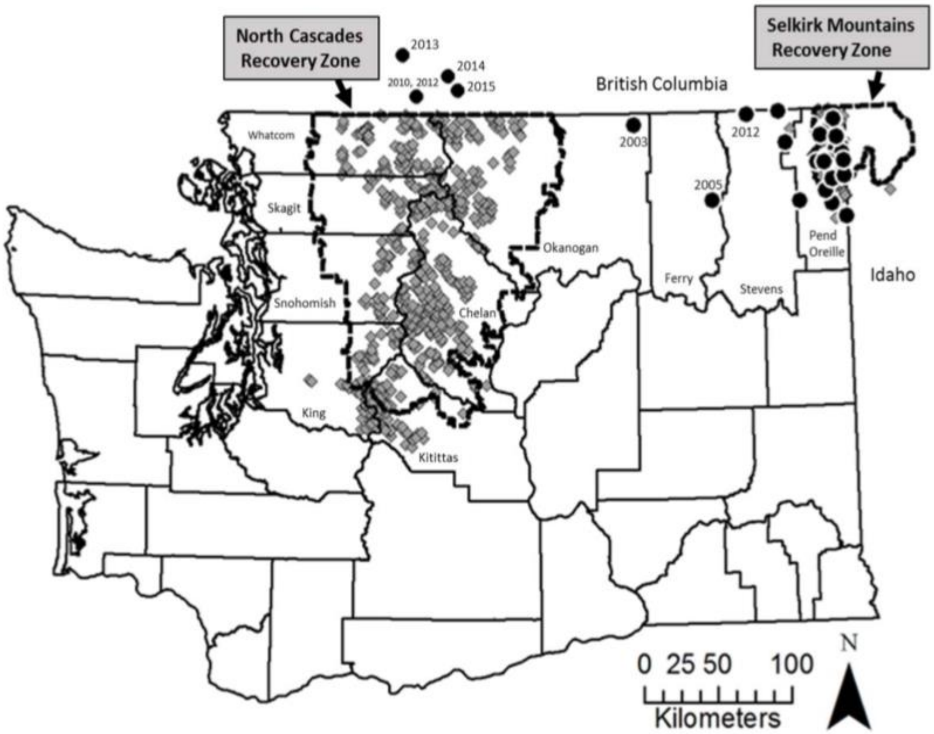

Figure 15. This map depicts the confirmed occurences of grizzly bear sightings within WA and Southern BC (symbolized by black dots). The diamonds symbolize monitoring and survey stations. Source: Lewis, J. C. (2018). *Draft Periodic Status Review for the Grizzly Bear in Washington* (p. 15+ iv pp). Olympia, Washington: Washington Department of Fish and Wildlife.

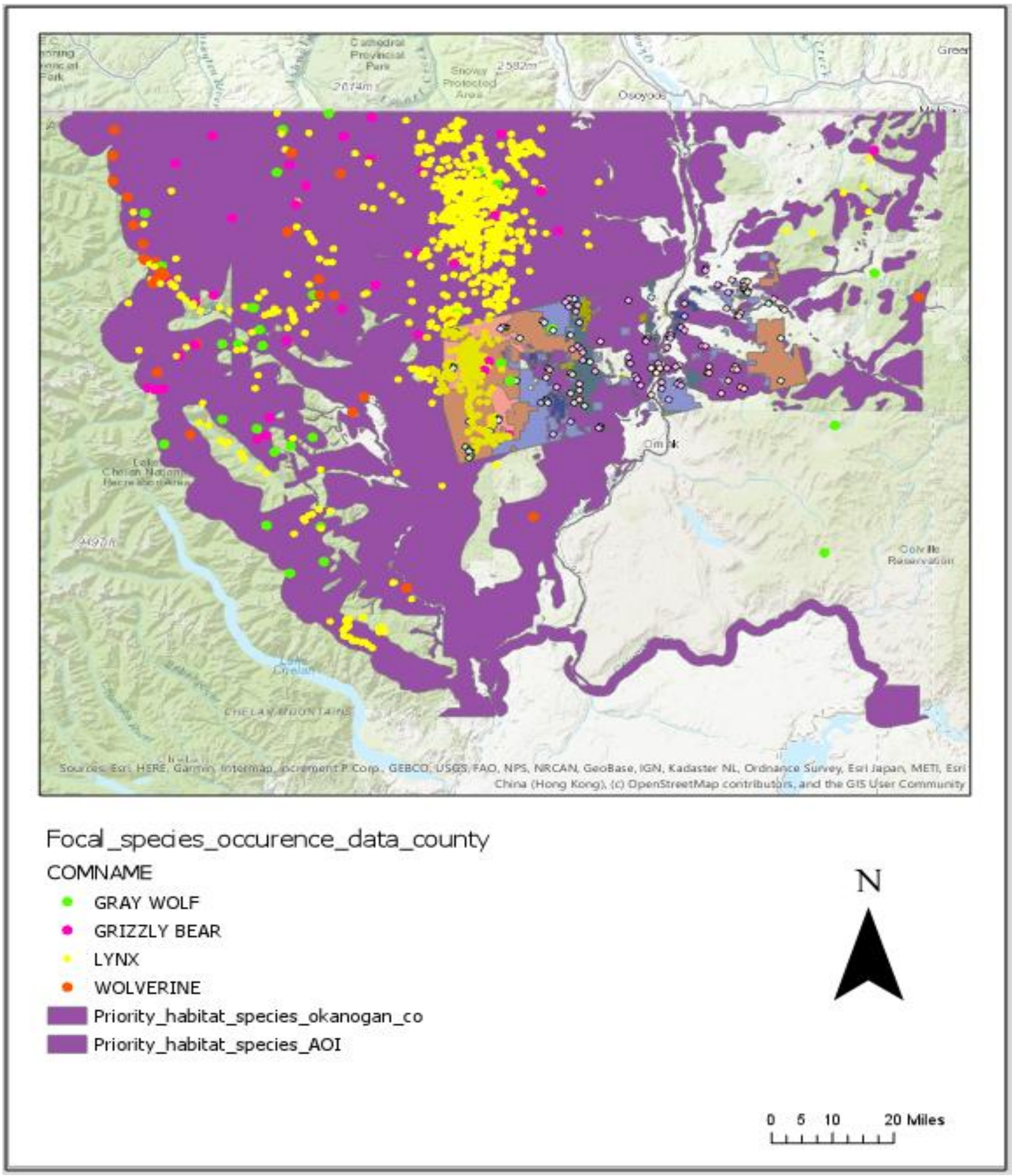

Figure 16. This map contains Priority Habitat & Species areas (dark purple)[12] for Okanogan County. The map displays the AOI extent (with protected areas layer active) within the

[12] PHS data retrieved from Okanogan County FTP (ftp://47.25.168.198/) in conjunction with the WDFW PHS on the Web Application (http://apps.wdfw.wa.gov/phsontheweb/)

county as well as occurrence data for all focal species represented by colored dot feature classes[13].

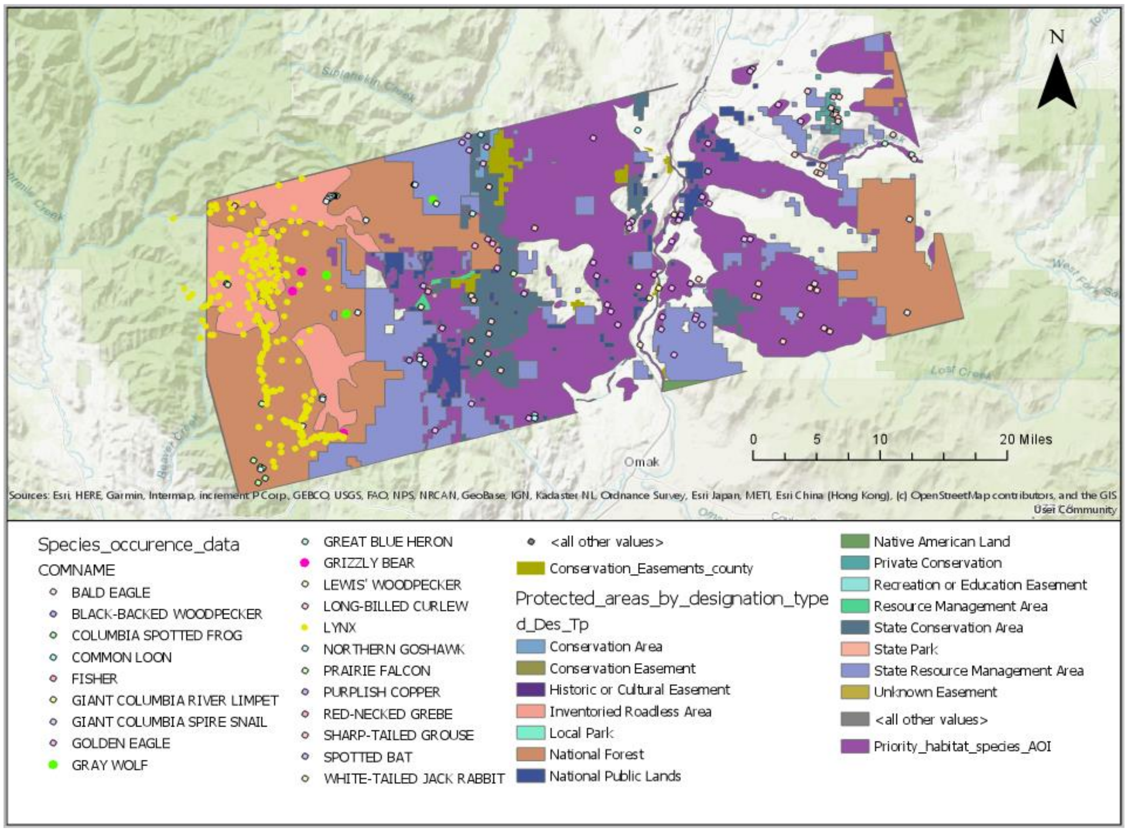

Figure 17. This map displays Priority habitat within the AOI (dark purple). This layer is overlapped by the protected areas layer in order to showcase unprotected areas that fall within the designation of PHS. Occurrence data includes focal species as well as all other PHS designated species within the AOI.

[13] Focal species occurrence data retrieved from Okanogan County Planning section of FTP site (http://apps.wdfw.wa.gov/phsontheweb/) in conjunction with WDFW Priority Habitat and Species List (https://wdfw.wa.gov/species-habitats/at-risk/phs/list

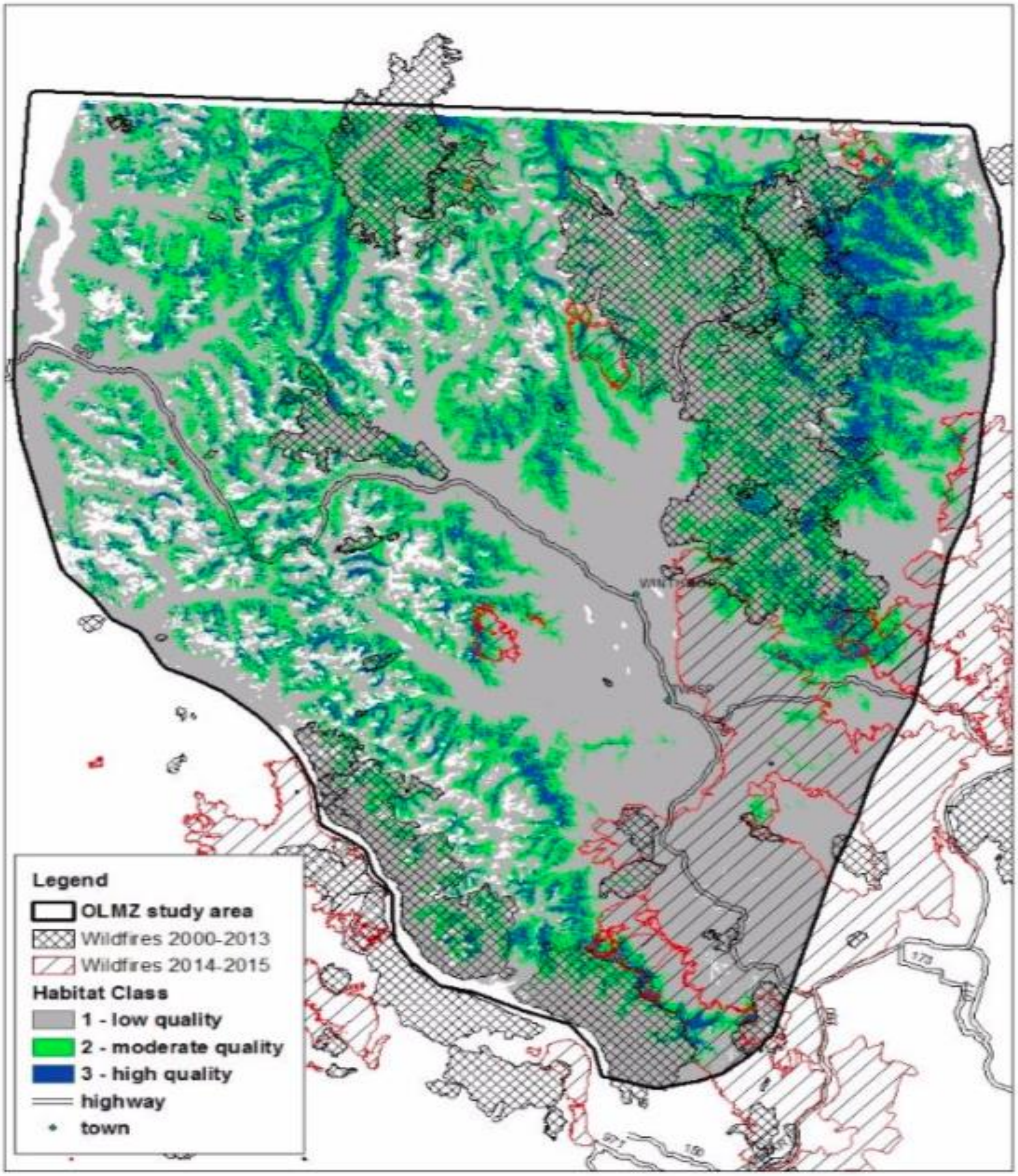

Figure 18. Fires within the Okanogan LMZ from 2000-2015. The map additionally displays habitat pos-fire habitat quality across the OLMZ. Source: Lyons, A. L., Gaines, W. L., Begley, J., Singleton, P. H., Lewis, J. C., & Maletzke, B. T. (2016). *Canada Lynx Carrying Capacity in Washington* (Final Report No. 16–06588; p. 32). Olympia, WA: Washington Conservation Science Institute, USDA Forest Service Pacific Northwest Research Station, Washington Department of Fish and Wildlife.

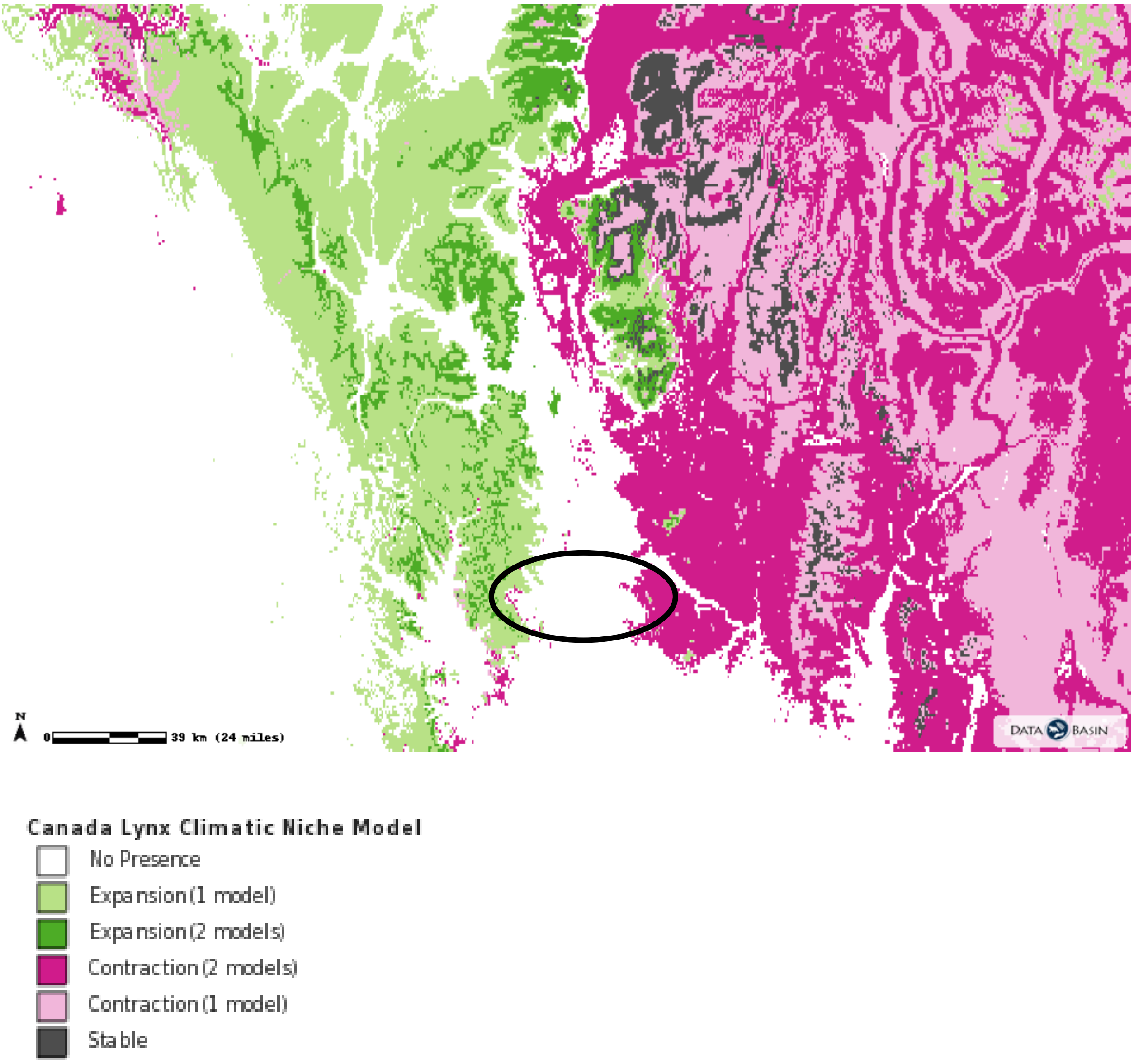

Figure 19. The above map displays Canada lynx range contraction and expansion projections based high emission scenarios (CMIP3 Global Circulation Models (GCMs): CGCM3.1 and Hadley CM3). The black outlined area represents the AOI of this case study. Directly east of the AOI, the gray (stable)habitat represents high elevations of the Kettle River Range. Source: Shafer, S. L., Bartlein, P. J.,Gray, E. M., & Pelltier, R. T. (2015). *Projected Future Vegetation Changes for the Northwest United States and Southwest Canada at a Fine Spatial Resolution Using a Dynamic Global Vegetation Model*. PLOS ONE, 10(10), e0138759. Retrieved from: Databasin profile for: The North Pacific Landscape Conservation Cooperative: Washington-British Columbia Climate Connectivity Project: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e#expand=105364%2C109

Wolverines rely on lingering spring snowpack for protection from other predators during their natal denning period. Additionally, deep snow drifts provide a means of preserving meat caches, thereby maintaining a high energy food supply for lactation and natal denning of wolverine mothers (February-April) (Inman et al., 2012). Occupying alpine habitat year-round precludes interspecific competition between wolverines and generalist predators that typically occupy habitat at lower elevations (Aubry et al., 2007). Wolverine occurrences appear within the larger Okanogan county map extent (Figure 16.) however, no recorded wolverine sightings occurred within the case study AOI (Figure 17.). As alpine habitat becomes scarce and isolated, range contraction for wolverines within Washington State could reach 100% east of the Cascades (Shafer et al., 2015) (Figure 20.). Spring snowpack projections for the Cascades show pockets of April snowpack retention at high elevations, though April snowpack appears to undergo a near 100% reduction by 2080 east of the Cascades to the Selkirk Mountains[14] (Figure 21.). Therefore, wolverines were excluded, as a focal species, from the case study due to the overwhelming evidence that wolverines will have very little to no viable habitat east of the Cascade Crest within Washington State under future climatic conditions.

[14] April 1 snowpack highest emissions scenario projection (CanESM2 estimate) for 2080. Change gradient symbolized by, 0 (yellow)-100% (dark red) change. Source: Integrated Scenarios of the Future Northwest Environment:http://climate.nkn.uidaho.edu/IntegratedScenarios. Retrieved from: Databasin profile for: The North Pacific Landscape Conservation Cooperative: Washington-British Columbia Climate Connectivity Project:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e#expand=105364%2C109

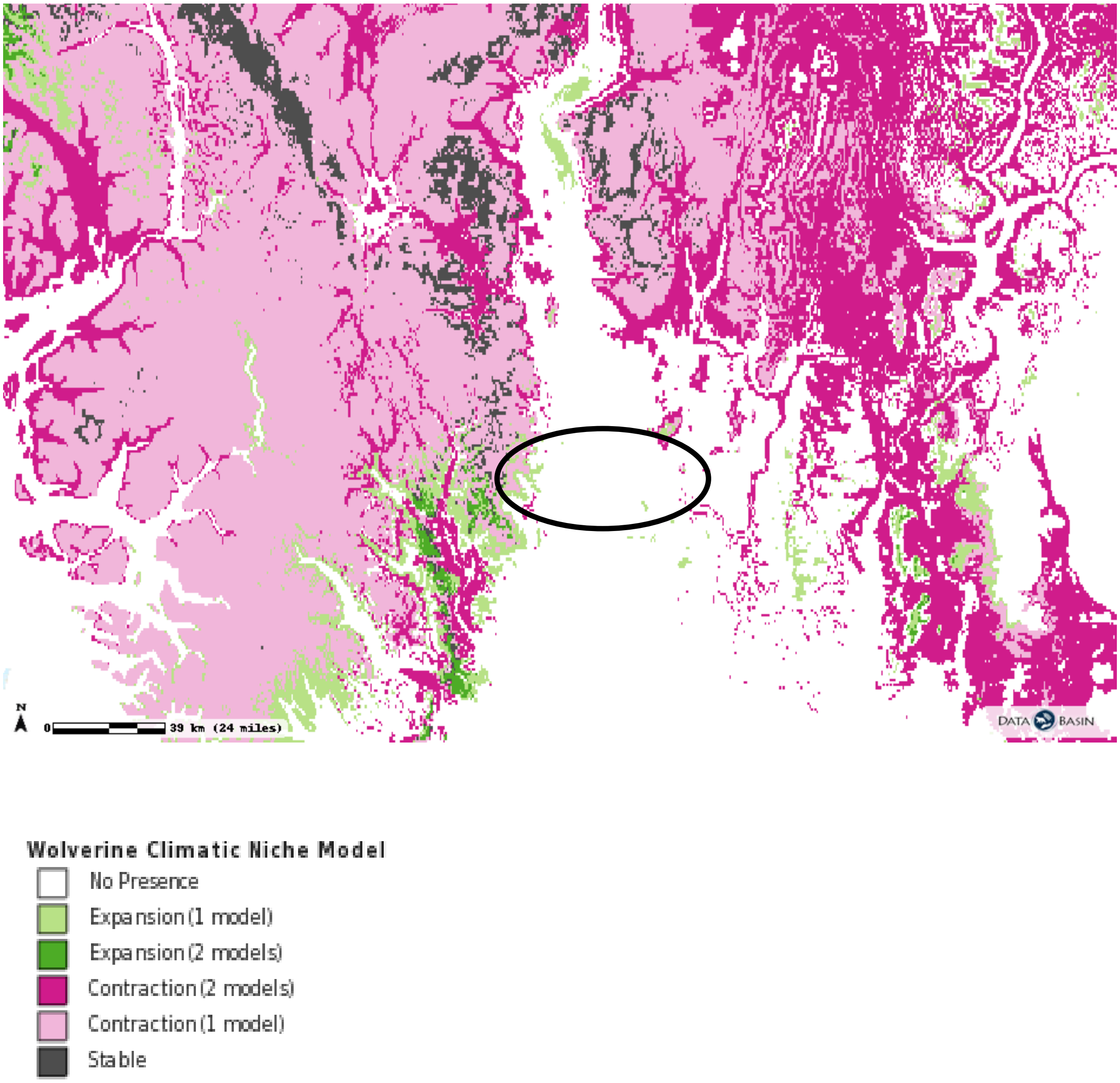

Figure 20. The map above displays projected wolverine range expansion/contraction across a transboundary area between WA and BC, Canada. The black outline represents the AOI for this case study. Source: Shafer, S. L., Bartlein, P. J., Gray, E. M., & Pelltier, R. T. (2015). *Projected Future Vegetation Changes for the Northwest United States and Southwest Canada at a Fine Spatial Resolution Using a Dynamic Global Vegetation Model*. PLOS ONE, 10(10), e0138759. Retrieved from: Retrieved from: Databasin profile for: The North Pacific Landscape Conservation Cooperative: Washington-British Columbia Climate Connectivity Project: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e#expand=105364%2C109

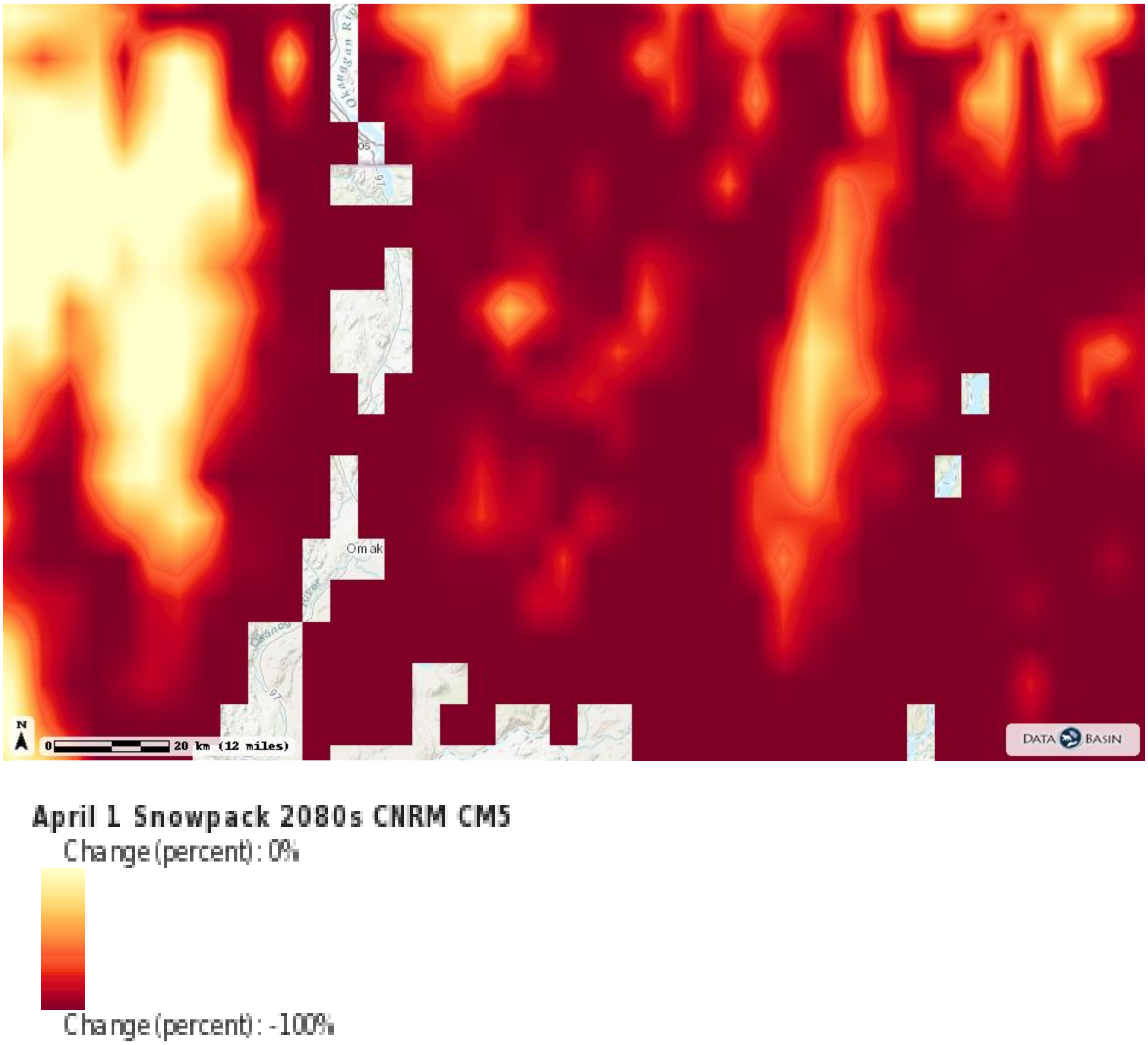

Figure 21. April 1 snowpack highest emissions scenario projection (CanESM2 estimate) for 2080. Change gradient symbolized by, 0 (yellow)-100% (dark red) change. Source: Integrated Scenarios of the Future Northwest Environment: http://climate.nkn.uidaho.edu/IntegratedScenarios. Retrieved from: Databasin profile for: The North Pacific Landscape Conservation Cooperative: Washington-British Columbia Climate Connectivity Project: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e#expand=105364%2C109

Focal species least-cost distance maps

Gray Wolves

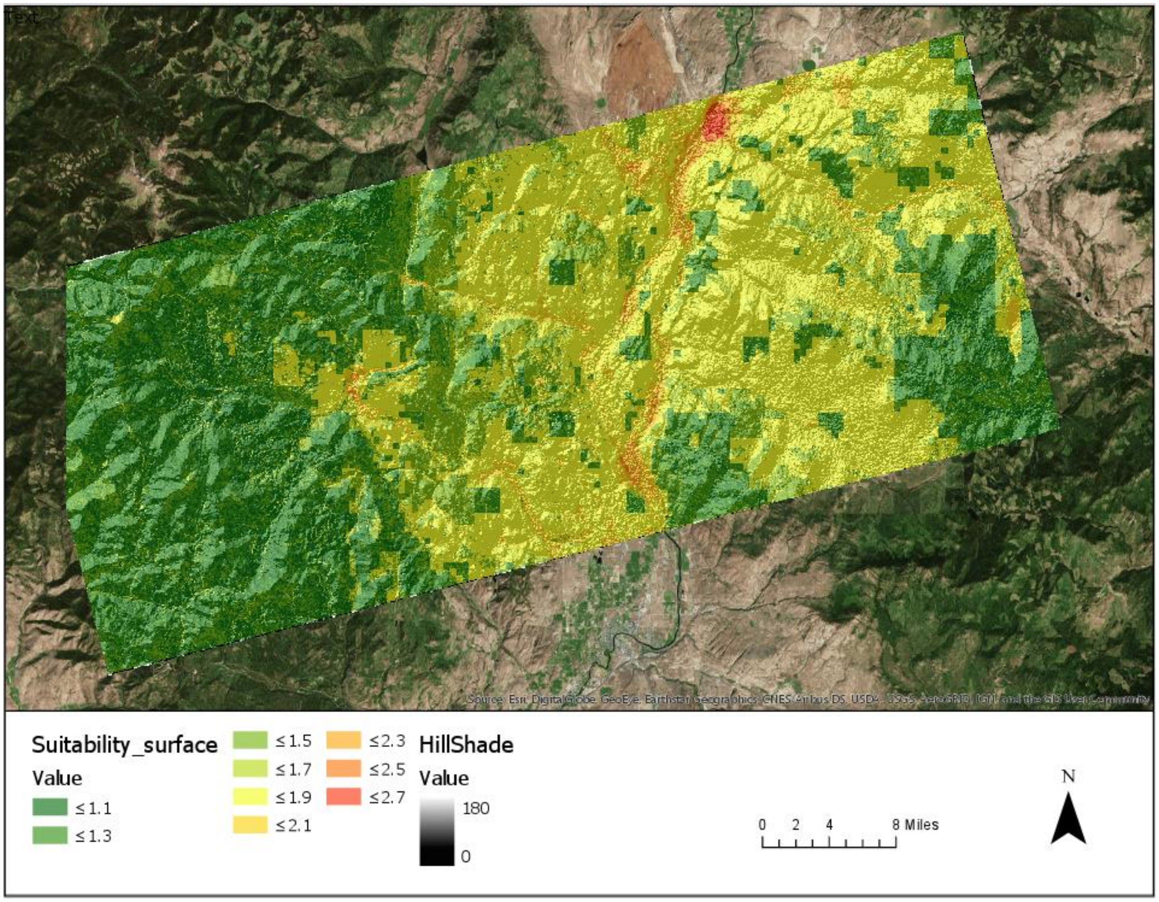

Figure 22. Habitat suitability map for gray wolves. This raster surface features a habitat suitability color gradient symbolized from green (optimal) to red (poor). Hillshade added to convey landscape dimension, elevation and ruggedness.

The Gray wolf habitat suitability surface (Figure 22.) depicts high suitability (dark green) habitat within National Forest and state public lands both west and east of the Okanogan River Valley. Suitable habitat gives way to moderate suitability (yellow) as elevation decreases and public lands give way to private property. The least suitable habitat occurs at the points where Highway 97 runs directly parallel to the Okanogan

River (red). Both road infrastructure as well as residential development along the river and Highway 97 contribute to this low suitability score at the fracture zone. In an arid climate, The Okanogan River provides a valuable irrigation resource for the agricultural industry of Okanogan County (Okanogan Conservation District & Martin, 2018). Additionally, the river proves equally essential to wildlife as a climate refuge (Quinn et al., 2018). The following set of corridor results isolates areas where extant development and infrastructure remain at low levels at the Highway 97/Okanogan River Valley fracture zone. As stated previously in the methods section, if conserved, these areas retaining riparian habitat can provide valuable connective habitat to the focal large carnivores of this study as well as invaluable umbrella habitat to other species guilds within the Okanogan Valley ecosystem.

The gray wolf suitability surface provides a spatial/visual representation of a habitat suitability gradient. The mean and standard deviation of the habitat suitability values was generated using ArcGIS Pro Statistics (ESRI). The Y axis shows the count of raster cells and the X axis displays a suitability gradient represented by values from 1-3 broken into 32 possible bins. The mean value of habitat suitability across the AOI (1.45) indicates that the overall habitat suitability for the AOI performs slightly above average. The standard deviation (0.32) demonstrates that the suitability values most often fall between one standard deviation from the mean. This puts most raster counts across the AOI between suitability values of 1.13 and 1.77. Interestingly, the suitability values between 1-1.05 on the left tail and 1.69-1.73 on the right tail of the histogram represent most of the overall cell values of the suitability surface. The suitability values 1.69-1.75 represent the highest number of raster cells by a count of 320,000 cells, nearly 50%

higher than any other suitability value. Although this suitability value (1.69-1.75) falls below the mean, the number of cells that represented above average suitability across the AOI = 630, whereas the number of cells below the mean (with higher than average suitability values) = 590 (Figure 23.).

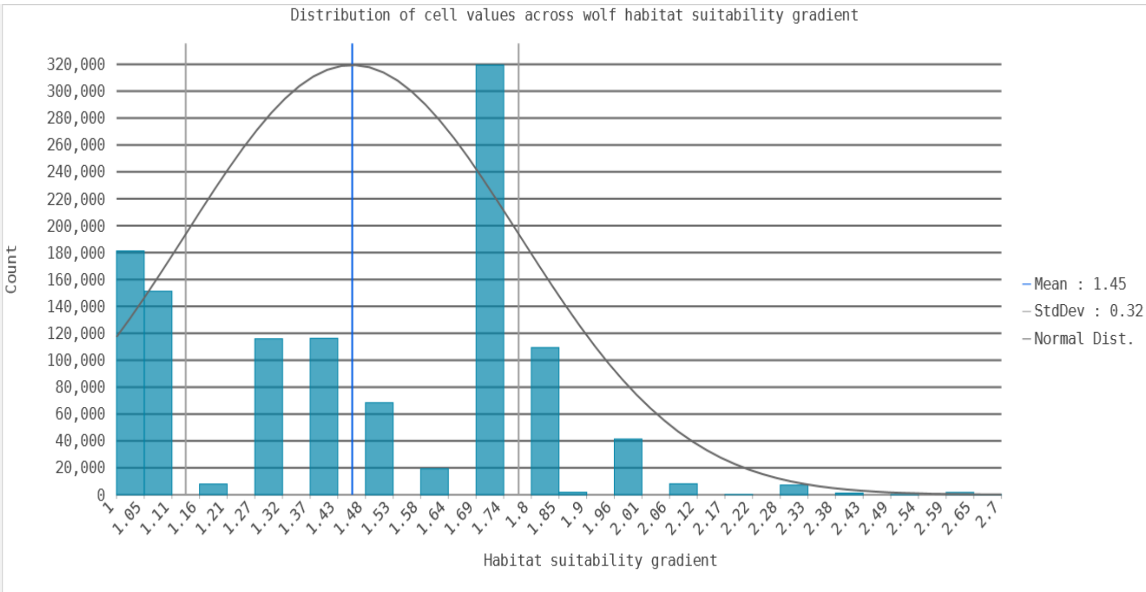

Figure 13. Histogram (normally distributed) shows the raster cell count (Y axis) by habitat suitability values (X axis) 1-3 divided into 32 bins. The mean suitability value = 1.45 and the standard deviation = 0.32.

The core areas and corridors map (Figure 24.) depicts the gray wolf habitat suitability surface. In addition, this map includes the gray wolf core areas and the all buffered corridor layers and the roads layer. Both this map as well as the previous map include the active hillshade layer in order to convey dimension, ruggedness and elevation of the landscape features across the AOI. The discussion of the resulting least-cost distance maps will not focus heavily on corridors completely contained within the bounds of protected public lands. For the purposes of this thesis study, these areas prove essential to linking core habitats within contiguous, conserved lands within and beyond the AOI.

They do not, however, illustrate the importance of linking habitat through unprotected, private lands. The focus of this thesis study will be on the corridors linking core areas across private lands and the fracture zone represented by the Okanogan River Valley and the Highway 97. The discussion of the results of the least-cost distance maps will additionally include the ways that the corridor networks link vulnerable, lateral habitat between core areas west and east of the Okanogan Valley and the Highway 97 fracture zone.

The gray wolf core areas east of the river valley that were not located within currently protected areas received the designation of core areas due to: A) distance from road infrastructure B) proximity to protected areas and C) the favorability of other variables such as slope, elevation and land cover. If conserved, these core areas outside of currently protected areas could prove vital to connecting terrestrial habitat across the AOI. They effectively reduce the corridor distance between currently protected areas and provide a larger area of umbrella habitat than that of the 1,000m corridor buffer width. As previously stated in the Methods section, one of the requisite qualifiers of a core area for this thesis study is that it must be ≥ 450 acres in area, or contiguous with public, protected lands.

The roads layer indicates the degree to which the suitability surface and the cost corridor tool in ArcGIS Pro (ESRI) worked to avoid areas with higher road density. It is important to note, when discussing road infrastructure and wildlife, that different road types (i.e. county, gravel, forest service, highways) can affect specific taxa to a lesser or greater degree (Van der Ree et al., 2011; Zimmermann et al., 2014). Forest service roads and logging roads represent routes that receive infrequent or seasonally dependent human

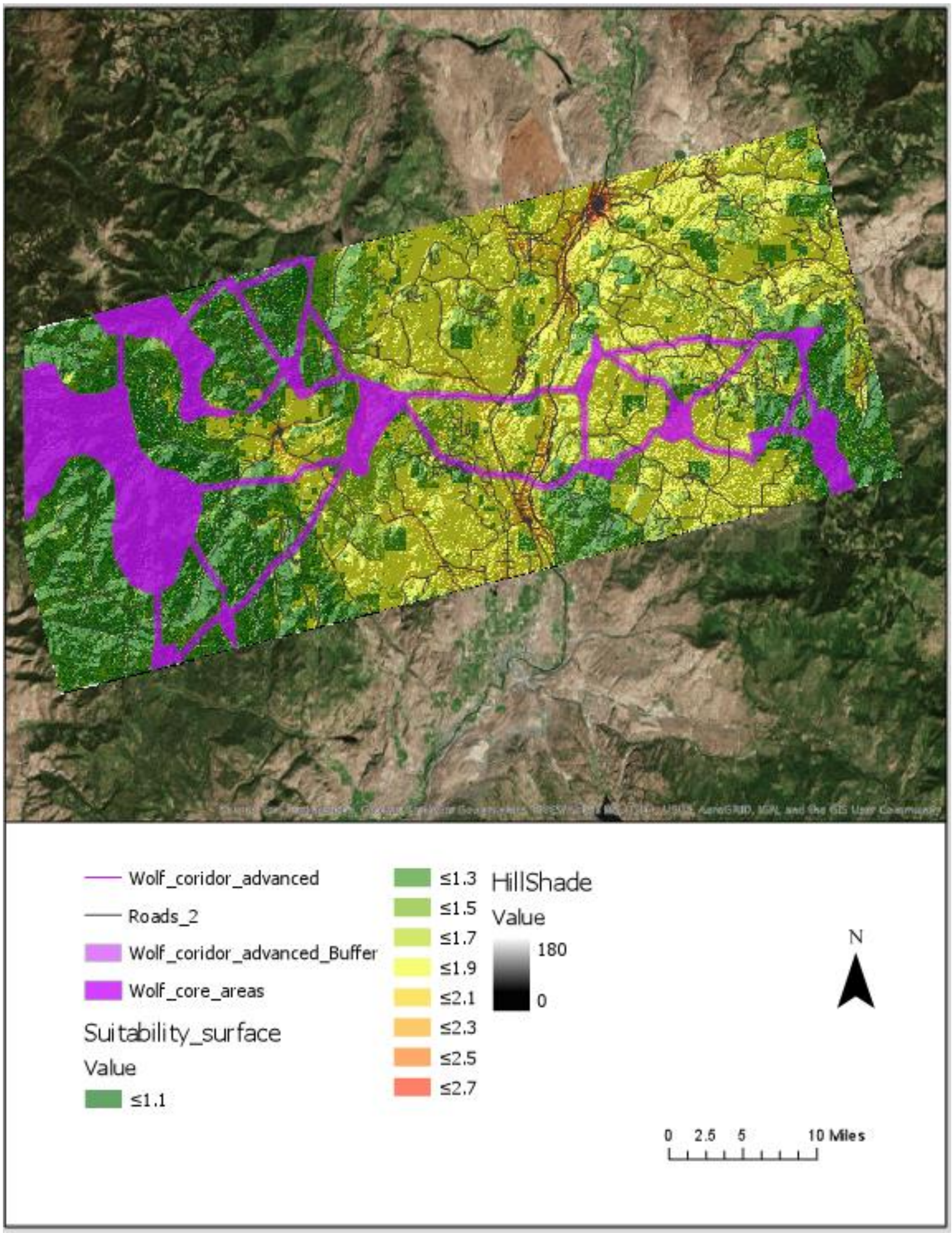

Figure 24. Grey Wolf suitability surface with core areas (purple) and all corridors (purple) active as well as the roads layer and hillshade layer active.

use. Private gravel roads tend to be travelled less frequently and at lower velocities than say, county roads. Even highways, though a barrier to most taxa, provide a benefit to others. Rytwinski & Fahrig (2013) found that some populations of mammalian prey species with high reproductive rates prospered in places with greater road densities due to the avoidance of these areas by large carnivore generalist species averse to high road densities. That said, high speed/traffic road infrastructure presents a clear and present danger to the focal species of this case study (Aubry et al., 2007; Bissonette & Cramer, 2006; Sawaya, et al., 2013). Habitat generalists, gray wolves also exhibit a high degree of habitat plasticity. In other words, they become highly adaptable to the habitat conditions of their home ranges over time (Zimmermann et al., 2014). Gray wolves will use gravel and dirt roads for travel, though they tend to use them at night when human activity is low, or nonexistent (Taylor, 2010). Unfortunately, any use of active (non-decommissioned) roads by gray wolves increases the odds of wolf/human interaction and wolf mortality (Way & Bruskotter, 2012). Because human/wolf conflict represents the greatest danger to wolves within the case study area, road density was the most heavily weighted variable within the habitat suitability and corridor models. Of the two corridors that cross the fracture zone, the northerly corridor option avoids most roads, whereas the southerly corridor option avoids main roads while providing the shortest linkage distance between currently protected areas. Additionally, this corridor follows the same trajectory across the AOI as the lynx and grizzly bear corridors.

Canada lynx

The habitat suitability surface for Canada lynx depicts the most viable habitat occurring within currently protected areas (DNR, WDFW and Okanogan National Forest lands). Canada lynx represent an ESA listed, Threatened Species, thus these state and federal agencies have management plans for Canada lynx on public lands. Much like the gray wolf suitability surface, habitat adjacent to public lands provides average suitability

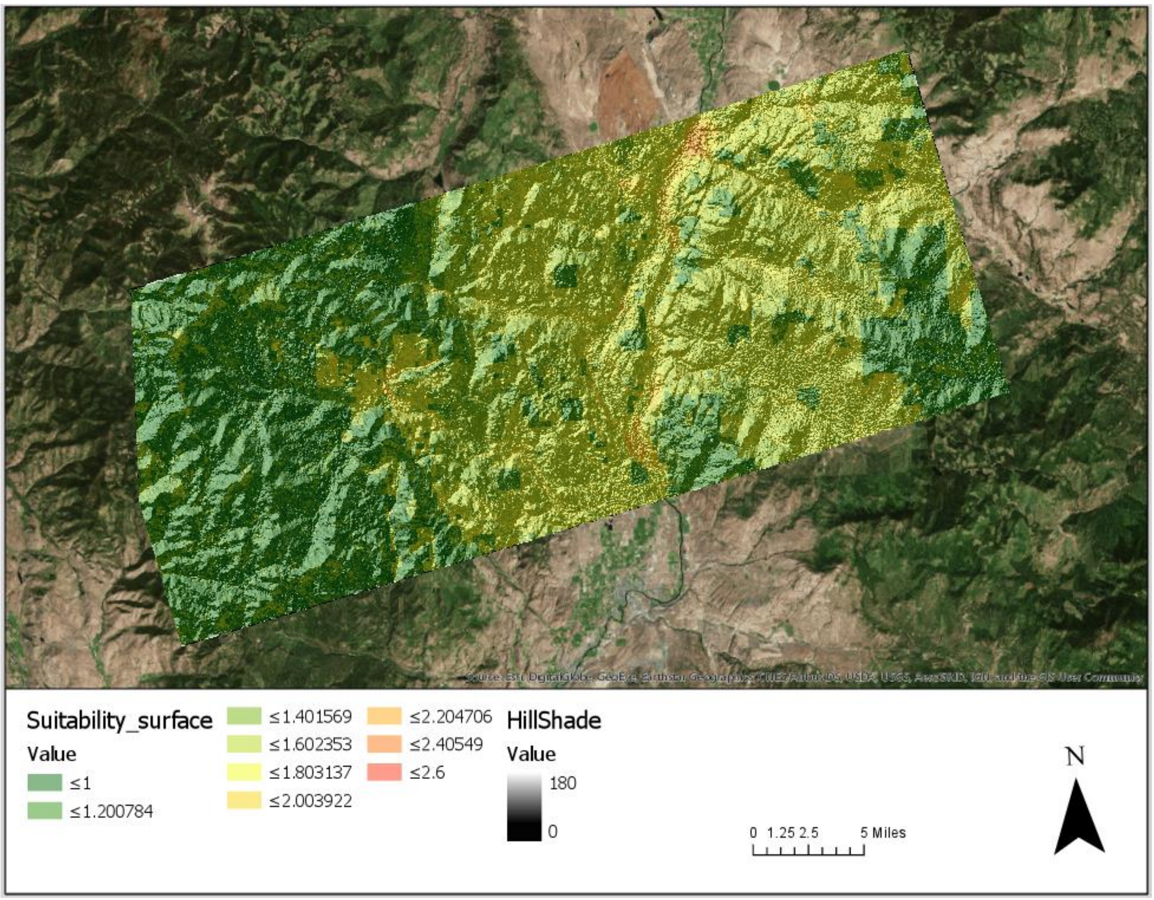

Figure 25. Canada lynx habitat suitability surface symbolized by 9 class color gradient between values 1-3. Suitability values: highest suitability = (dark green)/3 = lowest suitability (red).

(Figure 25). Additionally, habitat on the outskirts of the towns of Tonasket and Riverside appears the least suitable across the AOI for Canada lynx. The suitability surface for lynx includes lower elevation ecotypes that lynx would only use for the purpose of long-range dispersal. As cover obligates of subalpine forest habitat, Canada lynx movement patterns within the Okanogan LMZ tend to be north/south within a specific elevation band and ecotype (Quade et al., 2006). However, in the absence of prey availability, mates and suitable denning habitat, lynx will disperse widely across multiple ecotypes in search of optimal home range conditions (Lyons et al., 2016).

The normalized histogram of the Canada lynx suitability surface shows a mean suitability value of 1.43 and a standard deviation of 0.28 (Figure 26.). The mean falls slightly above average suitability, while the deviations from the mean fall within a nearly optimal (1.15) to slightly below average range (1.70). The mean and standard deviations indicate that the majority of the values of the suitability surface fall within a range of excellent to slightly below average habitat for dispersal across the AOI. The highest raster cell counts results could be found between below average suitability, 1.6-1.65 representing 350,000 cells. On the other hand, excellent suitability values between 1-1.05 and 1.2-1.25 accounted for 175,000 cell counts (1-1.05) and 250,000 cell counts (1.2-1.25) respectively. All suitability values beyond 1.9 represented the outliers. This would indicate that very little poor habitat exists across the AOI for Canada lynx. It appears somewhat misleading to suggest that, for a cover obligate species with a home range restricted to subalpine forest, this area of interest would provide any ideal habitat. It is important to stress that although the habitat types represented within the AOI primarily alternate between cool, montane conifer forest and shrub steppe at lower elevations, the AOI of this thesis study provides a wildlife linkage for long-range dispersal between larger habitat cores suitable for lynx home ranges.

The core areas and corridor network for lynx (Figure 27.) features fewer total core areas across the AOI. All locations of lynx core are located within the borders of currently protected areas. The upper corridor option connects the outer core areas. The lower Canada lynx corridor follows an almost identical path as that of the gray wolf corridor, from protected areas in the western portion of the AOI, across the fracture zone to protected areas east of the Okanogan Valley. Canada lynx favor travel under cover of

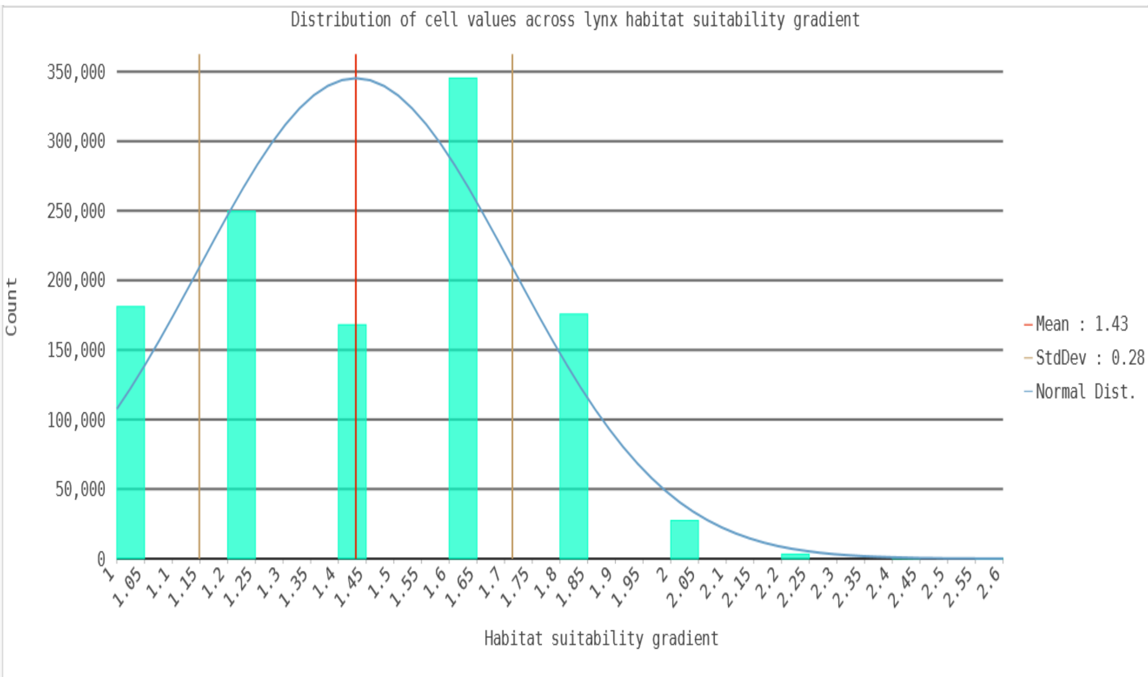

Figure 26. Normally distributed histogram of the Canada lynx habitat suitability surface with raster cell counts (X axis) by habitat suitability gradient (Y axis) with the mean and standard deviation of habitat suitability across the AOI.

contiguous tree canopy (Gary M. Koehler et al., 2008; Stinson, 2001). Thus, an essential feature of a habitat corridor for lynx includes forest continuity with minimal large breaks to facilitate the movement and dispersal of Canada lynx. It should be noted, however, that lynx have been observed using open meadows and natural breaks (<100 m) for movement, though not hunting, or denning (Koehler, 1990; Stinson, 2001). Therefore, coniferous forest land cover classes were assigned the highest possible value during the construction of the suitability surface model for Canada lynx. Despite the open Douglas fir *(Pseudotsuga menziesii)*/ponderosa pine *(Pinus ponderosa)* forest and shrub steppe landscape of the lower elevations within the AOI, the lynx corridor charts a path that features locations across the Okanogan Valley with the highest degree of contiguous forest possible.

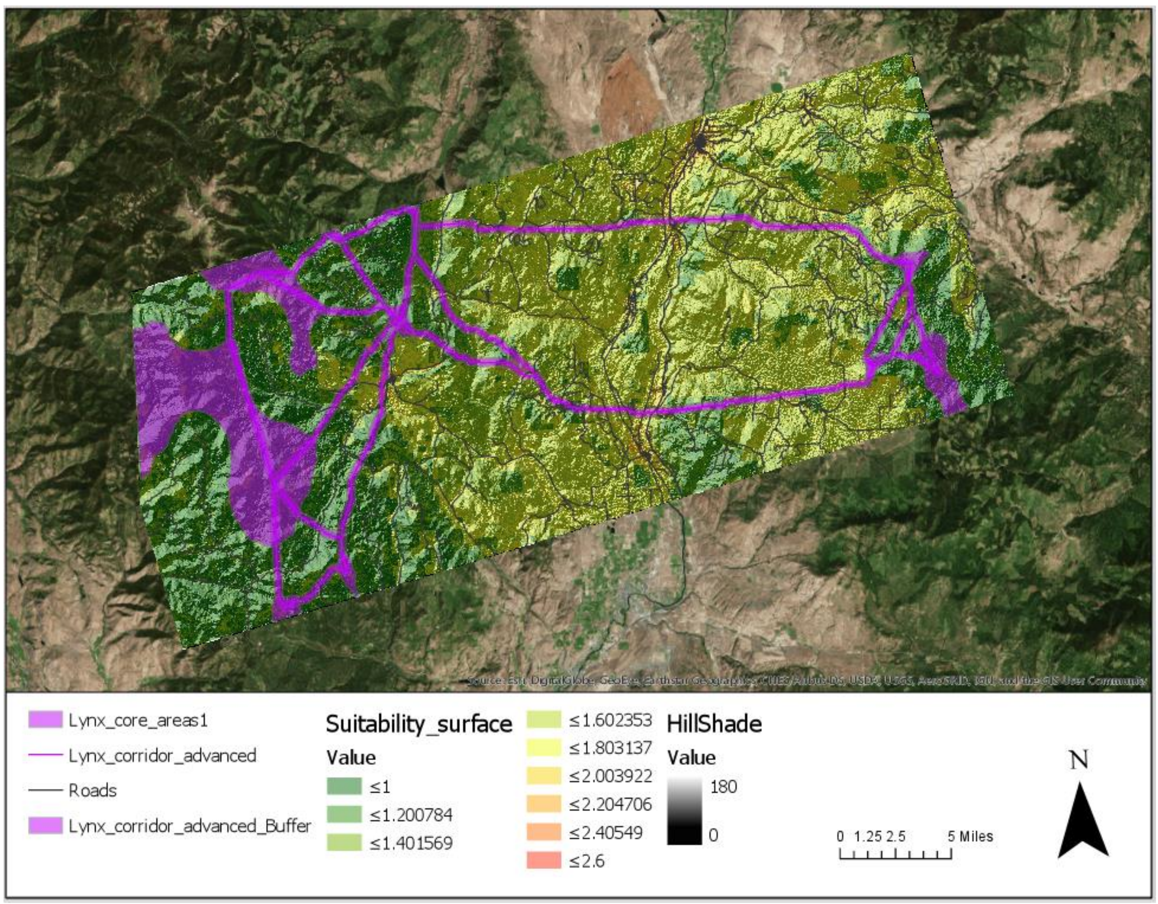

Figure 27. Canada lynx suitability map with core areas and all corridor options, as well as the roads layer active. The hillshade layer was activated to convey elevation, slope and ruggedness.

Canada lynx use all seral stages of forest within their home ranges for different purposes. Early seral lodgepole pine forests provide hare habitat and therefore, lynx hunting grounds (Vanbianchi et al., 2017). Whereas, mid to late seral stage conifer stands provide ease of movement and woody debris within the understory for denning (Stinson, 2001). The degree to which lynx can use managed forests depends on the retention of heterogeneity of seral stands and access to spatially linked mature stands (Squires et al., 2010). Due to lynx avoidance of open Douglas fir and ponderosa pine forest, long range lynx dispersal across the Okanogan Valley presents less favorable habitat conditions between west and east portions of the Okanogan National Forest. However, maintaining the integrity and connectivity of these forests throughout the suggested lynx corridor system (Figure 28.) will provide as much cover as possible for lynx dispersal between optimal, higher elevation, subalpine forest habitats. Limiting anthropogenic activity within the buffered, suggested movement corridors benefits all of the focal species of this case study while preserving umbrella habitat for biodiversity. Landscape, or ecological integrity remains especially important for the large carnivores of this thesis study. The lower the anthropogenic impact within a corridor, the greater the chance that it will be used by most taxa within the large carnivore guild. According to Krosby et al. (2015), the higher the degree of "naturalness" (as defined by healthy ecological functions with minimal human footprint) a movement corridor retains, the more likely the majority of species guilds will be to use the habitat within that corridor.

Grizzly bear

The grizzly bear suitability surface (Figure 28.) features fewer of the dark green, high suitability values (1.0) of the previous gray wolf and Canada lynx habitat suitability maps. The highest ratings for grizzly bear suitability across the AOI fall between values 1.1 and 1.3. Although average suitability values exist across the AOI, they appear scattered and minimal compared to the suitability surfaces of both Canada lynx and gray wolves. The grizzly suitability map shows a disparity between high value habitat (green) and poor habitat (red). There is very little habitat representing a middle ground and a

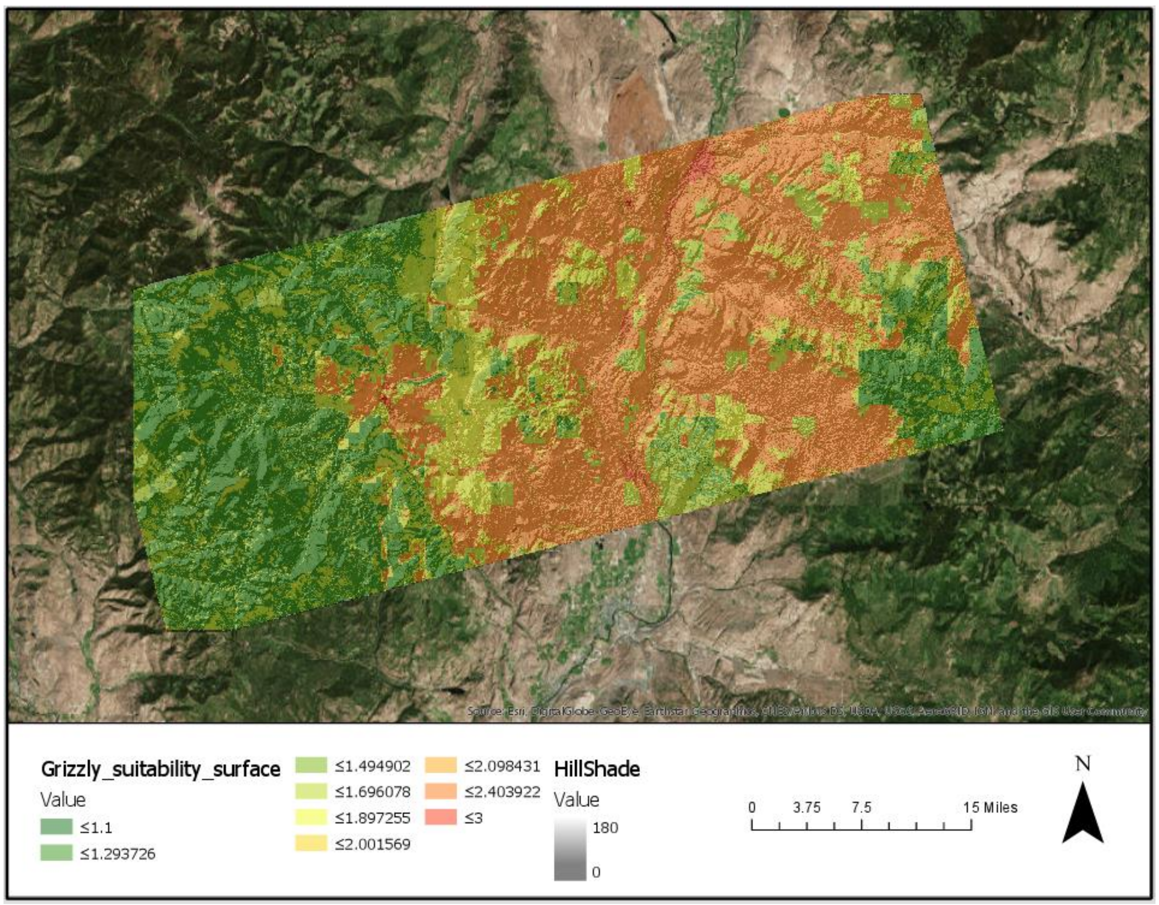

Figure 28. Grizzly bear suitability surface raster symbolized with color gradient, green (high suitability) suitability to red (low suitability). Hillshade layer active to show dimension and ruggedness at higher elevations.

steep divide between quality and poor habitat. Moreover, the spatial representation of the raster surface shows the lack of a gradient for suitability values. The Canada lynx and gray wolf suitability surfaces buffer protected areas retaining highly suitable habitat from unsuitable areas at the fracture zone with a gradient of gradually changing suitability levels. The implications of this map (Figure 28.) suggest a pattern of isolation for grizzly bears with protected areas within the Cascades abutting primarily impermeable landscape features directly outside of protected areas.

The histogram of habitat suitability for grizzly bears (Figure 29.) shows a spike in the numbers of raster cells representing a high suitability range (1.16-1.22) represented 325,000 raster cells. Much smaller numbers of raster cells represent the 1.46-1.52 and 1.75 and 1.75-1.82 ranges of suitability values. At the other end of the histogram the range of 2.05-2.11 suitability values represent 450,000 raster cells. This spike that occured in well below average suitability values could be responsible for skewing the mean of values for the grizzly bear suitability surface (1.71) below the overall average value of habitat suitability for the AOI (1.50). Additionally, the standard deviations from the mean (0.40) represent a much wider distance from the mean than the standard deviations of the Canada lynx and gray wolf suitability surface maps (0.28 and 0.32). This is indicative of the high values at the upper end of the suitability gradient and the lower end with fewer values close enough to the mean to draw the standard deviation closer to the mean.

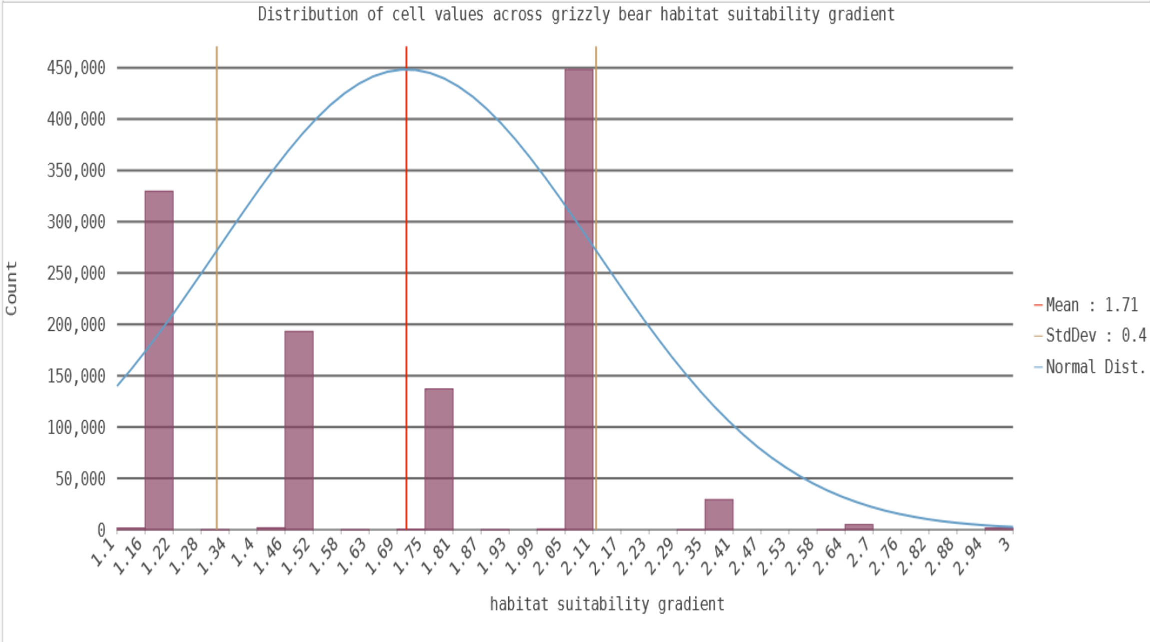

Figure 29. Normally distributed histogram of grizzly bear habitat suitability surface showing the mean (1.71) and standard deviation (0.40) of suitability values. Raster cell counts represented by the (Y axis) and suitability values (X axis) on a gradient between 1-3 divided into 32 bins.

The phenomena of near complete isolation within the Cascades, according to the suitability surface, remains consistent with the life history of grizzly bears within the North Cascades Ecosystem since colonization of the area by white settlers in the 19th century. Between 1827 and 1859, up to 4,000 grizzly bears had been killed in the Cascades by fur traders (Knibb, 2008). By 1860 there were ≤ 360 grizzly bears left in the Cascades (Knibb, 2008). The killing of grizzly bears continued over the 20th century for the fur trade and the purpose of settlement within and surrounding the Cascades. By the 1990s, the resident Cascade grizzly bear population had been reduced to a geographically isolated subpopulation of ≤ 20 individual bears within the Cascades of Washington State (Singleton et al., 2004). As previously stated, based on the lack of occurrence data over the past five years, extirpation of the resident subpopulation of Cascades grizzly bears in Washington State may now be complete (Lewis, 2018).

The plan to reintroduce grizzly bears to the North Cascades Ecosystem (pending completion of the environmental impact statement) could include over 200 individuals (Lewis, 2018). Due to the remote conditions of much of the North Cascades Ecosystem, the area retains the carrying capacity to support upwards of 300 grizzly bears (Lyons et al., 2018). Lateral dispersal between the Cascades and the Kettle River Range represents a tertiary benefit of grizzly bear reintroduction to the North Cascades Ecosystem. The Kettle River Range connects to the Monashee Mountains of Southern British Columbia. Grizzly bear populations local to the Monashee Mountains have been known to disperse north/south to the Kettle Range in Washington State (Apps et al., 2016). Metapopulation dispersal from the Northeast Cascades to the Kettle River Range will facilitate gene flow and demographic exchange between grizzly bear populations within the Monashee Mountains of Southern BC and Washington State (Proctor et al., 2012). Any corridor design for grizzly bear dispersal throughout Washington State remains entirely hypothetical until reintroduction occurs. However, in the event that reintroduction is approved, corridor locations and designs for grizzly bear dispersal will become useful tools in the effort to facilitate the recovery of the species within Washington State.

The grizzly core areas and corridors map (Figure 30.) produced fewer core areas than either gray wolves or Canada lynx. The grizzly bear suitability surface provides fewer areas of suitable habitat across the AOI. The only feasible core areas possible were located within currently protected areas (Okanogan National Forest east and west of the fracture zone). The corridor model produced two lateral corridors across the fracture zone connecting core areas west and east across the Okanogan Valley. The northerly corridor connects the outer core areas to one another. This advanced corridor option follows the same trajectory as that of the lynx advanced corridor option. There are two clear problems with this corridor path: 1) the trajectory intersects several roads and 2) the trajectory passes through few protected areas. Given that grizzly bears possess heightened sensitivity to high human use areas and fragmentation, a path that intersects multiple roads will probably not garner use by grizzly bears as a movement corridor. Additionally, open lands that abut currently protected areas have a greater conservation value in regard to habitat connectivity and umbrella habitat conservation. Connecting areas that are separated by short distances between currently protected areas proves not only feasible from a management standpoint, but favorable to wildlife like grizzly bears. Connecting protected areas proximal to one another provides greater spatial parameters within the protected areas for focal large carnivores than provided by the 1,000 m corridor width. Additionally, limiting the human use factor within the corridor trajectory as a whole, stands to improve the chances that a linkage will be used by the focal large carnivores of this thesis study. The southerly corridor option follows the same general path as the southerly lateral lynx and wolf corridors across the Okanogan Valley, while connecting proximal, scattered protected areas and avoiding roads as much as possible.

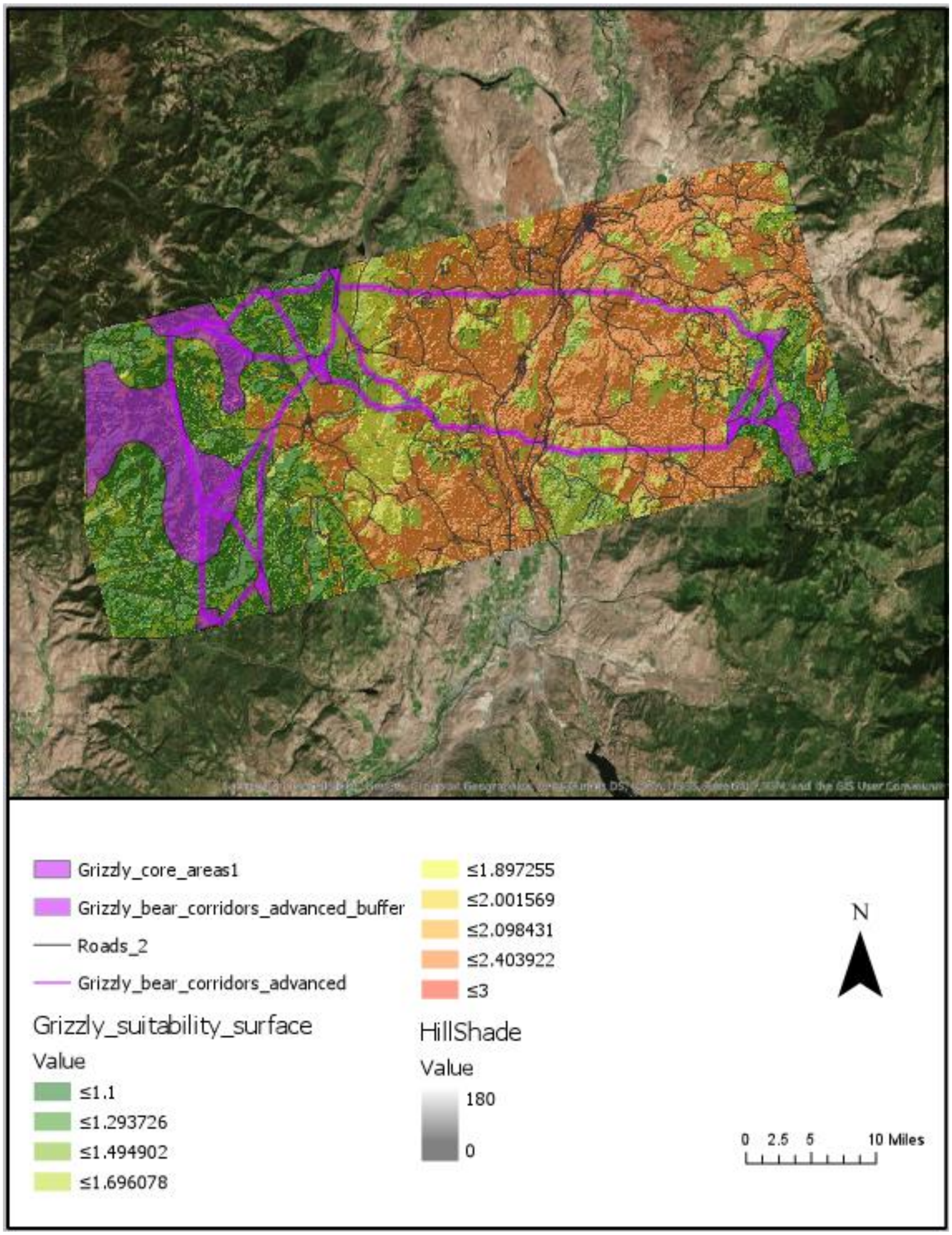

Figure 30. Grizzly bear habitat suitability surface with core areas and all buffered corridor options active. Roads and hillshade layers active.

Permeability of private property across the AOI

The analysis of the number of housing units and acres on census block groups provided a way to measure development across the AOI (Table 7.). This analysis produced both a snapshot of the current state of development as well as a methodology for understanding the rate of development over time. Additionally, the evaluation of development over three census years: 1990, 2000 and 2010 provided insight into the future of development within the AOI and the effect of development on the focal species of this study. The following map provides a spatial snapshot of permeability of private

Performance Standards	Performance metrics	Sum /acres	% Total private land
Optimal (1)	≤1 hu/80 + acres	156,103.12	%82
Acceptable (2)	≤1 hu/40-80 acres	21,066.66	%11
Poor (3)	>1 hu/≤40 acres	13,659.43	%7

Table 7. The table breaks down the results of the analysis of development on private land and the percentages of permeability of private land by performance optimally, acceptably and poorly performing block groups.

lands across the AOI (Figure 31.). The map features protected areas, polygons symbolized by USGS GAPs analysis protection status: = Preserved for biodiversity/symbolized by USGS GAPs analysis protection status: dark purple = Preserved for biodiversity/slate blue = Preserved for conservation and multiple uses. Additionally, the map features the performance standards for landscape permeability based on housing density on private property per census block group. The polygons representing the permeability performance standards were symbolized in the following way: sage green = optimal/pink = acceptable and peach = poor. The metrics by which each performance standard was derived appears beside the associated color on the legend of the map.

At first glance, the map would suggest that private lands generally appear to be overwhelmingly permeable aside from the Okanogan River Valley and the Highway 97 fracture zone. The area where three species corridors cross the fracture zone appears to be designated as optimal, meaning that there is much less development in this part of the AOI and the fracture zone in particular. This will be addressed in greater detail later, in the discussion of the housing density results in relationship to the focal species corridors. The highest number of poorly performing block groups occurs on the outskirts of the towns of Riverside and Tonasket. These results mirror the locations of the lowest suitability values in each of the focal species habitat suitability surface maps. Approximately half of the large Okanogan National Forest (slate blue) polygons west and east of the Okanogan Valley appear to be circumscribed by pink (acceptably) and peach (poorly) performing block groups.

The statistical results of the census data revealed that 87% of private lands across the AOI received an optimal ranking for permeability, whereas 11% received an acceptable ranking and 7% received a poor ranking (Figure 32.). These numbers confirm the initial visual snapshot of the results of the housing density map (Figure 31.). However, the analysis of development growth over time yielded results that tell a much different story.

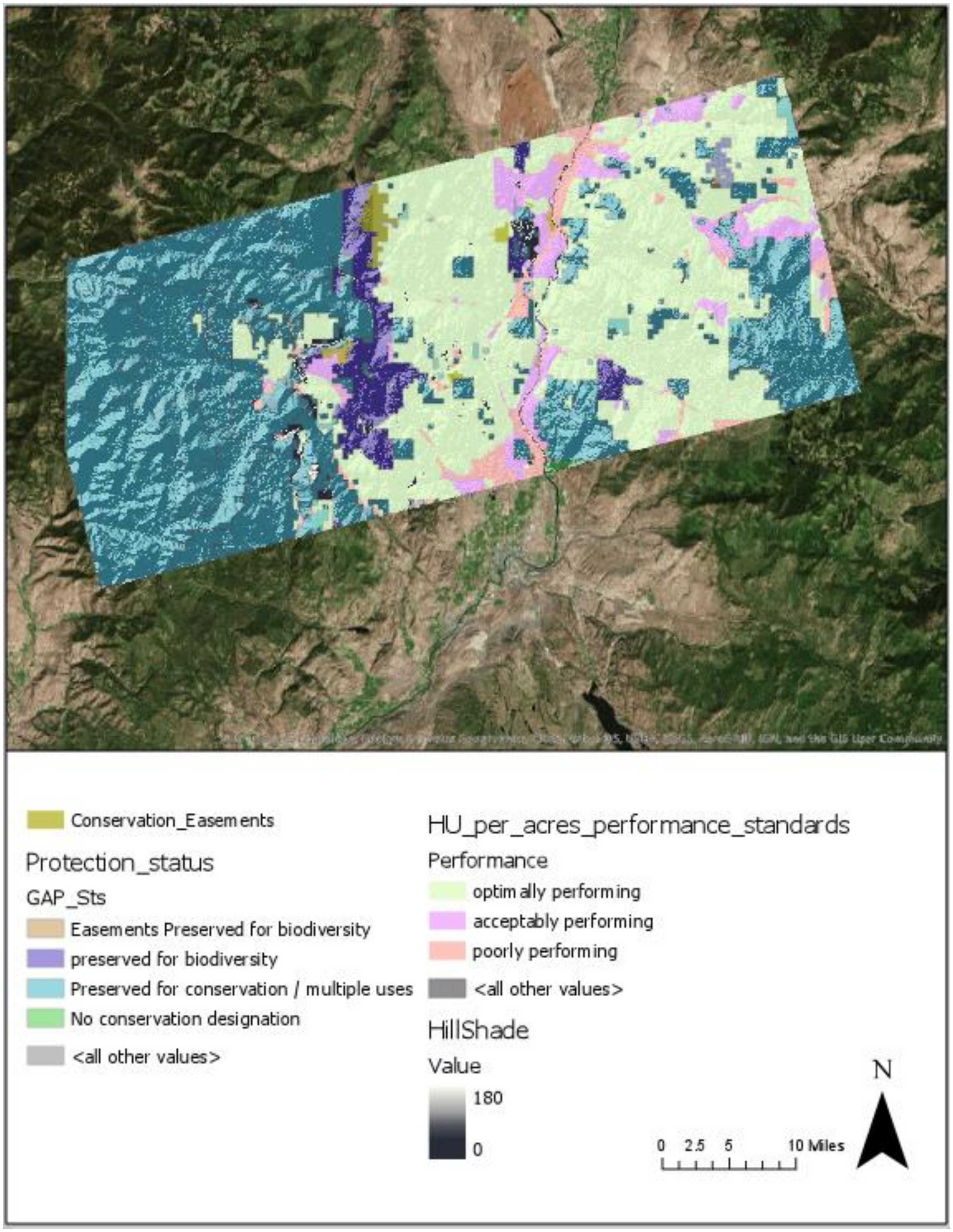

Figure 31. This map displays protected areas (refer to legend on map for color symbology of protected areas) and performance standards of census block groups representing private lands: optimal (sage green), acceptable (pink) and poor (peach). The text for performance standards on the legend shows the metrics on which performance of block

groups was measured. The hillshade layer is active to convey slope, elevation and ruggedness of terrain.

For the analysis of housing density over time, census block groups represented the independent variable, acres and housing units per block group represented the dependent variables (Tables 7 & 8.). The number of housing units per block group and the rate by which this number increased over time can tell us the degree to which the map of permeability of private lands has changed from 1990-2010. Analyzing the pattern of housing density change over three census years allowed for predictions as to the direction in which permeability will trend across the AOI in the future (Figure 33.). Between 1990 and 2000, mean housing units on optimally performing block groups (PS 1) grew from 2 to 4.5 (2000). From 2000 to 2010, the mean number of housing units on optimally performing block groups (PS 1) grew from 4.5 to 8.25. Between 1990 and 2000 mean housing unit numbers on acceptably performing block groups (PS 2) grew from 3 (1990) to 7 (2000). From 2000 to 2010, mean housing units on acceptably performing block groups (PS 2) increased from 7 (2000) to 13 (2010). Between 1990 and 2000, the mean number of housing units on poorly performing block groups grew from 5 (1990) to 10 (2000). From 2000 to 2010, the mean number of housing units on poorly performing block groups increased from 10 (2000) to 15.5 (2010).

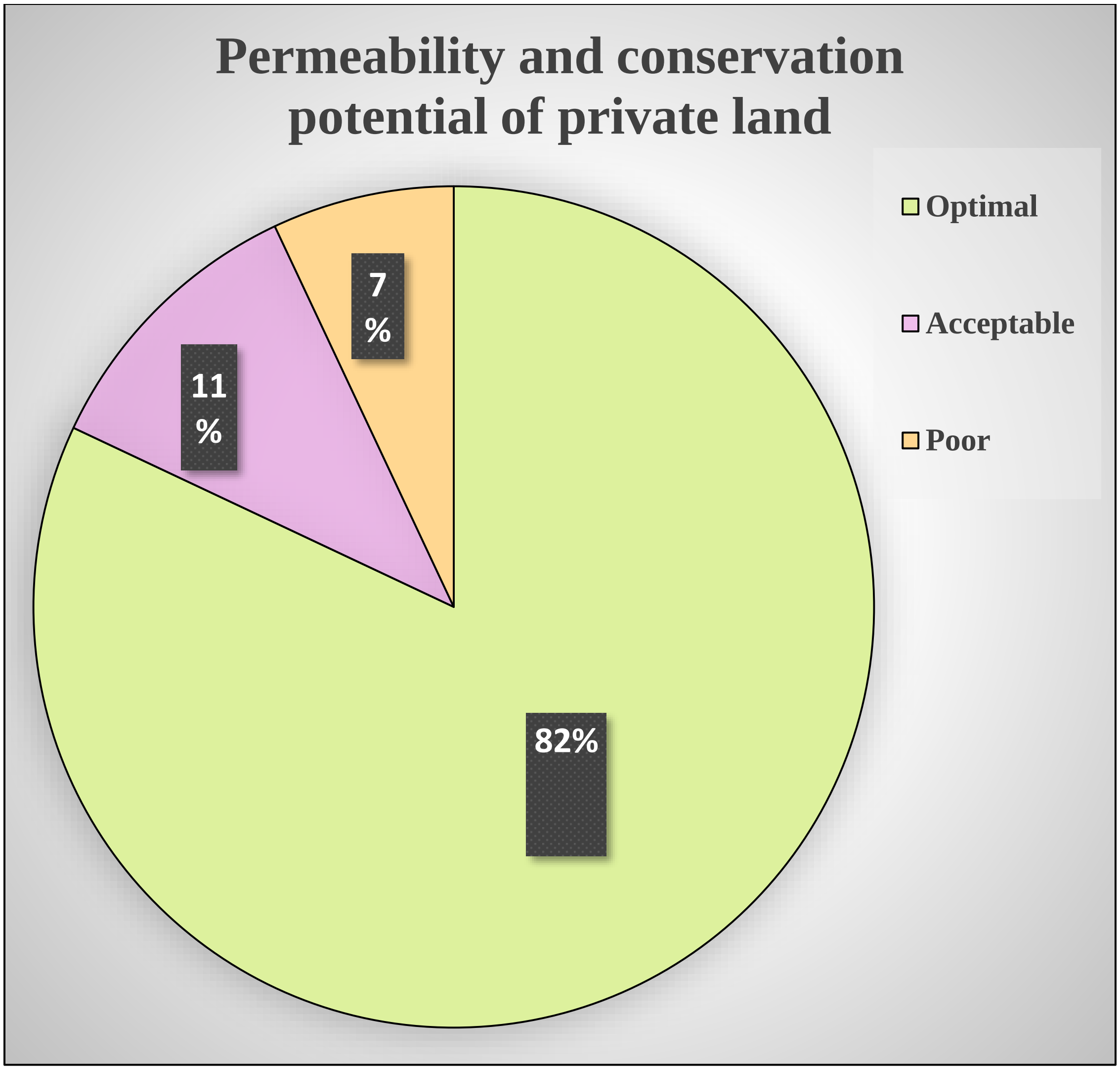

Figure 32. The pie chart shows percentages by ranked (performance standards: 1, 2 & 3) block group. The color symbology mirrors the symbology for optimally, acceptably and poorly performing block groups from the previous map (Figure 31.).

Total HUs on Private Property Within AOI in 1990	Total HUs on Private Property Within AOI in 2010	Percent Increase in HUs between 1990 and 2010
2,232	3,117	40%

Table 7. The total number of housing units within the AOI in 1990 vs the total number in 2010 and the percent change in housing density between 1990 and 2010.

Performance Standards	Total HUs in 1990	Total HUs in 2010	Percent Increase from 1990-2010
1	375	710	89%
2	180	351	95%
3	1,677	2,056	23%

Table 8. The sum of housing units on optimally (PS 1), acceptably (PS 2) and poorly (PS 3P performing block groups in 1990 and 2010. The last column shows the rate of increase in housing units on three categories of block group performance over 20 years.

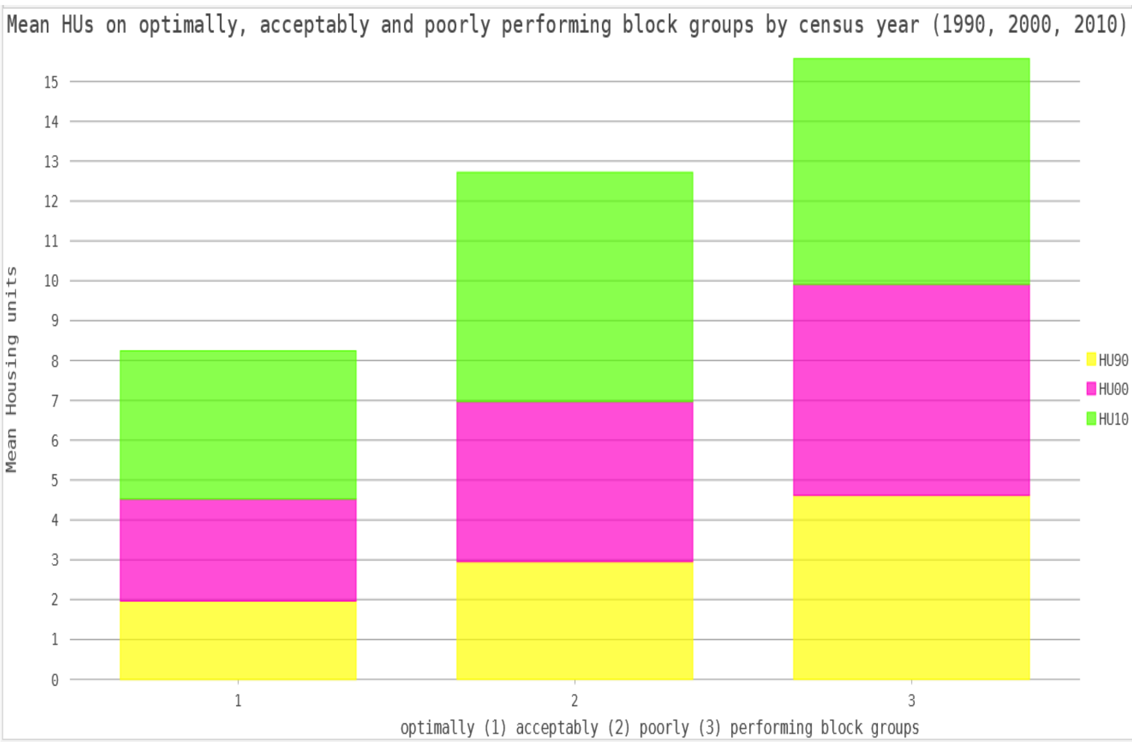

Figure 33. The bar graph measures mean housing units per block group (Y axis) by performance standards, over three census years (X axis): 1990, 2000 and 2010. 1990 (yellow)/2000 (pink)/2010 (green).

Housing unit numbers grew steadily across optimally, acceptably and poorly performing block groups from 1990 to 2000 (Figure 34.). All block groups within the three performance categories doubled in mean housing units per block group.

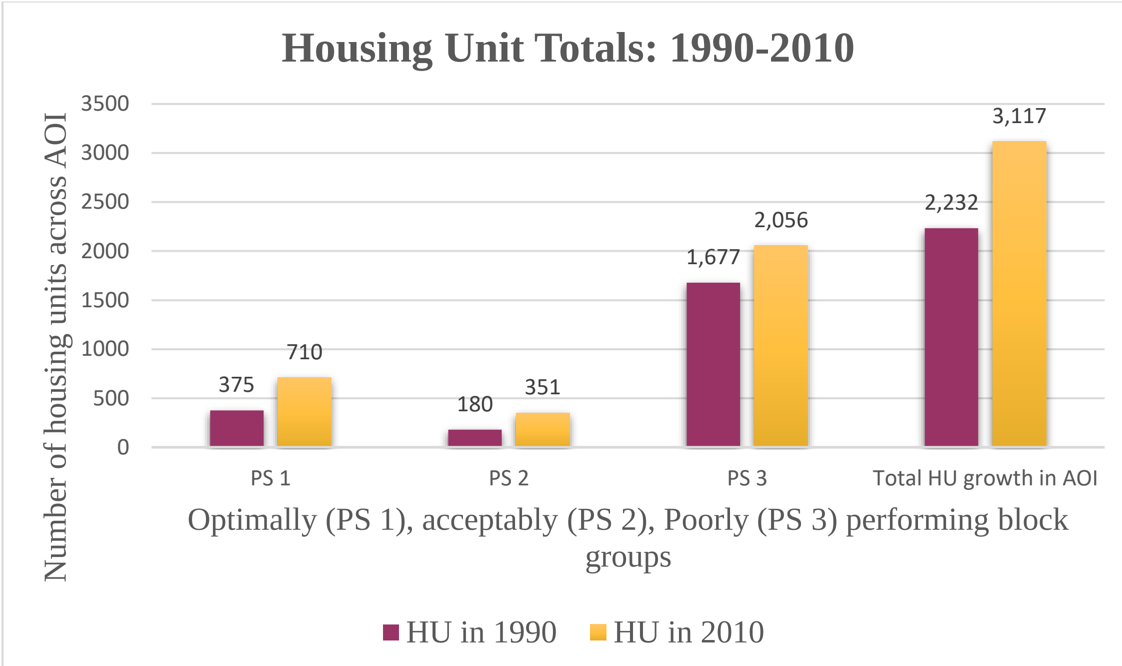

Figure 34. The Y axis = the number of housing units across the AOI. The X axis = comparisons of housing units per PS 1, PS 2 and PS 3 performing block groups in 1990 to 2010. The total number of housing units on all block groups in 1990 and 2010 is included on the X axis. The smaller overall number of housing units on optimally (PS 1) and acceptably (PS 2) performing block groups is due to the large size of these block groups in area. There are fewer of the PS 1 and PS 2 block groups across the AOI, but they are much larger in area than the more numerous, but much smaller PS 3 block groups.

Optimally performing block groups increased from 2 housing units to 4.5 housing units and acceptably performing block groups began at 3 mean housing units/block group in 1990 and increased to 7 mean housing units/block group by 2000. Interestingly, the most dramatic mean housing unit increases occurred on optimally and acceptably performing block groups from 2000 to 2010. Between 2000 and 2010, the mean number of housing units on optimally performing block groups increased from 4.5 to 8.25, effectively doubling the increase between 1990 and 2000. Acceptably performing block groups went from a mean of 7 housing units per block group in 2000 to 12.75 in 2010. Again, this increase nearly doubled the mean housing unit increase of 4 from 1990 to 2000. For comparison, the mean number of housing units on poorly performing block groups increased from 10 in 2000 to 15 in 2010. The mean number of housing units on poorly performing block groups increased incrementally by approximately 5 houses per census year, whereas housing unit numbers increased by order of magnitude on large acre block groups (PS 1 and PS 2) with conservation and landscape permeability value for wildlife.

Housing units on optimally performing block groups increased by 89% from 1990-2010 (Figure 35.). Housing units on acceptably performing block groups increased by 95% from 1990-2010 (Figure 35.). Housing units on poorly performing block groups increased by 23% from 1990-2000 (Figure 35.). The number of housing units on all block groups representing private land across the AOI increased by 40% from 1990-2010. The nearly 100% increase in housing units on optimally and acceptably performing block groups represents perhaps the most notable result of this analysis of development. This rate of development on acceptably performing block groups was triple the rate of development on poorly performing block groups and development on optimally performing block groups was nearly triple that of poorly performing block groups.

The results of the housing density analysis confirm a county-wide trend of housing development replacing large acre family farms and, an overall economic shift away from agricultural production in the Okanogan Valley. Craig et al., (2010) reports that 45% of farms changed hands between 1993 and 2008 and half of these lands fell out of agricultural production. Agriculture represents 57% of private lands in Okanogan County with a mean farm size of 825 acres (Okanogan Conservation District & Martin, 2018; USDA, 2011). Given that few housing units and large open spaces characterize large acre

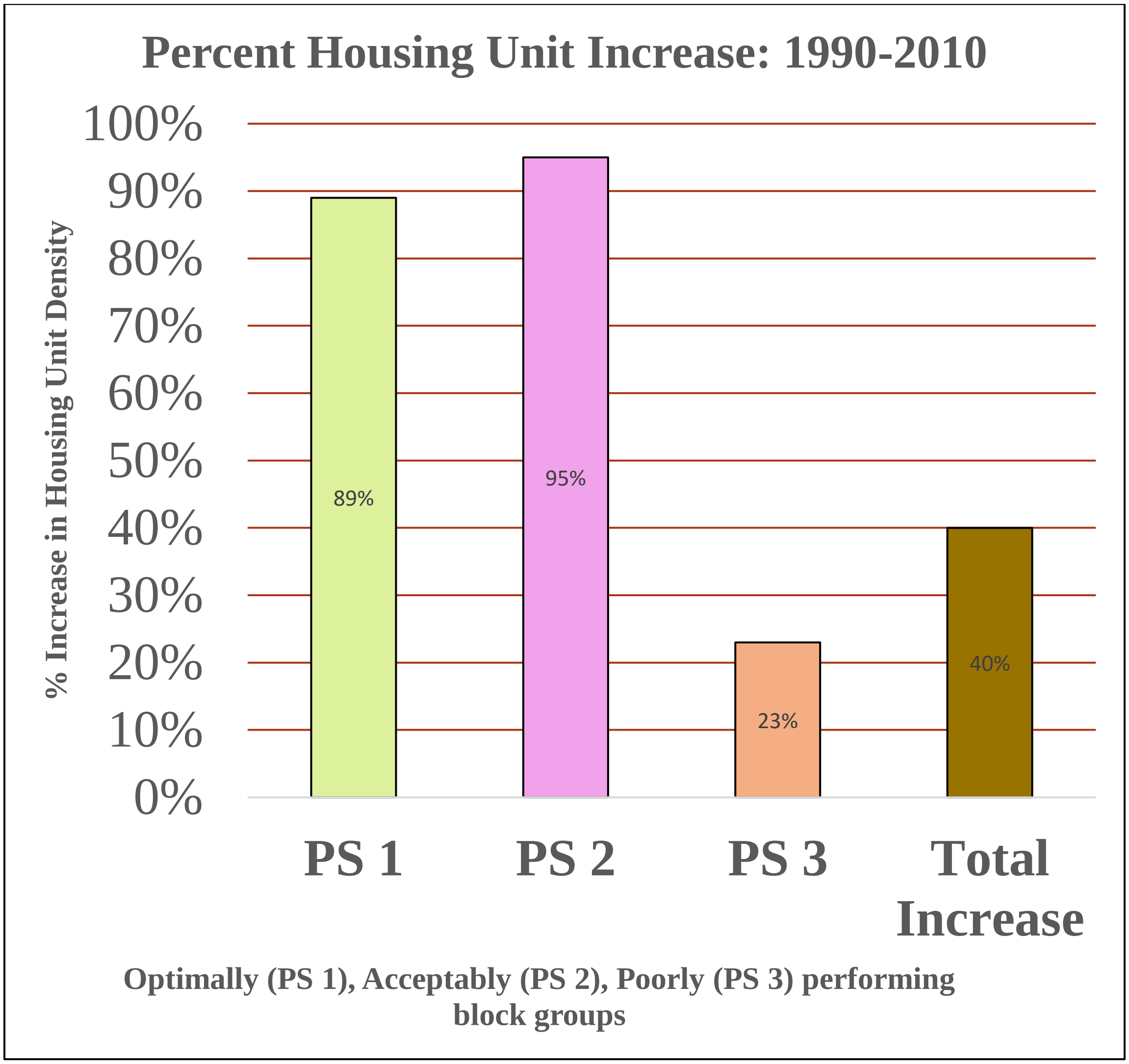

Figure 35. This graph measures the percentages of housing unit increase by optimally (PS 1)/acceptably PS 2)/poorly (PS 3) performing block groups from 1990-2010. The total percentage of housing unit growth across the AOI was included in this graph.

farms and ranches, these areas frequently represent block groups with acceptable, or optimal permeability values. However, increasing housing unit density on acceptably performing block groups trends towards these block groups becoming poorly performing over time. Spikes in residential development could contribute to habitat fragmentation of a landscape that currently retains high levels of permeability for the focal species of this study. Additionally, a continued increase in development over time compromises the potential for conservation of biodiversity within the AOI. The map of permeability of private property displays a high concentration of acceptable habitat (pink) for permeability along most of the Okanogan River. The 95% increase in housing units within acceptably performing block groups from 1990-2010 could correspond to the trend of agricultural lands changing hands. That being said, this thesis study does not provide evidential documentation of residential developments replacing parcels previously zoned for agricultural production.

The permeability of private lands map (Figure 31.) yielded a pattern of development on the outskirts of public lands both west and east of the Okanogan Valley. Both acceptably and poorly performing block groups line the edges of Loomis Forest (DNR) and the Okanogan National Forest. Private lands abutting the Scotch Creek Wildlife Area (WDFW) however, appear to be optimally performing block (Figure 36.). Optimally performing block groups primarily represent large acre areas with quality habitats like conifer forests and shrub steppe. The exponential rise in housing units on optimally performing block groups over time points to a spike in exurban development. The pattern of growing numbers of block groups along the borders of protected areas performing acceptably or poorly adds credence to this trend by indicating a concentration of exurban development may be occurring at the edges of protected areas. Local conservation groups like the Okanogan Land Trust and the Okanogan Conservation District work with community partners to: A) reverse the trend of increasing development that contributes to fragmentation of open spaces and agricultural lands across Okanogan

County and B) preserve large acre, family farms and ranching operations in perpetuity (National Fish and Wildlife Foundation, 2017). Additionally, both the WDFW PILT (Paid In-Lieu-of Taxes) program and the Okanogan County Voluntary Stewardship Program prioritize conservation of large acre farms/ranches and open spaces connected to public lands (Gustanski & Scarsella, 2014; Okanogan Conservation District & Martin, 2018).

Properties owned by WDFW cannot be levied with property taxes, thus PILT payments compensate for the loss of property taxes (Gustanski & Scarsella, 2014). In 2005, WDFW PILT properties along with conservation easements and land trusts accounted for .56 cents to every $1.00 received in revenue by Okanogan County (American Farmland Trust, 2007; Craig et al., 2010). Residential development resulted in a $4.8 million deficit, whereas open lands, forested lands and farmlands produced a $2.1 million revenue surplus in 2005 (American Farmland Trust, 2007; Craig et al., 2010). To relate these numbers to the thesis methodology for measuring and mapping development, acceptably and optimally performing block groups represent open lands, forests and large farmlands across the AOI. The monetary value added for conservation of acceptably and optimally performing areas within the AOI benefits the county at large while preventing the conversion of areas of high permeability to residential developments that contribute to fragmentation, habitat loss and low landscape permeability.

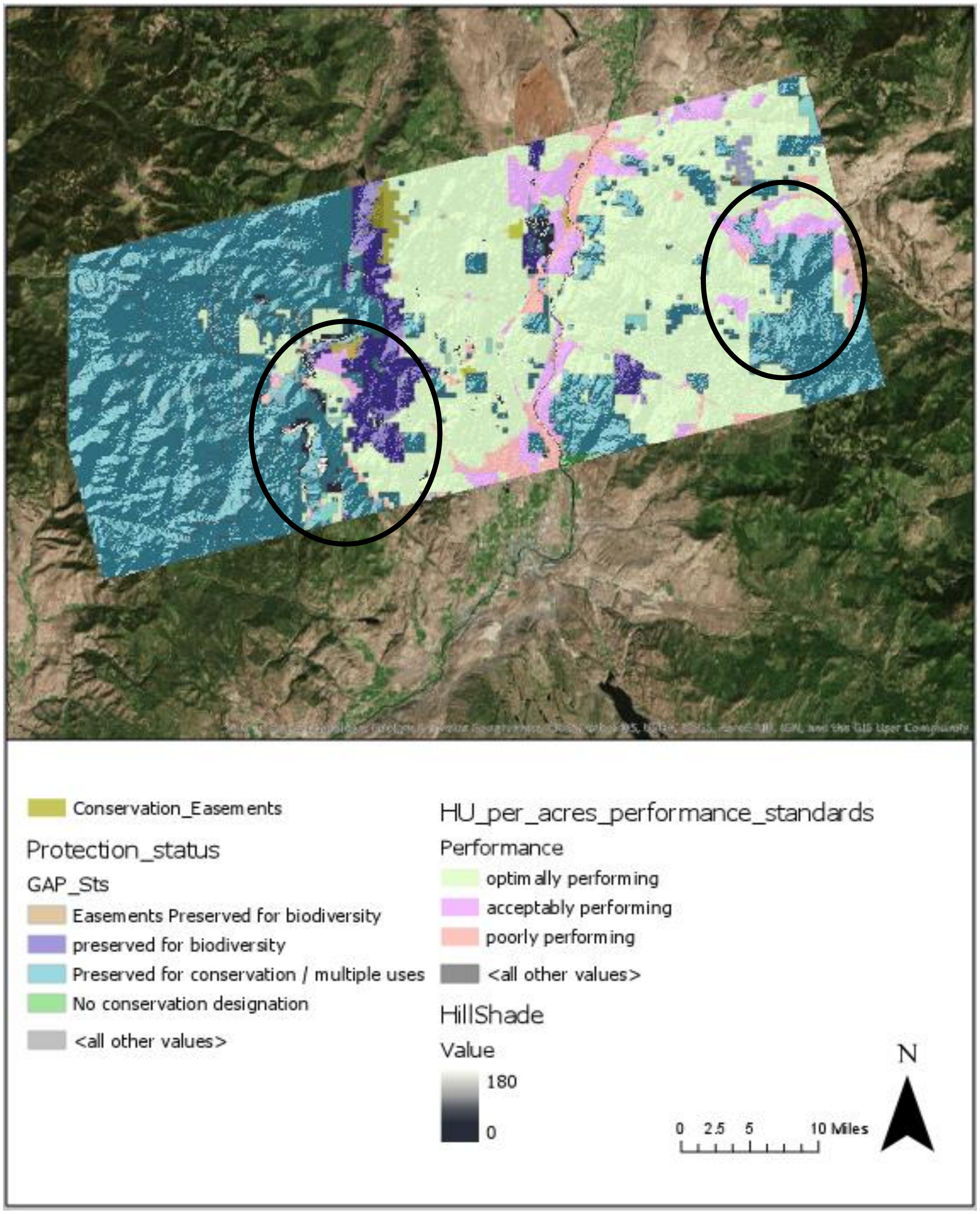

Figure 36. Permeability of private lands map with outlines of acceptably and poorly performing block groups on the edges of protected areas west and east of the fracture zone.

RECOMMENDATIONS FOR MANAGEMENT

The least-cost distance, focal species maps in conjunction with the evaluation of permeability of private lands provide a framework for conservation recommendations within the AOI. Additionally, areas recommended for conservation of connective habitat for the dispersal of the focal large carnivores of this study will provide umbrella habitat supporting increased biodiversity and ecosystem functions (Carroll et al., 2001; Winnie & Creel, 2017). The focal species corridor networks overlap a large portion of the Priority Habitat and Species designated, yet currently unprotected areas (Figure 37.). The following map displays all focal species corridor options over the permeability surface for private lands (Figure 37.). Many of the focal species corridors overlap, particularly across the area of the fracture zone. Three convergent corridor options cross highway 97 where housing unit block groups performed optimally for permeability. Following the corridor paths east, large acre farms line the eastern river bank which could account for the acceptably performing block groups in this location on the map. The three species corridors then connect to DNR land (slate blue polygon) proximal to large acre farms along the eastern bank of the Okanogan River. The DNR land abuts the WDFW Scotch Creek Wildlife Area (dark purple polygon). From this point open permeable lands with optimally performing block groups connect scattered protected areas until the corridors reach core areas within the Okanogan National forest (slate blue polygon, southeast corner of the map). The red corridors north of the three convergent species corridor trajectories, represent a portion of the gray wolf corridor network which connects wolf core areas outside of currently protected areas. The most northerly corridor (yellow)

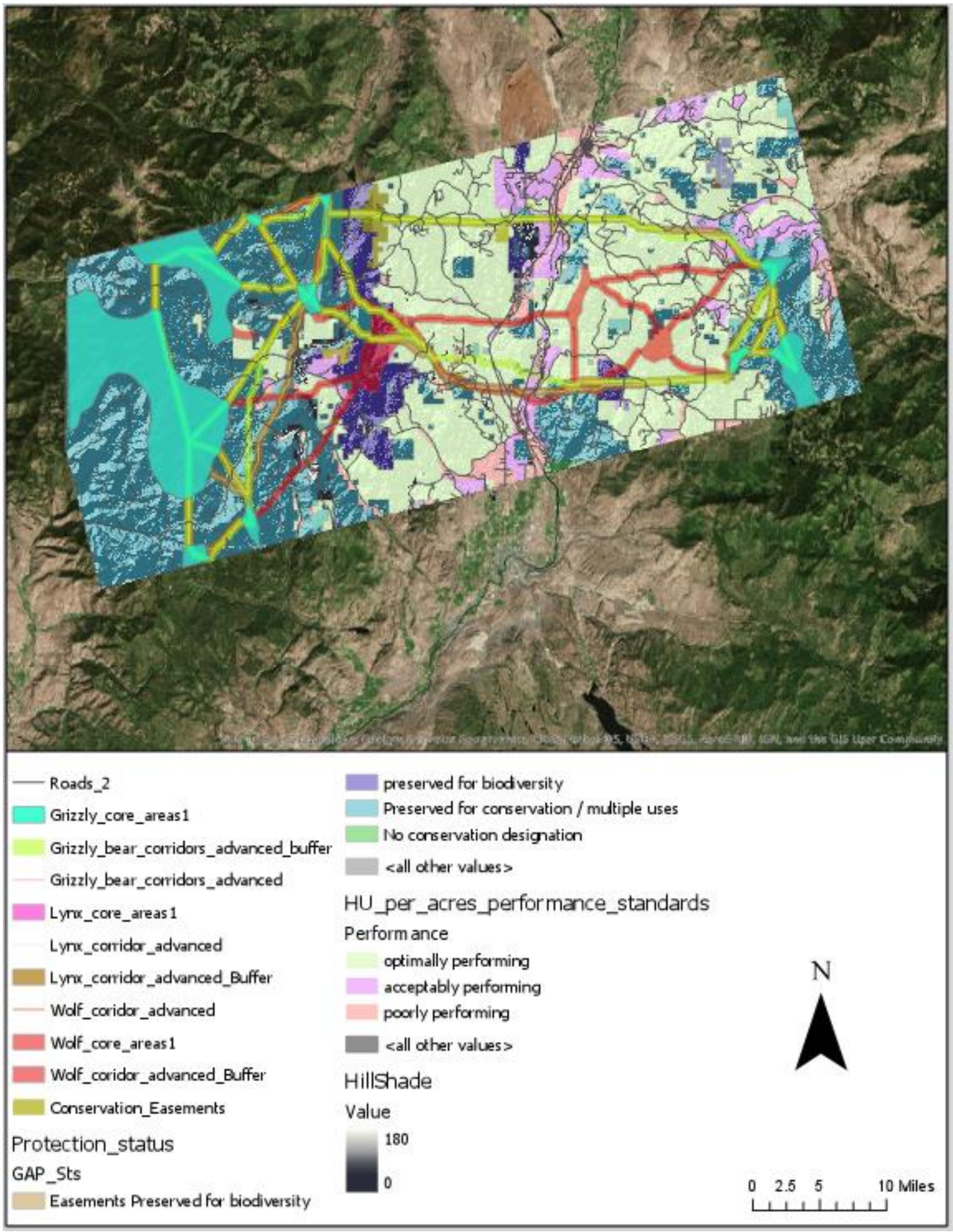

Figure 37. Map of all possible species corridors and core areas atop protected areas and permeability of private lands by performance standards. Additionally, the roads layer is active.

connects outer core areas west to east across the fracture zone. However, as previously discussed, the path of this corridor option presents several challenges to permeability including poorly performing block groups and multiple road crossings. These factors lead to a higher likelihood of human/carnivore interaction, thereby increasing the potential for conflict and accidental, or intentional harm to the focal species. Therefore, this most northerly corridor path cannot be recommended for conservation priority, as it presents the greatest resistance to dispersal of the focal species across the landscape.

The following considerations factored into a suggested area for conservation within the area of interest. Ideally, the area would include: A) the trajectories of three species corridors that converged across the AOI, B) locations with the highest degree of optimally performing block groups, C) the northerly gray wolf lateral corridor and core wolf areas outside of currently protected areas and D) the highest number of protected areas across the AOI. Fortunately, the corridor model was designed to follow a path that would ensure the shortest distance between protected areas possible. This reduces the size of connective habitat patches necessary to link currently protected areas. Thus, even small conservation easements between proximal conserved patches can go a long way in linking habitat between core areas west and east of the fracture zone. The following map outlines habitat to prioritize for conservation, according to the cumulative results of this thesis study (Figure 38.). The outlined area represents a 7 mi wide by 20 mi long, 140 square mile portion of the greater AOI. This area contains all viable corridor options from protected areas west to protected areas east of the Okanogan Valley. Any conservation project that falls between the northerly wolf corridors and the three convergent corridors will facilitate the movement and dispersal of focal large carnivores across the Okanogan

Valley. Additionally, the suggested corridor buffer width (1,000 m) will preserve species richness and ecosystem functions between protected areas (Washington Department of Fish and Wildlife, 2009).

Highway 97 presents the most significant infrastructural hurdle to lateral movement across the Okanogan Valley for the focal species of this case study. Highway 97 represents the most heavily trafficked roadway with the highest vehicle to wildlife collision rate in the study area, as well as one of the highest statewide rates (Figure 39.) (Wang et al., 2010; WSDOT, 2010). WSDOT drafted a comprehensive three-part plan to install wildlife undercrossings, cattlegaurds and fencing along a twelve mile stretch of highway 97 between Omak and Tonasket (Reynolds & Sabourin, 2018). The plan would cost $4.3 million and currently does not have the funding to be implemented (Reynolds & Sabourin, 2018) cost $4.3 million and currently does not have the funding to be implemented (Reynolds & Sabourin, 2018) Two WSDOT planned undercrossing[15] cost $4.3 million and currently does not have the funding to be implemented (Reynolds & Sabourin, 2018). Two WSDOT planned undercrossing[16]structures fall within the area outlined for conservation priority by the results of this thesis study to be implemented (Reynolds & Sabourin, 2018). Two WSDOT planned undercrossing structures fall within the area outlined for conservation priority by the results of this thesis study (Figure 40.). The "X" s mark the locations on Highway 97 where undercrossings have been planned

[15] WSDOT undercrossing locations were retrieved from: WSDOT / Improving Wildlife Habitat Connectivity / Future Projects: https://www.wsdot.wa.gov/environment/protecting-environment/improving-wildlife-habitat-connectivity

[16] WSDOT undercrossing locations were retrieved from: WSDOT / Improving Wildlife Habitat Connectivity / Future Projects: https://www.wsdot.wa.gov/environment/protecting-environment/improving-wildlife-habitat-connectivity

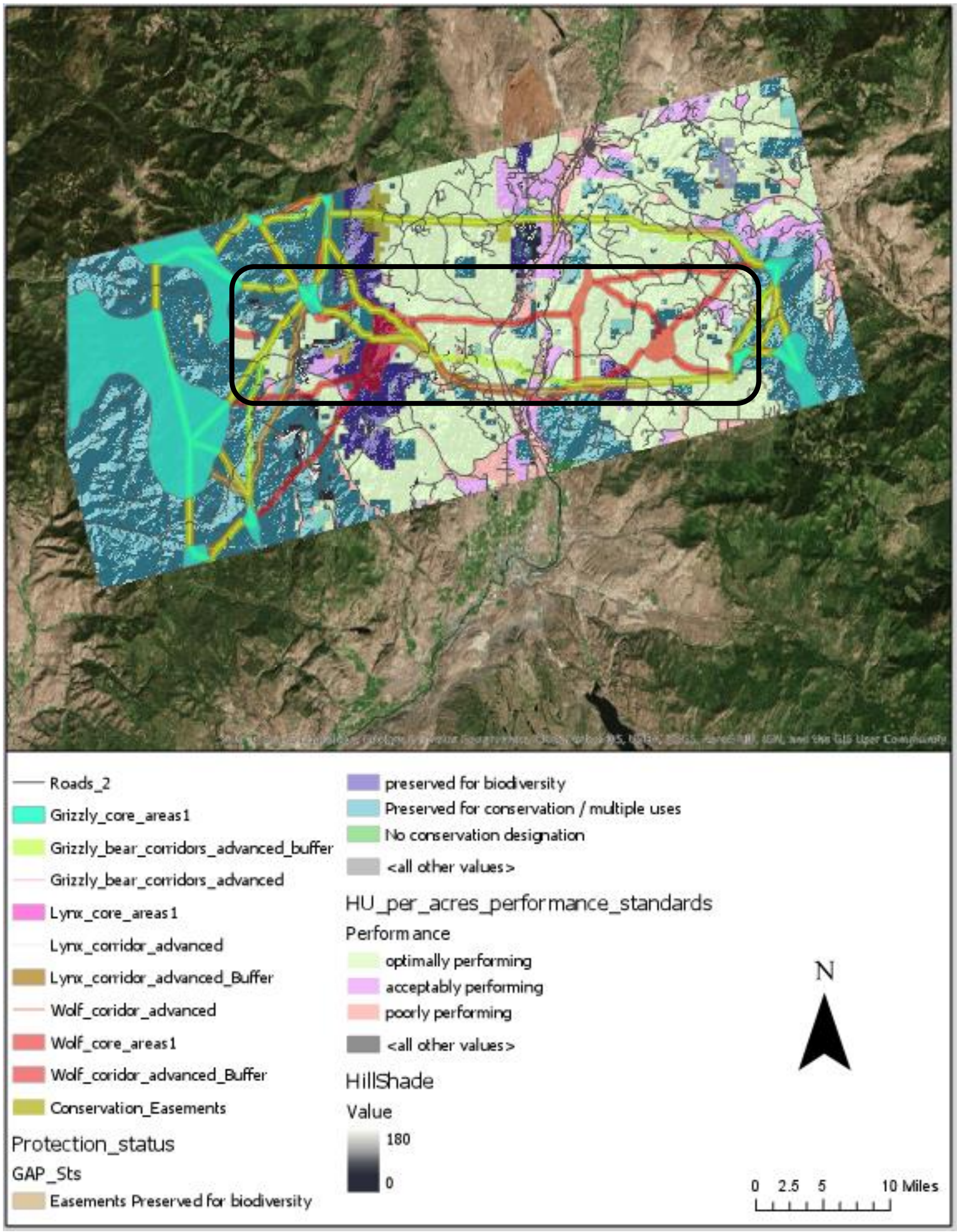

Figure 38. This map includes all species corridors, core areas as well as protected areas. The optimally, acceptably and poorly performing block groups surface is active to demonstrate permeability based on housing density. The roads and hillshade layers are active as well.

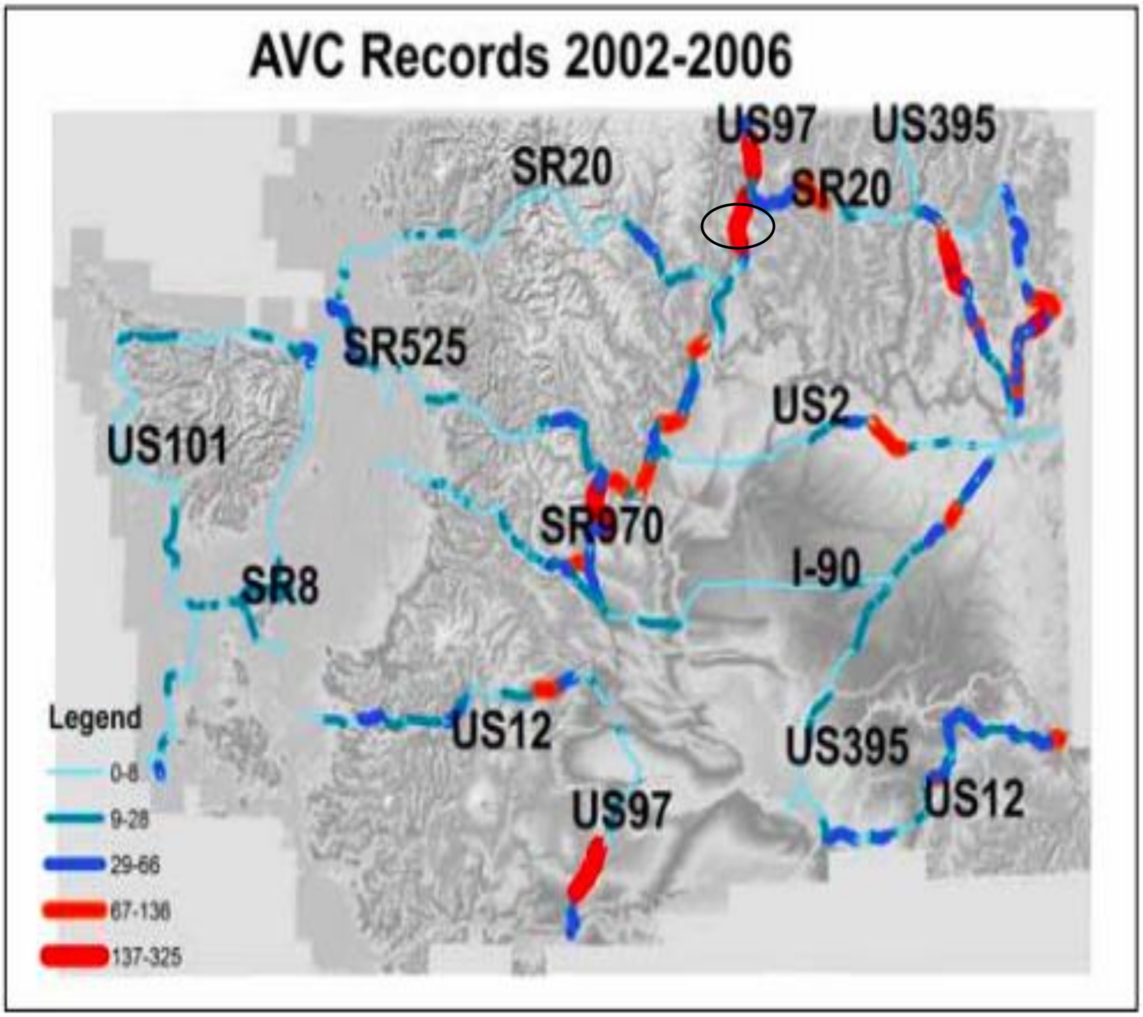

Figure 39. Animal-vehicle collision (AVC) rates based on location and distribution of highways and associated AVCs in Washington State between 2002-2006. The fracture zone of the AOI is outlined on the map. Source: Wang, Y., Lao, Y., Wu, Y., & Corey, J. (2010). *Identifying High Risk Locations of Animal-Vehicle Collision for Washington State Highways* (Research Note No. WA-RD #: 752.1). Olympia, WA: WSDOT Research Office.

implemented (Reynolds & Sabourin, 2018) Two WSDOT planned undercrossing[17] cost $4.3 million and currently does not have the funding to be implemented (Reynolds & Sabourin, 2018). Two WSDOT planned undercrossing[18]structures fall within the area outlined for conservation priority by the results of this thesis study to be implemented (Reynolds & Sabourin, 2018). Two WSDOT planned undercrossing structures fall within the area outlined for conservation priority by the results of this thesis study (Figure 40.). The "X" s mark the locations on Highway 97 where undercrossings have been planned for construction. One of these planned undercrossings falls directly above the grizzly bear habitat corridor (yellow) (Figure 40.). Moreover, this undercrossing location falls between the northerly and southerly gray wolf corridors as well as the lynx corridor. The addition of fencing will prevent prey animals from entering roadways. In turn, these measures prevent focal large carnivores from pursuing prey that enter the roadway.

There are two additional, essential features of an undercrossing structure specific to the focal large carnivores of this thesis study. The openness index of an undercrossing structure refers to: A) the field of vision the structure provides of the terrain on the other side and B) the actual width, height and length of the structure itself (Kintsch & Cramer, 2011). Unfortunately, the literature on crossing structures does not prescribe definitive, specific dimensions for species who require a high openness index (Kintsch & Cramer,2011). However, the design for these crossing structures requires them to be high,

[17] WSDOT undercrossing locations were retrieved from: WSDOT / Improving Wildlife Habitat Connectivity / Future Projects: https://www.wsdot.wa.gov/environment/protecting-environment/improving-wildlife-habitat-connectivity

[18] WSDOT undercrossing locations were retrieved from: WSDOT / Improving Wildlife Habitat Connectivity / Future Projects: https://www.wsdot.wa.gov/environment/protecting-environment/improving-wildlife-habitat-connectivity

wide and short, thus providing a panoramic view of the other side as they enter the structure

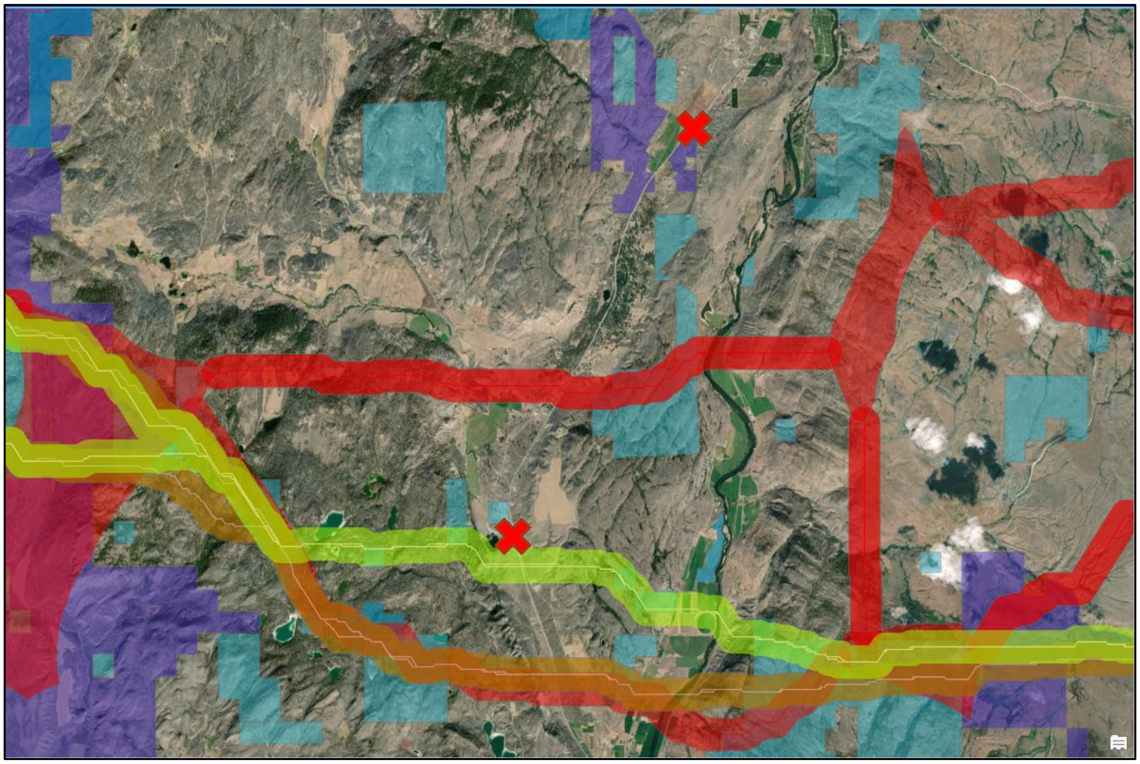

Figure 40. Protected areas and all species corridor layers active over a satellite imagery basemap. This map has been magnified to show planned WSDOT crossing structures (red Xs) at the fracture zone in relationship to the species corridor locations generated by this thesis study.

(Clevenger & Huijser, 2009; Sawaya, Clevenger et al., 2013). Clevenger and Waltho (2005) found that, anthropogenic activity near crossing structures was negatively correlated with the use of crossing structures for both gray wolves and grizzly bears. Therefore, the planned crossing structure located directly above the grizzly bear corridor (yellow) should be constructed with the highest possible openness index in order to accommodate large carnivores sensitive to fragmentation and human activity.

FUTURE RESEARCH

The small scale of this case study excluded variables outside of the scope of the area of interest. Additionally, the study did not account for certain variables within the area of interest. For instance, this thesis study did not evaluate the relationship between gray wolves and cattle within the area of interest. The literature on gray wolves and cattle has, thus far, focused on allotments on public lands (Hanley et al., 2018; Spence & Wielgus, 2017; Wielgus & Peebles, 2014). Over the course of the recovery of gray wolves in Washington State, denning and rendezvous sites have been located on public lands (Wiles, Allen, & Hayes, 2011). However, gray wolf recovery in Washington State remains very recent compared to northern Wisconsin and Michigan where recovery began decades earlier (Browne-Nuñez et al., 2015; Williams et al., 2002). Gray wolves exhibit a high level of habitat plasticity, adapting to the conditions of their surroundings, including anthropogenic activities, over time (Zimmermann et al., 2014). Thus, tracking gray wolf behaviors on private rangelands over time proves essential to preventing conflicts between wolf recovery and ranching. This becomes particularly important in Okanogan County where rangeland represents 49% of private lands (Okanogan Conservation District & Martin, 2018).

Riparian habitat was not analyzed for the connective habitat potential that it retains within the AOI. Riparian areas within protected lands provide important movement habitat for lynx as well as forage habitat for grizzly bears (Helfield & Naiman, 2006; Quade et al., 2006). Additionally, riparian habitat provides forage for ungulates which, renders these areas important to gray wolves as hunting grounds (Hauer et al., 2016). According to the Okanogan County Critical Areas Regulations (2103), anadromous fish bearing streams receive a buffer width of 150 ft. This represents the widest buffer width required for riparian areas in Okanogan County (Okanogan County Office Of Planning And Development, 2013). Given that the focal large carnivores of this study were assigned 1,000 m corridor widths, riparian terrestrial habitat did not meet the spatial requirements of viable terrestrial habitat for the focal species of this study. Whether or not the spatial conservation recommendations provided by this thesis could preserve umbrella riparian habitat would be a potentially impactful topic of future study. Additionally, a future study that tracks the use of riparian buffers outside of public lands by large carnivores could contribute new possibilities for: A) connecting quality habitat for the focal species of this study and B) an overall increase of biodiversity.

The scale of this thesis study provided detailed, spatial solutions for linking wildlife between core areas contained within public lands west and east of the Okanogan River Valley. However, the eastern extent of the AOI for this study ends long before reaching the Kettle River Range. The rationale for this scope involved facilitating dispersal of the focal species across a challenging fracture zone, Highway 97 and the Okanogan River Valley. However, a replication of this study that extends from the eastern extent of the AOI to the Kettle River Range could maintain the level of detail retained by analyzing a small-scale, fine-grained study area while continuing the wildlife linkage to its intended destination point.

The variable “Protected Areas” used within the scope of this case study, came from a USGS GAP analysis designation system: 1 & 2 = areas protected for biodiversity, 3 = areas protected for conservation and multiple uses (recreational and/or extractive) and 4 = no protection designation. Each state and federal resource agency must have a management plan that supports the recovery of all ESA listed species. All three focal species of this case study remain ESA listed, although gray wolves were delisted east of the Okanogan River within Washington State (Wiles et al., 2011). For the purpose of this thesis the GAPs analysis designations 1, 2 & 3 protected areas were considered places where public land management includes the conservation of habitat for the protection of gray wolves, Canada lynx and grizzly bears. However, anthropogenic recreation impacts, cattle allotments, roads, resource extraction, climate change and accelerated fire regimes call into question the conservation status of multiple use "Protected Areas" (USGS GAPs Analysis) like DNR State Forests, or National Forests. Therefore, additional research that examines the degree of habitat quality, conservation and connectivity on the areas that this thesis study designated as "Protected" could be warranted.

In order to protect the privacy of landowners across the AOI, census block groups were employed as the independent variable for the study of housing density. Unlike detailed parcel data, census data does not reveal personal information such as: property lines, landowner names, and exact locations of housing units. Quantitative assessments of the actual impacts of housing units on ecosystems must be conducted on a case by case, property by property basis. Suggested corridor paths must be adjusted on the ground to meet the requisite distance of a corridor from existing housing units, active agricultural operations and other forms of industry, development and infrastructure. This study provides detailed, fine-scale suggestions for conservation of connective habitat within the area of interest. However, on-the-ground adjustments and/or implementation of the products of this thesis study would be carried out by local conservation districts, land trusts, conservation working groups and the private landowners who cooperate with these organizations.

Lastly, this thesis study did not include an inventory of roads and fencing that have been identified as underused and slated for decommission or removal. The role that roads play in habitat fragmentation has been extensively reviewed, however the effects of fencing on the permeability of the landscape for wide-ranging large carnivores received little to no mention in the literature, or this thesis study. Thus, further study of the effects of fencing on the permeability of private lands within a wildlife linkage could provide invaluable data regarding ways to use fencing to: A) avoid livestock/predator conflicts and B) promote permeability of the landscape for wildlife.

CONCLUSION

From the Cascades to the Rocky Mountains, habitat loss, habitat fragmentation and climate change isolate large carnivores of concern, pushing them to the brink of extirpation and in some cases, local extinction. The anthropogenic activities that surround the North Cascades Ecosystem pose so many challenges to the dispersal of grizzly bears that the resident population requires translocation of bears from areas in BC, Canada and Montana in order to keep the North Cascades grizzly bear population from disappearing entirely. Climate change driven, accelerated fire regimes in the Lynx Management Zone of Washington State threaten to drive one of the last remaining Canada lynx populations in the contiguous United States north to Southern BC where they do not have federal protection[19]. Gray wolf recovery has been a major success story in Washington State. Gray wolves have reclaimed much of their historical range in Washington State over the course of the last two decades. Federal and state management policies favorable to gray wolf recovery have allowed them to reestablish stable populations across the eastern half of the state (Washington Department of Fish and Wildlife et al., 2018). However, recovery also led to the delisting of gray wolves from the ESA in 2011 in the eastern 1/3 of Washington State (Wiles, Allen, & Hayes, 2011). Today, ecosystem management has been integrated into much of the resource management policies on local, state and federal levels in the USA. Given the importance of large carnivores to food web dynamics they represent focal species for conservation from the perspective of landscape ecology and

[19] Species at Risk Act § 32 (2). Retrieved from the Library of Congress: https://www.loc.gov/law/help/bigcats/canada.php#_ftn12

ecosystem management. According to Linnell et al. (2001) the time when driving large carnivore populations into extinction represented a legitimate resource management goal is over. Furthermore, Linnell et al. (2001) found a positive relationship between large carnivore recovery and management policies favorable to carnivores, even in areas of high human population density. Conserving and linking habitat for large carnivores go hand in hand with upholding and supporting management and policies that favor the recovery of large carnivores of concern.

The products created for this thesis study provide options for linking habitat for large carnivores of concern from habitat patches within Okanogan National Forest land west and east of the Okanogan River Valley. This small-scale approach to facilitating dispersal across a major highway (US Highway 97) and an agriculturally active river valley can have large-scale implications for the viability of the focal species of this study. Landscape conservation assessments identified the Okanogan Valley of Washington State as a fracture zone preventing lateral dispersal for multiple species guilds including large carnivores. By magnifying the scale of least-cost path analyses for this thesis area of interest, specific, detailed corridor paths could be produced. These corridor options provide a strategic reference for land managers and local conservation workgroups for areas of conservation priority for focal large carnivores. Additionally, the study of development on private land demonstrated the high level of landscape permeability that still persists across the Okanogan Valley and the surrounding areas. The study of development over time, however, conveyed a trend toward open and forested spaces becoming less permeable for wildlife over time. Therefore, addressing the conservation needs of focal large carnivores becomes more pressing as development exacerbates fragmentation of an area that demonstrates great potential to be able to aid in the recovery of carnivores of concern across the transboundary, Okanogan-Kettle subregion of Washington State and British Columbia.

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APPENDIX A

Models and maps using Euclidean distance as a proxy for development

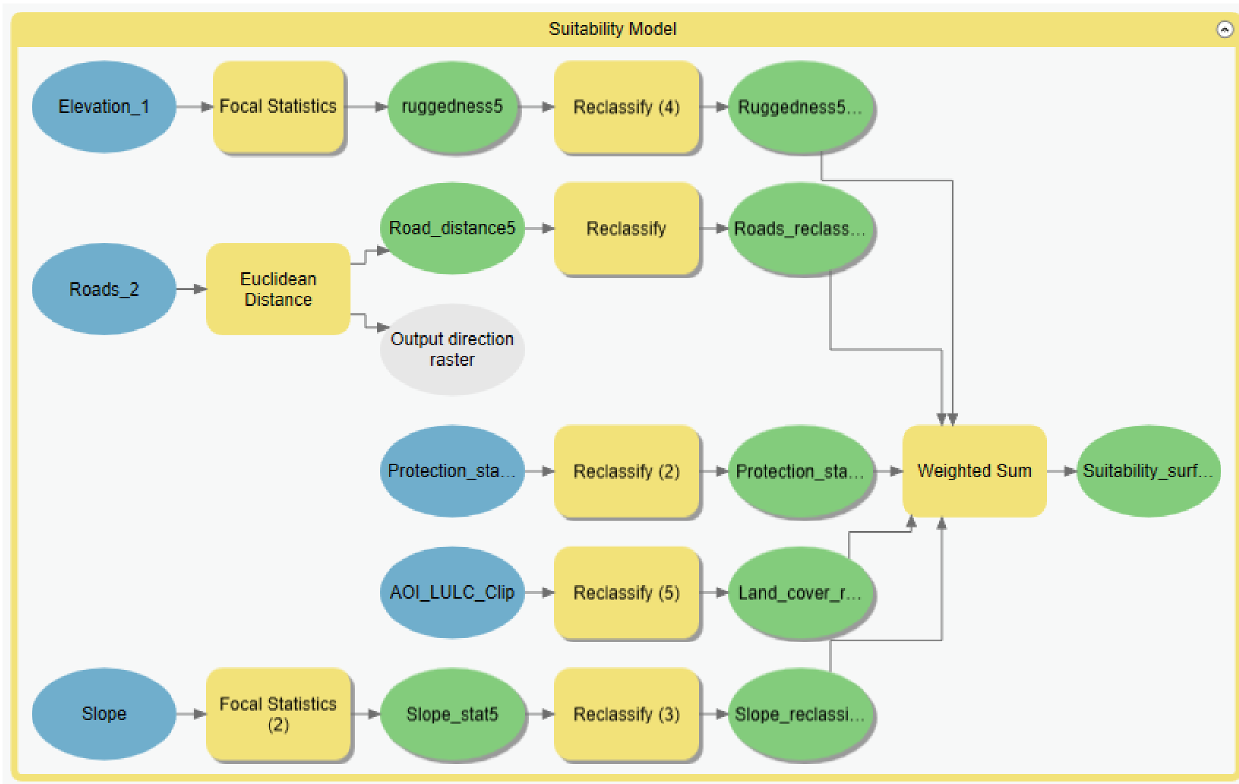

Figure. This figure represents the model I built to gray wolf habitat suitability using the Euclidean distance from roads as the development variable. The Euclidean formula for calculating distance is as follows.

$$d = \sqrt{\sum_{i=1}^{p} (v_{1i} - v_{2i})^2}$$

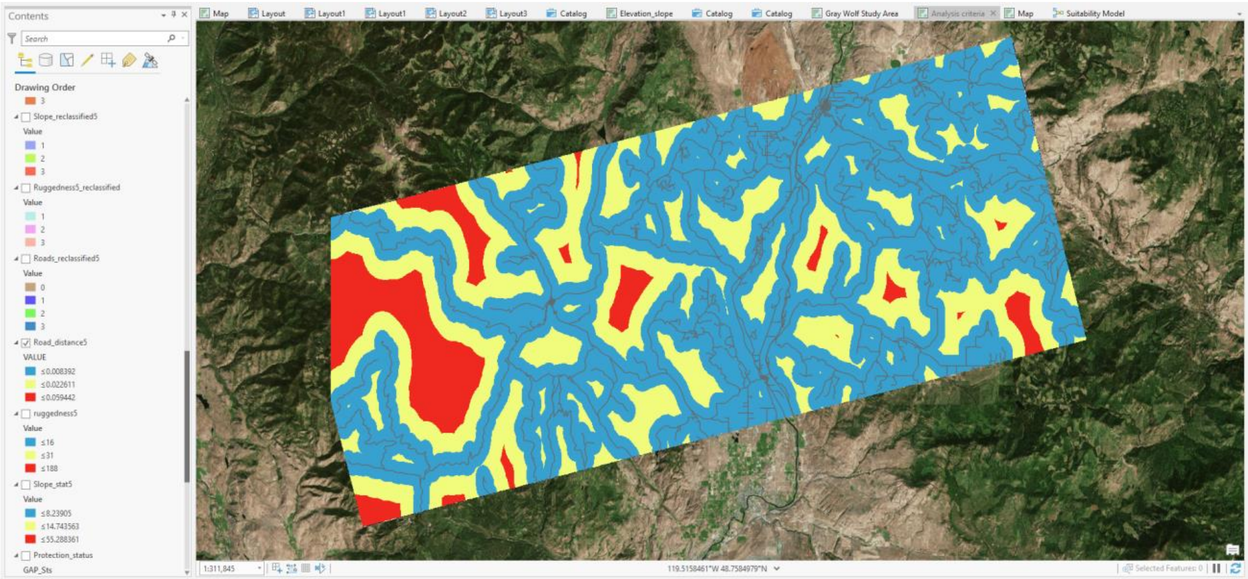

Figure. The above map represents the initial output of distance to roads with the roads layer active for reference. This map has been symbolized by three distance classes: blue (closest to roads) to red (furthest from roads).

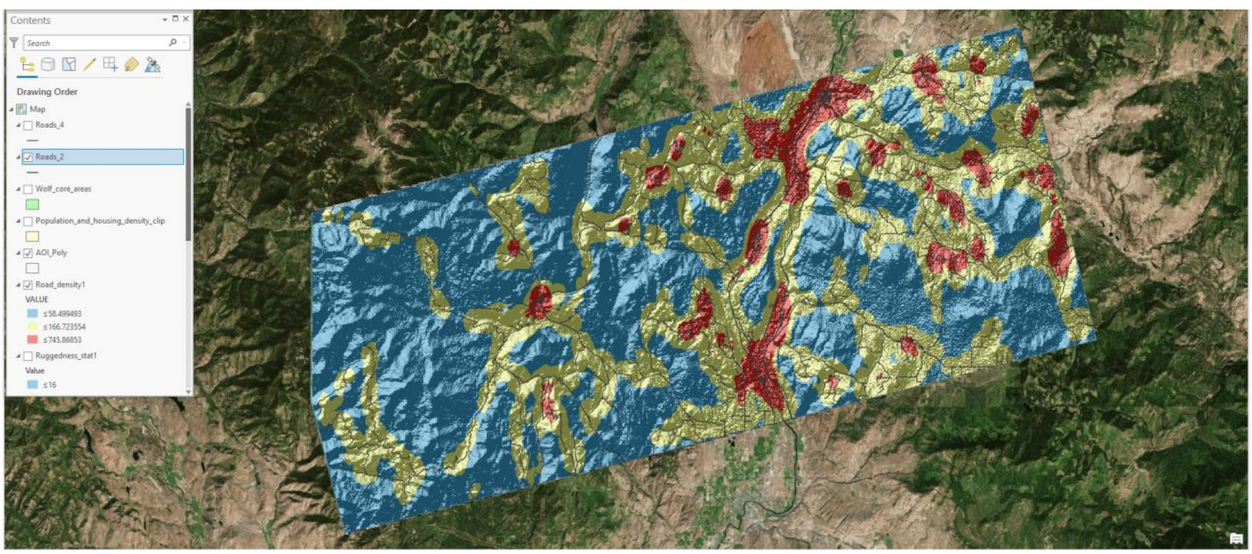

Figure. For comparison, this is the initial output using the variable road density instead of Eucledian distance from roads as a proxy for development for the suitability maps. Red = highest density, whereas blue = lowest density.

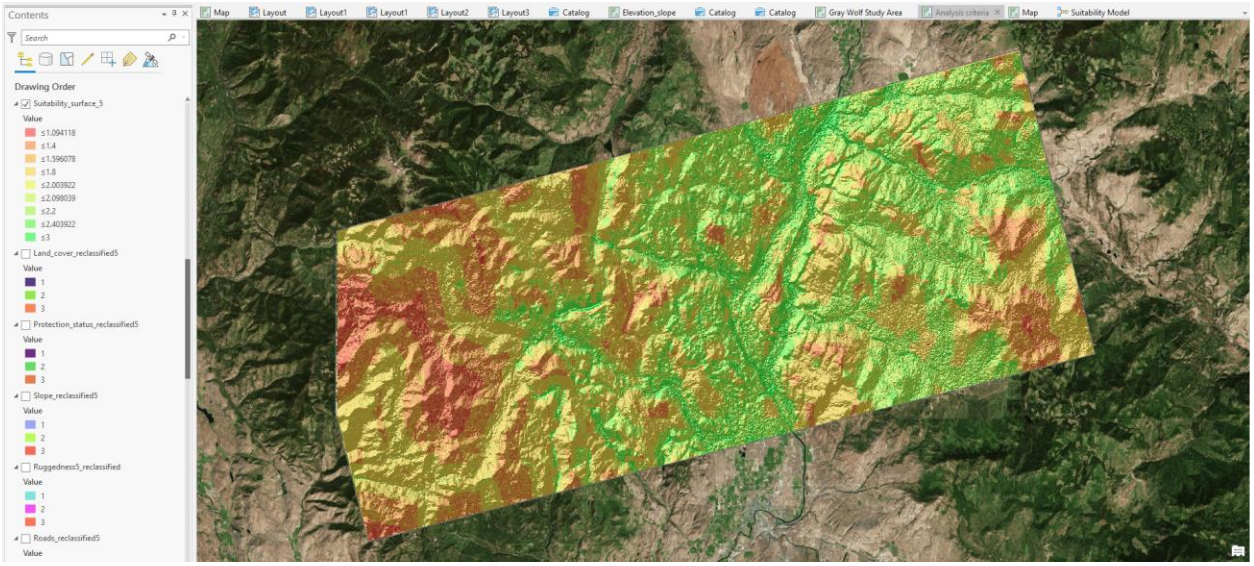

Figure. This map depicts habitat suitability for gray wolves within study area using Euclidean distance from roads vs. road density as the development variable. Red = highest suitability, green = lowest suitability.

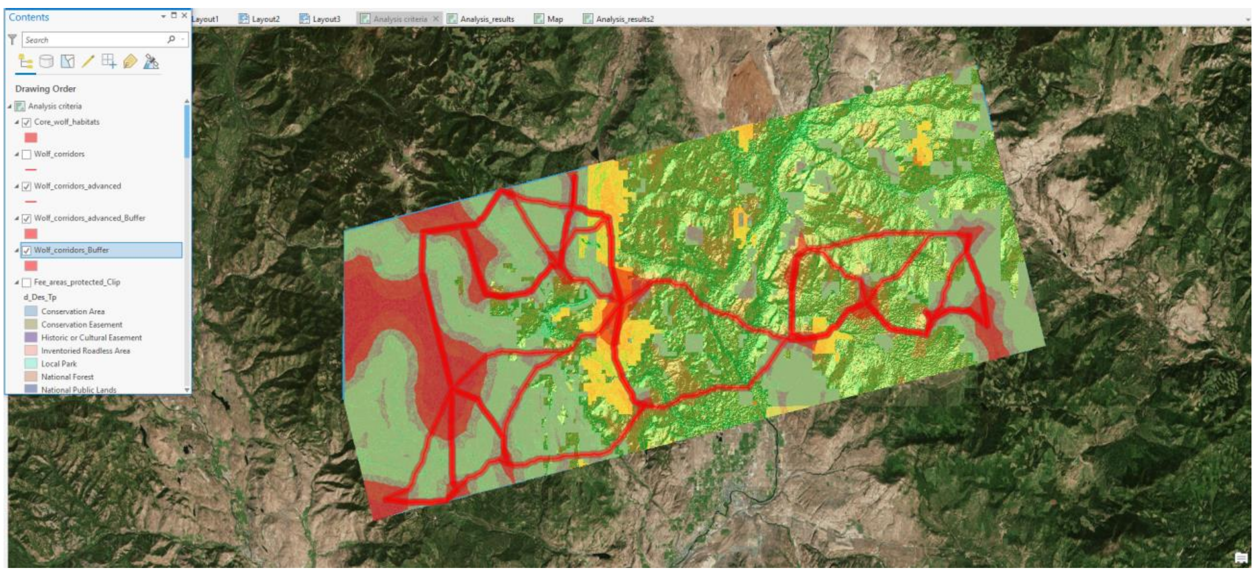

Figure. Core areas w/least-cost corridor network using Euclidean distance from roads as a proxy for development.