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Landscape Permeability for Large Carnivores in Washington: A Geographic Information System Weighted-Distance and Least-Cost Corridor Assessment

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Abstract

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We conducted a regional-scale evaluation of landscape permeability for large carnivores in Washington and adjacent portions of British Columbia and Idaho. We developed geographic information system based landscape permeability models for wolves (*Canis lupus*), wolverine (*Gulo gulo*), lynx (*Lynx canadensis*), and grizzly bear (*Ursus arctos*). We also developed a general large carnivore model to provide a single generalization of the predominant landscape patterns for the four focal species. The models evaluated land cover type, road density, human population density, elevation, and slope to provide an estimate of landscape permeability. We identified five concentrations of large carnivore habitat between which we evaluated landscape permeability. The habitat concentration areas were the southern Cascade Range, the north-central Cascade Range, the Coast Range, the Kettle-Monashee Ranges, and the Selkirk-Columbia Mountains. We evaluated landscape permeability in fracture zones between these areas, including the I-90 Snoqualmie Pass area, the Fraser-Coquihalla area, the Okanogan Valley, and the upper Columbia and Pend Oreille River valleys. We identified the portions of the Washington state highway system that passed through habitat linkages between the habitat concentration areas and areas accessible to the focal species. This analysis provides a consistent measure of estimated landscape permeability across the analysis area, which can be used to develop conservation strategies, contribute to future field survey efforts, and help identify management priorities for the focal species.

Keywords: Washington, corridors, fragmentation, habitat connectivity, landscape permeability, endangered species, reserve design.

Summary

Loss of habitat, isolation of small populations, and direct mortality from collisions with motor vehicles are major concerns in the conservation of large carnivores. To assist in addressing these issues in conservation planning, we conducted a systematic assessment of expected regional-scale landscape permeability for sensitive large carnivores in Washington and adjacent portions of British Columbia and Idaho. Major highways are important landscape features that influence patterns of human activities and can function as partial or complete barriers to large carnivore movement. Our analysis places particular emphasis on identifying areas where the Washington state highway system intersects potential large carnivore habitat and linkages between blocks of habitat.

Focal species for this analysis were gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), grizzly bear (*Ursus arctos*), and wolverine (*Gulo gulo*). We developed geographic information system (GIS) models to evaluate landscape permeability based on broad landscape characteristics that are likely to influence movement patterns for each of the focal species. We also developed a general large carnivore model to evaluate landscape permeability between areas of conservation concern (e.g., large roadless areas or areas identified in large carnivore recovery plans).

We used GIS weighted-distance and least-cost corridor analysis techniques in our models. These techniques are based on the idea that each cell in a map can be attributed with a relative “cost” or “weighted distance” associated with moving across that cell. The cell “cost” is determined by the habitat characteristics of the cell. Cells

with "good" habitat characteristics (e.g., forested land cover, low human population density, and low road density) have low movement costs, whereas cells with "poor" habitat characteristics (e.g., agricultural land cover, high human population density, or high road density) have high movement costs. The weighted-distance analysis produces a map of total movement cost for animals moving from specific source areas. These maps can be interpreted as contour maps of the cumulative effects of landscape barriers encountered during movements radiating from the source habitat areas. The least-cost corridor analysis complements the weighted-distance analysis by mapping the linkages between source habitats with the fewest landscape barriers. We conducted all the spatial analysis using ArcInfo 8.0.2 in a Windows NT environment, with maps compiled from 1:250,000-scale or finer data sources, and a 90-m raster cell size.

Our analysis consisted of five steps:

Step 1: We assembled regional GIS maps of road density, human population density, land cover, and slope.

Step 2: We identified areas with concentrations of suitable large carnivore habitat by using GIS habitat association models for each of the focal species. These were the areas between which we were interested in mapping habitat connectivity patterns.

Step 3: We conducted GIS weighted-distance analysis to map the cumulative effects of landscape barriers for animals moving from the modeled habitat concentration areas. We used these maps to identify areas near modeled source habitats that contained few landscape barriers to animal movements (available habitats) and areas between modeled source habitats where landscape barriers may direct or prevent animal movement (fracture zones).

Step 4: We conducted GIS least-cost corridor analysis to map the linkages between habitat concentrations with the fewest landscape barriers to animal movement.

Step 5: We compared a map of the Washington state highway network to the results of the weighted-distance and least-cost corridor analysis to identify where state highways pass through blocks of carnivore habitat or potential linkages between blocks of large carnivore habitat.

The results of the weighted-distance analysis highlighted five areas that were available habitat for two or more of the focal species:

Southern Cascade Range—Available habitat in the southern Cascade Range was centered on the roadless areas surrounding Mount Rainier and Mount Adams. Habitat concentration areas and available habitat were modeled for all four focal species in this area. Highway segments passing through these areas include Highway 410 around Chinook Pass, Highway 12 around White Pass, and Highway 123 in Mount Rainier National Park.

North-central Cascade Range—Habitat concentration areas were identified for all four focal species in or near the wilderness areas of the northern and central Cascade Range. Weighted-distance analysis indicated that these areas were connected by permeable landscapes. Highway segments passing through areas consistently identified as available large carnivore habitat included Highway 2 near Stevens Pass, Highway 97 around Blewett Pass, Highway 20 near Washington and Loup Loup Passes, and a short segment of Highway 153 along the Methow River near Carlton.

British Columbia Coast Range—Habitat concentration areas were identified for wolverine and grizzly bears in the Coast Range. Habitat concentration areas for wolves and lynx were identified east of the Coast Range in the Thompson River watershed. Weighted-distance analysis indicated that areas available to wolves and lynx extended well to the south and were connected with the northern Cascade Range. The only highway passing through areas available to wolverine and grizzly bears in the Coast Range was British Columbia Highway 99 between Squamish and Lilooet. Highways passing through areas available to lynx and wolves east of the Coast Range included B.C. Highway 1 between Lytton and Cache Creek, B.C. Highway 97c between Cache Creek and Merritt, B.C. Highway 8 between Spences Bridge and Merritt, B.C. Highway 5 between Hope and Merritt, and B.C. Highway 5a between Princeton and Merritt.

Kettle-Monashee Ranges—Habitat concentration areas and available habitats were identified for wolves and lynx in the U.S. portion of the Kettle Range. Grizzly bear and wolverine habitat concentrations were identified near the Monashee Range. Washington state highways passing through areas available to wolf and lynx near the Kettle Range include Highway 20 between Wauconda and Kettle Falls, Highway 21 between Keller and the Canadian border, and Highway 395 between Kettle Falls and the Canadian border. British Columbia Highway 3 passed through landscapes available to lynx and wolverine near Cristina Lake.

Selkirk-Columbia Mountains—Modeled habitat concentration areas were identified for wolverine, grizzly bear, and lynx in the Selkirk Mountains of Washington and British Columbia. Available habitat extended to the north into the Columbia Mountains for these three species. No major highways pass substantially within the U.S. portion of the Selkirk Mountains. British Columbia Highway 3 over Kootenay Pass bisects available habitat for wolverine, grizzly bear, and lynx just north of the Canadian border.

We identified four regional fracture zones, evaluated landscape permeability within them, and identified highways intersecting potential linkage areas:

Snoqualmie Pass—Available large carnivore habitat in the southern Cascade Range was separated from available habitat in the central Cascade Range by the landscape surrounding I-90 near Snoqualmie Pass. The most consistently identified linkage area along I-90 for all the focal species was east of Snoqualmie Pass, near Easton. Secondary linkage areas also were identified along I-90 west of Snoqualmie Pass at Granite Mountain (for wolverine and grizzly bear), and east of the pass at Thorpe Prairie (for lynx), and near Vantage (for wolves).

Fraser-Coquihalla—Available habitat identified for grizzly bears and wolverine in the northern Cascade Range was separated from habitat in the Coast Range by the Fraser River and Coquihalla Summit area. Consistent linkages for grizzly bears and wolverine were located in the northern portion of the Fraser River canyon, along B.C. Highway 1 between Spuzzum and Lytton, and along B.C. Highway 5 in the Coquihalla Summit area, 30 to 45 km south of Merritt. A second linkage area for grizzly bears was identified along B.C. Highway 1, between Chilliwack and Hope.

Okanogan Valley—Available habitat for all four focal species in the northern Cascade Range was separated from habitat in the Kettle and Monashee Ranges by the Okanogan Valley. One linkage area was identified for all four focal species in the Washington portion of the Okanogan Valley, along Highway 97 between Riverside and Tonasket.

Another linkage was highlighted by the wolverine, lynx, and grizzly bear models in British Columbia along B.C. Highway 97 between Oliver and Okanagan Falls, centered on the Vaseux Lake National Wildlife Refuge.

Upper Columbia and Pend Oreille River valleys—Available habitat for lynx and wolves in the Kettle Range was separated from habitats to the east by the Upper Columbia and Pend Oreille River valleys. Two linkage areas consistently identified for all the focal species passed through this area: one just south of the Canadian border, intersecting Highways 25 and 31 north of Kettle Falls and Ione, and the other north of the Canadian border, passing through the area between Trail and Castlegar, intersecting B.C. Highways 3, 3b, 22, and 6.

This assessment is intended to provide information for developing conservation strategies, to contribute to future field survey efforts, and to help identify management priorities. These analyses were conducted by using regional-scale spatial data sets that are effective for evaluating broad-scale patterns but should not be expected to provide precise information for specific locations on the ground. This analysis provides measures for comparing estimated landscape permeability between different areas; however, the actual functionality of the linkages we have identified remains to be demonstrated through field surveys and additional research.

Our modeling approach emphasized evaluating resistance to animal movement for the purpose of identifying important habitat linkages. We did not focus on evaluating the availability of food, denning habitats, or other features that are important components of habitat suitability assessments. Areas identified as available habitat in our analysis are not necessarily suitable habitat.

Contents

Introduction

The ability of animals to move across landscapes is critical at many scales. Animals need to be able to move efficiently within their home ranges to access food, shelter, mates, and other basic needs (Stephens and Krebs 1986). Animals also need to be able to move beyond their home ranges to find unoccupied habitat and maintain genetic exchange between groups (Hanski and Gilpin 1997, Young and Clarke 2000). Landscape features can influence an animal's ability to move at both of these scales. Although effects will vary for different species, major highways, rugged topography, human development, and land cover types all can affect an animal's ability to successfully move through an area (e.g., Beier 1995, Brody and Pelton 1989, Gibeau and Heuer 1996, McLellan and Shackleton 1988). Understanding patterns of landscape permeability is particularly important for the conservation of species with large home ranges and low-density populations, such as large carnivores (Clark et al. 1996, Noss et al. 1996, Weaver et al. 1996).

This work is an effort to quantitatively estimate, compare, and map the relative potential for animal movement between patches of large carnivore habitat, at a regional scale, in Washington state and adjacent areas. We were particularly interested in identifying where the Washington state highway system intersects areas that may be used by sensitive large carnivores. This analysis focused on the four largest endangered, threatened, or sensitive large carnivores in Washington: gray wolf (*Canis lupus*, endangered), wolverine (*Gulo gulo*, sensitive), lynx (*Lynx canadensis*, threatened), and grizzly bear (*Ursus arctos*, threatened). Understanding and managing landscape permeability for these species will be especially important because their populations in Washington are extensions of populations (or metapopulations) centered in British Columbia (Gaines et al. 2000). Populations of these species in Washington may not be viable without the exchange of individuals from larger populations to the north or east (Gaines et al. 2000). We have included a literature review of the regional distribution, habitat associations, dispersal characteristics, and habitat modeling efforts for each of these species in appendix 1 of this report.

Few features in the modern landscape have such dramatic influence on patterns of human development, landscape change, and habitat fragmentation as highways (Forman 1999, Forman and Hersperger 1996). Understanding how transportation networks interact with landscape patterns that influence animal movement is important for many species (e.g., Evink et al. 1996, 1998, 1999) but is especially important for the conservation of large carnivores (Gibeau and Heuer 1996, Ruediger et al. 1999, Weaver et al. 1996). Integrating highway alignment and design features with an understanding (and perhaps management) of landscape patterns that influence animal movement can contribute to safer highways for both animals and motorists (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996).

Much discussion in the ecological literature has focused on the role of habitat fragmentation and its genetic and demographic effects on species persistence (Lehmkuhl et al. 2001, Rochelle et al. 1999, Young and Clarke 2000). The early theoretical work in this field was largely based on island biogeography theory (MacArthur and Wilson 1967), which emphasized perceptions of "islands" of suitable habitat in a "hostile sea" of nonhabitat. Concepts of habitat corridors providing linear connections through this "hostile sea" developed from the application of island biogeography theory to conservation problems (Bunnell 1999). Several more recent discussions of this issue have pointed out that these approaches focusing on "suitable" corridors through "hostile" landscapes may be overly simplistic, and have proposed that different conditions on the landscape create different levels of resistance to movement for different species

(Bunnell 1999, Puth and Wilson 2001, Ricketts 2001, Wiens 2001). Landscapes between patches may encompass either habitats through which an animal can move easily or barriers that prevent or redirect movement. It is the composition and configuration of these characteristics that define the permeability of a landscape.

As an uncommon ecological term, landscape permeability warrants a definition. Forman and Godron (1986, p. 594) define a landscape as “a heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout.” Webster’s dictionary defines permeability as “the state or quality of being open to passage or penetration.” Thus, from an animal movement perspective, we would define landscape permeability as “the quality of a heterogeneous land area to provide for passage of animals.” Some authors have used the term “habitat connectivity” in a similar sense (e.g., Dobson et al. 1999, Tischendorf and Fahrig 2000); however, we feel that it is confusing to imply that patches of similar habitat must be physically connected to allow animal movement across a landscape, particularly when considering movements of large carnivores that are able to move through various habitats. In contrast to focusing on the identification of corridors or connected habitat patches, the evaluation of landscape permeability should provide a broader measure of resistance to animal movement and give a consistent estimate of the relative potential for animal passage across entire landscapes.

When discussing animal movement and landscape permeability, it is important to be clear about the type of movement under consideration. Animal movements can be broadly categorized into two classes (Dobson et al. 1999, Swingland and Greenwood 1984): (1) intraterritorial movements—short- and medium-distance movements in or near an established home range, usually associated with foraging, reproduction, or seasonal shifts in habitat; and (2) interterritorial movements—long-distance dispersal or exploratory movements outside of an established home range, usually associated with investigations of distant habitat areas or the establishment of new home ranges, as when a young animal leaves its natal home range. Landscape permeability to intraterritorial movement determines what resources are available to an animal in its daily or seasonal movements (Stephens and Krebs 1986). This resource availability can determine individual survival and reproduction. Landscape permeability to interterritorial movement influences the level of gene flow between groups (subpopulations) of animals, the ability of animal populations to become established in unoccupied suitable habitat, and other metapopulation functions (Hanski and Gilpin 1997). Maintaining landscapes in which large carnivores can move at both these scales will be important for their long-term conservation (Noss et al. 1996, Young and Clarke 2000).

Different species will have different behaviors related to long-distance interterritorial movements (Beier and Loe 1992). These behaviors need to be considered when evaluating the permeability of a landscape. Some species, e.g., wolves and lynx, are able to move long distances through diverse habitats (Forbes and Boyd 1997, Poole 1997). For these species, maintaining landscape linkages that have relatively few landscape barriers but do not support breeding individuals may be adequate to provide for movement between areas where populations of those species persist. However, other species (e.g., grizzly bears) have not been documented to make long-distance movements through marginal habitat areas (McLellan and Hovey 2001). For those species that are not inclined to make long-distance interterritorial movements, maintaining breeding habitat for at least a few individuals in the linkage area may be necessary to achieve a functional linkage between blocks of habitat supporting larger groups of animals.

Classic metapopulation theory (Hanski and Gilpin 1997, McCullough 1996, Meffe and Carroll 1994) tells us that the long-term survival of a species that has a patchy distribution across a large area depends on the rate of extinction in each of the patches and the rate of movement between the patches. Simply put, if the rate of movement between the patches exceeds the rate of extinction within the patches, the metapopulation (the group of population patches) should persist over time. If, however, the rate of movement between the patches does not keep up with the rate of extinction within the patches, the entire metapopulation will eventually become extinct (Hanski and Gilpin 1997, McCullough 1996, Meffe and Carroll 1994).

Highways have the potential to reduce the viability of metapopulations in two major ways: (1) within patches, highways can contribute to increased extinction rates by increasing mortality from motor vehicle collisions, increasing human disturbance, and decreasing availability of food or other resources by acting as barriers to intraterritorial movement; (2) between patches, highways can decrease movement because of landscape barrier effects or direct mortality from motor vehicle collisions. Explicitly identifying areas where highways have the potential to impact within-patch population viability or rates of between-patch movement is the first step in identifying potential impacts and taking steps to prevent or mitigate them.

Our regional-scale evaluation of large carnivore landscape permeability is intended to provide information for developing conservation strategies, to contribute to future field survey efforts, and to help identify management priorities. We view this analysis as a hypothesis development exercise in which we propose that the linkage areas we identify are more likely to provide for successful passage for the focal species than adjacent areas, based on the landscape characteristics we evaluated. We have attempted to develop a method that provides explicit measures of estimated landscape permeability. These measures can be used to compare landscape permeability between different areas at various scales. However, the actual functionality of the linkage areas we identify can only be tested through empirical field studies, and even then will be difficult to determine because of the challenges inherent in the study of dispersal movements (Nathan 2001).

Users of this information also must be aware of the appropriate range of scales for the application of our results. These analyses were conducted by using regional-scale spatial data sets that are effective for evaluating broad-scale patterns, but should not be expected to provide precise information for specific locations on the ground, such as is required for identifying locations for highway mitigation projects or locating animal crossing structures. The results of our analysis should not be considered a substitute for actual field surveys similar to those recently conducted along I-90 at Snoqualmie Pass (Singleton and Lehmkuhl 2000).

This exercise is not intended to be an assessment of suitable or critical habitat. Our modeling approach emphasized evaluating resistance to animal movement, not the availability of food resources, denning habitats, or other life history requisites for these species. Areas identified as available habitat in our analysis (areas within which movement is not restricted by substantial landscape barriers) are not necessarily suitable habitat (areas providing the requisite food, denning, and other resources necessary for an animal to survive and reproduce). Habitat assessments for the focal species are currently underway or have been conducted in concert with conservation and recovery planning (Almack et al. 1993, Stinson 2001, USFWS 1997). It is not our intention to duplicate those efforts.

Study Area

Our analysis focused on evaluating landscape permeability in the state of Washington. However, linkages to areas in a larger region needed to be addressed to effectively evaluate landscape permeability in Washington. Our analysis encompassed all of Washington and adjacent portions of Idaho and British Columbia (fig. 1). The analysis area extended from the Oregon-Washington border (latitude 42°) north to Revelstoke and Kamloops, British Columbia (latitude 51°), and from the Pacific coast (longitude 125°) east to the Idaho-Montana border (longitude 116°). The actual analysis encompassed about 326 000 km^2 of land area.

Broad-scale landscape patterns in Washington and adjacent portions of Idaho and British Columbia are largely defined by the gross geological features that dominate the region. In particular the north-south spine of the Cascade Range runs from the Columbia River east of Portland, Oregon, into British Columbia east of Vancouver, and meets the Coast Range along the Fraser River in southern British Columbia. These mountains substantially influence the climate, vegetation, and human development in the region. West of the Cascade Range, moist coastal conifer forest types and substantial urban development characterize the landscape surrounding Puget Sound. Southwestern Washington and the Olympic Peninsula also are characterized by moist coastal conifer forest, much of which is in private land ownership and managed for industrial timber production. The Olympic National Park and some surrounding national forest lands provide an isolated block of less disturbed forest and alpine habitat on the Olympic Peninsula.

East of the Cascade Range, relatively arid conditions dominate the agricultural and shrub-steppe landscapes of the Columbia basin. These arid conditions extend north in a narrow strip along the Okanogan Valley into central British Columbia. This broad valley provides some of the most temperate climate conditions in all of Canada and is well known for its agriculture and retirement communities. Northern portions of the Okanogan Valley are heavily developed, particularly along Okanagan Lake where the cities of Penticton, Kelowna, and Vernon are located. East of the Okanogan Valley in British Columbia and northeastern Washington, the Kettle and Selkirk Mountain ranges extend south from the Columbia Mountains to the Columbia River at Grand Coulee and the Pend Oreille River north of Spokane. These low mountain ranges are characterized by mixed interior coniferous forest, and the U.S. portions are largely within the Colville and Idaho Panhandle National Forests. Wildlife habitat conditions are well described for Washington by Johnson and O'Neil (2001).

This analysis emphasizes areas within and east of the Cascade Range because of the distribution of habitat for the focal species. This assessment does not address the various species and habitats for which barriers to movement could be a concern for forest-associated species of western Washington (particularly for southwestern Washington), or for species associated with nonforest habitats (for example, wetland or shrub-steppe species). Selection of other focal species and different scales of analysis is probably appropriate to adequately evaluate landscape conditions for other species and other areas.

We did not attempt to assess landscape permeability for potential carnivore habitat in adjacent portions of Oregon (in particular the Oregon Cascade Range and Blue Mountains) because of funding and data processing limitations. We also did not assess landscape permeability patterns in the Blue Mountains of Washington because this area is isolated from other blocks of large carnivore habitat in Washington. An assessment of landscape permeability for the Blue Mountains would be better incorporated into a regional assessment for Oregon and southern Idaho.

Methods

We used GIS weighted-distance and least-cost corridor analysis to evaluate landscape permeability for wolves, wolverine, lynx, and grizzly bears. We also developed a general forest-associated large carnivore model to provide a single generalized map of the predominant landscape permeability patterns for the four focal species. Our analysis builds on large carnivore landscape linkage modeling approaches developed by Servheen and Sandstrom (1993) and Walker and Craighead (1997). Researchers that have used least-cost techniques for the evaluation of animal movement routes include Walker and Craighead (1997), Kobler and Adamic (1999), Paquet et al. (1999), and Purves and Doering (1999).

Weighted-distance and least-cost corridor GIS techniques are two complementary analyses based on the idea that resistance to movement can be mapped by assigning each cell in a map a relative "weighted-distance" or "cost" of moving across that cell (ESRI 1992: 6-63 to 6-79). The cell "cost" is determined by the habitat characteristics of the cell. Cells with "good" habitat characteristics (e.g., forested land cover, low human population density, and low road density) have low movement costs, whereas cells with "poor" habitat characteristics (e.g., agricultural land cover, high human population density, or high road density) have high movement costs. In our analysis, the "cost" of moving across a cell was calculated as the cell size (90 m) times a weighting factor based on the habitat characteristics of the cell (fig. 2).

Weighted-distance analysis calculates, for each cell, the minimum sum of cell "costs" between the cell in question and the closest designated source area. The weighted-distance analysis results in a map that shows an estimate of how "hard" (in terms of the cumulative effect of landscape barriers or the total weighted distance) it would be for an animal to move from the closest source to any point on the map. Least-cost corridor analysis evaluates the "cost" of moving between two designated source areas by calculating, for each cell, the cumulative weighted distance between the cell in question and the two sources. The least-cost corridor analysis results in a map that shows the relative linkage value across the landscape (which routes through the landscape encounter more or fewer landscape barriers) between the two source areas.

We compiled GIS data sets representing land cover class, roads, highways, human population density, and topography (figs. 3 through 6). Metadata about the spatial data layers are presented in appendix 2. We compiled data from approximately 1:250,000 mapping scale source data. We used a 90-m raster cell size for all weighted-distance and least-cost corridor analysis. All spatial analysis was conducted by using ArcInfo 8.0.2[1] GIS software (ESRI 2000) in a Windows NT environment. Spatial analysis AML macro programs are included in appendix 3.

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

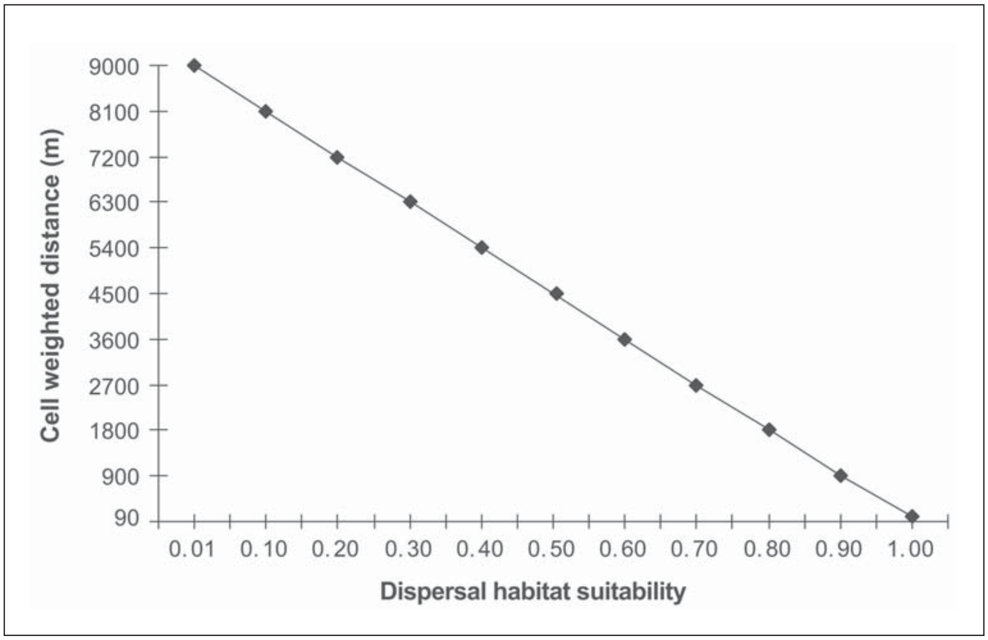

Figure 2—Map cell weighted distance in relation to dispersal habitat suitability for weighted distance and least-cost corridor analysis of landscape permeability. The weighted distance for moving across each cell was calculated as (cell size{100 - [100(dispersal habitat suitability)]}). All weighted-distance and least-cost corridor analysis was conducted by using a 90-m cell size, thus cells with a dispersal habitat suitability of 1.00 were attributed with a weighted distance of 90 m.

We developed habitat association and dispersal habitat suitability models for each of the focal species based on an extensive literature review and expert opinion (app. 1). We derived the general forest-associated large carnivore model from the species-specific models by using an approximate median value for each landscape parameter from the species-specific models. Concentrations of habitat for each species were identified by using species-specific habitat association models (table 1). Habitat concentrations for the general forest-associated large carnivore model were identified based on large roadless areas and habitat areas identified in regional management and recovery plans for the focal species (North Cascades Grizzly Bear Recovery Team 2001, Stinson 2001, USFWS 1993).

We evaluated dispersal habitat suitability across the entire analysis area based on road density, human population density, land cover, slope, and elevation (table 2). Each class for each landscape characteristic was given a value from 0.1 to 1 based on its estimated contribution to resistance to movement (table 2). Dispersal habitat suitability was calculated from these weighted values as road density × human population density × land cover × slope × elevation, resulting in a score between 0 and 1 for each cell. Although this model weights the parameters equally, the relative importance of each parameter is reflected in the permeability value assigned to it. For example, land cover type is expected to have more influence on landscape permeability than slope, therefore permeability values for different land cover classes range from 0.1 to 1, whereas permeability values for slope classes range from 0.6 to 1. The weighted distance or cost of moving across a cell was determined based on the dispersal habitat suitability within the cell (fig. 2).

Table 1—Habitat association model parameters used to identify habitat concentration areas for the focal species[a]

Species	Parameters
Wolf	Elevation <1500 m Slope <25º Road density <1.6 km per 0.9-km radius circle (<1 mi/mi^2) Dry interior forests (to correspond to ungulate winter ranges)
Lynx	Subalpine fir forest types (all seral stages) Road density <6.4 km per 0.9-km radius circle (<4 mi/mi^2) Elevation 1000–2250 m
Grizzly bear	Road density = 0 Forest/mesic shrub–alpine edge habitats
Wolverine	Alpine, interior or west-side mesic forest Road density = 0 Elevation >1500 m

[a] Potential habitat was mapped at 90-m resolution for each species by using these rules: Resulting habitat maps were converted to 1-km resolution and summed by using a 5-km radius circular moving window to identify habitat concentration areas. Habitat concentration area polygons were selected based on species-specific thresholds for size and percentage of habitat within the polygon.

The results of the weighted-distance analysis provide an index of landscape permeability around the modeled habitat concentration areas. We chose to report the area within 100 km weighted distance of modeled habitat concentration polygons as a common measure of areas that we expect are available to short- and medium-distance (intraterritorial) animal movements. We used the 100-km weighted-distance measure because movements of 100 km are not uncommon for the focal species in areas where large blocks of habitat are available (Banci 1994, Boyd et al. 1995, LeFranc et al. 1987, Poole 1997). Although the 100-km weighted-distance measure does not directly equate to energy or risk costs associated with actual 100-km movements in highly permeable landscapes, it does provide an intuitive, consistent measure of available habitat for comparisons between the models and for identification of highway segments passing through a matrix of potential large carnivore habitat. In this report, we refer to those areas within 100-km weighted distance of modeled habitat concentration areas as “available habitat,” indicating that there were not substantial landscape barriers between the evaluated area and modeled habitat concentration areas. This designation should not be interpreted as indicating that these areas are “suitable habitat” in the sense of providing food, denning sites, or other resources that may be required by the species.

We evaluated landscape permeability for areas up to 1000 km weighted distance from modeled habitat concentration polygons. We expect that areas in excess of 1000 km weighted distance from habitat concentration polygons are highly unlikely to provide for successful passage of animals moving from the modeled habitat concentrations owing to the cumulative effects of landscape barriers.

Table 2—Dispersal habitat suitability model parameters and permeability values for weighted-distance and least-cost corridor analysis [a]

Landscape characteristic	Relative permeability by species				
	General forest associate	Gray wolf	Lynx	Grizzly bear	Wolverine
Land cover class:					
Agriculture	0.3	0.4	0.3	0.3	0.3
Alpine	0.8	1.0	0.8	1.0	1.0
Dry forest	1.0	1.0	1.0	1.0	1.0
Dry shrub/grass	0.8	1.0	0.8	0.5	0.5
Interior mesic forest	1.0	1.0	1.0	1.0	1.0
Interior mesic shrub	0.8	1.0	0.8	0.8	0.6
Snow/ice	0.1	0.1	0.1	0.1	0.8
Urban/developed	0.1	0.1	0.1	0.1	0.1
Water	0.1	0.1	0.1	0.1	0.1
West-side mesic forest	1.0	1.0	1.0	1.0	1.0
West-side mesic shrub	0.8	1.0	0.8	0.8	0.6
Wetland/riparian	1.0	1.0	0.8	1.0	0.8
Bare ground	0.3	0.6	0.3	0.3	0.8
Population density (people per 0.9-km radius [1 mi^2] circle):					
0–10	1.0	1.0	1.0	1.0	1.0
10–25	0.8	0.5	1.0	0.5	0.8
25–50	0.5	0.3	0.8	0.3	0.5
50–100	0.3	0.1	0.5	0.1	0.5
100–100,000	0.1	0.1	0.1	0.1	0.1
Road density: [b]					
0–0.01	1.0	1.0	1.0	1.0	1.0
0.01–1.6 (0.01–1)	1.0	1.0	1.0	1.0	1.0
1.6–3.2 (1–2)	0.8	0.8	1.0	0.8	0.8
3.2–6.4 (2–4)	0.6	0.5	1.0	0.5	0.5
6.4–9.7 (4–6)	0.5	0.5	0.8	0.3	0.5
9.7–12.9 (6–8)	0.4	0.2	0.8	0.2	0.2
12.9–16.1 (8–10)	0.2	0.2	0.8	0.2	0.2
>16.1 (>10)	0.1	0.1	0.1	0.1	0.1
Elevation (m):					
0–1000	1.0	1.0	1.0	1.0	0.6
1000–1500	1.0	1.0	1.0	1.0	0.8
1500–2000	1.0	1.0	1.0	1.0	1.0
2000	1.0	1.0	1.0	1.0	1.0
Slope (degrees):					
0–20	1.0	1.0	1.0	1.0	1.0
20–40	0.8	0.8	0.8	1.0	0.8
>40	0.6	0.6	0.6	1.0	0.6

[a] Dispersal habitat suitability within each map cell was calculated as the product of the relative permeability score for each landscape characteristic at the cell (e.g. (land cover class) × (population density) × (road density) × (elevation) × (slope)).
[b] Road density is shown in kilometers per 0.9-km radius (1 mi^2) circle, with equivalent miles in parentheses.

We conducted least-cost corridor analysis in areas with reduced landscape permeability (weighted distance 100 to 1000 km or areas near major highways) between modeled habitat concentration areas. We refer to these areas of reduced landscape permeability between habitat concentrations as “fracture zones” (Servheen and Sandstrom 1993). Fracture zone polygons were hand digitized to encompass areas between groups of habitat concentration polygons where maintaining or improving landscape permeability could be a management objective. We conducted least-cost corridor analysis within the fracture zone polygons to identify the most permeable portions of the landscapes between habitat concentration areas. We used the same cost-weighting factors for the least-cost corridor analysis as were used for the weighted-distance analysis. The landscape within the fracture zone polygons was classified into 10 groups of equal area, ranging from the most permeable 10 percent of the fracture zone landscape (least-cost corridor rank 1) to the least permeable 10 percent (least-cost corridor rank 10). We report areas within least-cost corridor ranks 1 to 5 as potential linkage areas within the fracture zone landscapes.

The linkage minimum weighted-distance (the sum of the “cost” of all the map cells traversed along the most permeable route between the habitat concentration areas) provides an index of the overall difficulty of moving through a linkage area. We also calculated the average permeability for each fracture zone by taking the ratio of the minimum linkage weighted distance to the actual length of the least-cost route between the habitat concentration areas. Fracture zone landscapes with weighted-distance to actual-distance ratios approaching 1 were more permeable on average than landscapes with higher weighted-distance to linear-distance ratios.

We identified areas where the Washington state highway network could be impacting animal movement by overlaying a state highway system map on the results of the weighted-distance and least-cost corridor analysis for each model. We used the 100-km weighted-distance contour to identify areas where highways pass through “available” habitat where the focal species may be expected to encounter the highway during intraterritorial movements. Areas in fracture zones where highways intersect least-cost corridor ranks 1 to 5 are locations where the focal species may be more likely to encounter highways during long-distance movements.

Results

General Carnivore Model

Results of the dispersal habitat suitability modeling for the general carnivore model are displayed in figure 7. Six habitat concentration areas for the general carnivore model were identified based on large roadless areas and locations identified in focal species management plans (North Cascades Grizzly Bear Recovery Team 2001, Stinson 2001, USFWS 1993; table 3, fig. 8). Geographic information system overlays of the Washington state highway network on the weighted-distance map indicated that 721 km of state highways occur within available habitat identified by the general carnivore model near the Cascade Range and northern Washington (table 4, fig. 8). An additional 74 km of state highway occur within available habitat near the Olympic Mountains.

We identified five fracture zones between the habitat concentrations based on the weighted-distance analysis. The least-cost corridor analysis (fig. 9, table 5) indicated that the Fraser-Coquihalla fracture zone was the most permeable, followed by the Upper Columbia–Pend Oreille, Snoqualmie Pass, and the Okanogan Valley. The southwest Washington-Olympics fracture zone was substantially less permeable than the other fracture zones and passed through areas well beyond 1000 km

Table 3—Habitat concentration area sizes and available habitat identified by the general carnivore model[a]

Habitat concentration area	Concentration area size	Available habitat
	Square kilometers	
North Cascade Range	17 446	27 986
Coast Range[b]	9 947	15 188
Olympic Mountains	3 772	6 175
Kettle-Monashee[b]	3 329	12 786
Selkirk Mountains[b]	3 043	8 034
South Cascade Range	2 888	6 150

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area (app. 4 shows the location of habitat concentration areas).
[b] These areas extend beyond the analysis area for this assessment. Sizes listed here only include areas within the extent of our analysis.

Table 4—Highway segments passing through available habitat identified by the general carnivore model

Habitat concentration area	State route	Length	Milepost[a] Min.	Milepost[a] Max.	Description
		Kilometers			
Kettle-Monashee Mountains	20	53	310	340	Republic to Kettle Falls
	21	48	120	155	South of Republic
	21	19	175	190	Republic to Canadian border
	25	2	120	120	Northport to Canadian border
	31	24	15	25	Metaline Falls area
	395	40	255	270	Kettle Falls to the Canadian border
North Cascade Range	2	100	35	95	Stevens Pass, Gold Bar to Leavenworth
	20	148	95	190	Concrete to Winthrop
	20	5	215	220	Loup Loup Pass
	90	38	40	50	West Side of Snoqualmie Pass
	97	24	150	175	Blewett Pass
	153	13	15	20	Methow Valley, between Pateros and Twisp
	530	3	65	65	Skagit River
	542	36	35	55	Mount Baker Highway
	906	2	—	—	Snoqualmie Pass frontage road
	970	4	10	10	South of Blewett Pass
Olympic Mountains	101	66	115	235	Olympic National Park vicinity
	109	7	35	35	Olympic National Park vicinity
	119	1	10	10	Olympic National Park vicinity
Selkirk Mountains	20	20	380	400	South of Ione
South Cascade Range	12	44	140	170	White Pass, Cowlitz River to Tieton River
	123	26	0	15	East Side of Mount Rainier National Park
	165	2	—	—	Mount Rainier National Park
	410	67	55	90	Crystal Mountain to American River
	706	3	10	10	Mount Rainier National Park

[a] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Table 5—Landscape permeability within fracture zones identified by the general carnivore model[a]

Fracture zone	Minimum linkage weighted distance	Actual distance	Weighted-distance/ actual-distance ratio
	- - - - - - - - *Kilometers*	*- - - - - - - -*	
Fraser-Coquihalla	288.1	27.9	10.3
Upper Columbia–Pend Oreille	423.5	46.3	9.1
Snoqualmie Pass	630.4	33.5	18.8
Okanogan Valley	633.5	80.8	7.8
Southwest Washington	6 943.8	116.2	82.6

[a] Appendix 4 shows location of fracture zones.

weighted distance from the habitat concentration areas (minimum linkage weighted distance 6944 km). We expect that the southwest Washington landscape is an effective barrier for the focal species.

Overlays of the state highway network on the least-cost corridor maps indicate that 435 km of highway intersect areas identified as the most permeable 50 percent of the fracture zones in the Cascade Range and northern Washington (table 6), including 42 km in the Upper Columbia area, 90 km in the Pend Oreille area, 228 km in the Okanogan Valley, and 16 km along Snoqualmie Pass. An additional 505 km of state highway intersect modeled linkages in the southwestern Washington fracture zone; however, the results of the weighted-distance analysis indicate that this area is impermeable to movement by the focal species.

Gray Wolf (*Canis lupus*)

Dispersal habitat suitability modeling results for the gray wolf model are displayed in figure 10. Habitat association models identified four habitat concentration areas for wolves (table 7, fig. 11). No habitat concentration areas for wolves were identified in northern Idaho or eastern British Columbia. Because we were interested in investigating landscape permeability patterns across northeastern Washington for wolves, we added a hypothetical habitat concentration area along the eastern edge of our analysis area to represent potential dispersal from established wolf populations in western Montana and central Idaho.

The weighted-distance analysis indicated that landscapes through the Cascade Range, north-central Washington, and the interior lowlands of British Columbia were broadly permeable for wolves (fig. 11). A total of 1180 km of state highway in Washington passes through available habitat identified by the gray wolf model (table 8), including 246 km near the central Cascade Range, 318 km near the Kettle Range, 380 km near the northern Cascade Range, and 235 km near the southern Cascade Range.

Five fracture zones were identified for least-cost corridor analysis (table 9). The least-cost corridor analysis (fig. 12) indicated that the Okanogan Valley was the most permeable of the fracture zones for wolves, followed by the Fraser-Coquihalla, Stevens Pass–Lake Chelan, Snoqualmie Pass, and upper Columbia–Pend Oreille landscapes. The Okanogan Valley linkage contained areas within 100 km of the modeled habitat concentration areas, but we conducted least-cost corridor analysis through the area because of the obvious bottleneck in available habitat and the potential for loss of landscape permeability along Highway 97.

Table 6—Washington state highway segments passing through linkages between habitat concentration areas from the general carnivore model[a]

Fracture zone	State route	Length	Milepost[b] Min.	Max.	Description
		Kilometers			
Upper Columbia	20	42	380	405	South of Ione
Pend Oreille	31	33	5	20	Metaline Falls area
	25	30	95	115	North of Kettle Falls
	395	27	255	270	North of Kettle Falls
Okanogan Valley	97	41	280	315	Omak to Oroville
	21	83	125	180	North and south of Republic
	20	77	270	310	East and west of Republic
	155	28	55	7	East of Omak
Snoqualmie Pass	90	17	65	75	Near Easton
Southwest Washington	101	10	140	150	East of Queets
	101	72	90	135	Hoquiam to Queets
	12	36	0	20	Elma to Aberdeen
	101	23	65	80	Raymond to Aberdeen
	107	13	0	10	South of Montesano
	5	84	55	85	Centralia to Castle Rock
	6	43	20	50	Pe Ell to Chehalis
	7	22	10	20	Elbe to Carlson
	12	42	45	95	I-5 to Mossyrock
	122	13	0	10	Near Mossyrock
	504	24	10	20	Near Toutle
	505	31	0	15	I-5 to Toutle
	506	22	0	10	Near Vader
	507	15	0	10	Centralia to Bucoda
	508	34	0	30	Between Napavine and Morton
	706	22	0	15	Elbe to Ashford

[a] Linkage areas are the most permeable 50 percent of fracture zones identified by the general carnivore model.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

A total of 892 km of state highway in Washington passed through linkage zones identified by the least-cost corridor analysis (table 10, fig. 12), including 75 km associated with the Fraser-Coquihalla area, 177 km in the upper Columbia–Pend Oreille area, 254 km in the Okanogan Valley, 324 km in the Snoqualmie Pass area, and 61 km in the Stevens Pass–Lake Chelan area.

Table 7—Habitat concentration area sizes and available habitat identified by the gray wolf model[a]

Habitat concentration area	Concentration area size	Available habitat
	Square kilometers	
Thompson River[b]	5 067	
North Cascade Range[b]	2 056	63 108
Kettle Range[b]	1 472	
Central Cascade Range[b]	692	
South Cascade Range	1 503	10 928

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] These areas were connected by areas within 100 km weighted distance of modeled habitat concentration areas. Surrounding available habitat is reported as a single area.

Table 8—Highway segments passing through areas within available habitat identified by the gray wolf model[a]

Habitat concentration area	State route	Length	Milepost[b] Min.	Milepost[b] Max.	Description
		Kilometers			
Central Cascade Range	2	58	35	100	Steven's Pass
	28	13	19	29	West of Quincy (peripheral)
	82	40	3	19	Between Ellensburg and Yakima
	90	51	38	142	Between Ellensburg and Vantage
	97	48	150	180	Blewett Pass
	821	31	2	25	Yakima River
	970	6	6	10	East of Cle Elum
Kettle Range	17	6	129	137	North of Bridgeport
	20	106	270	340	Tonasket to Kettle Falls
	21	94	107	191	Keller to Canadian border
	25	31	68	121	Kettle Falls to Canadian border
	155	40	33	77	Omak to Nespelem
	395	42	244	275	Kettle Falls to Canadian border
North Cascade Range	20	177	100	225	Rockport to Okanogan
	97	142	3	316	Pateros to Riverside
	153	48	0	31	Twisp to Pateros
	542	13	39	57	Mount Baker
South Cascade Range	12	45	123	176	White Pass
	14	49	101	152	Columbia Gorge (peripheral)
	22	2	25	29	Near Prosser
	97	55	25	55	Goldendale to Zillah
	123	26	0	16	Cayuse Pass
	410	58	36	83	Chinook Pass

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Table 9—Landscape permeability within fracture zones identified by the gray wolf model

Linkage analysis area	Minimum linkage weighted distance	Actual distance	Weighted-distance/ actual-distance ratio
	- - - - - - - *Kilometers* - - - - - - -		
Okanogan Valley	152.4	42.5	3.6
Fraser-Coquihalla	186.0	113.4	1.6
Stevens Pass–Lake Chelan	259.0	66.8	3.9
Snoqualmie Pass	396.5	82.2	4.8
Upper Columbia–Pend Oreille	560.8	127.6	4.4

Table 10—Washington state highway segments passing through linkages between habitat concentration areas identified by the gray wolf model[a]

Fracture zone	State route	Length	Milepost[b]		Description
			Min.	Max.	
		Kilometers			
Fraser Coquihalla	20	76	125	190	Newhalem to Winthrop
Upper Columbia River	20	67	370	415	Colville to Cusick
	25	45	91	121	Kettle Falls to Canadian border
	31	43	0	27	Ione to Canadian border
	395	22	246	275	Kettle Falls to Canadian border
Okanogan Valley	17	13	128	137	North of Bridgeport
	20	19	205	230	Loup Loup Pass
	20	43	270	340	Tonasket to Kettle Falls
	21	39	117	160	South of Republic
	97	5	325	330	South of Oroville
	97	11	195	305	Riverside
	97	47	255	285	Pateros to Okanogan
	153	21	2	31	Twisp to Pateros
	155	58	31	77	Omak to Grand Coulee
Snoqualmie Pass	24	5	13	30	East of Yakima (peripheral)
	12	59	143	190	White Pass
	82	58	1	24	Selah to Ellensburg
	90	61	70	142	Ellensburg to Vantage
	97	23	150	180	Blewett Pass
	123	20	0	16	Cayuse Pass (peripheral)
	410	55	49	107	Chinook Pass and Tieton
	821	38	0	25	Yakima River
	970	6	6	10	East of Cle Elum (peripheral)
Stevens Pass–Lake Chelan	2	62	51	99	Skykomish to Leavenworth

[a] Linkage areas are the most permeable 50 percent of fracture zones identified for wolves.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Table 11—Habitat concentration area sizes and available habitat identified by the wolverine model[a]

Habitat concentration area	Concentration area size	Available habitat
	Square kilometers	
South Cascade Range[b]	589	[b]
Central Cascade Range[b]	587	[b]
North Cascade Range	6 905	20 216
Columbia Mountains[c]	8 774	38 648
Coast Range[c]	5 795	12 074

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] These areas were connected by areas within 100 km weighted distance of modeled habitat concentration areas. Surrounding available habitat is reported as a single area. Available habitat of 4937 km^2 surrounds both the South and Central Cascade Ranges.
[c] These areas extend beyond the analysis area for this assessment. Sizes listed here only include areas within the extent of our analysis.

Table 12—Highway segments passing through available habitat identified by the wolverine model[a]

Habitat concentation area	State route	Length	Milepost[b] Min.	Milepost[b] Max.	Description
		Kilometers			
Central Cascade Range	2	40	54	99	Skykomish to Leavenworth
	97	4	135	166	Blewett Pass (peripheral)
Columbia Mountains	31	20	4	27	Metaline to Canadian Border (peripheral)
North Cascade Range	20	96	123	193	Newhalem to Winthrop
	153	6	14	21	Twisp to Pateros
South Cascade Range	12	28	135	166	White Pass
	123	26	0	16	Cayuse Pass
	410	65	36	83	Chinook Pass

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Wolverine (*Gulo gulo*)

Dispersal habitat suitability modeling results for the wolverine model are displayed in figure 13. The wolverine habitat association model indicated that wolverine habitat was well distributed across the higher elevation portions of the Cascade and Coast Ranges and the Columbia Mountains. Five wolverine habitat concentration areas were identified by the habitat association model (table 11). Areas available to wolverine moving from the modeled habitat concentration areas, based on 100 km weighted distance, were generally limited to higher elevation habitats in the Cascade and Coast Ranges and the Columbia Mountains (fig. 14).

A total of 285 km of Washington state highway was identified passing within 100 km weighted distance of wolverine habitat concentration areas (table 12), including 43 km in the central Cascade Range, 19 km near the Selkirk Range (associated with the Columbia Mountains habitat concentration area), 102 km in the northern Cascade Range, and 119 km in the southern Cascade Range.

Table 13—Landscape permeability within fracture zones identified by the wolverine model

Fracture zone	Minimum linkage weighted distance	Actual distance	Weighted-distance/ actual-distance ratio
	- - - - - - - *Kilometers* - - - - - - -		
Stevens Pass	98.7	24.6	4.0
Fraser-Coquihalla	459.2	86.8	5.3
Snoqualmie Pass	875.5	53.4	16.4
Okanogan-Kettle	1 010.2	87.2	11.6

Table 14—Washington state highway segments passing through linkages between habitat concentration areas identified by the wolverine model[a]

Fracture zone	State route	Length	Milepost[b] Min.	Max.	Description
		Kilometers			
Okanogan-Kettle	20	5	312	338	Sherman Pass
	21	5	132	148	South of Republic
	97	2	305	300	North of Riverside
	395	5	258	275	North of Kettle Falls
Snoqualmie Pass	90	12	44	75	Near Easton
	97	17	150	180	Blewett Pass (peripheral)
	123	8	8	16	Cayuse Pass
	410	67	36	107	Chinook Pass
	970	3	7	10	East of Cle Elum (peripheral)
Stevens Pass	2	27	55	99	Stevens Pass

[a] Linkage areas are the most permeable 50 percent of fracture zones identified by the wolverine model.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

We identified four fracture zones for wolverine based on the weighted-distance results (table 13, fig. 15). The Stevens Pass and Fraser-Coquihalla fracture zones were evaluated as being substantially more permeable than the Snoqualmie Pass and Okanogan-Kettle areas. Despite having similar distances between habitat concentration areas, the Fraser-Coquihalla area was estimated to be about twice as permeable as the Okanogan-Kettle area.

A total of 151 km of Washington state highway passed through areas identified as being the most permeable 50 percent of the fracture zone landscapes for wolverine (table 14), including 16 km in the Okanogan-Kettle area, 107 km in the Snoqualmie Pass–southern Cascade Range area, and 26 km in the Stevens Pass area.

Table 15—Habitat concentration area sizes and available habitat identified by the lynx model

Habitat concentration area	Concentration area size	Available habitat
	Square kilometers	
South Cascade Range	1 051	14 406
Central Cascade Range	459	4 136
North Cascade Range	7 158	28 791
Kettle Range [b]	1 130	[b]
Granby River Watershed [b c]	3 887	[b]
Selkirk Range [b c]	3 048	[b]

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] These areas extend beyond the analysis area for this assessment. Sizes listed here only include areas within the extent of our analysis. Available habitat of 52 227 km^2 surrounds the Kettle Range, Granby River Watershed, and Selkirk Range.
[c] These areas were connected by areas within 100 km weighted distance of modeled habitat concentration areas. Surrounding available habitat is reported as a single area.

Lynx (*Lynx canadensis*)

Dispersal habitat suitability modeling results for the lynx model are displayed in figure 16. Six habitat concentration areas for lynx were identified by the habitat association model (table 15, fig. 17). Habitat concentration areas in northern Washington (northern Cascade, Kettle, and Selkirk Ranges) correspond to lynx management units identified in the Washington State Recovery Plan for the Lynx (Stinson 2001). Owing to the high mobility of lynx and their relative resilience to human disturbance, weighted-distance analysis indicated substantial landscapes surrounding the habitat concentration areas were available to lynx movement (fig. 17).

Total length of Washington state highway segments passing through areas within available habitat identified by the lynx model was 1229 km (table 16, fig. 17). Of these highway segments, 142 km were on the periphery of the 100-km weighted-distance contour. Highway segments passing through available habitat include 309 km in the southern Cascade Range, 143 km in the central Cascade Range, 169 km in the northern Cascade Range, and 462 km in the Kettle-Selkirks area.

We identified seven fracture zones of interest for assessing landscape permeability between the six modeled habitat concentration areas for lynx (table 17). Least-cost corridor analysis indicated that the Cristina Lake area was the most permeable of the fracture zones, followed by the Castlegar-Trail, Upper Columbia–Pend Oreille, Southern Okanogan, Stevens Pass–Lake Chelan, Snoqualmie Pass, and Okanogan Valley landscapes (table 17, fig. 18).

A total of 945 km of Washington state highway was identified passing through the most permeable 50 percent of the lynx fracture zone landscapes (table 18, fig. 18). These highways included 267 km in the Snoqualmie Pass fracture zone, 212 km in the Stevens Pass–Lake Chelan area, 223 km in the Okanogan Valley, and 242 km in the upper Columbia–Pend Oreille area.

Table 16—Highway segments passing through areas within available habitat identified by the lynx model[a]

Habitat concentration area	State route	Length	Milepost[b] Min.	Max.	Description
		Kilometers			
South Cascade Range	12	74	135	180	White Pass
	14	17	30	80	Columbia Gorge (peripheral)
	97	39	15	35	Satus Pass
	123	26	0	15	Cayuse Pass (Mount Rainier National Park)
	141	33	10	30	Bingen to Trout Lake
	142	41	0	25	Lyle to Goldendale
	410	96	60	115	Crystal Mtn. to Naches
	503	4	0	10	Mount St. Helens (peripheral)
Central Cascade Range	2	99	35	100	Index to Leavenworth
	97	37	125	170	Blewett Pass
	207	7	0.0	5	Lake Wenatchee
	970	2	5	10	Near Cle Elum (peripheral)
North Cascade Range	20	154	120	230	Newhalem to Okanogan
	97	6	285	290	North of Riverside (peripheral)
	153	17	15	30	South of Twisp
Kettle-Selkirk Mountains	20	106	275	340	Between Tonasket and Republic
	20	103	355	435	Colville to Newport
	21	127	105	190	Keller to Danville
	25	87	40	120	South of Kettle Falls to Canadian Border
	31	40	0	25	Ione to Canadian Border
	155	46	40	75	Nespelem to Omak (peripheral)
	211	4	5	10	South of Cusick (peripheral)
	395	64	215	275	North of Chewelah (peripheral)

[a] Available habitats are those areas within 100 km weighted distance of habitat concentration areas.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Table 17—Landscape permeability within fracture zones identified by the lynx model

Fracture zone	Minimum linkage weighted distance	Actual distance	Weighted-distance/ actual-distance ratio
	- - - - - - - *Kilometers*	- - - - - - -	
Cristina Lake	54.5	37.1	1.5
Castlegar-Trail	115.3	34.3	3.4
Upper Columbia–Pend Oreille	124.6	75.4	1.6
Southern Okanogan	217.6	93.9	2.3
Stevens Pass–Lake Chelan	282.8	97.6	2.9
Snoqualmie Pass	373.7	70.6	5.3
Okanogan Valley	406.5	80.9	5.0

Table 18—Washington state highway segments passing through linkages between habitat concentration areas from the lynx model [a]

Fracture zone	State route	Length	Milepost [b] Min.	Max.	Description
		Kilometers			
Snoqualmie Pass	10	16	0	10	Between Cle Elum and Thorpe
	12	49	140	180	White Pass
	90	35	65	95	Easton and Indian John Hill
	97	58	145	180	Blewett Pass (peripheral)
	123	22	0	15	Cayuse Pass (peripheral)
	410	74	60	105	Chinook Pass to Naches
	903	1	5	10	West of Roslyn
	970	12	0	10	East of Cle Elum
Stevens Pass–Lake Chelan	2	86	40	100	Skykomish to Leavenworth
	20	91	130	190	Ross Lake to Winthrop
	20	27	210	225	Loup Loup Pass
	153	3	15	20	Between Twisp and Pateros
	207	7	0	5	Lake Wenatchee
Okanogan Valley	20	61	280	315	East and west of Republic
	21	104	110	190	Keller to Canadian Border
	97	15	300	310	Between Riverside and Tonasket
	155	43	40	75	Between Nespelem and Omak
Upper Columbia–Pend Oreille Valley	20	95	310	415	Colville to North of Cusick
	25	56	80	120	Kettle Falls to Canadian Border
	31	36	0	25	Ione to Canadian Border
	395	55	245	270	Kettle Falls to Canadian Border

[a] Linkage areas are the most permeable 50 percent of fracture zones identified by the lynx model.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Grizzly Bear (*Ursus arctos*)

Dispersal habitat suitability modeling results from the grizzly bear model are displayed in figure 19. Five habitat concentration areas were identified based on the habitat association models for grizzly bear (table 19, fig. 20). The grizzly bear habitat association model did not identify habitat concentrations in the Selkirk Range in Washington and Idaho. However, because of the documented presence of grizzly bears in the Selkirks (Wakkinen and Kasworm 1996) and the designation of the area as a recovery zone (USFWS 1993), we felt that it was appropriate to incorporate this area into our analysis of landscape permeability for northeastern Washington. We accomplished this by appending the habitat concentration polygons identified in the Selkirks for the general carnivore model to the grizzly bear modeled habitat concentration map.

Modeled habitat concentration areas were well connected by available habitat within the Coast Range and north-central Cascade Range (table 19, fig. 20). Landscapes in the Columbia Mountains show some evidence of substantial landscape barriers associated with the large lakes (particularly Upper Arrow and Kootenay Lakes) and human development patterns in the major valleys.

Table 19—Habitat concentration area sizes and available habitat identified by the grizzly bear model [a]

Habitat concentration area	Concentration area size	Available habitat
	Square kilometers	
South Cascade Range	1 291	5 156
Central Cascade Range [b]	764	[b]
North Cascade Range [b]	6 834	[b]
Coast Range [c]	11 756	24 481
Columbia Mountains [c]	17 154	36 217

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] These areas were connected by areas within 100 km weighted distance of modeled habitat concentration areas. Available habitat of 23 888 km^2 surrounds both the Central and North Cascade Ranges.
[c] These areas extend beyond the analysis area for this assessment. Sizes listed here only include areas within the extent of our analysis.

Table 20—Highway segments passing through areas within available habitat identified by the grizzly bear model [a]

Core area	State route	Length	Milepost [b] Min.	Milepost [b] Max.	Description
		Kilometers			
Central Cascade Range	2	38	54	99	Stevens Pass
	90	8	44	53	Snoqualmie Pass (peripheral)
	97	19	127	166	Blewett Pass (peripheral)
Columbia-Selkirk Mountains	20	17	385	400	South of Ione (peripheral)
	31	21	4	27	North of Metaline (peripheral)
North Cascade Range	20	130	100	190	Rockport to Winthrop
	542	32	35	57	Mount Baker
	153	6	14	21	Between Twisp and Pateros (peripheral)
South Cascade Range	12	34	135	176	White Pass
	123	26	0	16	Cayuse Pass
	410	65	36	83	Chinook Pass

[a] Available habitat is the area within 100 km weighted distance of a habitat concentration area.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

A total of 395 km of Washington state highways pass through areas within 100 km weighted distance of modeled grizzly bear habitat concentration areas (table 20, fig. 20). This includes 64 km in the central Cascade Range, 38 km near the Columbia and Selkirk Mountains, 168 km in the northern Cascade Range, and 125 km in the southern Cascade Range.

Table 21—Landscape permeability within fracture zones identified by the grizzly bear model

Fracture zone	Minimum linkage weighted distance	Actual distance	Weighted-distance/ actual-distance ratio
	- - - - - - - *Kilometers* - - - - - - -		
Stevens Pass	84.4	25.5	3.3
Fraser-Coquihalla	348.5	23.7	14.7
Okanogan Valley–Upper Columbia	598.6	162.5	3.7
Snoqualmie Pass	760.7	42.4	17.9

Four fracture zones were identified from the weighted-distance map for least-cost corridor analysis. Our least-cost corridor analysis indicated that Stevens Pass was the most permeable of the fracture zones analyzed, followed by the Fraser-Coquihalla, Okanogan Valley–Upper Columbia, and Snoqualmie Pass fracture zones (table 21, fig. 21). Despite the relatively long distance between modeled habitat concentration areas in the northern Cascade Range and Columbia Mountains (linear distance 162 km), the average landscape permeability (expressed as the weighted-distance to linear-distance ratio) in the best linkages through the Okanogan–Upper Columbia fracture zone was substantially better than the best linkages identified through the Snoqualmie Pass or Fraser-Coquihalla fracture zones.

A total of 329 km of Washington state highway was identified within the most permeable 50 percent of the fracture zone landscapes (table 22, fig. 21). These highway segments included 203 km of highway in the Okanogan Valley–Upper Columbia fracture zone, 64 km in the Stevens Pass fracture zone, and 60 km in the Snoqualmie Pass fracture zone.

Discussion

At a regional scale, gross landscape features such as large mountain ranges and major river drainages broadly influence the distribution of vegetative communities and human land use activities that shape the current extent of large carnivore habitat in Washington. Habitat concentrations and related available habitat areas identified in our analysis correspond to the larger mountain ranges and public lands associated with those ranges (fig. 22). Our analysis identified six areas containing habitat concentrations and associated available habitat for two or more of the focal species: the southern, central, and northern portions of the Cascade Range, the Coast Range, the Kettle-Monashee Ranges, and the Selkirk-Columbia Mountains. Our modeling highlighted that fracture zones between those blocks of habitat generally correspond to developed valley bottoms where forest cover is often discontinuous, where human population centers are usually located, and where road densities are often high. Four areas were consistently identified as fracture zones for two or more of the focal species: Snoqualmie Pass, the Fraser-Coquihalla area, the Okanogan Valley, and the Upper Columbia–Pend Oreille area. We discuss the characteristics of these habitat concentration areas and fracture zones in the following sections.

The patterns that were identified by our general carnivore model closely followed patterns identified by the focal species models. Broadly similar (though not identical) habitat concentration areas and linkage patterns were identified by the general carnivore model and the species-specific models. One substantial difference between the general carnivore model and the species-specific models was the inclusion of the Olympic

Table 22—Washington state highway segments passing through linkages between habitat concentration areas identified by the grizzly bear model [a]

Fracture zone	State route	Length	Milepost [b] Min.	Max.	Description
		Kilometers			
Okanogan Valley–Upper Columbia	20	27	150	190	Washington Pass to Winthrop
	20	17	380	400	South of Ione
	20	28	315	340	Republic to Kettle Falls
	21	59	120	155	South of Republic
	25	11	115	120	Northport to Canadian border
	31	13	5	30	North of Metaline
	97	10	300	305	North of Riverside
	155	12	45	70	Omak to Nespelem
	395	27	260	275	North of Kettle Falls
Stevens Pass	2	59	50	100	Skykomish to Leavenworth
	153	6	15	20	Between Twisp and Pateros (peripheral)
Snoqualmie Pass	90	9	45	75	Easton area
	97	16	150	180	Blewett Pass (peripheral)
	410	35	35	110	Chinook Pass

[a] Linkage areas are the most permeable 50 percent of fracture zones identified by the grizzly bear model.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Mountains as a habitat concentration in the general carnivore analysis. The extremely high minimum linkage weighted distance (6944 km) for the southwestern Washington fracture zone indicated that this area was a barrier to the focal species for this assessment. Landscape permeability patterns through this area may be of interest for other species, e.g., cougar (*Felis concolor*), black bear (*U. americanus*), elk (*Cervus elaphus*), and late-successional forest associates. Analysis for these species should focus on identifying habitat concentration areas and landscape permeability patterns within southwestern Washington, and not focus solely on identifying linkages between the southern Cascade Range and the Olympic Mountains.

Habitat Concentration Areas and Available Habitat

Southern Cascade Range habitat concentration—Habitat concentration areas identified in the southern Cascade Range were centered on Mount Rainier National Park, and the Norse Peak, William O. Douglas, Goat Rocks, and Mount Adams Wilderness Areas (fig. 22). Wolf habitat concentration areas extended farther east onto the Yakama Indian Reservation and adjacent Washington Department of Fish and Wildlife lands. Although the habitat concentration areas identified in the southern Cascade Range were centered on the rugged alpine environments of Mount Rainier, Goat Rocks, and Mount Adams, much of the adjacent landscape is relatively gentle compared to other portions of the Cascade Range. Ungulate winter ranges in the Ahtanum, Naches, and Wenas drainages also may contribute to the suitability of this area for large carnivores.

The southern Cascade Range is outside the recovery zone identified in the U.S. Grizzly Bear Recovery Plan (USFWS 1993) and does not contain designated lynx management units (Stinson 2001). However, linkage between this area and the northern Cascade Range is considered important for other forest-associated species (USDA Forest Service 1997, 1999).

Distribution of available habitat for the focal species was constrained by high road densities and discontinuous forest cover on all sides. Agricultural lands and human population centers along the Yakima River defined the eastern extent of available habitat identified for wolves. Our assessment did not address habitat linkages to the south through the Columbia River Gorge into the Oregon Cascade Range.

A total of 187 km of Washington state highway was identified passing through consistently identified available large carnivore habitat in the southern Cascade Range (table 23). The highways on the east side of Mount Rainier National Park (Highways 410, 12, and 123) passed through habitat available to all four focal species. Highways 410 and 12 also pass through ungulate winter range areas in the Tieton and Naches River drainages that could be important for large carnivores. Highway 97 over Satus Pass was identified as passing through habitat available to wolves and lynx.

Central-northern Cascade Range habitat concentration—Habitat concentration areas in the central Cascade Range for lynx, wolverine, and grizzly bear were centered in the Chiwaukum Mountains, Icicle Creek, and Ingalls Creek drainages, all within the Alpine Lakes Wilderness Area (fig. 22). Wolf habitat concentrations were modeled on Wenatchee National Forest lands along Teanaway Ridge and Mission Creek, and on Washington Department of Fish and Wildlife lands in the Clockum Wildlife Area.

In the northern Cascade Range, habitat concentration areas for lynx, wolverine, and grizzly bear were centered in the Pasayten Wilderness Area east of Ross Lake, and extended across the Canadian border into Manning and Cathedral Provincial Parks. Wolf habitat concentration areas were modeled in the Salmon Creek watershed near Conconully, and along the Stehekin and Methow River valleys. Landscapes south of Highway 20 in the Glacier Peak Wilderness Area were identified as habitat concentrations for wolverine and grizzly bear. This portion of the Glacier Peak Wilderness did not contain substantial amounts of lynx or wolf habitat owing to the rugged topography and naturally fragmented forest pattern resulting from the restriction of forest habitat to low-elevation narrow valley bottoms.

Substantial portions of the northern Cascade Range are designated as recovery zones for grizzly bear under the U.S. Grizzly Bear Recovery Plan (USFWS 1993) and are designated as special management areas under the British Columbia North Cascades Grizzly Bear Recovery Plan (North Cascades Grizzly Bear Recovery Team 2001). This area supports a breeding population of lynx (Koehler 1990). Wolverine and wolves also have been documented in this area (Gaines et al. 1995, 2000).

Available habitat was well connected throughout the central and northern Cascade Range for wolverine, wolf, and grizzly bear, though a bottleneck in available habitat was apparent for all these species near Highway 2 at Stevens Pass and Lake Wenatchee. A substantial break in available habitat connectivity for lynx was highlighted in the area between Lake Chelan and Glacier Peak. This break in modeled available habitat was due to limited connectivity of forested habitat in the steep, mountainous landscape between Lake Chelan and Glacier Peak.

Table 23—Washington state highway segments passing through areas most consistently identified as available habitat for wolf, grizzly bear, wolverine, and lynx[a]

Habitat area	State route	Length	Milepost[b] Min.	Max.	Description
		Kilometers			
South Cascade Range	12	56	140	175	Highway 123 to Naches
	123	26	0	15	Highway 12 to Cayuse Pass
	410	105	50	115	Crystal Mountain to Naches
Central Cascade Range	97	48	150	180	Blewett Pass area
	2	97	40	100	Skykomish to Leavenworth
North Cascade Range	20	137	100	185	Rockport to Mazama
	20	16	210	220	Loup Loup Pass
	153	8	15	20	Between Carlton and Methow
Kettle Range	155	32	50	70	Disautel Summit area
	21	64	115	155	Keller to Republic
	20	56	305	340	Sherman Pass
	395	40	245	270	Kettle Falls to Canadian Border

[a] We defined available habitat as areas within 100 km weighted distance of habitat concentration areas. These are areas that could be most important for maintaining multispecies landscape permeability for short- and medium-distance movements within blocks of large carnivore habitat.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

The distribution of large carnivore habitat in the northern and central Cascade Range was restricted to the south by high road density and discontinuous forest cover along the I-90 Snoqualmie Pass corridor. The western extent of available habitat was defined by high human population and road densities in the Puget Sound lowlands. The northern extent was defined by high road densities and discontinuous forest cover in the Coquihalla and Similkameen areas, and the eastern extent by the transition to shrub-steppe habitats and human population centers in the Okanogan Valley and along the Columbia River.

A total of 145 km of state highways in Washington was identified as passing through areas consistently identified as available habitat for all the focal species in the central Cascade Range (table 23). These highway segments include Highway 2 over Stevens Pass and Highway 97 over Blewett Pass. Highway 97 over Blewett Pass is somewhat peripheral to habitat identified as available to wolverine and grizzly bear. However, the presence of substantial ungulate winter range areas east of Highway 97 in the Wenatchee Mountains is likely to contribute to the importance of this area as large carnivore habitat.

In the U.S. portion of the northern Cascade Range, 161 km of Washington state highway were identified as passing through available habitat for all the focal species (table 23). The majority of this highway length is along Highway 20 over Washington and Loup Loup Passes. A short segment of Highway 153, along the Methow River between Methow and Carlton, also was identified. Although the Loup Loup Pass and Carlton-Methow highway segments were largely peripheral to available wolverine and

Table 24—British Columbia highway segments passing through areas most consistently identified as available habitat for wolf, grizzly bear, wolverine, and lynx [a]

Habitat area	Provincial route	Length	Description
		Kilometers	
North Cascade Range	3	84	Manning Provincial Park area
Kettle Range	3	31	East of Cristina Lake
Selkirk Range	3	57	Kootenay Pass area

[a] We defined available habitat as areas within 100 km weighted distance of habitat concentration areas. These are areas that could be most important for maintaining multispecies landscape permeability for short and medium distance movements within blocks of large carnivore habitat.

grizzly bear habitat, the presence of substantial ungulate winter range areas on the southwest exposures above the Methow River are likely to contribute to the importance of this area as habitat for all the focal species.

In the Canadian portion of the northern Cascade Range, 84 km of B.C. Highway 3 through Manning Provincial Park were identified as passing through available habitat for all the focal species (table 24).

Coast Range habitat concentration—Our habitat modeling indicated that the Coast Range contained habitat concentrations for wolverine and grizzly bear (fig. 22). The British Columbia North Cascades Grizzly Bear Recovery Team (2001) identifies this area as having a threatened population of grizzly bears. Habitat suitability for large carnivores in the Coast Range may be limited owing to the predominance of rugged alpine habitats, extremely heavy snowfall, and a short snow-free season.

Available habitat identified by weighted-distance analysis for grizzly bear and wolverine in the Coast Range was limited on the south and east by discontinuous forest cover and high road densities. Habitat for both of these species extends north beyond the bounds of this analysis. British Columbia Highway 99 between Squamish and Lillooet is the only highway segment that passes through available grizzly bear and wolverine habitat in this area.

Modeled wolf and lynx habitat concentrations were identified east of the Coast Range in the Thompson River watershed. Available habitat for wolves and lynx in this area was limited to the east by human population centers near Kamloops, and by the rugged topography and predominance of alpine habitats in the Coast Range. To the south, the modeling indicated broad landscape permeability for lynx and wolves between the Thompson River watershed and the U.S. portion of the northern Cascade Range. Highways passing through available lynx and wolf habitat in this area include British Columbia Highway 1 (the Trans-Canada Highway) between Lytton and Cache Creek, B.C. Highway 97c between Cache Creek and Merritt, B.C. Highway 8 between Spences Bridge and Merritt, B.C. Highway 5 between Hope and Merritt, and B.C. Highway 5a between Princeton and Merritt.

Kettle-Monashee Ranges habitat concentration—Habitat concentration areas were identified for lynx and wolf in the U.S. portion of the Kettle Range (fig. 22). Habitat concentration areas for wolverine and grizzly bear were identified in the Monashee

Range. Modeled habitat suitability for grizzly bear and wolverine in the Kettle Range was limited by the presence of roads. Habitat concentration areas identified in the Kettle Range correspond to lands near the Colville National Forest and Colville Indian Reservation. Lynx management units have been designated in this area under the Washington State Lynx Management Plan (Stinson 2001). Wolverine and lynx detections have been recorded in these areas (Edelmann and Copeland 1999, Stinson 2001).

Available habitat for lynx and wolf near the Kettle Range is bordered on the east and south by the Columbia River, and on the west by the Okanogan Valley. Because of the well-connected forest cover and patchy human population distribution, broad landscape permeability for lynx was apparent between the Kettle Range, areas to the north in the Granby watershed and the Monashee Mountains, and areas to the east in the Selkirks. The weighted-distance analysis for wolves indicated that available habitat was narrowly connected between the Kettle Range and the North Cascade Range between Brewster and Omak.

Habitat available to grizzly bears and wolverine was well connected between the Monashee and Columbia Mountains but did not extend into the U.S. portion of the Kettle Range owing to high road densities. The landscape north of the Kettle Range, in the Kettle and Granby watersheds, was highly permeable for grizzly bears and wolverine. Landscapes within 100 km weighted distance for wolverine, and within 200 km weighted distance for grizzly bear, extended south nearly to the U.S. border.

Washington state highways passing through areas available to wolf and lynx near the Kettle Range include Highway 20 between Wauconda and Kettle Falls, Highway 21 between Keller and the Canadian border, and Highway 395 between Kettle Falls and the Canadian Border (table 23). In addition, British Columbia Highway 3 also passes through landscapes available to lynx and wolverine near Cristina Lake (table 24).

Selkirk-Columbia Mountains habitat concentration—Modeled habitat concentration areas were identified for wolverine, grizzly bear, and lynx in the Selkirk Mountains of Washington and British Columbia (fig. 22). The U.S. portions of the Selkirk Mountains encompasses lynx management units designated under the Washington State Lynx Management Plan (Stinson 2001) and identified in the U.S. Grizzly Bear Recovery Plan (USFWS 1993). Wolverine and lynx detections have been reported in these areas (Edelmann and Copeland 1999, Stinson 2001). A small population of grizzly bears has been documented in the Selkirk area (Wakkinen and Kasworm 1996). Although extensive roadless areas exist farther north in the Columbia Mountains, the rugged topography and high alpine conditions common in the Columbia Mountains may limit its suitability for lynx and wolves, and perhaps for grizzly bear and wolverine as well.

Modeled habitat concentration areas for grizzly bears were identified in the Canadian portion of the Selkirk Mountains but not in the U.S. portion owing to high road density. Because of the presence of a well-documented population of grizzly bears in the U.S. portion of the Selkirk Mountains, we included roadless areas in the Selkirks as source areas for the weighted-distance and least-cost corridor analysis for grizzly bears, although these areas were not identified as habitat concentration areas in the habitat suitability modeling. Habitat concentration areas for wolves were not identified in the Selkirk Mountains owing to the rarity of dry interior forest cover type.

Available areas for lynx, wolverine, and grizzly bears were limited to the south by high road density, discontinuous forest cover, and human population centers near Newport and the northern suburbs of Spokane. Available landscapes extend to the north for wolverine, grizzly bear, and lynx; however, this assessment did not address landscape barriers to the north, near Nelson, British Columbia, and beyond.

No major highways pass substantially within the U.S. portion of the Selkirk Mountains, though Highway 31 near Metaline Falls passes along the periphery of the area (table 23). In British Columbia, Highway 3 over Kootenay Pass bisects available habitat for wolverine, grizzly bear, and lynx (table 24).

Regional Fracture Zones and Habitat Linkage Areas

Snoqualmie Pass fracture zone—The I-90 Snoqualmie Pass fracture zone separates available large carnivore habitat in the southern Cascade Range from large carnivore habitat in the central Cascade Range (fig. 23). The least-cost corridor models indicate that this fracture zone is relatively permeable for wolves and lynx (minimum linkage weighted distance 396 and 373 km, respectively), and less permeable for wolverine and grizzly bear (minimum linkage weighted distance 875 and 760 km, respectively). Compared to the other fracture zones, the linear distance between habitat concentration areas was relatively short (between 33 km for the general carnivore model and 82 km for the wolf model), but landscape permeability was generally poor. Weighted-distance to linear-distance ratios were higher in the Snoqualmie Pass fracture zone than for all the other fracture zones evaluated for the species-specific models.

Factors contributing to decreased landscape permeability in this area are discontinuous forest cover, high road density, substantial recreational and residential development, and the presence of a major interstate highway (Singleton and Lehmkuhl 2000). Many of these landscape features are the consequence of the “checkerboard” land ownership pattern in this area. Current land acquisition activities are underway to consolidate federal land ownership along Snoqualmie Pass (USDA FS 1999).

Areas that were identified as substantial barriers to movement in this fracture zone, for all of the focal species, were associated with the residential and agricultural development near Roslyn, Cle Elum, and Ellensburg. Recreational developments at Snoqualmie Pass, high road density, and discontinuous forest cover in the checkerboard land ownership areas south of Keechelus Lake formed another barrier for all the focal species just east of the Cascade crest.

The only linkage through the Snoqualmie Pass landscape consistently identified in the least-cost corridor analysis for all four focal species was near Easton, approximately 22 km west of Cle Elum (fig. 23). This area also was identified as being the most permeable portion of the landscape for moderate- and high-mobility species during field surveys and finer scale modeling conducted along I-90 (Singleton and Lehmkuhl 2000, USDA FS 1997, 1999). Secondary linkage areas were identified for grizzly bear and wolverine on the west side of Snoqualmie Pass near Granite Mountain and Humpback Creek, and for lynx near Thorpe Prairie and Lookout Mountain. A linkage for wolves also was identified through the shrub-steppe habitats connecting the Clockum Wildlife Area to the Yakima Firing Range and Umptanum Ridge. Segments of I-90 intersect all of these linkage areas (table 25). The secondary linkage area for wolves along Umptanum Ridge also is intersected by I-82 and Highway 821.

Table 25—Washington state highway segments intersecting consistently identified habitat linkage areas in fracture zones for wolf, grizzly bear, wolverine, and lynx[a]

Fracture zone	State route	Length	Milepost[b] Min.	Milepost[b] Max.	Description
		Kilometers			
I-90 Snoqualmie Pass	I-90	24	40	55	West side of Snoqualmie Pass
	I-90	16	65	75	Easton area
Okanogan Valley	97	24	295	310	Riverside area
Upper Columbia River	25	24	105	120	Marble to Canadian Border
	20	48	380	410	South of Ione
	31	32	5	25	Ione to Canadian Border

[a] These are areas that could be most important for maintaining multispecies landscape permeability for long-distance movements between blocks of large carnivore habitat in Washington.
[b] Mileposts are rounded to the nearest 8-km (5-mi) interval.

Fraser-Coquihalla fracture zone—The Fraser-Coquihalla fracture zone separates available habitat for wolverine and grizzly bear in the northern Cascade Range from available habitat in the Coast Range (fig. 24). The least-cost corridor modeling for wolverine and grizzly bear indicated that this area was relatively permeable compared to the other fracture zones evaluated for these species (minimum weighted-distance 459 km for wolverine and 348 km for grizzly bear). The Stevens Pass fracture zone was the only one that our models indicated was more permeable for wolverine and grizzly bears. Habitat concentrations for wolves and lynx were not identified in the Coast Range, and most of the area east of the Fraser River was available habitat for wolves and lynx; therefore, this area was not considered a fracture zone for these species.

Factors contributing to reduced landscape permeability for grizzly bears and wolverine in this area include the rugged topography of the Fraser and Coquihalla Canyons, two major highways (Highway 5 and the Trans-Canada Highway), and human population centers along the Trans-Canada Highway. Areas that were identified as substantial barriers to movement in this fracture zone were formed by the developed areas near Hope and Merritt. The extremely rugged topography just northeast of Hope (near Ogilvie Peak, Jorgenson Peak, and Squeah Mountain) also limited landscape permeability through this area.

Consistent linkages modeled for grizzly bears and wolverine skirted north of the developed areas and steep landscapes around Hope into the Coquihalla Summit area, through the Anderson River drainage, and into the Fraser Canyon between Hell Gate and Lytton. Another linkage for grizzly bears was identified just west of Hope, where modeled habitat concentrations for the Coast Range and North Cascade Range come within 24 km of each other. Despite its short length, this linkage has poor landscape permeability (weighted distance 349 km and weighted-distance to linear-distance ratio of 14.5) compared to the much longer linkage route to the north (weighted distance 474 km and weighted distance to linear-distance ratio of 3.1).

Table 26—British Columbia highway segments intersecting consistently identified habitat linkage areas in fracture zones for wolf, grizzly bear, wolverine, and lynx [a]

Fracture zone	Provincial route	Length	Description
		Kilometers	
Fraser-Coquihalla	1	58	Spuzzum to Lytton
	5	50	Coquihalla Summit
Okanogan Valley	3	58	Princeton to Keremeos
	3a	15	Keremeos to Kaleden
	97	12	Okanagan Falls to Oliver
	33	64	West Kettle River
Upper Columbia River	3b	19	Rossland to Highway 3
	22	19	Castlegar to Trail
	3	23	Castlegar to Erie
	6	34	Nelson to Salmo

[a] These are areas that could be most important for maintaining multispecies landscape permeability for long-distance movements between blocks of large carnivore habitat in portions of British Columbia adjacent to Washington.

Highways intersecting these linkages include Highway 5 over Coquihalla Summit, the Trans-Canada Highway between Hell Gate and Lytton, and the Trans-Canada Highway west of Hope (table 26).

Okanogan Valley fracture zone—The transition to arid shrub-steppe vegetation, agricultural development, and human population centers in the Okanogan Valley all contribute to the separation of large carnivore habitat in the northern Cascade Range from habitat in the Kettle and Monashee Ranges (fig. 25). This area was identified as a fracture zone for three of the focal species and the general carnivore model. The weighted-distance model for wolves indicated that the portion of the Okanogan Valley south of Omak was within 100 km weighted distance of modeled habitat concentrations in the Kettle Range and the Methow River watershed. We conducted least-cost corridor analysis for wolves in the Okanogan Valley anyway, because of the substantial bottleneck in landscape permeability identified by the weighted-distance analysis and because we felt that it was important to illustrate the landscape permeability patterns in the Highway 97 corridor for all of the focal species.

Because of the lack of contiguous forest cover through the valley, the estimates of permeability for the Okanogan Valley depended on a species' ability to move through nonforested shrub-steppe habitats. The Okanogan Valley was the most permeable fracture zone analyzed for wolves (minimum weighted distance 152 km). The lynx model indicated that the Okanogan Valley was relatively permeable (minimum linkage weighted distance 217 km), with only the Upper Columbia River fracture zone being more permeable for lynx. The Okanogan Valley was substantially less permeable for grizzly bear (minimum linkage weighted distance 598 km) and wolverine (minimum linkage weighted distance 1010 km). The Okanogan Valley was the least permeable fracture zone for wolverine, and only Snoqualmie Pass was less permeable for grizzly bear.

Substantial barriers to movement were identified by all the models near the many towns and adjacent agricultural areas in the Okanogan Valley. In Washington, these barriers were centered on the towns of Okanogan, Omak, Tonasket, and Oroville. In British Columbia, barriers were centered on the towns of Osoyoos, Oliver, Okanagan Falls, Penticton, Summerland, Kelowna, and Vernon. In the British Columbia portion of the Okanogan Valley, landscape permeability also was limited by Okanagan Lake, which extends 95 km north from Penticton to Vernon and is 2 to 5 km wide. Recreational and residential development along the shores of Okanagan Lake is extremely heavy in some areas. In 1996, the population of the Canadian portion of the Okanogan Valley from Vernon to the U.S. border was 241,500 people and growing rapidly, with an increase of 19 percent over the previous census in 1991 (Statistics Canada 2001). This compares to the 2000 population of 39,564 for all of Okanogan County in Washington (U.S. Department of Commerce, Census Bureau 2001). These development patterns substantially limit landscape permeability in the Canadian portion of the Okanogan Valley.

The only modeled linkage through the Okanogan Valley that was consistently identified for all four focal species passed through the U.S. portion of the Kettle Mountains south of Republic and crossed Highway 97 just north of Riverside, between Omak and Tonasket, to habitat in the vicinity of the Loomis State Forest and the Pasayten Wilderness Area (fig. 25). Two other potential linkage areas for wolves were identified, one between Okanogan and Brewster, and the other just south of Oroville; however, these areas were not highly permeable for the other focal species.

Linkages for wolverine, lynx, grizzly bear, and the general carnivore model were identified north of the Canadian border. The linkages that the models predicted were most permeable for wolverine and grizzly bear in the Canadian portion of the Okanogan Valley connected areas in the Monashee Mountains with areas in the Similkameen and Pasayten by crossing the valley through Okanagan Lake between Summerland and Kelowna or across Skaha Lake between Penticton and Okanagan Falls. We expect that the functionality of these linkages is severely compromised by the long water crossings that would be involved in traveling through them. The only modeled linkage that provided a contiguous terrestrial travel route through the Canadian portion of the Okanogan Valley passes through the valley at Vaseux Lake Provincial Park, between Oliver and Okanagan Falls. This area was modeled as the best linkage for lynx in the Canadian portion of the Okanogan Valley. We expect that this area may be the most functional of the linkages our models identified in the Canadian portion of the Okanogan Valley.

Highway 97 intersects all the modeled linkage areas in the Washington portion of the Okanogan Valley (table 25). In the Canadian portion of the Okanogan Valley, B.C. Highway 97 intersects the modeled linkages (table 26). British Columbia Highways 3 and 3a also intersect the modeled linkages along the Similkameen River, and Highway 33 intersects the modeled linkages along the West Kettle River.

Upper Columbia and Pend Oreille River fracture zone—The lowlands of the upper Columbia and Pend Oreille River drainages contain landscape barriers that separate large carnivore habitat in the Selkirk and Columbia Mountains from habitat in the Kettle and southern Monashee Ranges (fig. 26). Factors reducing landscape permeability include human population centers, high road density, and discontinuous forest cover resulting from industrial forest management and agricultural development. Our models indicated that this area was highly permeable for lynx but less permeable for grizzly bear and wolf. The upper Columbia and Pend Oreille River fracture zone was estimated to be the most permeable fracture zone analyzed for lynx. Much of the area around the Kettle, Monashee, and Selkirk Ranges fell within available habitat for lynx. We analyzed this area as a fracture zone for lynx anyway because we were interested in explicitly illustrating possible linkages in relation to the major highways in the area. The estimates of landscape permeability for wolves in this area were influenced by the lack of modeled wolf habitat concentration areas in the eastern portions of our analysis area. We expect this area to be more permeable for wolves than these models suggest.

Identification of habitat linkages through the upper Columbia River drainage for wolverine and grizzly bear was compromised because habitat concentration areas for these species were not identified in the Kettle Range. Linkage through the Kettle Range for these species was evaluated based on least-cost corridor analysis between habitat concentrations in the northern Cascade Range and the Selkirk and Columbia Mountains. No linkage for wolverine was identified through the upper Columbia River drainage because more permeable landscapes were available to the west, extending from the Granby River drainage, through the Kettle Range, to the North Cascade Range.

Landscape permeability for grizzly bears through this area was estimated to be relatively poor because of the long distance (162 km) between grizzly bear habitat concentrations in the North Cascade Range and the Selkirk and Columbia Mountains. However, the average landscape permeability through this fracture zone (weighted-distance to actual distance ratio = 3.7) was close to the average permeability through the Stevens Pass fracture zone, the most permeable fracture zone for grizzly bears. The functionality of this area as a linkage for grizzly bears will depend on its ability to support a low-density population of reproductive individuals in the Kettle and Monashee Ranges that would provide for genetic exchange between the North Cascade Range and the Selkirk Mountains over multiple generations.

Human population centers and industrial developments along the Columbia River were particularly important factors contributing to consistently identified barriers. In particular, residential and industrial development near Trail and Castlegar in British Columbia, and near Kettle Falls and Colville in Washington, contributed to substantial landscape barriers identified by the models. Landscape permeability south of Kettle Falls, along the east shore of Lake Roosevelt, was limited by high road density, agricultural development, and human population density along Highway 395.

Two primary linkages for wolves, lynx, and grizzly bears were identified in the upper Columbia River drainage (fig. 26): one in Washington, centered just south of the Canadian border, north of Ione and Kettle Falls, and the other in British Columbia, centered between Highways 3 and 3a, passing between Castlegar and Trail.

Three Washington state highway segments intersect modeled linkage areas in the U.S. portion of the upper Columbia River drainage (table 25). These are Highway 25 north of Kettle Falls, Highway 31 from Ione to the Canadian Border, and Highway 20 south of Ione. Highways intersecting modeled linkages in the Canadian portion of the upper Columbia River drainage include Highway 22 between Trail and Castlegar, and Highway 3b north of Rossland (table 26).

Future Research and Management Considerations

The explicit consideration of highways in relation to broad-scale habitat patterns often is a critical component of landscape planning. Major highways are often a central landscape feature in valley bottoms, where they connect human population centers and contribute to changes in the patterns of vegetative communities and human development (Forman 1995). The design of the highway and management of the adjoining landscape to provide for animal movement in a manner that is safe for both animals and motorists are important considerations (Jackson 1999). However, highways are only one component of broader landscape barriers configured by topography, vegetation patterns, and human development (Forman 1995). Proactive land management that maintains options for directing human development and managing vegetation may be important for maintaining or improving wildlife linkages at a regional scale.

Land managers face many challenges in developing strategies for maintaining landscape permeability for wide-ranging sensitive wildlife (Beier and Loe 1992, Knight and Landres 1998). Developing local and regional public support for landscape-level plans is perhaps the most important, though often difficult because of concerns about conflicts with large carnivores and government bureaucracies (Clark et al. 1996). However, successful regional-scale landscape planning initiatives have been undertaken in other areas (Knight and Landres 1998). Without such coordinated landscape planning, attempts to conserve wide ranging carnivores in Washington may prove futile (Gaines et al. 2000).

The importance of interagency and cross-boundary cooperation and coordination is obvious (Stinson 2001, USFWS 1993). Cooperation between land management agencies, landowners, and local governments will be valuable in planning for regional-scale landscape permeability issues. International cooperation in managing landscape linkage is particularly important because present populations of lynx, wolverine, wolves, and grizzly bears in Washington may be southern extensions of populations (or metapopulations) centered in British Columbia (Gaines et al. 2000).

Maintaining vegetation cover that provides security for moving animals is another challenge in the drier, fire-prone landscapes of central Washington and British Columbia. Desired vegetation conditions that provide visual barriers and security cover for animal movement may conflict with fire management or forest insect and disease control objectives (Tiedemann et al. 2000). Attention to the sustainability of desired linkage conditions, from the perspectives of both human land use (Kline and Alig 2001) and vegetation community dynamics (Hessburg et al. 2000) may be critical to the retention of effective linkages. Identification of local topographic features like ridges or draws that can provide nonvegetative visual barriers should be considered when conducting finer scale evaluations of the linkages we have highlighted. Maintenance of multiple linkages within a fracture zone also may be crucial to provide options for animal movement when natural disturbances temporarily reduce the utility of a linkage area.

Future survey needs and research opportunities highlighted by our analysis include evaluating historical habitat distribution and linkage conditions, using higher resolution GIS data to evaluate the individual predicted linkages, conducting field surveys and genetic analysis to evaluate the functionality of the modeled linkage areas, and using the predictions of these models to develop testable hypotheses for basic research on animal movement and habitat selection. Fine-scale evaluation and management of the linkage areas we have identified will benefit from analyses of higher resolution road, vegetation, and human development data sets. Such analyses should provide a better understanding of local landscape patterns and management practices that were not apparent from our regional-scale data sets. Field surveys also will be an important component of these evaluations. The focal species addressed in this report are unlikely to be regularly detected near most of the linkages we described. However, site-specific information on movements of more common species (black bear, coyote, bobcat, and cougar) would contribute substantially to the understanding of local animal movement patterns (e.g., Singleton and Lehmkuhl 2000).

This analysis is based on our current understanding of the nature of animal movements and habitat selection during those movements. It provides predictions about relative landscape permeability at both intraterritorial and interterritorial scales. We have focused on assessing existing regional landscape patterns that have the potential to channel animal movement. As such, it is only one component to contribute toward the development of a regional approach to managing large carnivore habitat in the Pacific Northwest.

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English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	0.39	Feet
Kilometers (km)	0.62	Miles
Square kilometers (km^2)	0.38	Square miles
Hectares (ha)	2.47	Acres

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Appendix 1: Model Development Literature Review

Introduction

This literature review was compiled to provide a conceptual basis for identifying relative landscape permeability based on broad-scale landscape characteristics for wolf (*Canis lupus*), lynx (*Lynx canadensis*), grizzly bear (*Ursus arctos*), and wolverine (*Gulo gulo*). We have attempted to briefly summarize the available literature on regional species distribution, habitat associations, dispersal characteristics, and previous habitat modeling efforts for each of these species. This information is used to develop a conceptual model of landscape permeability for each species. The conceptual models are translated into relative landscape permeability parameters presented in table 2 of this report. These models are not intended to be precise simulations of animal movement, but instead are intended to investigate regional-scale landscape patterns and how they may influence the distribution of large carnivore habitat and potential linkages between blocks of large carnivore habitat.

Gray Wolf (*Canis lupus*)

Distribution

Wolves are habitat generalist predators (Mech 1970). The historical distribution of the many subspecies of wolves throughout the Northern Hemisphere reflects the species' ability to adapt to a variety of conditions (Mech 1970). Wolves were extirpated from the Western United States in the 1930s by aggressive antipredator activities (Mech 1970). Recolonization of habitat in the vicinity of Glacier National Park, Montana, by wolves dispersing from Canada started in the late 1970s (Pletscher et al. 1991). By the mid-1980s, a population of about 30 individuals (in three packs) was established in this area (Pletscher et al. 1997). Reintroduction of wolves into Yellowstone National Park and central Idaho took place in the mid-1990s. Wolf populations are presently well established in the northern Rocky Mountains of Idaho, Montana, and Wyoming. Recent detections of wolves in the Northern Cascade Range have been recorded (Fritts 1992, Gaines et al. 1995) and are reviewed in Gaines et al. (2000). Consistent reproductive activity has not been confirmed in the North Cascades ecoregion (Gaines et al. 2000).

The distribution of wolves in British Columbia is not well documented. A 1988 map produced by the British Columbia Ministry of Environment, Lands, and Parks (BCMELP 1988) indicates that wolves were absent from the southernmost portion of the province between Vancouver and Nelson, as well as from the Okanagan valley and highlands south of Revelstoke. Moderate to high densities of wolves (one wolf per 100 to 300 km^2) are indicated for the Rocky Mountains east of Cranbrook and the Interior Plateau north of Cache Creek.

Habitat Associations

Security from human persecution and abundance of prey are the primary habitat conditions necessary for wolf survival (Mech 1970). In western North America, ungulates are the primary prey of wolves (Huggard 1993, Kunkel and Pletscher 1999, Pletscher et al. 1991). Wolf presence is strongly associated with adequate ungulate populations at both regional and local scales. Huggard (1993) argued that wolf intraterritorial movement patterns in Banff National Park, Alberta, were largely determined by the wolves' attempts to maximize prey encounter rates. Singleton (1995) found that habitual winter travel routes of wolves in Glacier National Park, Montana, served to efficiently connect wintering concentrations of ungulate prey.

The primary mortality factors for wolves are human related, and avoidance of human disturbance is an important influence on habitat selection by wolves in many areas. All 14 documented adult wolf mortalities for the population near Glacier National Park, Montana, between 1979 and 1990 were human caused (Pletscher et al. 1991). Mech et al. (1988) found that wolves generally did not occur in portions of northern Minnesota where road densities were more than 0.59 km/km^2, though some wolves did persist in areas with higher road densities where there were larger blocks of unroaded or low road density habitat nearby. Thurber et al. (1994) documented wolf avoidance of secondary roads open to the public and attraction to roads closed to the public for a wolf population in Alaska. Theil (1985) found that wolf survival decreased when road densities exceeded 1 mi/mi^2 and recommended that areas being managed for wolf habitat should maintain road densities below 1 mi/mi^2.

Attraction to prey concentration areas and avoidance of human disturbance drives wolf habitat selection at a landscape scale in western North America. Singleton (1995) found that wolf home ranges in and near Glacier National Park, Montana, encompassed more western, southwestern, and flat aspects, valley bottoms and lower slopes, and areas with road density less than 4 mi/mi^2 than were expected based on availability in the basin. Within home ranges, habitual travel routes were located more often than available in valley bottoms; on lower slopes; gentler slopes; southern, southwestern, and flat aspects; areas >500 m from open roads, and road density <2 mi/mi^2. Boyd (1997) found that dispersing wolves in western Montana selected landscapes with relatively low elevations, flatter terrain, and closer proximity to water and roads than expected based on availability inside and outside their new home ranges.

Dispersal

Wolves are capable of long-distance dispersal movements (Mech 1970). Boyd et al. (1995) found that 17 of 42 marked wolves in the Rocky Mountains of Montana and British Columbia made long-distance movements (>40 km). Movement distances for six dispersing wolves from Glacier National Park between 1979 and 1990 were 50 to 840 km (Pletscher et al. 1991). Most of the dispersers moved north along the Continental Divide into Canada. Forbes and Boyd (1997) found that naturally recolonizing wolves in northwestern Montana retained much of the genetic diversity of a reference wolf population in Canada, indicating that the number of dispersers from Canada into the United States was sufficient to maintain genetic diversity.

Modeling Efforts

Several watershed to regional-scale models have been applied to evaluate wolf habitat. Mladenoff et al. (1995) found that several variables were significant in comparing new pack areas in Wisconsin to nonpack areas, but that a simple model based on road density was effective for predicting wolf presence. Corsi et al. (1999) developed a regional-scale model of wolf distribution in Italy by using geographical information system (GIS) information on land cover, human population density, road density, garbage dump density, sheep density, and number of ungulate species present. Harrison and Chapin (1997) conducted an analysis of wolf habitat in New England and adjacent areas of Canada. They identified wolf habitat as areas with forested land cover, road density less than 0.7 km/km^2, and human population density less than four people per square kilometer. Purves and Doering (1999) developed a model for evaluating cumulative effects of recreational activities and development on wolves in Jasper National Park, Alberta. They developed maps of potential wolf habitat based on availability of prey (derived from land cover type), slope, aspect, and elevation. Maps of human use intensity were combined with the potential habitat map. They also incorporated a least-cost path component to identify potential travel routes in relation to proposed developments. Paquet et al. (1999) evaluated wolf habitat in Adirondack Park, New York, based on slope, aspect, distance to roads, road density, expected snowfall, and prey density. They used least-cost path analysis to evaluate landscape connectivity between core areas they identified within the park. Movement cost was evaluated based on land use, road density, water, town locations, and slope for summer habitat. Snowmobile trails and snowfall were incorporated for winter habitat analysis. Carroll et al. (2000) compiled a conceptual model to evaluate wolf habitat in the Rocky Mountains based on a combination of road density and population density, slope, and greenness (from Landsat imagery). Washington gap analysis program (GAP) (Johnson and Cassidy 1997) identified all habitats within the North Cascades and Selkirks regions (except ice, developed, and agriculture) as potential core wolf habitat.

Conceptual Basis for Model Development

Wolves are habitat generalist predators subject to substantial human persecution, though not as sensitive to human disturbance as grizzly bears or wolverines. Vegetation generally does not influence movement patterns, though land cover types associated with human activity are poor dispersal habitat. Habitats providing security cover reduce the impacts of human presence. Road density will be the driving factor. Population density also will be important for higher density areas. Forest and shrub land cover types will be high quality, grasslands slightly less, agriculture poor, and urban/developed very poor. Wolves tend to select more gentle areas for movement. Slopes <20º will be best, 20º to 40º will be moderate, and >40º will be poor.

Wolverine (*Gulo gulo*)

Distribution

In North America, wolverine are distributed across northern boreal and tundra habitats in Alaska, the Yukon, and the Northwest Territory. Wolverine distribution extends south through British Columbia and western Alberta (Wilson 1982). Johnson (1977) reported presence of wolverine in the Cascade Range and northern Washington prior to 1919. He documented few reports of wolverine from 1919 to 1959. Increasing numbers of wolverine reports in the 1960s and 1970s led him to conclude that wolverine numbers in the Cascade Range were increasing, most probably owing to recolonization from Canada (Johnson 1977). Edelmann and Copeland (1999) compiled wolverine sightings for Washington, Oregon, and Idaho for 1886 to 1998. They identified three clusters of sightings corresponding to the Washington Cascade Range, the Oregon Cascade Range, and the northern Rocky Mountains in Idaho. Wolverine sightings were scattered across northern Washington, with smaller clusters near the Kettle and Selkirks Ranges (Edelmann and Copeland 1999). Wolverine distribution in British Columbia is poorly documented.

Habitat Associations

Wolverine habitat is generally understood to be best defined by adequate year-round food supplies in large, sparsely inhabited wilderness areas (Banci 1994). Wolverines are not associated with particular types of topography or plant associations, though certain landscape and habitat structure characteristics are associated with denning and resting sites (Banci 1994). The presence of large mammals underlies the distribution and abundance of wolverines (Banci 1994). Banci (1994) suggests that "the perception that wolverines are a high-elevation species has arisen because where wolverines are surrounded by people, they are usually found in the most inaccessible habitats, the mountain ranges." Hornocker and Hash (1981) believed that wolverines in northwestern Montana used higher ranges during the snow-free season because they were avoiding high temperatures and human recreational activity. Hornocker and Hash (1981) found a preference for mature to intermediate-aged forest in Montana; however, this association was not consistent with findings in the Yukon (Banci 1987) or Alaska (Gardner et al.1986). Lofroth (2000) reported that wolverines appeared to be funneled into forested corridors in their movements through altered landscapes in north-central British Columbia. Hornocker and Hash (1981) reported that wolverines in

Montana occasionally crossed clearcuts, though they usually crossed in straight lines and at a running gait, compared to more leisurely, meandering patterns in forested areas. Wolverines may be particularly sensitive to winter recreational activities, including heli-skiing and snowmobiling (Banci 1994, Krebs 2000b). Krebs (2000a) reported that about one-half of documented wolverine mortalities were human caused (primarily hunting or trapping and road or railroad collisions).

Dispersal

Wolverines can travel long distances, with daily movements of 30 to 40 km having been regularly documented from snow tracking (Haglund 1966, Krott 1960, Pulliainen 1968 in Banci 1994). Home range sizes vary from 100 to 900 km^2 and seem to be largely dependent on food abundance (Banci 1994). In Washington, cervids are likely to be the primary prey and carrion species for wolverine. Wolverine distribution and travel routes are likely to be substantially influenced by the distribution of cervids (elk and deer). Adult wolverines have been reported to make long-distance extraterritorial movements not necessarily related to dispersal (Banci 1994). In discussing management considerations for wolverine, Banci (1994) suggests the following:

> The dispersal and travel corridors that connect refugia [source areas], at least for males, likely need not have the habitat attributes necessary to support self-sustaining populations. Atypical or low quality habitats may be important to wolverines if they connect otherwise isolated populations and allow for genetic exchange or colonization. Because females establish home ranges next to their natal areas and their dispersal distances are less than for males, requirements for dispersal corridors may be more specialized [for females]. The biggest limiting factor in recolonization likely is the dispersal of young females.

In discussing wolverine dispersal, Banci (1994) suggests that:

> Rivers, lakes, mountain ranges, or other topographical features do not seem to block movements of wolverines (Banci 1987, Hornocker and Hash 1981). At times, wolverines will use rivers and streams as travel routes probably because prey species also use these travel routes (pers. obs.). Considering the wolverine's avoidance of human developments, extensive human settlement and major access routes may function as barriers to dispersal.

Modeling Efforts

Modeling applications for wolverine habitat evaluation are not well developed. Hart et al. (1997) composed a model based on Copeland (1996) to identify potential denning habitat and incorporated measures of landscape curvature (for identifying alpine cirques), land cover type (rock and ice), and elevation (areas >2400 m). Carroll et al. (2000) developed a regression model based on wolverine sightings from Montana, Idaho, and Wyoming. The model incorporated precipitation, human population density, road density, alpine cirque habitat, and wetness (from satellite imagery). Washington GAP (Johnson and Cassidy 1997) modeled wolverine habitat, evaluating cooler forest and alpine cover types (silver fir [*Abies amabilis* Dougl. ex Forbes], mountain hemlock [*Tsuga mertensiana* (Bong.) Carr], subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.], alpine/parkland, interior western hemlock [*T. heterophylla* (Raf.) Sarg.], interior red cedar [*Thuja plicata* Donn ex. D. Don], interior Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], and grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.]) as core habitats. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) was peripheral.

Conceptual Basis for Model Development

Wolverine are habitat generalists that occupy relatively high-elevation habitats and are sensitive to human disturbance. Dispersal routes are expected to be influenced by human disturbance patterns (road density and population density), and hiding cover (forest types better than shrub, agriculture, and urban-developed relatively impermeable). Road density and human population density negatively impact landscape permeability. Higher elevation areas are preferred. Slope is not expected to be a factor.

Lynx (*Lynx canadensis*)

Distribution

Lynx are broadly distributed within the northern boreal forest ecosystems in Alaska, the Yukon, and the Northwest Territory (Koehler and Aubry 1994). Lynx distribution extends south coincident with interior forest types of British Columbia and portions of western Alberta. British Columbia trapping records (Hatler 1988) indicate that 50 to 60 percent of the 2,256 lynx trapped from 1985 to 1987 came from northern regions of the province (north of Prince George), whereas 10 to 15 percent of the harvest came from southern interior regions (including the Okanagan highlands and areas to the east). No lynx were reported harvested from the Coast Range and Vancouver Island.

Historically, lynx were distributed through the forested portions of north-central and northeast Washington, and on the east slope of the Cascade Range south to the vicinity of Mount Rainier and Mount Adams (McKelvey et al. 2000a, Ruediger et al. 2000, Stinson 2001). If present, lynx were never common on the west side of the Cascade Range. Lynx in Washington are likely to represent the southern extension of populations centered in British Columbia. Recent extensive hair-snaring surveys have failed to confirm lynx presence in the Cascade Range outside of the Okanogan National Forest (McKelvey et al. 1999 cited in Stinson 2001). Stinson (2001) reports recent documentation of lynx in the Salmo-Priest (Selkirks), Kettle, and Okanogan lynx management zones (LMZs). Intervening LMZs (the Wedge and Vulcan-Swan) serve primarily as connecting habitat areas (Stinson 2001). Based on the amount of available habitat, the maximum lynx population that could occur in Washington has been estimated at 300 individuals (McKelvey et al. 1999 cited in Stinson 2001). Stinson (2001) estimated that there are currently no more than 100 to 200 lynx present in Washington.

Habitat Associations

Morphologically, lynx are adapted to deep snow conditions and tend to occupy habitats with deeper snowpacks (and in the southern portions of their range, higher elevations) than other medium-sized carnivores such as bobcat (*L. rufus*) or coyote (*C. latrans*) (Koehler and Aubry 1994, McKelvey et al. 2000a). In their review of the literature, Aubry et al. (2000) indicate that lynx in the western mountains of North America are associated with Douglas-fir, spruce-fir, and fir-hemlock forests at elevations ranging from 1500 to 2000 m. Koehler and Aubry (1994) state that “lynx habitat in the western mountains consists primarily of two structurally different forest types occurring at opposite ends of the stand-age gradient. Lynx require early-successional forests that contain high numbers of prey (especially snowshoe hares) for foraging and late-successional forests that contain cover for kittens (especially deadfalls) and for denning (Brittell et al. 1989, cited in Aubry et al. 2000; Koehler and Brittell 1990). Intermediate successional stages may serve as travel cover for lynx but function primarily to provide connectivity within a forest landscape.” Apps (2000) found that lynx tended to avoid higher elevations (>1850 m) and steeper slopes (>40 percent) in his study area in the Canadian Rocky Mountains. McKelvey et al. (2000a) found that primary areas of occurrence of lynx sightings in Montana were in or near Rocky Mountain (interior) coniferous forest, between 1500 and 2250 m elevation. Only 4 of 3,803 lynx records were >100 km from coniferous forest, indicating that lynx are closely associated with interior conifer forest types.

Koehler and Brittell (1990) described lynx by using mature forest stands with low hare density for travel habitat. These stands did not provide foraging opportunities but did provide security cover. They found that lynx traveled the edges of meadows but only crossed meadows where openings were less than 100 m wide, indicating a strong avoidance of open areas. In their reanalysis of Koehler and Brittell's (1990) data, McKelvey et al. (2000b) found that 22 radio-collared lynx in the Okanogan National Forest showed little use of areas below 1400 m or above 2150 m from 1981 to 1988. Analysis of telemetry data for these animals indicated selection for lodgepole pine (*Pinus contorta* Dougl. ex Loud.), subalpine fir, and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) habitats, with selection against ponderosa pine, Douglas-fir, and nonforested habitats. Areas with higher stream density and flatter slopes also were associated with lynx use. Lynx were recorded in areas with low to moderate road density more than expected based on availability, and used areas with high road density only slightly less than expected based on availability (McKelvey 2000b used a road density index that weighted roads by distance from the center point of the area measurement, so it cannot easily be translated into km/km^2 measurements). Observed road crossing rates did not differ from expected for unpaved forest roads. Forest types and elevation zones with the highest densities of hares corresponded to those classes strongly selected by lynx. McKelvey's reanalysis supported Koehler and Brittell's (1990) original findings that lynx use lodgepole pine more than expected and Douglas-fir less than expected. Forest roads do not appear to have a substantial effect on habitat use (Aubry et al. 2000, McKelvey et al. 2000b), though major highways seem to act as filters to intraterritorial movement (Apps 2000, Aubry et al. 2000).

Dispersal

Lynx are capable of making long-distance dispersal movements and regularly do so in northern parts of their distribution. Poole (1997) reported lynx dispersal distances up to 970 km in the Yukon. Apps (2000) recorded exploratory movements of 40 to 74 km for lynx in the southern Canadian Rocky Mountains.

No successful dispersals (long-distance movements ending in establishment of a home range) have been recorded for lynx in southern boreal forest habitats (Aubry et al. 2000), though long-distance movements ending in mortality have been recorded (Aubry et al. 2000). One adult male trapped in north-central Washington moved 616 km north into British Columbia, where it was trapped (Brittell et al. 1989, cited in Aubry et al. 2000). Dispersal movements in excess of 100 km are considered typical for lynx in northern habitats (Aubry et al. 2000). Dispersing lynx have been recorded crossing major highways and large rivers during their long-distance movements (Aubry et al. 2000). Squires and Laurion (2000) reported exploratory movements by four radio-collared lynx in Montana of 20 to 30 km, though distances traveled are likely to be longer because the animals were not detected during extensive aerial searching while they were away from their home ranges. These movements occurred during late June and July. Squires and Laurion (2000) report daily intraterritorial movement distance for lynx to be 2 to 4 km per day. Although shrub-steppe communities do not provide typical resting or foraging habitat, lynx may disperse through shrub-steppe (Ruediger et al. 2000; p. 33).

Modeling Efforts

Landscape-scale modeling applications for lynx are not well developed. Carroll et al. (2000) composed a regression model based on lynx sighting records from Montana, Wyoming, and Idaho in which low topographic complexity, increased normalized differenced vegetation index (NDVI) and increased brightness from satellite imagery, and road density <0.6 km/km^2 improved habitat quality. Washington GAP (Johnson and Cassidy 1997) included interior western hemlock, interior western redcedar, and subalpine fir zones in their definition of core habitat for lynx.

Conceptual Basis for Model Development

Travel habitat for lynx is characterized by all forest successional classes, with boreal forest types (interior western hemlock, interior western redcedar, and subalpine fir zones) being preferred. Other forest types can provide travel cover but are lower quality. Shrub types are expected to be marginal travel habitat. Grasslands, agriculture, and urban areas are poor dispersal habitat. Lynx prefer areas with <40º slope. Lynx generally use habitats 1000 to 2500 m elevation. Roads (except at very high densities) are not expected to substantially influence lynx habitat selection. Lynx are not as sensitive to human disturbance as some other species; however, they have not been documented to frequent heavily populated areas. Population density will influence lynx movement at relatively high levels compared to other species.

Grizzly Bear (*Ursus arctos*)

Distribution

In western North America, grizzly bears are distributed across Alaska, the Yukon, portions of the Northwest Territory, northern British Columbia, and western Alberta (USFWS 1993). Within the conterminous United States, grizzly bears occur in five areas: the Yellowstone Ecosystem of Idaho, Montana, and Wyoming; the Northern Continental Divide Ecosystem of Montana; the Cabinet/Yaak Ecosystem of Montana; the Selkirks Ecosystem in northern Idaho and Washington; and the Northern Cascades Ecosystem of Washington (USFWS 1993).

The North Cascades Grizzly Bear Recovery Plan for British Columbia (North Cascades Grizzly Bear Recovery Team 2001) states that viable populations of grizzly bears are well distributed across British Columbia, north of Prince George. Viable populations of grizzly bears extend south through the Columbia Mountains to the Valhalla and Central Monashee Mountains, north of Nelson, British Columbia, and through the Coast Range south to the Kliniklini-Homathko region (approximately the same latitude as the north end of Vancouver Island). Threatened populations of grizzly bears are present along the southern edges of these peninsular populations in the Kettle and Granby River drainages and southern Selkirk Mountains, as well as the Coast Range west of the Fraser River (North Cascades Grizzly Bear Recovery Team 2001).

Consistent detections of grizzly bears near Manning Provincial Park, British Columbia, indicate the presence of 17 to 23 individuals, including an estimated 5 to 6 reproductive females, in the North Cascades ecosystem (Gyug 1998). Intermittent reports of grizzly bears in the U.S. portion of the North Cascades Ecosystem may be the result of movements by bears from the Manning Provincial Park area (Almack et al. 1993).

Past management plans have assumed that the grizzly bear population in the North Cascades Ecosystem is isolated from other populations of grizzly bears (Almack et al. 1993, North Cascades Grizzly Bear Recovery Team 2001). The closest threatened populations of grizzly bears to the North Cascades are in the Kettle-Granby area (about 50 air miles to the east) and the Stein-Nahatlatch area of the Coast Range (about 20 air miles to the northwest). These threatened populations occur at relatively low densities with substantial amounts of unoccupied habitat and are not expected to produce dispersing animals (North Cascades Grizzly Bear Recovery Team 2001). The closest viable populations of grizzly bears are in the Valhalla Mountains (about 150 km to the east) and the Kliniklini-Homathko region of the Coast Range (about 320 km to the northwest). Grizzly bears are considered to be extinct from the heavily developed Okanogan and Fraser River valleys in south-central British Columbia (North Cascades Grizzly Bear Recovery Team 2001).

Habitat Associations

Grizzly bear habitat selection is a function of food availability and avoidance of human disturbance (LeFranc et al. 1987). Both vegetal matter (e.g., stems, leaves, roots, corms, bulbs, and fruit) and animal matter are important food sources for grizzly bears (LeFranc et al. 1987). In the absence of human disturbance, grizzly bear habitat selection is largely driven by food availability. *Equisetum* spp., *Heracleum lanatum*, *Trifolium* spp., *Taraxacum* spp., *Hedysarum* spp., *Vaccinium* spp., and *Shepherdia* spp. are important food plants (LeFranc et al. 1987). Some of these species are most abundant in moist, open areas (often avalanche chutes or early successional forest openings) (LeFranc et al. 1987). Grizzly bears are strongly associated with areas providing plant foods, in particular avalanche chutes (providing spring food plants) and mesic shrub communities (providing summer and fall berry crops) (Mace et al. 1996). Grizzly bears may make use of high alpine habitats. In some areas, they forage on army cutworm moth concentrations in high-elevation talus slopes for a high-protein food source (White et al. 1998).

In areas with human disturbance, grizzly bears tend to select habitats that are either remote (e.g., rugged alpine habitats) or close to security cover (LeFranc et al. 1987). McLellan et al. (1999) analyzed mortality data for 388 grizzly bears radio-collared for several studies in the Rocky Mountains of Canada and the United States and found that 77 to 85 percent of the 99 bears that died while radio-collared died from human-related causes (i.e., hunting, poaching, and control killings). Wakkinen and Kasworm (1996) found that grizzly bears in the Selkirks and Cabinet-Yaak recovery zones used areas with >2 mi/mi^2 total road density or >1 mi/mi^2 open road density less than expected compared to availability. Mattson et al. (1987) found that grizzly bears in Yellowstone avoided areas close to roads, and those that did use habitats close to roads showed disrupted foraging patterns. McLellan and Shackleton (1988) found that bears used habitats within 100 m of roads less than expected. Mace et al. (1999) found that the value of an area for grizzly bears was substantially influenced by human activities in the area. Gibeau (2000) found that grizzly bear crossing locations along the Trans-Canada highway in Banff National Park, Alberta, were concentrated in areas characterized by lower-than-average total access density, closer to a major drainage, more rugged terrain, and higher quality habitat (Gibeau 2000). Because of their sensitivity to human disturbance, maintaining core security areas (generally defined as areas >1 mi from roads) has been identified as a priority in managing for viable grizzly bear populations (Gibeau 2000, North Cascades Grizzly Bear Recovery Team 2001, USFWS 1993).

Dispersal

Although physically capable of long-distance movements, bears do not appear to be behaviorally inclined to make such movements, particularly in the fragmented habitats characteristic of the Northwestern United States and Southwestern Canada (McLellan and Hovey 2001). Minimum convex polygon home range sizes for grizzly bears throughout North America were reported by the Interagency Grizzly Bear Committee

(LeFranc et al. 1987). Adult male home ranges were generally 500 to 2500 km^2 in size, indicating the ability to move long distances. However, McLellan and Hovey (2001) found that the average natal dispersal distance for 18 male grizzly bears was 30 km, and for 12 females was 10 km. Maximum dispersal distances they recorded were 67 km for a male and 20 km for a female. Gyug (1998) reported on the movements of two “problem” grizzly bears that were relocated into the North Cascade Range. In June 1994, a female was released in the Anderson River area and recaptured in May 1995 near Agassiz (about 30 km linear distance). In October 1992, a male was released in the Pasayten River area, moved about 64 km west to the Chilliwak River that fall, then returned to its original capture area near Pemberton by June 1993 (at least 260 km total distance).

Modeling Efforts

Habitat modeling applications for grizzly bear habitat evaluation are well developed. Servheen and Sandstrom (1993) developed a model to identify grizzly bear linkage zones. It incorporates road density, distance to developments, hiding cover, and riparian habitat. This model has been applied in a number of areas in the Rocky Mountains of Montana, Alberta, and British Columbia (Apps 1997, Mietz 1994, Sandstrom 1996). Boone and Hunter (1996) used an individual-based diffusion model to evaluate landscape permeability in the northern Rocky Mountains. They used land cover and ownership to calculate resistance to movement. Walker and Craighead (1997) conducted least-cost path analysis investigating potential movement corridors for grizzly bears in the Rocky Mountains. Their model incorporated vegetation type, edge length, and road density as predictors of landscape permeability. Mace et al. (1999) developed a model based on female grizzly bear resource selection functions for western Montana that incorporated elevation, human activity points, roads, trails, and greenness (determined from Landsat TM imagery and related to increased amounts of deciduous, green vegetation). Kobler and Adamic (1999) used decision tree analysis of bear sighting locations and least-cost corridor analysis to develop and apply a model of Eurasian brown bear movement relative to highways in Slovenia. Predictive factors identified from their decision tree analysis included percentage of forest cover, human population density, proximity to settlements, elevation, and forest type information. Clevenger et al. (1997) conducted an assessment of brown bear habitat in the Cantabrian Mountains of northern Spain based on forest cover type, elevation, distance to nearest village, and distance to nearest roadway. Merrill et al. (1999) evaluated habitat suitability for grizzly bears in Idaho by using an index of habitat productivity combined with an index of habitat effectiveness based on recreation visitor days, distance to and size of human population centers, and density of road and trail access. Carroll et al. (2000) used a modified version of Merrill’s model for application to a large analysis area in the Rocky Mountains. Washington GAP (Johnson and Cassidy 1997) classified all habitat types within the North Cascades and Selkirk regions as good habitat.

Conceptual Basis for Model Development

Grizzly bear movements are most strongly influenced by human activity patterns, food availability, and security cover. Human activity has a substantial influence on grizzly bear activity. Areas with moderate to high road and population density will have poor landscape permeability. Habitat types providing substantial vegetative food resources include avalanche chutes, moist and mesic shrub lands, timber harvest units, riparian zones, and other habitats with high canopy coverage of deciduous shrubs. Dry shrub types do not provide substantial food resources. All forest types would be expected to provide effective security cover. Slope has not been noted to have a substantial influence on grizzly bear movement.

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Appendix 2: Base Map Metadata

Introduction

Digital data were compiled from various sources for assessing regional-scale patterns of landscape permeability for large carnivores. Data sources and major processing steps are summarized below for each of the primary modeling coverages. All weighted-distance and least-cost corridor analysis was conducted by using raster coverages with 90-m cell size. These base data sources provided regional data at approximately 1:250,000-map scale. All base data layers were compiled and stored by using Albers projection (described below).

Map projection parameters for spatial data used in this project:

Coordinate System Description

Projection ALBERS

Datum NAD27

Units METERS Spheroid CLARKE1866

Parameters:

1st standard parallel	43 0 0.000
2nd standard parallel	48 0 0.000
central meridian	-117 0 0.00
latitude of projection's origin	41 0 0.000
false easting (m)	700 000.00000
false northing (m)	0.00000

Vegetation

This coverage maps vegetation at a 90-m cell size, by using approximately 1:250,000-map scale source data. Vegetation data were compiled from the sources below and crosswalked into a common set of classifications.

Washington

Title: Washington Gap Project 1991 land cover for Washington state

Publication date: 1997

Data source: Washington Department of Fish and Wildlife, Olympia, WA. (http://www.wa.gov/wdfw/wlm/gap/landcov.htm).

Mapping scale: 30-m cell size, approximately 1:100,000

Abstract: Polygon land cover and land use data for Washington state derived from 1991 TM data, with a nominal minimum mapping unit of 100 ha. These products were developed for use at approximately 1:100,000 map scale.

British Columbia

Land cover/land use baseline thematic mapping (BTM) maps were combined with biogeoclimatic zone (BEC) maps to derive land cover by biogeoclimatic zone classes that could be crosswalked with gap analysis program (GAP) data for Washington and Idaho.

Title: baseline thematic mapping (BTM)—present thematic land use mapping at 1:250,000

Publication date: 1998

Data source: British Columbia Ministry of Environment, Lands, and Parks, Victoria, BC. (http://home.gdbc.gov.bc.ca/products/btm.htm).

Mapping scale: 1:250,000

Abstract: The baseline thematic mapping present land use phase is a thematic map database that is derived from satellite imagery and digital topographic base mapping. The satellite imagery utilized is Landsat Thematic Mapper (TM) data. The topographic data used was produced by scanning lithographic layers of the published National Topographic Series (NTS) mapsheets and structuring the data into a geographic information system (GIS) compatible dataset.

Title: Provincial digital biogeoclimatic subzone/variant mapping, version 1.2.

Publication date: 1998

Data source: British Columbia Ministry of Forests, Victoria, BC. (http://www.for.gov.bc.ca/research/becmaps/becmaps.htm).

Mapping scale: 1:250,000

Abstract: The BEC system consists of two components: a zonal classification and a site classification. The zonal classification is a hierarchical system that integrates climate, vegetation, and soil classifications at a broad landscape level. The zonal or regional climate (reflected by vegetation and soil relationships) defines the basic biogeoclimatic unit, the subzone. Examples of biogeoclimatic zones include alpine tundra, coastal Douglas-fir, and ponderosa pine.

Idaho

Title: GRID IDVEG—Idaho land cover

Publication date: 1999

Data source: Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID. (http://www.wildlife.uidaho.edu/idgap.htm).

Mapping scale: 30-m cell size, approximately 1:100,000

Abstract: The Idaho Cooperative Fish and Wildlife Research Units Landscape Dynamics Lab compiled the Idaho Land Cover Classification from the 1997 Current Vegetation Map of Northern Idaho and Western Montana and the 1998 Idaho/Western Wyoming Landcover Classification. These sources were crosswalked and merged to produce a unified land cover map for Idaho. This coverage is stored as an ARC/INFO grid with a 0.09-ha (30-m) cell size and a 2-ha minimum mapping unit.

Roads

Road data were compiled from the following sources to calculate road density. Line features representing roads were selected from these data sets. Moving window road density analysis using a 900-m radius (1 mi^2) moving circle with 30-m cell size were used to calculate road density from the data below. The road density surface was resampled to 90-m cell size to match other data sets. Road data were not attributed with management status.

Washington

Title: Washington State Department of Natural Resources transportation data layer

Publication date: 1998

Data source: Washington State Department of Natural Resources, Olympia, WA.

Mapping scale: 1:24,000

Abstract: The transportation data layer represents road, trail, railroad and other land and water routes existing within the state of Washington. The purpose of this coverage is for forest practice regulation and analysis applications, natural resource planning, and general mapping reference.

British Columbia

Title: Terrain resource inventory mapping (TRIM) transportation data layer

Publication date: 1996

Data source: British Columbia Ministry of Environment, Lands, and Parks, Victoria, BC (http://home.gdbc.gov.bc.ca/TRIM/trim/)

Mapping scale: 1:20,000

Abstract: The TRIM transportation map tiles represent roads, trails, railroads, and other transportation facilities for the province of British Columbia.

Idaho

Title: U.S. Census Bureau TIGER files.

Publication date: 1996

Data source: Interior Columbia Basin Ecosystem Management Project (http://www.icbemp.gov).

Mapping scale: 1:100,000

Abstract: Streets of Idaho, compiled from U.S. Census Bureau TIGER files for reference and scientific analysis in the Interior Columbia Basin Ecosystem Management Project.

Digital Elevation Models

Elevation data were compiled for United States and Canadian portions of the analysis area and resampled to 90-m cell size. These data were used to generate the slope surface used in the landscape permeability modeling.

Washington and Idaho

Title: 90-m digital terrain model

Publication date: 1997

Data source: Interior Columbia Basin Ecosystem Management Project. (http://www.icbemp.gov).

Mapping scale: 90-m cell size

Abstract: Northwestern U.S. Digital Terrain Model, compiled from Defense Mapping Agency, Digital Map Atlas for reference and scientific analysis in the Interior Columbia Basin Ecosystem Management Project.

British Columbia

Title: 25-m digital elevation model

Publication date: 1999

Mapping scale: 25-m cell size

Data source: British Columbia Ministry of Environment, Lands, and Parks, Victoria, BC.

Abstract: Reference data compiled by the British Columbia Ministry of Environment.

Human Population Density

Human population density on private lands was calculated by compiling population information from U.S. and Canadian censuses, combining census data with land ownership maps, and calculating population density by private land area within each census block. Overall mapping scale is approximately 1:250,000.

Washington and Idaho

Title: U.S. Census Bureau, Census Block Groups

Publication date: 1997

Data source: Interior Columbia Basin Ecosystem Management Project. (http://www.icbemp.gov).

Mapping scale: 1:100,000

Abstract: U.S. Census Bureau, Census Block Groups attributed with 1990 census data for the states of Washington and Idaho.

Title: Land ownership—Washington and Idaho

Publication date: 1995

Data source: Interior Columbia Basin Ecosystem Management Project. (http://www.icbemp.gov)

Mapping scale: 1:100,000

Abstract: Reference data compiled from data provided by Washington Department of Natural Resources and Idaho Department of Water Resources.

British Columbia

Title: Population by electoral district

Publication date: 1989

Data source: Statistics Canada, Ottawa, Ontario.

Mapping scale: approximately 1:500,000

Abstract: Electoral district polygons attributed with 1989 Canadian census data.

Title: Alienated lands

Publication date: 1997

Data source: British Columbia Ministry of Environment, Lands, and Parks, Victoria, BC.

Mapping scale: 1:250,000

Abstract: Lands in private ownership.

Appendix 3: Landscape Permeability Modeling Advanced Macro Language Programs

The following ArcInfo advanced macro language (AML) programs were used to conduct the indicated steps for modeling landscape permeability. All analysis was conducted by using ArcInfo 8.0.2 on a Windows NT platform.

*Create info look up tables from *.dbf files with dispersal habitat suitability parameters:*

```
Note: Values for the <base data layer>.dbf files are summarized in table 2 of
this report.
/*      Program; dbftolut.aml
/*      Author; Peter Singleton
/*      Workspace; d:\ccon\work\
/*      Date; 3/23/01
/*
/* Modification History;
/* This file was created for the regional-scale large carnivore landscape
/* permeability assessment.
/*
/* Purpose; To prepare .lut info tables called up in prep<date>.aml.
/* This aml creates info .lut files attributed with habitat suitability codes
/* and a LINK attribute for the base data coverages. These are most easily
/* attributed in excel(friction tables.xls), saved as .dbf files and imported
/* with this aml.
/*
/* Files Needed to Run This AML;
/* base data layer>.dbf - .dbf files with dispersal habitat suitability values
/*
/* Output files;
/* <base data layer>.lut – info files with dispersal habitat suitability
modeling parameters

&do f &list rdden popd elev lcc slope
  dbaseinfo %f%.dbf %f%.lut
  additem %f%.lut %f%.lut link 3 3 i
&end
```

Create dispersal habitat suitability and distance weighting (friction) surfaces:

```
/*      Program; prep<date>.aml
/*      Author; Peter Singleton
/*      Workspace; d:\ccon\work\
/*      Date; 3/23/01
/*
/* Modification History;
/* This file is a modification of the costb4_22.aml written for the I-90
/* project.
/*
/* Purpose; To prepare dispersal habitat suitability and weighted-distance
/* friction coverages for landscape permeability modeling.
/*
/* Coverages Needed to Run This AML;
/*              RDDEN90M       - Road density coverage
/*              POPD90M - population density coverage
/*              ELEV90M - DEM
/*              LCC90M  - land cover class
/* Info files attributed with habitat suitability codes and a LINK attribute
/* for the above coverages (<cover name>.lut), and a friction lookup table
/* (fri.lut) are also needed. These are most easily attributed in excell
```

```
/* (friction tables.xls), saved as .dbf files and imported with dbftolut.aml.
/* Output Covers;
/* DHS<sp> - dispersal habitat suitability
/* FRI<sp> - friction cover &severity &error &ignore

/* SPECIFY IN COMMAND LINE WHICH SPECIES TO ANALYZE:
/* FORGEN, GUGU, URHO, LYCA, CALU
&args sp
grid

setwindow d:\ccon\extg
setmask d:\ccon\landg
setcell 90

&type *******GENERATING DISPERSAL FRICTION COVERS*****************
&type <<<<<<<<<<< Calculating remap values >>>>>>>>>>>>>>>>>>>>>>>
calc rdden.lut info link = %sp% * 10
calc popd.lut info link = %sp% * 10
calc slope.lut info link = %sp% * 10
calc lcc.lut info link = %sp% * 10

&type <<<<<< Generating dispersal habitat suitability code grids >>>>>>>
rdd%sp% = (reclass(d:\ccon\roads\rdcl90m, rdden.lut)) * 0.1
popd%sp% = (reclass(d:\ccon\popd\pdcl90m, popd.lut)) * 0.1
elev%sp% = (reclass(d:\ccon\topo\elcl90m, elev.lut)) * 0.1
lcc%sp% = (reclass(d:\ccon\lcc\lcc90m, lcc.lut)) * 0.1
slope%sp% = (reclass(d:\ccon\topo\slcl90m, slope.lut)) * 0.1

&type <<<<<< Generating dispersal habitat suitability grid >>>>>>>
dhs%sp% = (rdd%sp% * popd%sp% * lcc%sp% * slope%sp%) * 100
kill rdd%sp% all
kill popd%sp% all
kill lcc%sp% all
kill slope%sp% all

&type <<<<<<<<<Reclassing DHS Grid>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
fri%sp% = reclass(dhs%sp%, fri.lut)
q
&return

Contents of FRI.LUT (weighting factor lookup table).
0  1  :  100
1  2  :  99
2  3  :  98
3  4  :  97
4  5  :  96
5  6  :  95
6  7  :  94
7  8  :  93
8  9  :  92
9  10  :  91
10  11  :  90
11  12  :  89
12  13  :  88
13  14  :  87
14  15  :  86
15  16  :  85
16  17  :  84
17  18  :  83
18  19  :  82
19  20  :  81
```

```
20  21  :  80
21  22  :  79
22  23  :  78
23  24  :  77
24  25  :  76
25  26  :  75
26  27  :  74
27  28  :  73
28  29  :  72
29  30  :  71
30  31  :  70
31  32  :  69
32  33  :  68
33  34  :  67
34  35  :  66
35  36  :  65
36  37  :  64
37  38  :  63
38  39  :  62
39  40  :  61
40  41  :  60
41  42  :  59
42  43  :  58
43  44  :  57
44  45  :  56
45  46  :  55
46  47  :  54
47  48  :  53
48  49  :  52
49  50  :  51
50  51  :  50
51  52  :  49
52  53  :  48
53  54  :  47
54  55  :  46
55  56  :  45
56  57  :  44
57  58  :  43
58  59  :  42
59  60  :  41
60  61  :  40
61  62  :  39
62  63  :  38
63  64  :  37
64  65  :  36
65  66  :  35
66  67  :  34
67  68  :  33
68  69  :  32
69  70  :  31
70  71  :  30
71  72  :  29
72  73  :  28
73  74  :  27
74  75  :  26
75  76  :  25
76  77  :  24
77  78  :  23
78  79  :  22
79  80  :  21
```

```
80  81  :  20
81  82  :  19
82  83  :  18
83  84  :  17
84  85  :  16
85  86  :  15
86  87  :  14
87  88  :  13
88  89  :  12
89  90  :  11
90  91  :  10
91  92  :  9
92  93  :  8
93  94  :  7
94  95  :  6
95  96  :  5
96  97  :  4
97  98  :  3
98  99  :  2
99  100 :  1
```

Run weighted-distance analysis on previously identified “source” areas:

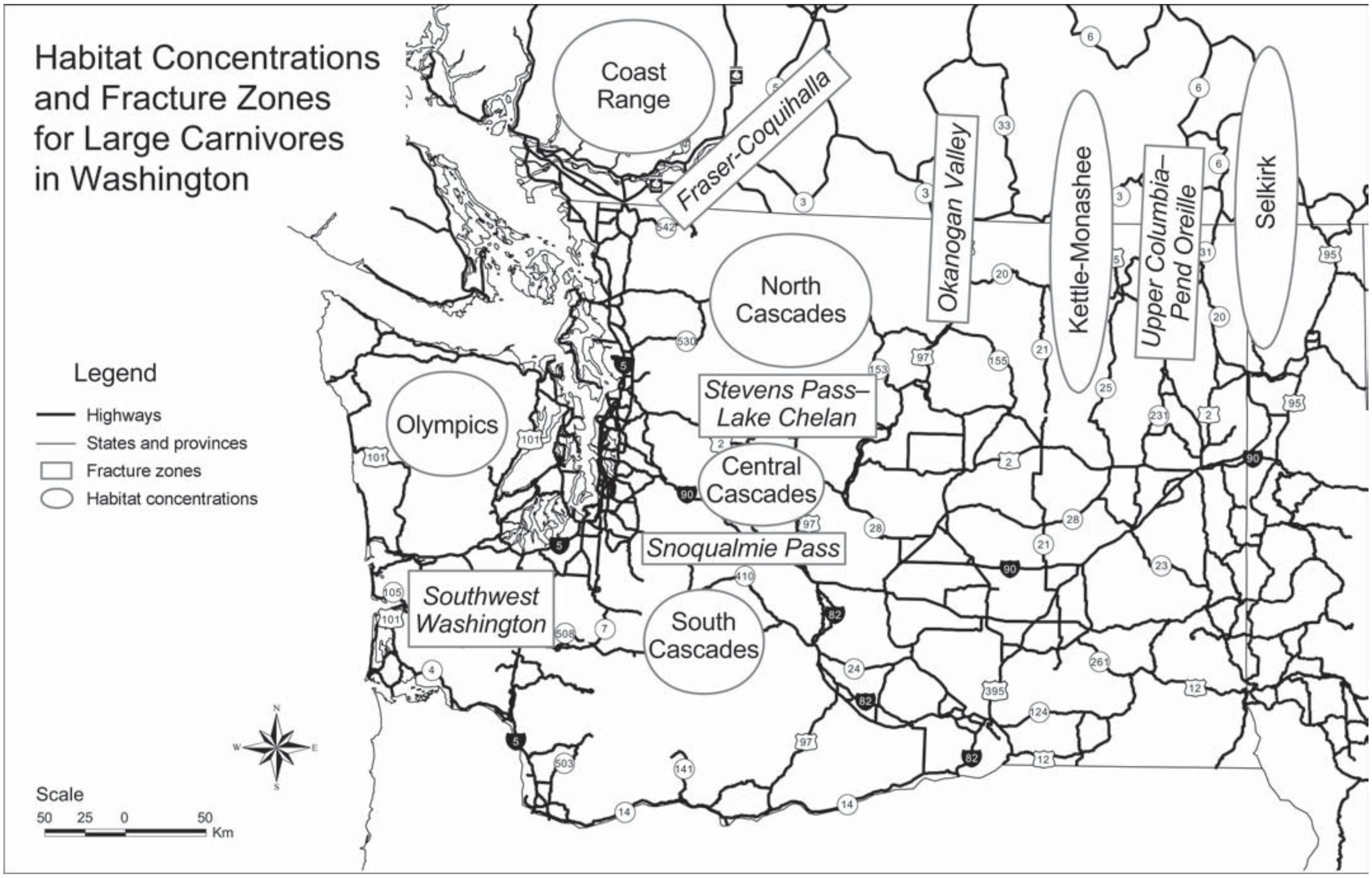
```
/*      Program; wdist<date>.aml
/*      Author; Peter Singleton
/*      Workspace; d:\ccon\work\
/*      Date; 3/23/01
/*
/* Modification History;
/* This file was created for the regional-scale large carnivore landscape
/* permeability assessemnt.
/*
/* Purpose; To run weighted-distance analysis for landscape permeability
/* modeling.
/*
/* Coverages Needed to Run This AML;
/*              SO<sp>6g - grid of habitat concentration areas of interest
/*              FRI<sp> - friction (distance weighting factors) grid (created by
                prep.aml)
/*
/* Output Cover;
/*              COS<sp> - weighted-distance from habitat concentration area grid
/*
/* SPECIFY ANALYSIS SPECIES IN THE COMMAND LINE (forgen, calu, gugu, lyca, urho)
&args sp
grid
setwindow d:\ccon\landg
setmask d:\ccon\landg
cos%sp% = costdistance(so%sp%, fri%sp%)
q
```

Run least-cost corridor analysis on fracture zones identified from the weighted-distance analysis:

```
/*      Program; cost<date>.aml
/*      Author; Peter Singleton
/*      Workspace; d:\ccon\work\
/*      Date; 3/23/01
/* Modification History;
/* This file is a modification of the costb4_22.aml written for the I-90
/* project.
/*
/* Purpose; To run least-cost corridor analysis for landscape permeability
/* modeling.
/*
/* Coverages Needed to Run This AML;
/*              SO<sp>          - Source polygons of interest, numbered
/*                              consecutively in 'source' field
/*              RDDEN90M        - Road density coverage
/*              USPOPD90M       - population density coverage
/*              ELEV90M         - DEM
/*              LCC90M          - land cover class
/*
/* Output Cover;
/*      CORR<sp><aa> - raw average weighted-distance between sources 1 & 2
/*      CR<sp>sl_<aa> - sliced least-cost corridor surface indicating the most
/*      permeable 10% of the fracture zone landscape to the least permeable 10%
/*
/* SPECIFY THE FOLLOWING IN THE COMMAND LINE:
/* WHICH SPECIES TO ANALYZE <sp>: FORGEN, GUGU, URHO, LYCA, CALU
/* SOURCE AREAS 1 & 2 (USE SOURCE NUMBERS FROM THE SO%SP%6 COVERAGES)
/* ANALYSIS AREA POLYGON COVERAGE <aa>
/* The Syntax Is: &r cost5_29 <species> <source1> <source2> <analysis area>
&args sp so1 so2 aa

&type ***********PREPARING SOURCE GRIDS FOR %sp% %so1% &
%so2%*******************

ae
ec %sp%\so%sp%6
ef polys
asel source = %so1%
put so%so1%p
unsel all
asel source = %so2%
put so%so2%p
q

clean so%so1%p
clean so%so2%p

grid
setcell 90
setmask d:\ccon\landg
so%so1%%sp% = polygrid(so%so1%p)
kill so%so1%p all
so%so2%%sp% = polygrid(so%so2%p)
kill so%so2%p all
aext%so1%g = polygrid(%sp%\aa%sp%%aa%)
setwindow aext%so1%g
setmask aext%so1%g
```

```
&type ***********RUNNING CORRIDOR ANALYSIS %sp% %aa%***************
&type <<<<<<<Running Costdistance %so1%>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
cos1%sp% = costdistance(so%so1%%sp%, fri%sp%)
cos2%sp% = costdistance(so%so2%%sp%, fri%sp%)

&type <<<<<<<<Running Corridor Function %aa%>>>>>>>>>>>>>>>>>>>>>>>>>>
corr%sp%%aa% = corridor(cos1%sp%, cos2%sp%)
kill cos1%sp% all
kill cos2%sp% all

&type <<<<<<<< Creating Sliced Corridor Coverages >>>>>>>>>>>>>>>>>>>>>
setwindow d:\ccon\extg
setmask d:\ccon\landg
cr%sp%sl_%aa% = slice(corr%sp%%aa%, eqarea, 10)
kill so%so1%%sp% all
kill so%so2%%sp% all
kill aext%so1%g all
q
&return
```

Appendix 4: Habitat Concentration Areas and Fracture Zones



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