WASHINGTON CONNECTED LANDSCAPES PROJECT: STATEWIDE ANALYSIS

WASHINGTON WILDLIFE HABITAT CONNECTIVITY
WORKING GROUP

DECEMBER 2010

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Statewide Analysis

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Working Group

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CONNECTIVITY
WORKING GROUP

Mission Statement of the Washington Wildlife Habitat Connectivity Working Group

Promoting the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities and priorities to conserve and restore habitat connectivity.

Full Document Citation

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

Document Availability

This document and companion files are available online at:
http://www.waconnected.org

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Acknowledgements

Funding

In addition to the generous contributions of Washington Wildlife Habitat Connectivity Working Group organizations, we wish to extend appreciation to the following entities that have provided funding critical to the accomplishment of this effort:

- 444S Foundation
- Great Northern Landscape Conservation Cooperative
- Northwest Wildlife Conservation Initiative, supported by the Doris Duke Foundation
- TransWild Alliance
- United States Fish and Wildlife Service (State Wildlife Grants)
- Wilburforce Foundation
- Wildlife Conservation Society, supported by the Doris Duke Foundation

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Reviewers and Collaborators

We would also like to thank the many reviewers and collaborators who generously contributed their time, expertise, and support during the development of this document and associated products. These individuals assisted with data layers and species information, participated in review meetings, pored over maps, participated in discussions about each species and product, reviewed written products, and supported our efforts to obtain funding. Throughout, these reviewers and collaborators provided suggestions that were extremely important in the process of improving the data analysis, the overall science, and the writing of the Washington Connected Landscapes Project Statewide Analysis. If we have omitted the names of anyone who helped with the development of this document and associated products, we sincerely apologize for the error, and thank you for your help.

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Executive Summary

Animals move across landscapes to find food and other resources, migrate between seasonal habitats, find mates, and shift to new habitats in response to environmental changes. The ability to successfully move between habitats is essential for the long-term survival of many wildlife species, from large, migratory species such as elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*), to smaller animals like white-tailed jackrabbits (*Lepus townsendii*), Greater Sage-Grouse (*Centrocercus urophasianus*), and western toads (*Anaxyrus boreas*). Landscape connectivity is also important for maintaining other natural processes such as nutrient cycling and seed dispersal. Maintaining and restoring connectivity is a key conservation strategy to preserve ecological processes and maintain the genetic and demographic health of wildlife populations. Connected landscapes will help wildlife weather future habitat changes resulting from natural disturbances such as fire, or from other factors including human population growth, development, and climate change.

The state of Washington, like other states, faces pressures that have compromised the connectivity of habitats and wildlife populations. The imprint of development, transportation, and agriculture on the landscape is prevalent and many wildlife habitats have been highly fragmented. And, despite being the smallest western state, Washington has the second highest human population. Sustaining wildlife habitat connectivity, while at the same time meeting the needs of people and communities, is an increasingly difficult challenge.

The Washington Wildlife Habitat Connectivity Working Group

In this context it became apparent that piecemeal efforts to avoid habitat fragmentation would not be successful in maintaining landscape connectivity over time. An effective program to maintain or improve connectivity requires a statewide approach using the best available science to guide coordinated action by many agencies and organizations. The Washington Wildlife Habitat Connectivity Working Group (WHCWG) was formed to address this need.

The WHCWG is a voluntary public-private partnership between state and federal agencies, universities, tribes, and non-governmental organizations. The WHCWG is co-led by the Washington Department of Fish and Wildlife (WDFW) and the Washington Department of Transportation (WSDOT). The mission statement of the WHCWG is "*Promoting the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities and priorities to conserve and restore habitat connectivity*."

The WHCWG has also responded to the Western Governors' Association initiative to identify key wildlife habitats and migration corridors. We work in collaboration with the Western Governors' Association Wildlife Corridors Initiative and our analyses are part of Washington's contributions to this effort.

The Washington Connected Landscapes Project

It became clear that we needed a systematic approach with multiple components and a sustained effort to support our mission statement. We call this approach the *Washington Connected Landscapes Project*. The primary thrusts of the project at this time include: (1) scientific analyses of connectivity issues at different spatial scales for current and future landscape conditions, (2) development of suitable analytical methods and tools necessary to support these analyses, (3) coordination with transboundary partners to maintain connectivity across Washington's borders, (4) research and adaptive management to test and improve our models, and (5) outreach and education about connectivity to a broad array of stakeholders. This statewide report of the WHCWG is the first scientific analysis product of the Washington Connected Landscapes Project.

The Statewide Analysis

Assessing the current condition of wildlife habitat connectivity in the state is an important step for connectivity conservation. This statewide analysis quantifies current connectivity patterns for Washington State and neighboring areas in British Columbia, Idaho, and Oregon. It provides the foundation for analyses of connectivity at three spatial scales: (1) the statewide scale using connectivity maps and data presented here, (2) ecoregional scale connectivity analyses, and (3) detailed local analyses and linkage designs. The data and analysis techniques we've presented also provide the foundation for assessing changes brought about by energy development, climate change, and human population growth.

This document includes descriptions of the methods and results of the statewide analysis, lessons learned while completing the analysis, and planned future work of the WHCWG. It also gives guidance for interpreting and using these products. Appendices provide greater detail about species models, modeling methods, and GIS tools produced by the working group.

A primary product of our statewide analysis are maps which depict linkage networks, including areas of suitable habitat and the best remaining linkages connecting them. Sometimes those linkages include good habitat, such as stepping stones of small but exceptionally high-quality habitat patches. Other times the models may identify what is the best, albeit marginal, swath of land through poor or degraded habitat.

The maps that accomplish this were derived from two modeling approaches. Our *focal species* approach produced linkage networks for 16 representative species, while our *landscape integrity* approach produced networks of lands exhibiting high degrees of landscape integrity and relatively intact natural areas with low levels of human modification.

Focal Species

We selected focal species using criteria designed to favor species with geographic ranges, habitat associations, and vulnerabilities to human-created barriers that made them representative of the habitat connectivity needs of many terrestrial species at a statewide scale. That is, we intended the linkages identified for our 16 focal species to benefit a broad array of species sensitive to habitat fragmentation. The focal species we chose represent not only diverse vegetation types, but varied life histories as well. They include animals that need large areas to meet their needs, like American black bears (*Ursus americanus*), elk, and wolverines (*Gulo gulo*). They also include smaller species whose habitat has become fragmented, such as northern flying squirrels (*Glaucomys sabrinus*) and white-tailed jackrabbits. And they include less mobile species such as western toads.

Our results for each focal species include maps of: (1) overall resistance to movement across the landscape, (2) important habitat patches (habitat concentration areas – HCAs), (3) cost-weighted distance, which depicts how resistance to movement accumulates while traversing the landscape outward from HCAs, and (4) modeled linkages between HCAs (Fig. ES.1; see Chapter 3). Close inspection of maps for each focal species can provide insight into baseline connectivity conditions in different parts of Washington State.

Landscape Integrity

Our landscape integrity approach to modeling connectivity seeks to identify the best available areas to maintain connectivity for animal movement and ecological processes. To implement this approach, we first identified large, contiguous areas that have retained high levels of "naturalness" (i.e., core areas characterized by a relatively light "human footprint"). Then, we identified linkages of highest landscape integrity between core areas. These linkages tend to avoid urban, residential, and industrial zones, transportation infrastructure, and agricultural lands. Note that our landscape integrity models are intended to be broad scale and are not tailored to specific categories of wildlife species.

Products of this analysis include maps of: (1) landscape integrity scores (Fig. ES.2); (2) linkages based on four different landscape integrity resistance models each reflecting different sensitivities to human-modified landscapes (See Chapter 3); and (3) composite landscape integrity linkages using the four different sensitivity levels (Fig. ES.3).

Many landscape integrity linkages coincided with focal species linkages, and the landscape integrity maps complemented the focal species results in that they represented connectivity conditions across our entire study area in a single map. For example, the maps allow one to compare the relatively natural conditions in the Olympic and Cascade Mountains with more converted lands in the eastern Puget Trough, the Interstate 5 (I-5) transportation corridor, and the Columbia Plateau in eastern Washington.

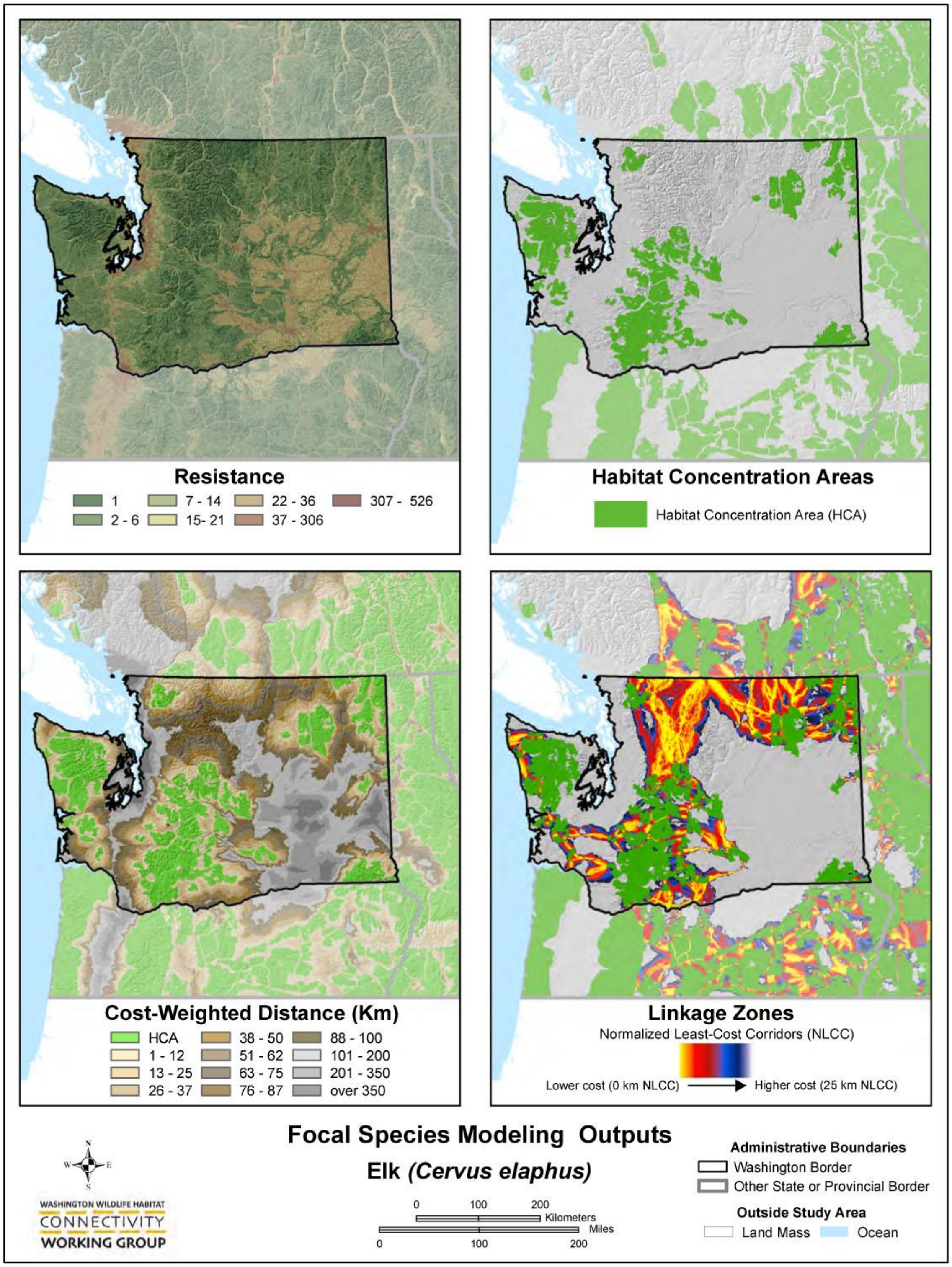


Figure ES.1. Example overview of map products for elk showing progression from landscape resistance (top left) and habitat concentration areas (top right), to cost-weighted distance (bottom left) and linkage zones (bottom right). The cost-weighted distance map illustrates the cumulative effects of impediments to movement changes as elk travel outward from HCAs. The linkage zone map highlights the "easiest" (i.e., least landscape resistance) movement pathway for elk to travel between adjacent HCAs.

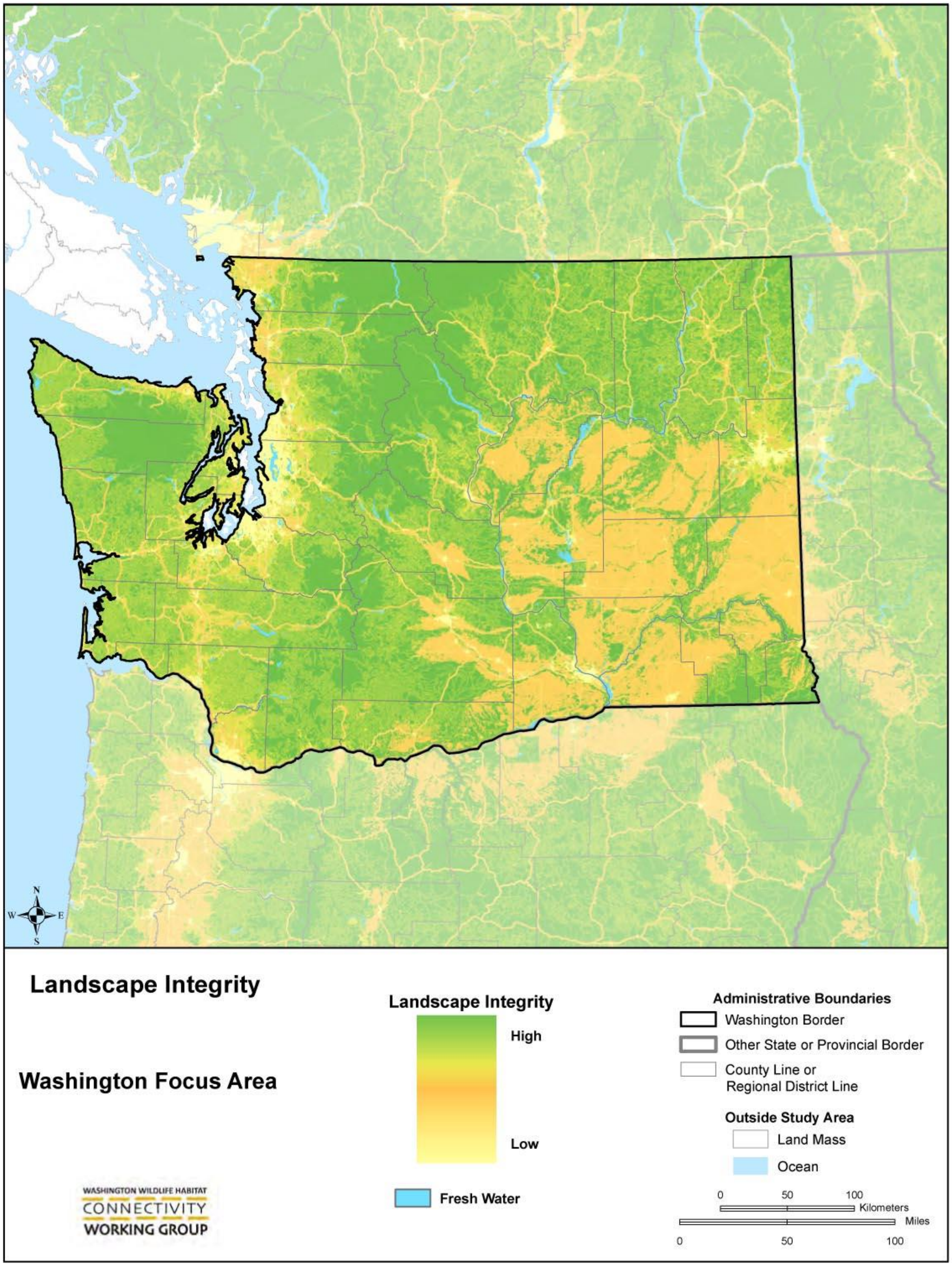


Figure ES.2. Landscape integrity map. Areas of highest landscape integrity have the lowest human footprint (e.g., natural land-covers, low housing density, and minimum roads).

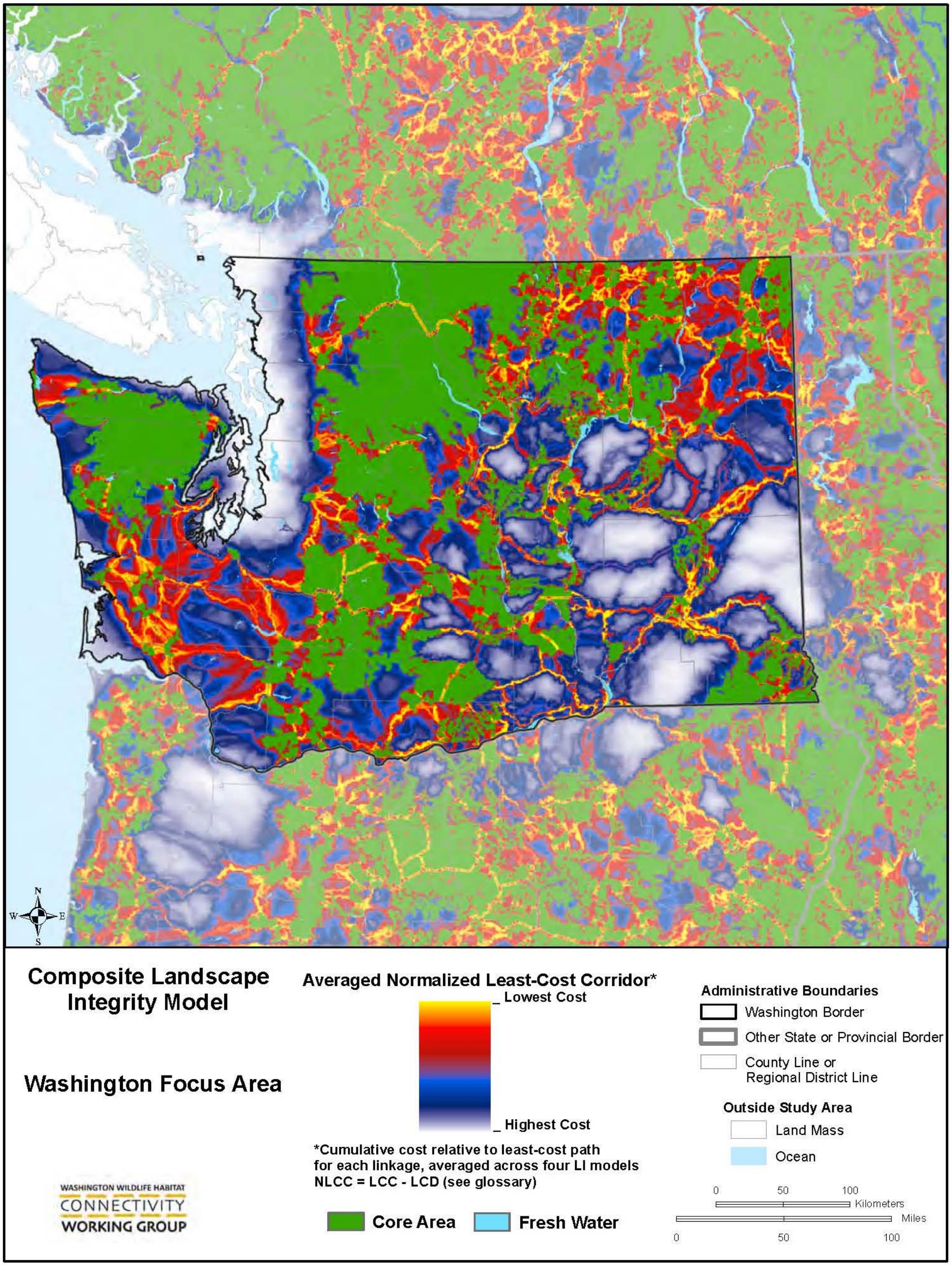


Figure ES.3. Composite landscape integrity linkage map which combines four sensitivity models. Cost values indicate relative ease of movement within each linkage.

Linkage Networks

Our 16 focal species and landscape integrity analyses yielded diverse patterns of wildlife habitat and landscape connectivity. We investigated the consistency between the analyses to compare results and to identify common patterns through the use of linkage networks. These networks depict a connected system of landscape conditions representing the best remaining habitat and the connecting lands that link it all together. The linkage networks we've modeled are comprised of habitat concentration areas or landscape integrity core areas, the linkage zones that connect them, and a cost-weighted distance buffer surrounding the HCAs or core areas (See Chapter 2).

Based on this investigation, our focal wildlife species can be grouped and mapped as three different connectivity guilds: (1) generalist (including species such as mule deer and western toads; Fig. ES.4); (2) montane (including species such as American black bears and wolverines; Fig. ES.5); and (3) shrubsteppe (including species such as American badgers (*Taxidea taxus*) and white-tailed jackrabbits; Fig. ES.6).

We found broad consistency between the linkage patterns identified by the focal species and landscape integrity approaches. Further examination of the overlap between networks mapped for different focal species, and between focal species and landscape integrity networks, should help calibrate estimates of how well these networks are likely to serve broader suites of species.

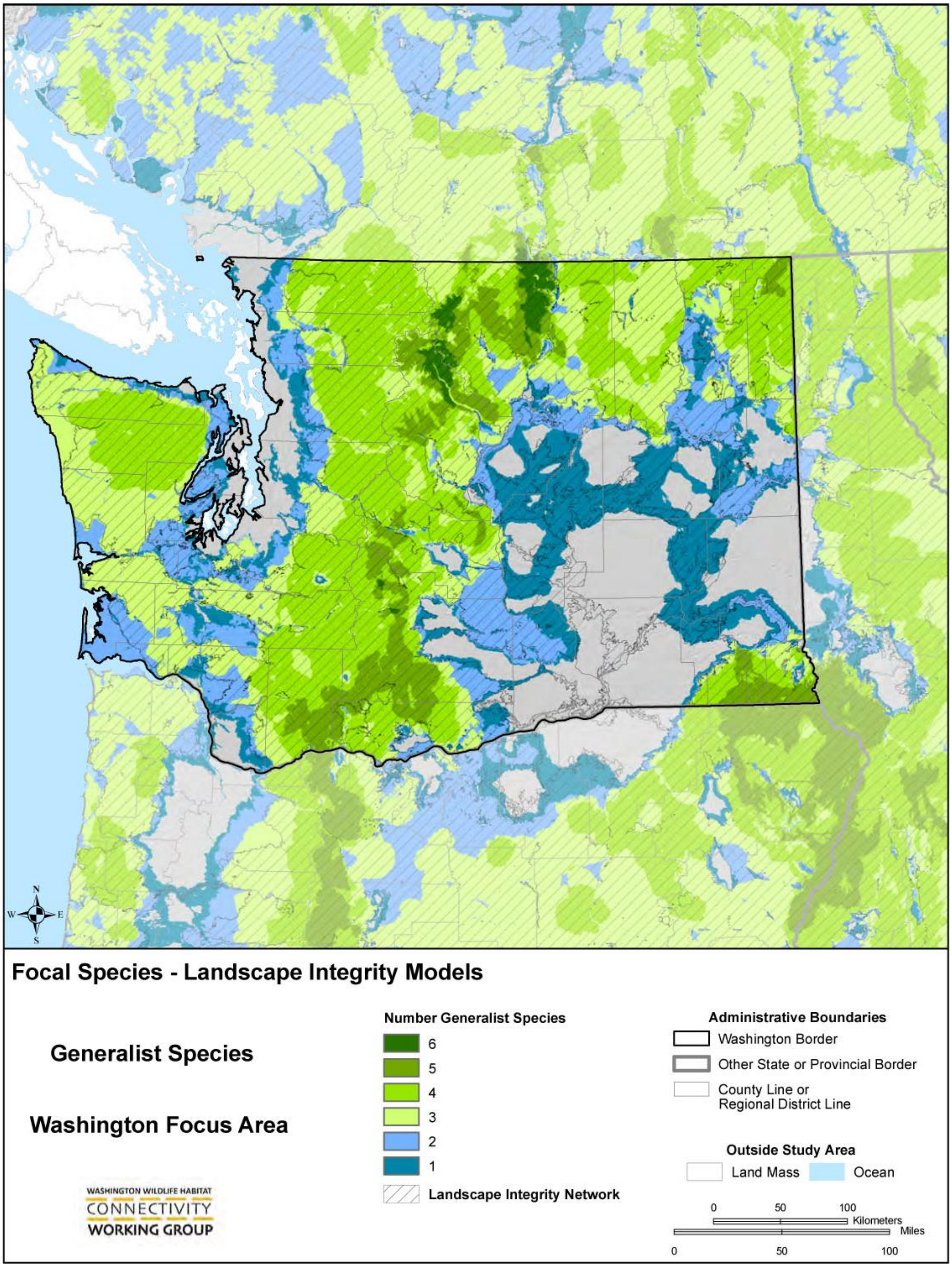


Figure ES.4. Composite focal species and landscape integrity map for generalist connectivity guild. Includes species that can inhabit a variety of habitats such as mule deer and western toads.

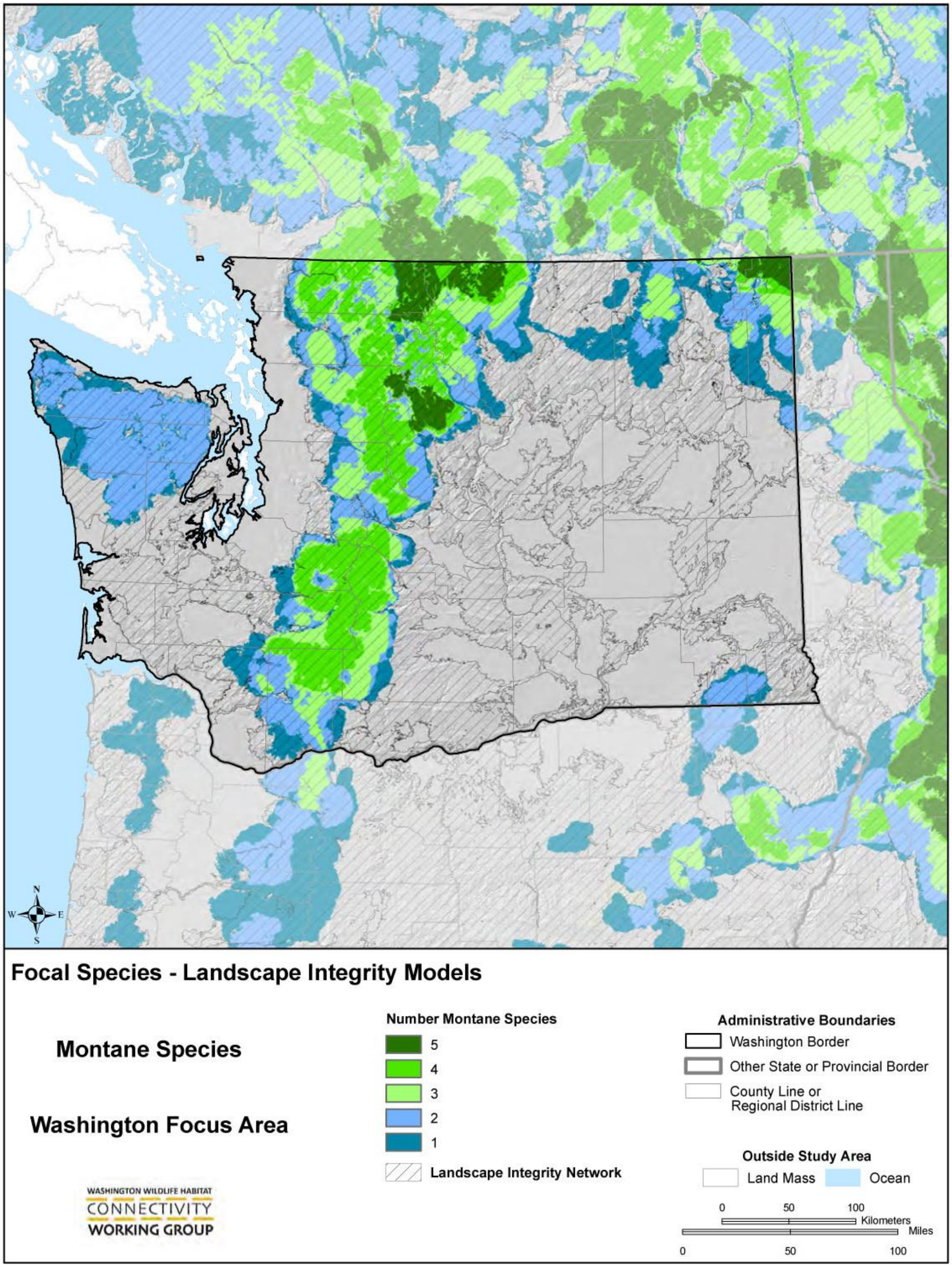


Figure ES.5. Composite focal species and landscape integrity map for montane connectivity guild. Includes species found in forests and mountainous areas such as American black bears and wolverines.

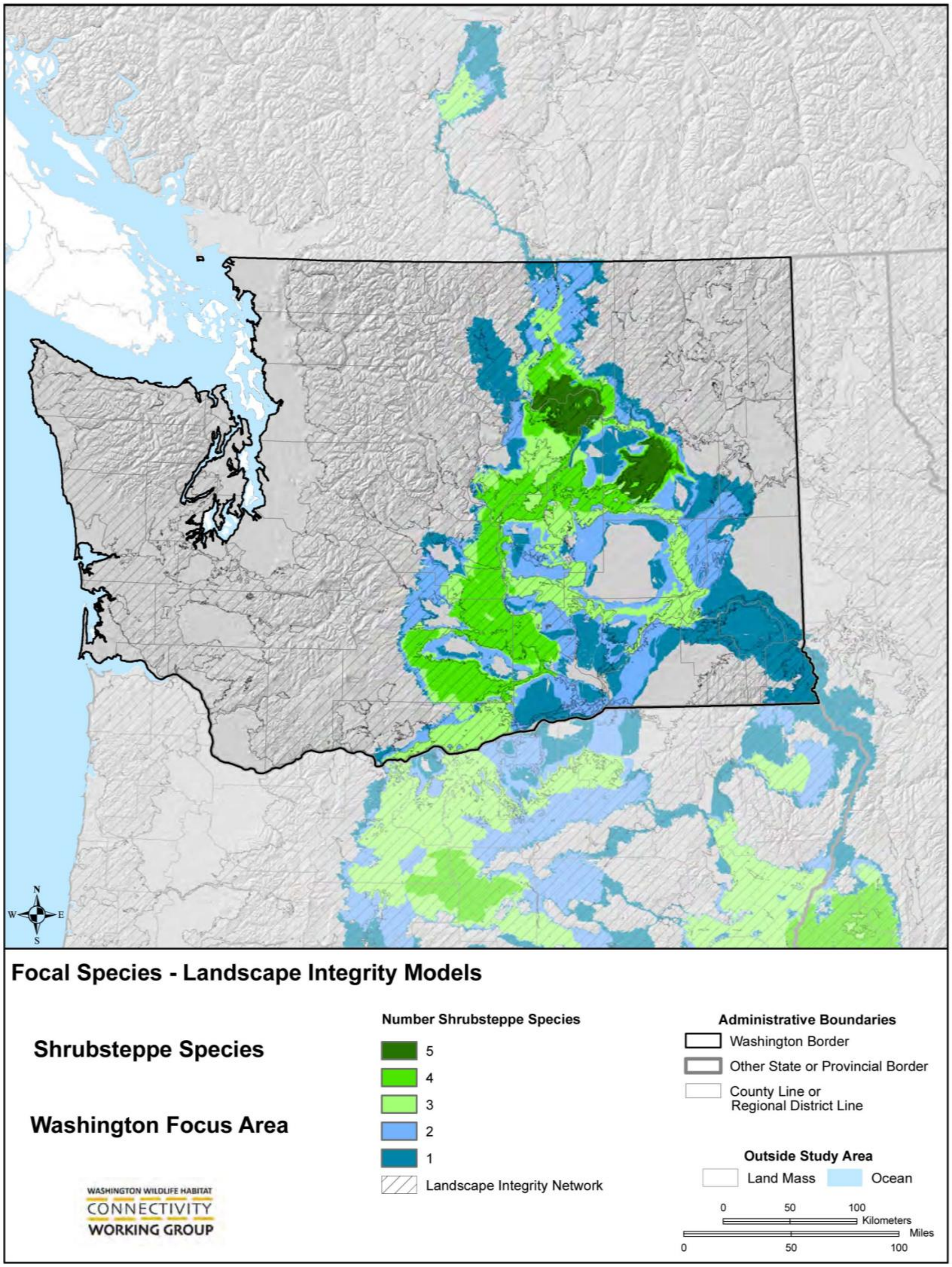


Figure ES.6. Composite focal species and landscape integrity map for shrubsteppe connectivity guild. Includes arid lands species such as American badgers and white-tailed jackrabbits.

Observations and Insights

Key findings of the statewide analysis include:

- Two different analysis approaches (focal species and landscape integrity) identified broadly consistent habitat connectivity patterns in Washington.
- Synthesis of the focal species connectivity modeling results highlighted three overlapping linkage networks: the generalist species network, montane species network, and the shrubsteppe species network.
- Previously undocumented patterns of potential habitat connectivity for shrubsteppe species within the Columbia Basin were highlighted in this analysis.
- The Okanogan Valley provides habitat connectivity values for all three linkage networks.
- This analysis identified broad-scale landscape patterns that may provide the best opportunities for restoring habitat connectivity along I-5 south of Olympia.
- Additional work is needed in southwestern Washington to adequately map connectivity patterns due to the complex patterns of land ownership and land use history in that area.

Our analyses provided valuable insights into current patterns of wildlife habitat connectivity in Washington. We noted some wildlife habitats are well connected and others are discontinuous across parts of Washington State and its borders. We identified fewer habitat areas and linkages in areas of extensive urban development such on the east side of Puget Sound within the Puget Trough-Willamette Valley ecoregion. A similar example is the agricultural development in the Columbia Plateau ecoregion of eastern Washington. Here, our analyses of landscape integrity and focal species revealed previously undocumented landscape patterns that may contribute to habitat connectivity for shrubsteppe species. Habitat connectivity patterns in southwestern Washington remain uncertain due to the effects of complex patterns of land ownership and a historical emphasis on commercial timber production.

Many important habitat areas and connecting landscapes are found on public lands, such as those in the Cascade and Olympic Mountains. Private lands also contribute important habitat areas, and frequently help link wildlife habitats on public lands.

Major highways hinder movement of wildlife, and their impacts are worsened by associated development. For example, I-5 between Olympia and the Columbia River, together with development along it, is a potential barrier to wildlife movement. This analysis has highlighted areas along I-5 where broad-scale landscape patterns may provide the best opportunities for restoring habitat connectivity. Similarly, Interstate 90 (I-90) across Snoqualmie Pass creates a major disruption to north-south movement of wildlife in the Cascades, and has been recognized by WSDOT as a priority for implementing wildlife-friendly crossing structures. Some of the habitat linkages we identified provide passage around natural obstacles, such as large lakes and mountain ranges. For example, a linkage along the south shore of Hood Canal is the only terrestrial path linking the Olympic and Kitsap Peninsulas, and this passage is constrained by human development. Other examples of linkages around natural obstacles are found in the most rugged sections of the Cascade Mountains, where high peaks are impassable to most species, highlighting the importance of low-elevation passes and valley bottoms for wildlife movement.

Comparing our results to observed movements of focal and non-focal species, or to the relative success of restoration efforts, will constitute important tests of the effectiveness of our choice of focal species, our modeling approaches, and the spatial data upon which our analyses are based. These tests of the usefulness of our results at different spatial scales and for different wildlife species of concern will help to focus and refine future connectivity modeling efforts.

Interpreting and Using the Analysis

The products and data from this statewide analysis convey a wealth of information relevant to conservation of Washington's wildlife, but they rely on imperfect data, knowledge, and assumptions. We strongly suggest that readers thoroughly understand our methods and the limitations of those methods prior to applying our results: we cover this extensively in Chapter 4. To better understand underlying landscape conditions and how they are represented in the final linkage maps, we also suggest that readers view our products in the order of their creation: (1) base information, (2) resistance maps, (3) habitat concentration and core area maps, (4) cost-weighted distance maps, and (5) linkage maps.

The results of the statewide wildlife habitat connectivity analysis can be used to inform:

- The Western Governors' Association Wildlife Corridors Initiative.

- The Washington State Department of Fish and Wildlife's Wildlife Action Plan, while allowing for ecoregional analyses to continue to contribute to these plans at a finer scale.

- Implementation of safe wildlife passage structures and complementary measures by the Washington State Department of Transportation in accordance with Executive Order 1031 (e.g., enlarged culverts, wildlife overpasses, and fencing).

- Land management plan revisions and decisions for public lands in Washington State, including our national forests, state parks and forests, and state and federal arid lands.

- Decision-making by conservation organizations.

- Local governments about opportunities to protect habitat connectivity and initiate coordination regarding finer-scale analyses for comprehensive planning.

- Investments through state and federal grant programs for conservation of habitat and working lands (e.g., Washington Wildlife and Recreation Program, Land and Water Conservation Fund, and Farm Bill incentives).

Conclusions

This science-based document is an important tool to inform work to maintain, restore, and conserve habitat connectivity in Washington State and bordering areas. Thoughtful interpretation of this analysis is crucial, including an understanding of its limitations. This analysis is intended to provide information for conserving connected landscapes at the broadest scale and to provide a context for finer-scale analyses; all regions of Washington will require finer-scale analyses to identify habitats and linkages important to local wildlife populations. Moreover, this initial analysis only considers current habitat conditions, and must be complemented by additional products such as those that incorporate the effects of climate change. Our document establishes a foundation for detailed approaches, which are next steps in the Washington Connected Landscapes Project.

Partnership and collaboration have been instrumental in the completion of this statewide analysis and will be all-important to sustaining momentum to complete subsequent analyses at the ecoregional and local scales. Continued and expanded efforts by this partnership and by others is vital to completing the additional analyses needed to translate the information within this document into site-scale planning.

Chapter 1. Introduction

This statewide analysis provides a consistent assessment of wildlife ***habitat connectivity*** for Washington and adjacent lands. It describes current patterns of connectivity and identifies opportunities and challenges for maintaining and enhancing connectivity in the future. This assessment is meant to inform broad scale connectivity conservation and to give context for subsequent finer scale assessments.

1.1. Why is Habitat Connectivity Important?

Growing human populations and expanding infrastructure often result in the loss and fragmentation of habitat, contributing to declines in wildlife populations and loss of important ecosystem processes (Noss & Harris 1986; Kareiva & Wennergren 1995; Ricketts 2001; Moilanen et al. 2005; Hansen & DeFries 2007). Buildings, roads, dams, crops, and other features can hinder the movement of wildlife and the flow of ecological processes (Fig. 1.1). These and other stressors reduce habitat quality and contribute to increased mortality rates in wildlife populations. For instance, some animals may be unable to find mates or get to important sources of food, water, or shelter. Animals are often killed or injured while crossing roads and developed areas. Reduced immigration rates mean that fragments of habitat support fewer animals, and that local populations face higher extinction rates and reduced likelihood of recolonization following extinction (Verboom et al. 1991; Hanski 1994). Connected landscapes are especially important for wide-ranging species such as carnivores (Beier 1993), and for migratory species such as large herbivores and migratory birds (Bennett 2003). They can be critical for maintaining genetically healthy populations, because immigration helps small populations avoid inbreeding (Hanski & Gilpin 1997). In addition to these considerations, climate change may force new patterns of wildlife movements in response to changing environmental conditions and shifting habitats (Heller & Zavaleta 2009).

In Washington State, the imprint of development, transportation, and agriculture on the landscape is prevalent. Despite being the smallest western state, Washington has the second highest human population, and many wildlife habitats have been highly fragmented. Conservation and land-use planning efforts in Washington have generally focused on areas of high-quality habitat and overlooked the value of conserving portions of the intervening landscape that connect habitat patches. In this context, sustaining wildlife and natural areas, while at the same time meeting the needs of people and communities, is an increasingly difficult challenge.

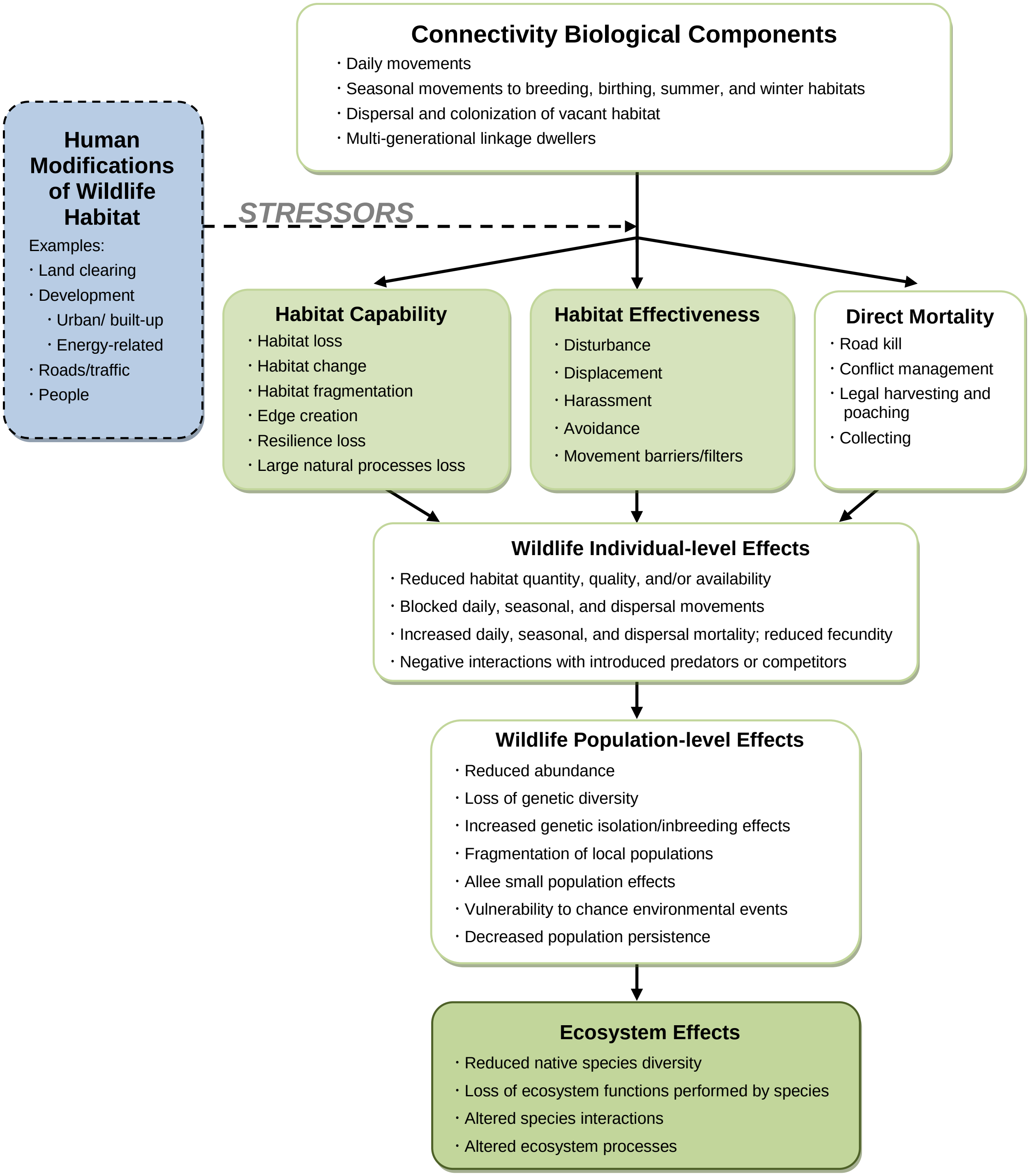


Figure 1.1. Wildlife habitat connectivity conceptual model. This model indicates ways in which human modifications of wildlife habitat interact with wildlife needs for habitat connectivity.

One way to meet this challenge is to conserve and restore conditions that sustain connected, functioning ecosystems and enable species to move. We use the term "***linkages***" to refer to potential ecological connections that may take a variety of forms, not just simple linear ***corridors*** connecting patches of habitat. A growing body of evidence indicates that enhancing habitat connectivity using such linkages can cost-effectively achieve many conservation objectives, including conserving ecosystem processes and plant and animal populations (Beier & Noss 1998; Bennett 2003; Crooks & Sanjayan 2006; Damschen et al. 2006; Haddad & Tewksbury 2006; Hilty et al. 2006; Beier et al. 2008; Gilbert-Norton et al. 2010). In some cases, the movement needs of wildlife can be served with different land cover types than those needed to sustain resident wildlife populations, creating opportunities for new strategies and new partnerships that can contribute to connectivity conservation in working landscapes.

Habitat connectivity is not a conservation panacea. Linkages are necessary for conservation, but may not be sufficient to ensure population persistence or to maintain biodiversity (Taylor et al. 2006). Compared to other conservation strategies, however, enhancing connectivity offers the distinctive benefit of creating the opportunity to build interconnected systems of habitat. Integrating conservation efforts across local, ecoregional, state, and international levels is a conspicuous advantage in view of uncertainties associated with climate change (Bennett et al. 2006; Lawler et al. 2010), and the performance of whole systems may exceed that of isolated parts (Noss & Harris 1986). Moreover, connectivity conservation is the most frequently recommended climate adaptation strategy (Heller & Zavaleta 2009), because many species will require highly permeable, well-connected landscapes to maintain movement and gene flow as vegetation patterns change, and to allow range shifts in response to shifting habitats.

Throughout the West, people treasure wildlife and natural places. These amenities inspire and nurture us, enriching our lives in subtle and profound ways. The benefits that society derives from functioning ecosystems are often referred to as "ecosystem services." Examples include air and water purification, drought and flood control, and crop pollination. In addition to these services, ecosystems also provide food, medicines, and other valuable commodities. Nature-based recreation improves mental and physical health, and provides economic value. Our ethical and philosophical traditions reflect these complex interactions, urging us to respect and enjoy nature and allow future generations the opportunity to do the same. Sustaining the capacity of ecosystems to continue providing the full array of services that support human well-being is the crux of sound ecosystem stewardship (Chapin et al. 2010). As the human population grows, developed areas expand, and climate change rearranges wildlife habitats, linkages across the landscape will become an increasingly important conservation tool that can promote human well-being, the long-term viability of species populations, and the integrity of ecological processes.

Recognizing the value of linkages as part of an integrated strategy of economic development and natural resource conservation, the Western Governors' Association launched in 2007 the Wildlife Corridors Initiative. It called for identification of "key wildlife migration corridors and crucial wildlife habitats in the West." Stewardship of these natural resources, as development continues, requires knowing where they are.

1.2. The Washington Wildlife Habitat Connectivity Working Group (WHCWG)

The Washington Wildlife Habitat Connectivity Working Group (WHCWG) is an open, science-based collaboration of land and resource management agencies, NGOs, universities, and Washington Treaty Tribes. The group is co-led by the Washington State Departments of Fish and Wildlife (WDFW) and Transportation (WSDOT), with active participation from member organizations including The Nature Conservancy (TNC), Conservation Northwest (CNW), Washington Department of Natural Resources (WDNR), U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), Western Transportation Institute (WTI), the University of Washington (UW), and others.

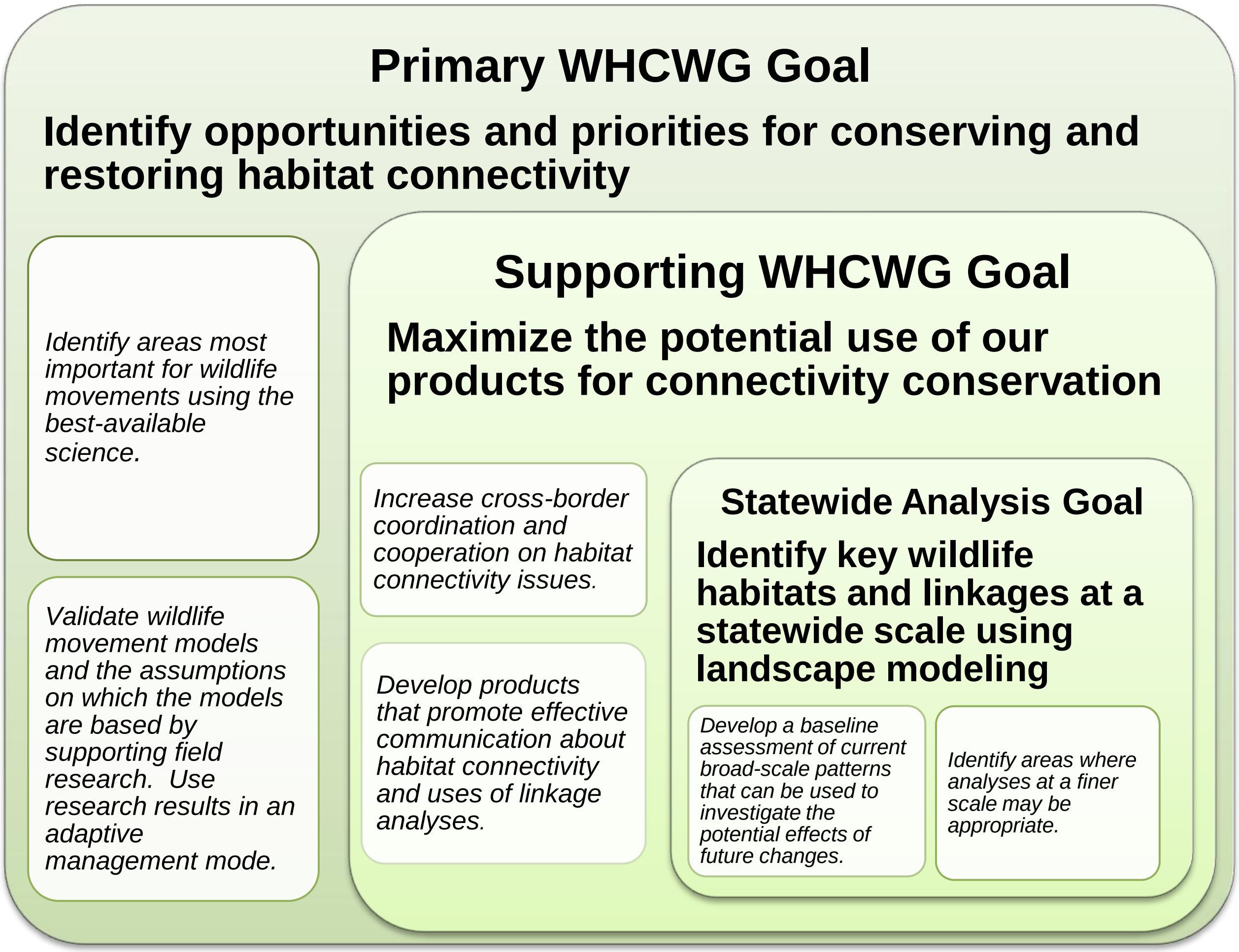
The WHCWG was originally convened to help incorporate wildlife habitat connectivity into updates of WDFW's Wildlife Action Plan and WSDOT's transportation planning. The WHCWG subsequently took on the task of responding to the Western Governors' call for identification of key wildlife migration corridors and wildlife habitats. We work in collaboration with the Western Governors' Association Wildlife Corridors Initiative, and our analyses are part of Washington's contribution to this effort. The statewide analysis of baseline conditions presented in this document is the first science product of the WHCWG. Additional information about the WHCWG is available at http://www.waconnected.org.

The internal organization of the working group includes a "full group," with broad representation from diverse organizations as well as interested individuals, a "core team" which oversees the work of the group, and multiple subgroups that are responsible for completing specific tasks. There is considerable overlap in participation between the core group and the subgroups. The subgroups manage spatial data, select ***focal species***, lead focal species analyses, arrange for peer review, develop and implement communication strategies, conduct ***landscape integrity*** analyses, develop modeling protocols, initiate ecoregional-scale analyses and incorporate climate change modeling into our connectivity analyses. This division of responsibilities enables us to make focused progress on the variety of topics relevant to meeting our objectives, while also maintaining communication, integration, and cohesion among the subgroups.

1.2.1. Goals and Objectives of the WHCWG

The primary goal of the WHCWG is to identify opportunities and priorities for conserving and restoring habitat connectivity in and adjacent to Washington State (Fig. 1.2). We also seek to maximize the use of our analysis products through partnership and outreach.

Potential users of this document have a wide range of missions and mandates, and fulfill them by applying a correspondingly broad array of land-management approaches and tools. This analysis provides an additional set of information about how conservation actions may contribute to the maintenance and enhancement of a connected landscape. Additional guidance on how to interpret this analysis and potential uses for this information are provided in Chapter 4.



Primary WHCWG Goal

Identify opportunities and priorities for conserving and restoring habitat connectivity

Identify areas most important for wildlife movements using the best-available science.

Validate wildlife movement models and the assumptions on which the models are based by supporting field research. Use research results in an adaptive management mode.

Supporting WHCWG Goal

Maximize the potential use of our products for connectivity conservation

Increase cross-border coordination and cooperation on habitat connectivity issues.

Develop products that promote effective communication about habitat connectivity and uses of linkage analyses.

Statewide Analysis Goal

Identify key wildlife habitats and linkages at a statewide scale using landscape modeling

Develop a baseline assessment of current broad-scale patterns that can be used to investigate the potential effects of future changes.

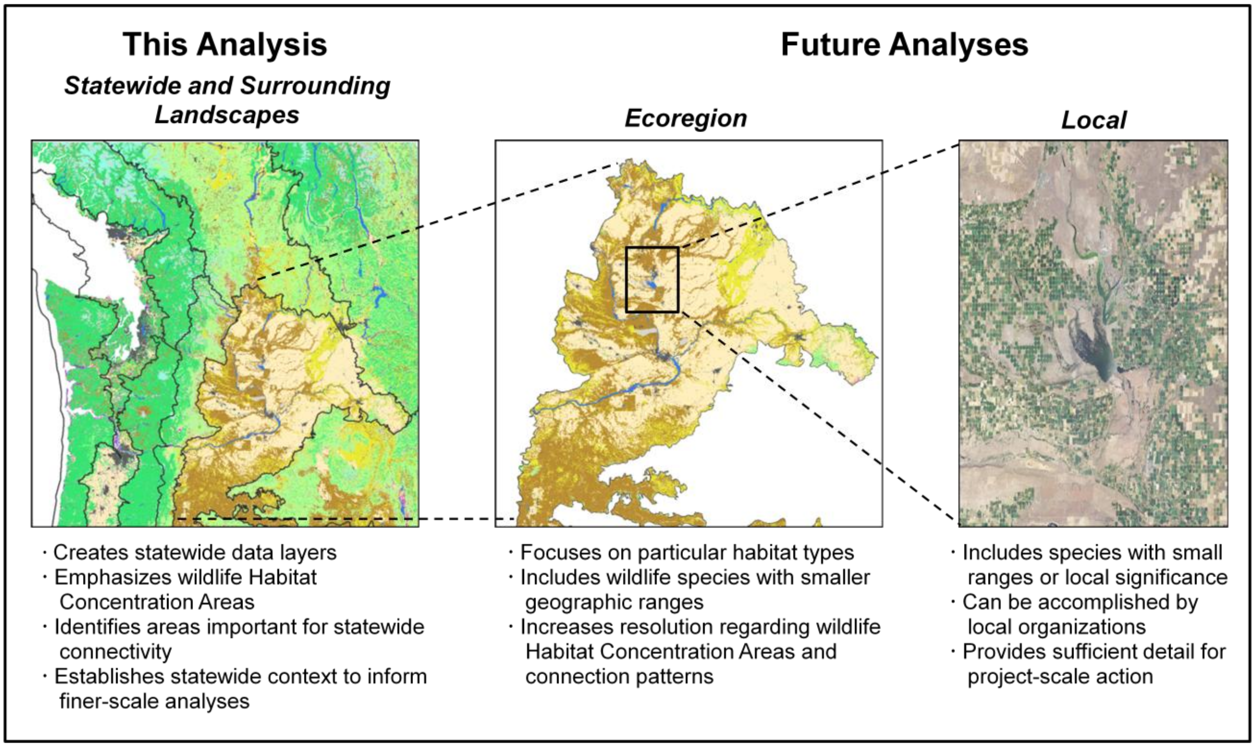
Identify areas where analyses at a finer scale may be appropriate.

Figure 1.2. Goals and objectives of the WHCWG and for the statewide analysis.

We recognized early on that clear and transparent communications about our analysis were critical to our success. Throughout our process to date, we have worked to engage partners internal and external to our working group. Our products will be easily accessible to the public on our website, and the WHCWG is committed to supporting future connectivity analyses and implementation. We are also promoting research to validate our wildlife movement models, increasing coordination and cooperation on connectivity issues across borders, and building support for the implementation of connectivity conservation.

Partnership and collaboration have been instrumental in the completion of this statewide analysis, and will be critical to sustaining momentum to complete subsequent analyses at the ecoregional and local scales. For example, we are currently partnering with Washington's Arid Lands Initiative to complete a connectivity analysis for the Columbia Plateau ***ecoregion***, and the Hells Canyon Preservation Council is developing a similar analysis for the Blue Mountains Ecoregion. We believe ongoing partnership is essential to gathering the resources and expertise needed to conduct these complex analyses, and that building connections among people and organizations will promote conservation of habitat connectivity. Good communication also ensures that our products meet the needs of diverse potential users.

The statewide analysis is a broad scale assessment of habitat connectivity patterns. Within the scope of the Washington Connected Landscapes Project, we viewed gaining a broad perspective as a necessary first step that would enable us to see how smaller areas fit into broader regional patterns. Finer-scale analyses, at ecoregional and local scales, are needed to guide project-level connectivity conservation, but the statewide analysis provides essential context for interpreting these finer-scale assessments (Fig. 1.3).



- Creates statewide data layers
- Emphasizes wildlife Habitat Concentration Areas
- Identifies areas important for statewide connectivity
- Establishes statewide context to inform finer-scale analyses

- Focuses on particular habitat types
- Includes wildlife species with smaller geographic ranges
- Increases resolution regarding wildlife Habitat Concentration Areas and connection patterns

- Includes species with small ranges or local significance
- Can be accomplished by local organizations
- Provides sufficient detail for project-scale action

Figure 1.3. Scales of wildlife habitat connectivity analyses in Washington.

Additional analyses that are underway or envisioned for the future include analyses of connectivity across predicted future landscapes resulting from climate change and urban, residential, and energy-related development. Climate change analyses will focus on identification and prioritization of areas most likely to provide wildlife habitat and connectivity as climate changes, including the types of connectivity necessary to accommodate climate-driven shifts in species' ranges.

1.3. Goals and Objectives of the Statewide Analysis

The focus of this analysis is on identifying wildlife movement opportunities at a statewide scale. To enable us to identify transboundary movement opportunities, we extended our analysis beyond Washington to include adjacent areas of Idaho, Oregon, British Columbia and a small portion of Montana (Fig. 1.3). We refer to this geographic extent as the statewide or "statewide-plus" scale of analysis. We believe that by coordinating with partners to complete connectivity analyses that cross boundaries, we will promote the scope of connectivity necessary for wide-ranging species, for species whose populations occur near our borders, and for processes that occur over relatively longer distances and time scales, such as gene flow and movement in response to climate change.

At the statewide scale, we can identify patterns of habitat distribution that are apparent across large landscapes. This analysis has a relatively coarse level of resolution and can be thought of as a view of the land from a high-flying aircraft a perspective that allows you to see patterns across the landscape, but obscures details. We expect this analysis to inform subsequent analyses done at finer scales, such as ecoregional analyses. In particular, this statewide analysis will help to identify candidate locations for finer-scale analyses.

This analysis establishes a foundation upon which future efforts of the WHCWG and others can build. The baseline assessment of habitat connectivity presented in this document provides a framework for future scenario evaluations, planning, and conservation action. Identification of priorities is not part of this analysis, but will be considered in future work.

1.4. Statewide Connectivity Analysis Approach

All subgroups of the WHCWG contributed to the statewide analysis. We coordinated efforts through meetings and conference calls, with most of the work being accomplished through the independent efforts of subgroup members. We completed our analysis by:

1) Defining our project area to accommodate analysis of linkages across Washington's jurisdictional boundaries.

2) Compiling base GIS layers to characterize wildlife habitat and features that affect landscape ***resistance*** to animal movement, including land cover/land use, elevation, slope, housing density, roads and forest structure.

3) Using published information and expert opinion to assign resistance-to-movement values associated with each of the base GIS layers for selected focal species.

4) Applying broad-scale landscape modeling methods appropriate for the identification of habitat connectivity patterns at a statewide scale.

5) Using a two-pronged strategy to analyze statewide connectivity, including a focal species approach and an approach focused on connecting lands with relatively little human modification (high landscape integrity).

We applied this two-pronged strategy because it enabled us to gain the advantages associated with both approaches while addressing shortcomings associated with using each approach alone (See Chapters 2 and 3). The focal species approach has the advantage of being closely related to functional connectivity for particular species, but it is challenging to integrate results across focal species, modeling is labor intensive, and results may not adequately represent the connectivity needs of some non-focal species. Landscape integrity modeling is relatively efficient and can yield a unified map, but its results do not assess specific ecological functions, are difficult to validate and can be more challenging to communicate. By considering both approaches, we have an increased likelihood of representing the connectivity needs of biodiversity in our analysis area, and we provide ample opportunities for investigating the advantages and disadvantages of both.

We benefitted greatly from the insights of a panel of experts in the field of connectivity conservation who generously agreed to serve as peer reviewers of our process and products. This review panel provided extensive and constructive feedback on the study plan we developed to guide our analysis, and on this document. Although these reviewers are not members of the WHCWG, they have strongly influenced many aspects of our approach.

1.4.1. Focal Species Modeling

This approach identifies connectivity conservation opportunities based on the needs of carefully chosen focal species (See Chapter 2 and Appendix A). We selected a suite of 16 focal species using criteria designed to favor species with geographic ranges, habitat associations, and vulnerabilities to human-created barriers that made them representative of the habitat connectivity needs of many species and ecological processes at a statewide scale. We stratified our selection of species to ensure representation of major vegetation types in Washington. We intended that the linkages identified for focal species would have a high probability of meeting the needs of a substantial number of terrestrial species that are sensitive to loss of habitat connectivity. Our focal species include relatively large, area-sensitive species like American black bear, elk, and wolverine, as well as smaller, barrier-sensitive species such as Greater Sage-Grouse, and white-tailed jackrabbit, and less mobile species such as the western toad.

Our results for each focal species include maps of: (1) overall resistance to movement across the landscape; (2) important habitat patches (***habitat concentration areas*** – HCAs); (3) ***cost-weighted distance***, which depicts how resistance to movement accumulates while traversing the landscape between HCAs; and (4) modeled linkages between HCAs. For each focal species we provide a literature review containing information we used to develop our estimates of landscape resistance, and to define characteristics of HCAs (See Chapter 3 and Appendix A).

1.4.2. Landscape Integrity Modeling

The landscape integrity approach to modeling connectivity seeks to identify the best available routes for the flow of ecological processes across the landscape by connecting large, contiguous areas that retain high levels of naturalness (i.e., ***core areas*** characterized by low levels of modification by humans). Similar to the approach used in the California Essential Habitat Connectivity Project (Spencer et al. 2010), our landscape integrity modeling is intended to be broad scale and is not tailored to specific categories of species. Instead, it identifies linkages of highest landscape integrity between core areas (See Chapter 2). As a result, linkages identified by landscape integrity analysis tend to avoid urban, residential, and industrial zones, transportation infrastructure, and agricultural lands.

Products of our landscape integrity analysis include maps of landscape integrity, ***resistance surfaces*** for four levels of sensitivity to human modification, linkage maps for the four sensitivity levels, and composite landscape integrity linkages (See Chapter 3).

1.4.3. Composite Analyses

We also conducted composite analyses to find common patterns across ***linkage networks*** for both the focal species and landscape integrity analysis approaches (See Chapters 2 and 3). We looked for common patterns among focal species by overlaying focal species linkage networks, systematically sampling to find the level of overlap among them, and applying hierarchical cluster analysis to resulting overlap summaries. This process distilled linkage patterns for our 16 focal species into three "connectivity guilds:" (1) shrubsteppe associates, (2) montane associates, and (3) habitat generalists and edge-associated species. Each of these guilds shows a distinct linkage pattern within the analysis area. Comparison of linkage networks for focal species to networks for landscape integrity revealed a high level of consistency between the two approaches.

1.5. How Can the Statewide Connectivity Analysis Be Interpreted and Used?

Using this analysis effectively requires thoughtful interpretation and careful evaluation of its limitations (See Chapter 4). For instance, users must recognize how the spatial resolution of linkage maps is affected by the scale of the data used to construct the base layers that support the entire analysis. We encourage users to gain an understanding about the information that each type of map in our statewide analysis package has to offer. Although linkage maps represent the "bottom line" of connectivity analyses, resistance surfaces and cost-weighted distance maps can provide many additional insights into decisions and tradeoffs we made in the modeling process. We urge users to read the appendices, especially the species accounts, to get a deeper appreciation of underlying models. This level of understanding will enable users to interpret our products appropriately and make the most of each component of this document in their particular application.

The statewide connectivity analysis provides baseline information and consistent habitat connectivity models that can be used in a variety of ways to inform further analysis, planning, and conservation action. As described above, we expect this statewide analysis to serve as a foundation for evaluations of predicted future landscapes and smaller scale areas within our analysis boundary. We also expect that many users will incorporate connectivity into their planning and prioritization processes by combining information from this statewide analysis with other sources of information they typically consider.

1.6. Organization of This Document

This document presents the statewide wildlife habitat connectivity analysis in six chapters, a glossary of terms, and five appendices. After the general introduction we provide here in Chapter 1, we shift in Chapter 2 to a detailed presentation of methods. We include descriptions of all major steps in our analysis: defining our analysis area, developing spatial data layers, selecting focal species, building resistance surfaces for focal species and landscape integrity, delineating areas to connect, modeling linkages, and investigating correspondence among linkage networks. Chapter 3 presents our results and discussion. This chapter begins with an overview of focal species results, which introduces the ensuing summaries for each focal species. Each summary features a family of maps illustrating the steps in our process of modeling and mapping habitat linkages. Landscape integrity results and discussion follow. Chapter 3 concludes with a discussion about integrating focal species and landscape integrity networks and a summary of our key findings. Chapter 4 provides guidance to readers about how to interpret the various components of our statewide analysis, and offers suggestions about how to use the statewide analysis, illustrated with specific examples. In Chapter 5, we share some lessons learned in the process of conducting the statewide analysis. Chapter 6 presents our conclusions and looks ahead to the exciting opportunities for additional connectivity analyses that can build on the foundation presented here.

The appendices provide supporting information and many of the technical details about the statewide analysis. Appendix A includes detailed accounts for each focal species describing habitat associations, movement patterns, and other aspects of focal species biology. Appendix B contains tables compiling the parameters used in focal species and landscape integrity models of connectivity. Appendix C describes the assembly and content of our base data layers to facilitate assessment of our information base, and to explain the complexities associated with compiling spatial data layers that cover all or part of four states and cross an international border. Appendix D describes new connectivity analysis tools for GIS that we developed. The final appendix (E) provides statistics about individual linkages, such as their length and quality.

Chapter 2. Methods

We took a two-pronged approach to analyzing connectivity across Washington State and portions of adjacent states and British Columbia (Fig. 2.1). First, we developed habitat and connectivity models for 16 focal animal species. We selected these using criteria designed to identify species with geographic ranges, habitat associations, and vulnerabilities to human-created barriers that make them good representatives of the connectivity needs of many species and important ecological processes. We stratified our selection of species to ensure representation of major vegetation types in Washington.

Second, we modeled connectivity between areas of high ***landscape integrity***, i.e., areas that have low levels of human modification and are in relatively natural condition. This approach mirrors that used in the California Essential Habitat Connectivity Project (Spencer et al. 2010) in that it is not tailored to specific species or habitats. It is indifferent to vegetation type—apart from degree of departure from natural conditions—and is intended to provide a coarse filter for species and processes that are sensitive to human disturbance.

Such approaches are not a replacement for species-based analyses but an attempt to cost-effectively identify coarse-filter networks that can then be supplemented by fine-filter planning for species or systems of special concern. They require fewer data and less knowledge about species' habitat associations or behavior (Spencer et al. 2010; Theobald 2010). Still, such approaches are relatively new and their ability to effectively inform conservation planning remains untested. Given the need to understand the relative merits of species- and integrity-based methods for future connectivity analyses within Washington and in other regions, we implemented both in order to provide information needed to evaluate how the methods may be complementary, and to compare their respective strengths and weaknesses.

We used ***cost-weighted distance*** modeling (Singleton et al. 2002; Adriaensen et al. 2003) as the basis for identifying the best linkages connecting habitat blocks (for focal species) and intact natural areas (for landscape integrity). Such analyses produce maps of cumulative movement '***cost***', reflecting barriers or mortality risks encountered, as animals move outward from habitat blocks. They require GIS data layers describing areas to connect and the resistance of the intervening landscape to movement of animals or ecological processes. We developed these for each of our 16 focal species and for four landscape integrity-based models. We then modeled ***least-cost corridors***, which identify continuous swaths of land expected to encompass the best route for a species to travel between habitat blocks. The resulting habitat, integrity, and linkage maps are intended to help identify important areas for connectivity conservation both for the focal species and for more general plant and animal communities.

2.1. Analysis Area

Although our focus is on the connectivity needs of wildlife in Washington State, we expanded our analysis area to incorporate potential linkages to important habitat blocks outside of Washington. We extended the area northward approximately 200 km, eastward 100 km, and southward 130 km to ensure connections with large natural areas in the Coast Range, Cascade

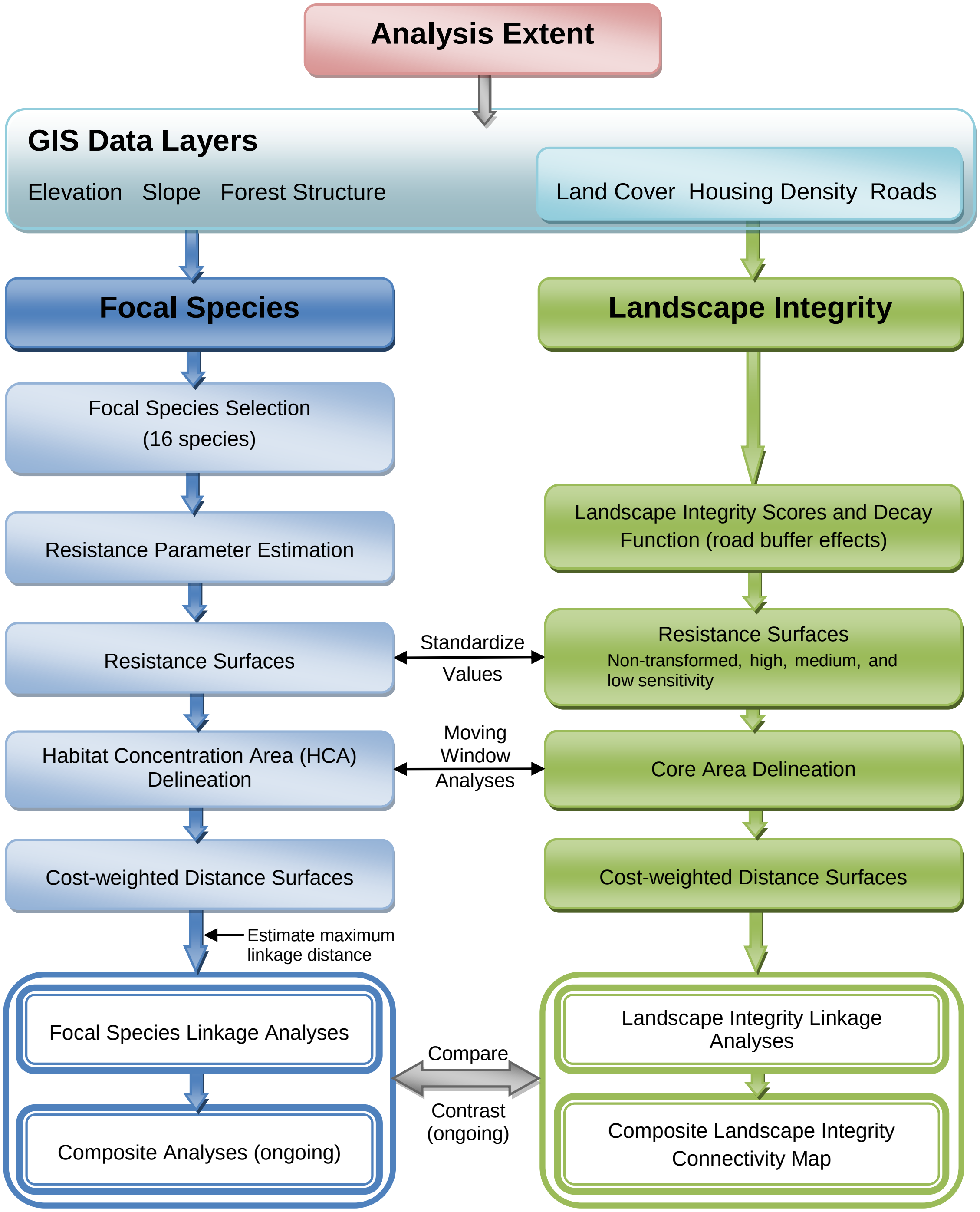


Figure 2.1. Flow of the statewide analysis.

Mountains, and Rocky Mountains in British Columbia, the Rocky Mountains and Columbia Plateau in Idaho, and the Coast Range, Cascade Mountains, Blue Mountains, Wallowa Mountains, and Columbia Plateau in Oregon. The resulting analysis area encompasses 447,000 km^2 of land area, including all of Washington State (except islands in Puget Sound) plus adjacent lands in Oregon, Idaho, British Columbia (excluding islands), and a small portion of Montana (Figs. 2.2 and Fig. 2.3).

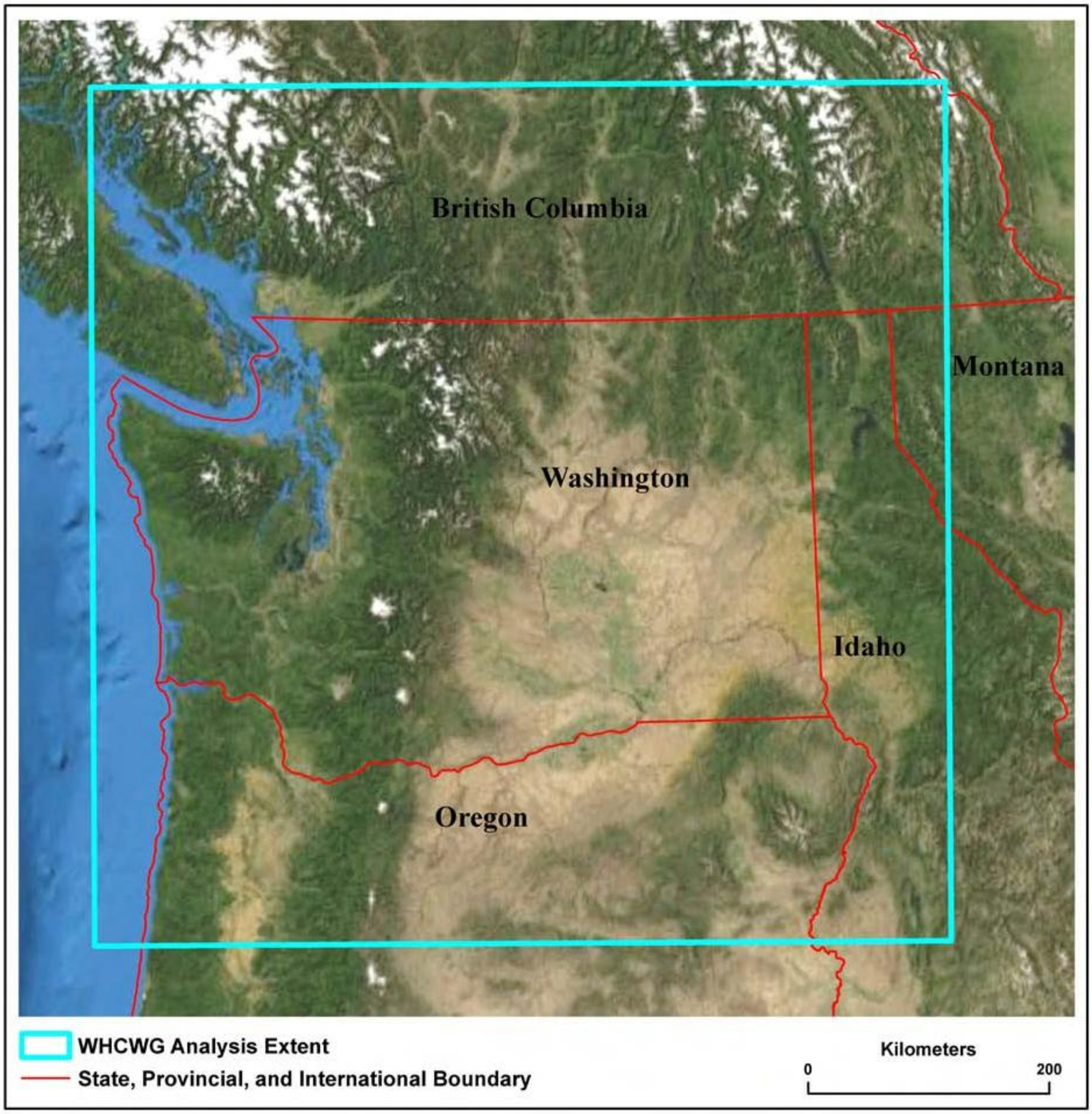


Figure 2.2. Project area map. Analysis extent included all of Washington State (except islands in Puget Sound) plus adjacent lands in Oregon, Idaho, and British Columbia (excluding islands), and a small portion of Montana.

2.2. Data Development

We compiled GIS base data suitable for characterizing wildlife habitat quality and landscape resistance at a broad (statewide plus) scale. These included land cover/land use, elevation, slope, housing density, roads, and forest structural characteristics (Fig. 2.3; Appendix C Figs. C.1–C.5). Ancillary data sets, such as species distribution data, were used as necessary for focal species modeling (See Appendix A for details on species models).

Figure 2.3. Land cover/land-use base layer for project area. See Appendix C (Figs. C.1–C.5) for other base layers.

Development of GIS base layers that were consistent across the entire analysis area often required modification of existing spatial information across jurisdictional boundaries (See Table 2.1 for a summary of our base data sources). All analyses were conducted using an Albers Conical Equal Area map projection with a 100 m square grid cell size. See Appendix C for more detail on data layer development and metadata.

Table 2.1. Summary of GIS spatial data layers used for habitat connectivity modeling.

Spatial Layer	*Summary*
Land Cover/land-use	*USA* – Our primary data source was Northwest Gap Analysis Program (GAP) data. Harvested forest regeneration areas were labeled with an ecosystem type using LANDFIRE Existing Vegetation (EVT) or NW GAP Potential Ecosystem Modifiers. *British Columbia* – Ecosystem boundaries were derived using Biogeoclimatic Subzones/Variant (BGC) data. Forest cover was primarily derived from Vegetation Resource Inventory (VRI) and Baseline Thematic Mapping (BTM).
Forest Structure	*USA* – Forest structure was developed from LANDFIRE Existing Vegetation Cover and LANDFIRE Existing Vegetation Height layers. We filled gaps in a forest cover data near the international border using 2001 National Land Cover Database (NLCD) data. *British Columbia* – VRI was the primary data source for forest cover and height. Data from Earth Observation Sustainable Development (EOSD) and BTM were used in VRI data gaps and in areas where VRI required refinement. In limited areas without any forest information, BGC was used.
Roads	*USA* – We used Washington Department of Natural Resources Transportation data in non-urban areas in Washington, and TIGER/Line Roads Census 2000 data in remaining areas. *British Columbia* – We used Digital Road Atlas (DRA) data for all road classes.
Housing Density	*USA* – We obtained housing density data from a raster layer based on US Census 2000 data. The data were compiled using methods described by the U.S. Environmental Protection Agency (2009). *British Columbia* – Dwelling counts were derived from 2001 Statistics Canada total private dwellings census subdivision-level summaries. Census subdivision polygons were partitioned with polygons primarily from Singleton et al. (2002) and BTM to isolate areas of human development. Housing counts were linked to the partitioned polygons.
Elevation	*USA* – Elevation data were assembled from the USGS 1 arc second, 30-meter National Elevation Dataset (NED). *British Columbia* – Elevation data were derived from the 25-meter Terrain Resource Information Management (TRIM) elevation layer.
Slope	We derived slope data using a mosaic of the USA and British Columbia elevation data described above.

2.3. Focal Species Selection

A carefully chosen set of focal species can serve an “umbrella” function by encompassing the diverse habitat needs of a broader array species of conservation concern (Roberge & Angelstam 2004; Beier et al. 2008). We chose focal species that we believed would efficiently represent the connectivity needs of wildlife species for which coarse-scale (statewide-level) planning is relevant. We also chose species that were sensitive to landscape features of interest to planners, such as transportation infrastructure and urban development.

Focal species selection followed a series of carefully reviewed steps (Fig. 2.4). To begin constructing a list of candidates for selection, we identified sources of population status ranking information that would give us a list of species with demonstrated declines or known vulnerabilities—potential indications of the effects of human-induced habitat change. Our list was initially composed of Washington's native vertebrate species with NatureServe Global or State Ranks of G1, G2, or G3 or S1, S2, or S3.

We then reviewed Washington's list of Species of Greatest Conservation Need (WDFW 2005), adding those that weren't already included by virtue of their state or global rank. Finally, we reviewed the list of species identified by the WDFW Landscape Priority Habitats and Species (PHS) project (WDFW 2009) as having High Sensitivity or Very High Sensitivity to development. Specifically, we added those that were members of a response group indicating movement over broad spatial scales and/or those that were indicated as having sensitivity to loss of connectivity or a negative response to the presence of roads or traffic.

To ensure that focal species represented a range of ecoregions and ecological systems in the state, we used the National Vegetation Classification Standard (NVCS) to divide the state into five dominant vegetation classes. These included: (1) Semi-desert, (2) Northern Rocky Mountain Forests, (3) Vancouverian Forests, (4) Subalpine Forests, and (5) Alpine Rock, Grassland and Shrubland (Fig. 2.5). All of the candidate focal species were assigned to one or more habitat associations (Cassidy et al. 1997; Johnson & O'Neil 2001).

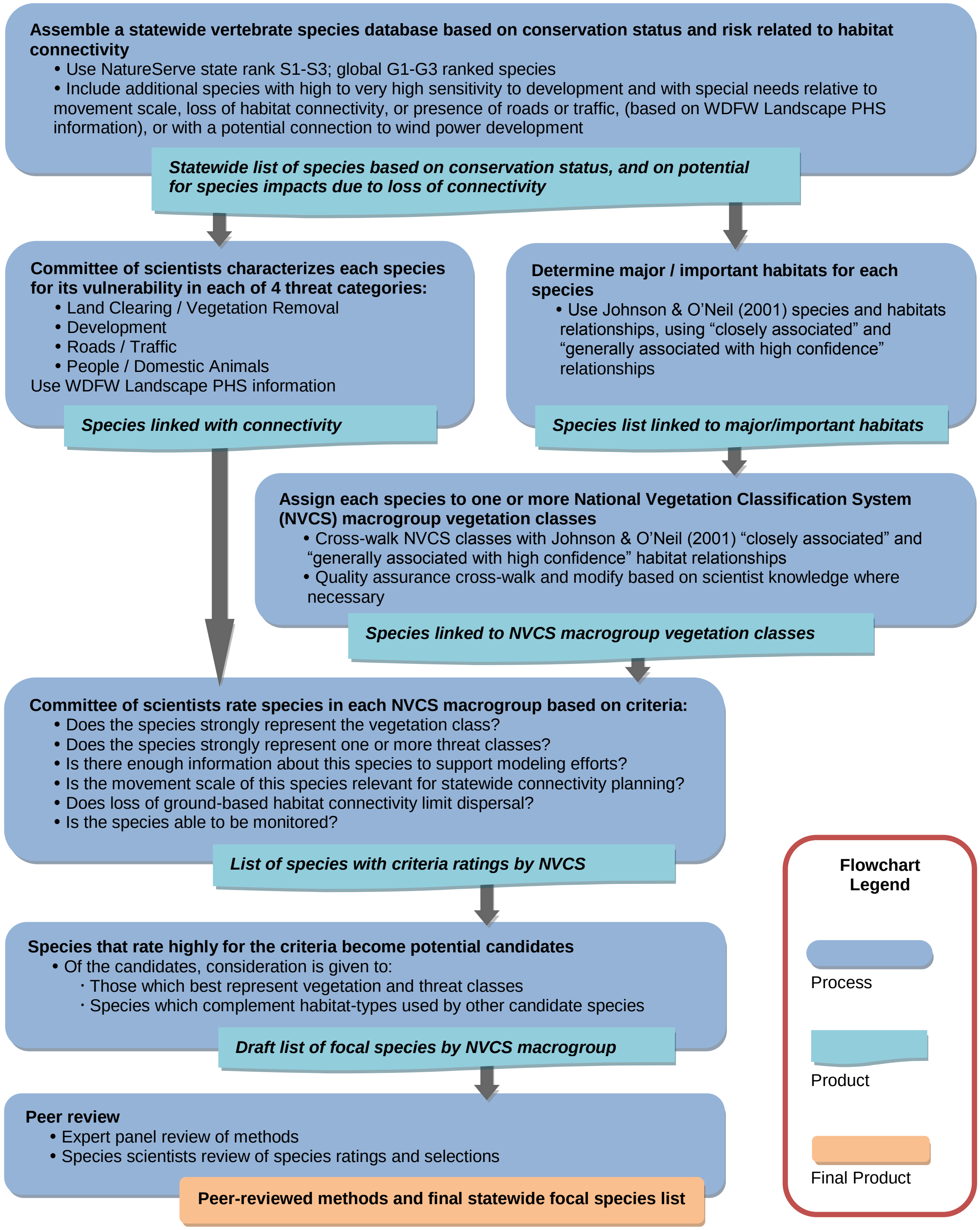


Figure 2.4. Schematic of focal species selection methods.

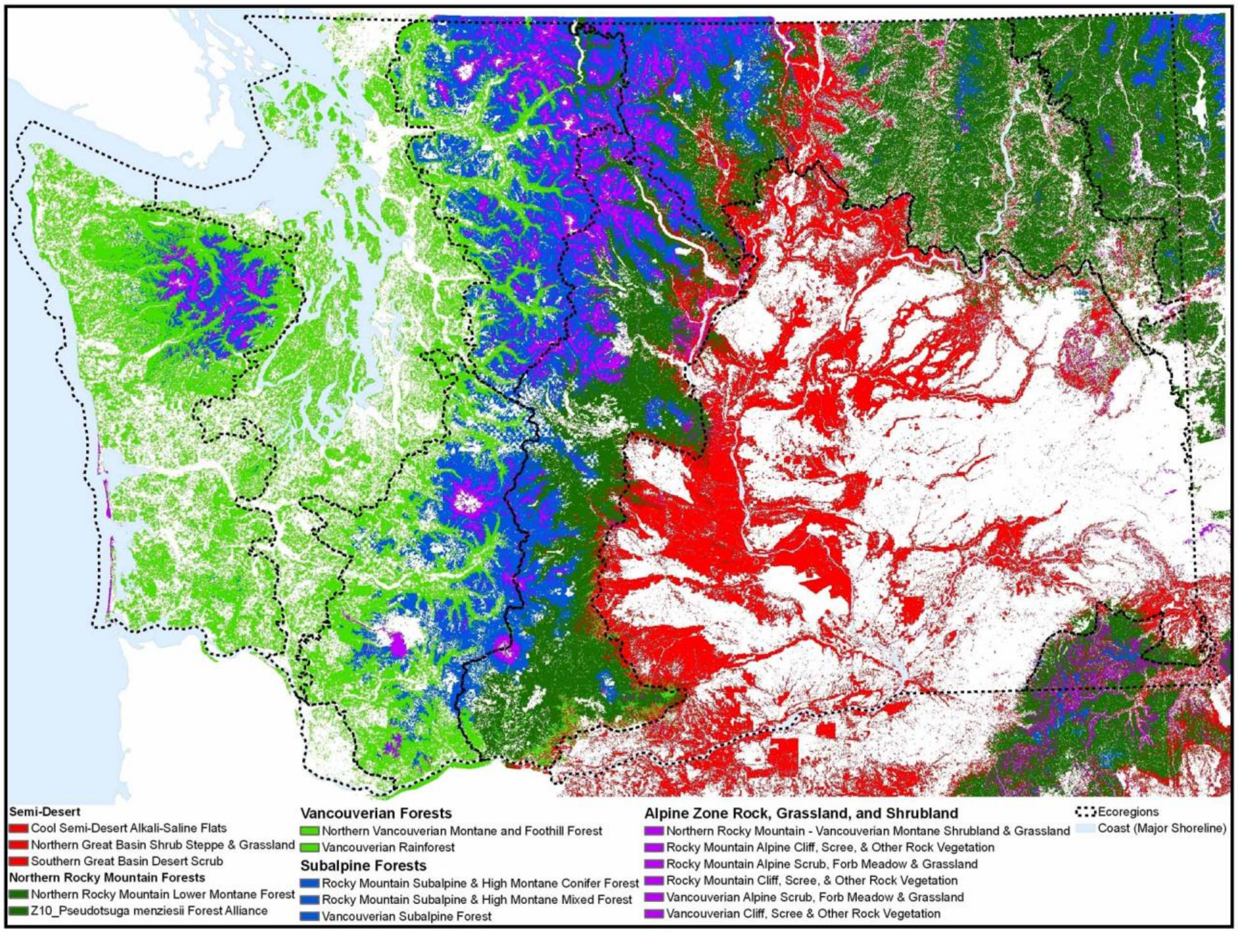


Figure 2.5. Major vegetation classes in Washington used to stratify focal species selection. Note: lands that do not contain one of the five major vegetation classes (including those converted to human uses and all lakes) are shown in white.

Each species was evaluated for its vulnerability to threats and barriers to movement caused by human-created landscape changes. We identified four overarching types of threats/barriers and their potential effects on focal species' movements:

1) *Land clearing/vegetation removal,* which limits connectivity through
    - ***Alienation*** due to lack of security cover
    - Change to inhospitable environment (e.g., desiccating conditions for amphibians)
    - Alienation due to lack of forage or prey
    - Increases in competing species, predators, invasive exotics

2) *Buildings and Infrastructure*, which limit connectivity through
    - Barriers to movement created by fences, walls, buildings, asphalt, canals, etc.
    - Alienation due to noise, lighting, lack of forage or prey
    - Increases in competing species, predators, invasive exotics
    - Making important habitat areas inaccessible (e.g., streams diverted into culverts)

3) *Roads and Traffic*, which limit connectivity through
    - Creation of inhospitable conditions (e.g., desiccating conditions for amphibians)
    - Creation of physical barriers (e.g., Jersey or Texas barriers, right-of-way fences)
    - "Fatal attraction" (e.g., attraction of snakes to warm road surface)
    - Increased mortalities due to collisions
    - Behavioral alienation (i.e., avoidance of roads or high traffic volumes)

4) *Presence of people or domestic animals*, which limit connectivity through
    - Legal harvest and poaching
    - Harassment and disturbance
    - Disease transmission (e.g., domestic sheep to bighorn sheep [*Ovis canadensis*])
    - Intolerance (e.g., conflict resolution removals)

Species identified as vulnerable to one or more of the overarching threats to habitat connectivity (See Table 2.2) were further evaluated against six criteria to determine whether each would make a good focal species choice. The criteria were:

1) *Is the species a good representative of the vegetation class?* We sought to identify species that were broadly distributed within a vegetation class and associated habitat conditions typically found there. Species with a very limited range within the class were considered to be poor choices compared to species that were more broadly distributed in the vegetation class.

2) *Is the species representative of most or all of the threat classes?* The intent of this criterion was to assure that the species chosen were, as intended, vulnerable to movement impairments caused by human-created landscape changes. Priority was given to those species considered vulnerable to multiple threats.

3) *Is there enough information on the species to support modeling efforts?* Suitable focal species are those for which there is available information on conditions that promote or deter movements; species we know more about are better candidates for modeling than those with less information.

4) *Are the species' movement choices based on features that are coarse enough for modeling?* A suitable focal species must make habitat selection choices at scales that are reasonably matched to the scale of the GIS data used for modeling. For statewide modeling, documented home range sizes and ***dispersal*** distances were used as a surrogate for the animal's scale of habitat selection. If either suggested short-term movement capabilities of at least 10 km, the species was considered compatible with the statewide modeling scale. Species with more restricted movement capabilities require analyses at finer (ecoregional, local) scales.

5) *Is the species sensitive to habitat barriers?* We focused on identifying species whose movements can be limited by human-created landscape alterations. Most of the identified species move on the ground and would be sensitive to barriers. Highly mobile species that easily move through human-altered landscapes were discarded.

6) *Can the species be monitored?* The best focal species are those that can be monitored to understand the effects of human-created barriers to movements, validate model results, and evaluate effectiveness of efforts to conserve and restore habitat connectivity. This criterion was used as a “tie breaker” when multiple species were equally ranked based on other criteria.

For each of the above-listed criteria, we rated candidate species as *excellent*, *acceptable*, *marginal*, or *poor*. In cases where multiple species scored similarly, we chose the best representative and excluded the others from further consideration. We stress that because we limited our focal species to those appropriate for modeling at the statewide scale (See item 4 above), our focal species may not represent the needs of species with more limited movement capabilities. Such species will be better addressed by future analyses at ecoregional and local scales.

Table 2.2. Vertebrates identified as highly vulnerable to loss of terrestrial habitat connectivity.

Birds	*Mammals*	*Amphibians*	*Reptiles*
Bald Eagle	American badger*	Cascade torrent salamander	California mountain kingsnake*
Common Poorwill	American marten*	Cascades frog	night snake
Ferruginous Hawk	bighorn sheep	Columbia spotted frog*	Pacific gopher snake*
Flammulated Owl	American black bear	Columbia torrent salamander	Pacific pond turtle*
Golden Eagle	black-tailed jackrabbit*	Cope’s giant salamander	painted turtle
Gray Flycatcher	California myotis	Dunn’s salamander	pygmy horned lizard
Great Blue Heron	Columbian white-tailed deer*	Larch Mountain salamander	ring-necked snake
Great Gray Owl*	cougar	northern leopard frog*	rubber boa
Greater Sage-Grouse*	elk*	northern red-legged frog	sagebrush lizard
Gyrfalcon	fisher*	Olympic torrent salamander	sharp-tailed snake
Lapland Longspur	fringed myotis	Oregon spotted frog	side-blotched lizard
Lewis’ Woodpecker	gray wolf*	Rocky Mountain tailed frog	striped whipsnake*
Long-eared Owl	gray-tailed vole	tiger salamander*	western rattlesnake
Merlin	grizzly bear*	Van Dyke’s salamander	western yellow-bellied racer*
Mountain Quail	hoary marmot	western toad*	
Northern Goshawk	least chipmunk	Woodhouse’s toad	
Northern Spotted Owl*	long-legged myotis		
Pileated Woodpecker*	Canada lynx*		
Prairie Falcon	Merriam’s shrew		
Pygmy Nuthatch*	moose		
Sharp-tailed Grouse*	mountain caribou*		
Short-eared Owl	mountain goat		
Snow Bunting	mule deer		
Spruce Grouse	northern flying squirrel		
White-breasted Nuthatch	Olympic marmot*		
White-headed Woodpecker	pygmy rabbit*		
White-tailed Kite	pygmy shrew		
White-tailed Ptarmigan	red-tailed chipmunk		
Williamson’s Sapsucker	sagebrush vole		
	silver-haired bat		
	Townsend’s big-eared bat*		
	Townsend’s ground squirrel*		
	Washington ground squirrel*		
	western gray squirrel*		
	western pocket gopher*		
	white-tailed jackrabbit*		
	wolverine*		
	yellow-bellied marmot		

*Species of Greatest Conservation Need (SGCN; WDFW 2005). For elk, western yellow-bellied racer, and gopher snake, only the Nooksack elk herd and the extirpated western Washington populations of gopher snake and yellow-bellied racer are SGCN.

2.4. Resistance Models

Cost-weighted distance models require GIS data layers that quantify estimates of the resistance presented by different landscape features to movement of animals or ecological processes (Singleton et al. 2002; Adriaensen et al. 2003; Beier et al. 2008). For focal species-based analyses, we developed resistance layers for each of the 16 species using species-specific ***dispersal habitat*** suitability models. For landscape integrity-based analyses, we developed resistance layers by reviewing and adapting published models with similar aims.

2.4.1. Focal Species Resistance Parameters

For each of the 16 focal species, we assigned relative resistance values to different landscape features, such as different classes of roads or various land cover/land-use types (See Appendix C for GIS base layers). Conceptually, we defined the resistance contributed by each landscape feature as the number of additional grid cells of ideal habitat a given species would move through to avoid one grid cell of the feature being considered. For each landscape feature, we estimated the additional resistance to movement imposed by the feature relative to “ideal” habitat, ranging from zero for ideal habitat to infinity for complete barriers. The final resistance layer for each species was then derived by summing the resistances from each input layer and adding one (to account for ***Euclidean distance***). Each cell in the resulting resistance layer for each species had a resistance value summing the individual resistances from up to six GIS base layers, including land cover/land-use, elevation, slope, housing density, roads, and forest structure.

In practice, scoring features required using professional judgment to synthesize how factors would limit movement through behavioral responses (e.g., avoidance of roads) and through mortality (e.g., vehicle collisions). In most cases, the parameters used to build each resistance model were developed based on literature review and expert judgment. In one case, mountain goats (*Oreamnos americanus*), we used an analysis of genetic data from our study area (Shirk et al. 2010) to assist in parameterization (See Appendix A for details of species models).

Species experts external to our project reviewed and critiqued draft resistance models. A master list of resistance parameters is provided in Appendix B.

2.4.2. Landscape Integrity Resistance Parameters

For our landscape integrity-based analyses, we adapted methods developed elsewhere to create an index of human impacts to lands across our study area, which we refer to as ***landscape integrity***. We then used this index to develop a set of resistance layers reflecting a range of hypotheses as to how human alterations affect connectivity for species and for ecological processes.

LANDSCAPE INTEGRITY MAP

We developed a map of landscape integrity by adapting the methodology used by NatureServe in developing a similar map of national landscape condition (Comer & Hak, unpublished). Comer and Hak’s approach is similar in intent to a series of spatially explicit indices of human ecological impact, including Sanderson et al. (2002), Leu et al. (2008), and Theobald (2010). These indices all provide a spatially explicit ranking of the degree of human impact on the integrity of ecosystems, their component organisms, and processes. While we use the term *landscape integrity*, it is analogous to *landscape condition* (Comer & Hak, unpublished), *human footprint* (Sanderson et al. 2002; Leu et al. 2008), and *landscape naturalness* (Theobald 2010). We decided not to use existing human footprint maps for two main reasons: (1) we wanted landscape integrity and focal species analyses to be as consistent as possible, including using the same base data, in order to compare results between the two approaches, and (2) we wanted a human footprint map that was consistent across jurisdictional boundaries (i.e., the U.S. and Canada).

To assure comparability with the focal species connectivity maps and to provide coverage into British Columbia, we applied Comer and Hak's parameter values (multiplied by 10, to convert to a range of 1–10) to the same GIS base layers used in our focal species analyses for land cover/land-use, housing density, and roads. All grid cells in the study area were assigned a landscape integrity score based on the minimum score for all data layers used in the model (Table 2.3). We also used the distance from road categories defined by focal species models. Although Comer and Hak's methods used a decay function to model effects of roads on integrity of adjacent areas, we used the focal species buffer distances and interpolated buffer landscape integrity scores assuming a linear relationship from the road feature to the outer buffer distance.

Table 2.3. Landscape condition factors and associated values used to describe landscape integrity on the study area, modified from Comer and Hak (unpublished) as described above.

Data Source	*Condition*	*Landscape Integrity Value*
Land cover/land-use	urban/developed	0.5
	agricultural lands	3.0
	water	5.0
	all other land cover	9.0
Housing density	≤10 acres per dwelling unit	0.5
	>10 to ≤40 acres per dwelling unit	5.0
	>40 to ≤80 acres per dwelling unit	6.0
	> 80 acres per dwelling unit	9.0
Freeways and major highways	centerline	0.5
	>0–500 meter buffer	3.0
	>500–1000 meter buffer	7.0
Secondary highways	centerline	2.0
	>0–500 meter buffer	3.0
	>500–1000 meter buffer	7.0
Local roads	centerline	5.0
	>0–500 meter buffer	8.0
No roads		9.0

LANDSCAPE INTEGRITY RESISTANCE MODEL

Landscape integrity values (Table 2.3) reflect generic ecological conditions, and were not developed with the movement behavior of specific classes of animals in mind. Because there is no clear way to translate integrity into resistance, we developed four resistance models based on differing hypotheses about the relationship between landscape integrity and resistance. The first used a simple linear transformation of the landscape integrity scores assigned to all grid cells (Table 2.3) for all *LI* values <9.0:

$$R_{LI} = 10 * (10 - LI) - 9$$

Where R_{LI} is the resistance used in the linear resistance model, and *LI* is the minimum landscape integrity value (Table 2.3) at each grid cell, taken across all input layers. The value of 9 was subtracted from the transformed value to set the lowest resistance value to 1.0, following the convention used in focal species models.

In addition to the resistance model based on the simple linear transformation above, we created three resistance models reflecting different levels of sensitivity to human modification. These were designed to more closely correspond to ranges of resistances assigned to human-modified landscapes in the focal species models (which had maximum resistances ranging from 100 to 10,000). To create resistance models reflecting low, medium, and high sensitivities to human modification, we transformed the landscape integrity values so that areas with greatest human alteration were 100, 1000, and 10,000 times more resistant to movement than the least altered areas (representing the smallest, median, and largest maximum resistance values used in the suite of 16 focal species models, respectively);

$$R_{sens} = (10 - LI)^{P_{sens}}$$

Where R_{sens} is the resistance derived for each sensitivity model, and *LI* is the minimum landscape integrity value (Table 2.3) at each grid cell, taken across all input layers. P_{sens} is a constant chosen for each sensitivity model such that the maximum value of R_{sens} is 100, 1000, or 10,000 for the low, medium, and high sensitivity models respectively.

The transformed resistance values used to create the different resistance layers for landscape integrity modeling are provided in Appendix B; example values for different features are shown in Fig. 2.6.

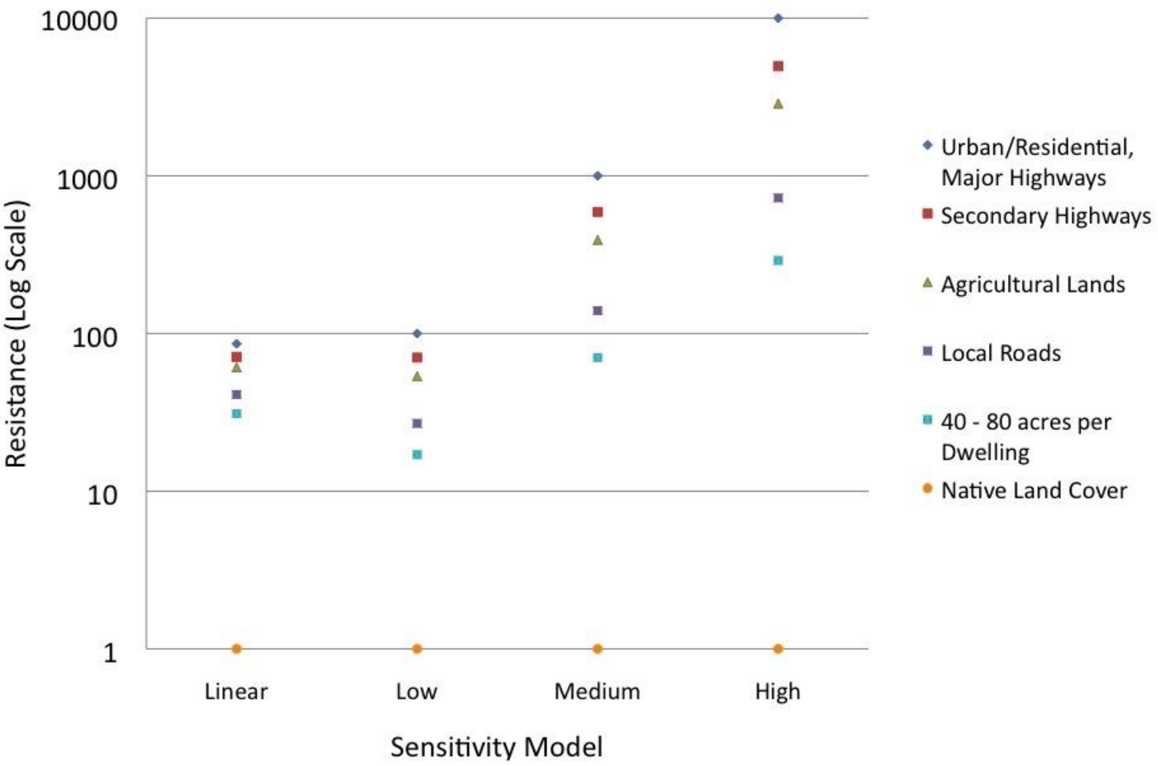


Figure 2.6. Resistance values (R_{sens}) for selected model parameter conditions for each of the four sensitivity models used in the landscape integrity connectivity analysis.

2.5. Delineating Areas Important to Connect

2.5.1. Focal Species Habitat Concentration Areas

We use the term ***habitat concentration area*** (HCA) to refer to areas between which we evaluated patterns of habitat connectivity for focal species. Habitat concentration areas are defined as significant habitat areas that are expected or known to be important for focal species based on actual survey information or habitat association modeling. We used known centers of distribution for species whose populations and habitats have been documented through extensive surveys, including bighorn sheep, mountain goat, Greater Sage-Grouse, and Sharp-tailed Grouse (*Tympanuchus phasianellus*, Appendix A).

For species with extremely broad or poorly defined populations, we defined HCAs using habitat models following these steps:

1) Develop a binary habitat surface where each grid cell in a ***raster*** is designated as either habitat or non-habitat based on habitat suitability models using the GIS base layers compiled for this project. Habitat suitability models were identical to resistance models for black-tailed jackrabbit (*Lepus californicus*), white-tailed jackrabbit, American badger, American black bear, Canada lynx (*Lynx canadensis*), mule deer, and northern flying squirrel. Habitat suitability differed from resistance for elk, wolverine, western gray squirrel (*Sciurus griseus*), and western toad. Habitat suitability and resistance models are described in Appendix A.

2) Calculate the proportion of habitat within a circular ***moving window*** with an area equal to the species' home range size. This step generated a surface representing where the largest concentrations of habitat exist.

3) Delete habitat cells in areas where habitat is sparse. We removed habitat cells from the binary habitat raster if the proportion of habitat within a home range radius was <0.5. This prevented habitat concentrations from forming in areas where habitat is not sufficiently concentrated.

4) Join remaining habitat cells together if they are within a home range movement distance. We expanded the designated habitat area outwards (from the remaining habitat cells after step 3) up to a total cost-weighted distance equal to the species home range movement radius. This has the effect of joining nearby habitat cells together if the intervening landscape supports within-home range connectivity.

5) Eliminate small patches unlikely to contribute significantly to a species' habitat. We calculated the area of each habitat patch and removed those patches where the area was less than a species-specific threshold.

2.5.2. Landscape Integrity Core Areas

The landscape integrity approach links together large, contiguous patches, or core areas, of high landscape integrity. To identify core areas, we used the same computational methods used to identify focal species HCAs described above and following these rules:

1) Core area minimum size = 10,000 acres (4047 ha) for all ecoregions.

2) Core areas only include native land-cover types.

3) Core areas do not include freeways, major highways, or secondary highways.

4) Core areas can include local roads, but local road density must be ≤10%, except:

    a. West Coast Ecoregion, where road density must be ≤20%.
    b. Willamette Valley-Puget Trough-Georgia Basin Ecoregion, where road density must be ≤30%.

We selected a 10,000 acre (4047 ha) minimum to represent areas large enough to allow for natural disturbance processes (R. Crawford, personal communication; Spencer et al. 2010). The local road density layer was created using a 20 x 20 grid cell moving window on the Local Roads raster layer. Density values were calculated by the number of grid cells containing local roads divided by the total number of cells in the window (i.e., 400).

2.6. Linkage Modeling

In this section we describe methods for mapping linkages using the resistance and HCA/core area layers described above. Although we refer to *HCAs* and *species* throughout for simplicity, these methods also apply to linkages connecting landscape integrity core areas.

Cost-weighted distance maps represent the least accumulative cost required to move between a cell and a specified source. The cost accumulated by moving through each intermediate cell is equal to the cell's resistance value multiplied by the cell size (100 m in the case of this study). For example, if a given target cell is two cells away from a specified source, and both of the intervening cells have a resistance value of 5, the cost accumulated moving from the source through the two cells is 1000 m. However, if there is an alternate route that passes through four cells, each with a resistance of 1, the cost distance at the given cell would be 400 m. The central concept in these analyses is that the cost distance from a source to a cell increases as the resistance of the intervening landscape (measured along the most efficient path from the source to the target cell) increases.

We used the ArcGIS Cost Distance function to create cost-weighted distance maps representing, for each target cell, the minimum sum of cell costs accumulated as an animal moves from the nearest HCA to the target cell. The resulting map provides an estimate of the relative "accessibility" of each cell to the nearest HCA, considering the cumulative effect of features that facilitate or impede movement (Singleton et al. 2002). This map is particularly useful for identifying barrier effects and broad areas that contribute to connectivity.

Least-cost corridor maps represent the cost of moving between a *specific pair* of HCAs through any given cell on the landscape by calculating, for that cell, the sum of cost-weighted distances from the cell to each of the HCAs. The result is a map that shows the relative value of each grid cell in providing connectivity between the HCA pair, allowing users to identify which routes encounter more or fewer features that facilitate or impede movement while moving between the two HCAs.

2.6.1. Linkage Modeling Algorithms

We automated our linkage modeling by developing a set of Python scripts bundled as an ArcGIS toolbox. The scripts took the HCA and resistance layers described above as input, and automatically mapped least-cost corridors between adjacent HCA pairs. To display multiple least-cost corridors on a single map, we normalized each corridor by subtracting its minimum cost-weighted distance. Thus, the ***normalized least-cost corridor*** between HCA *A* and *B* was calculated by the following formula:

$$CWD_A + CWD_B - LCD_{AB}$$

Where CWD_A is the cost-weighted distance from HCA *A*, CWD_B is the cost-weighted distance from HCA_B, and LCD_{AB} is the cost-weighted distance accumulated moving along the ideal (least-cost) path connecting the HCA pair. This step mapped all corridors in the same "currency;" grid cells in each normalized corridor raster range in value from 0 (the best or least-cost path) on up. Cell values were still in cost distance units, and reflected how much more costly the (locally optimal) path between the HCAs passing through each cell was relative to the (globally optimal) least-cost path connecting the HCA pair. The normalized corridor maps were then combined using the ArcGIS Mosaic function to create a composite linkage map in which each cell represented the minimum value of all individual normalized corridor layers. The scripts also generated linkage statistics (e.g., ratio of cost-weighted distance to Euclidean map distance) that are informative for comparing and ranking linkage quality and degree of connectivity between HCA pairs.

Taken together, the linkage maps and linkage statistics are useful for comparing the contribution to functional habitat connectivity of different portions of the landscape. Additional documentation of these scripts is provided in Appendix D and linkage statistics are provided in Appendix E.

2.6.2. Focal Species Linkage Modeling

For most focal species, we limited the length the least-cost path of each mapped linkage between a pair of HCAs to a maximum cost-weighted distance value, discarding linkages with ***least-cost distances*** that exceeded this value (Table 2.4). Values were chosen based on documented movement events from the literature and expert judgment. Table 2.5 illustrates how maximum cost-weighted distance values and per-cell resistance values combine to affect modeled movement potential for a hypothetical species. The underlying concept is fairly simple: an animal cannot successfully move as far through land cover types that are difficult or hostile as it can through other types.

Table 2.4. Maximum cost-weighted distances specified for focal species linkage modeling. See Appendix A for details regarding individual species.

Focal Species	*Maximum corridor length, in cost-weighted distance units*
Sharp-tailed Grouse	80 km
Greater Sage-Grouse	200 km
American badger	301 km
Black-tailed jackrabbit	no limit
White-tailed jackrabbit	no limit
Mule deer	250 km
Bighorn sheep	1000 km
Western gray squirrel	200 km
American black bear	400 km
Elk	250 km
Northern flying squirrel	126 km
Western toad	51 km
American marten	300 km
Canada lynx	1350 km
Mountain goat	200 km
Wolverine	1500 km

The normalized least-cost corridor algorithms produced “wall-to-wall” linkage maps, with every grid cell in the study area having a value that represented its deviation from the least-cost movement route. To create linkage maps focusing on portions of ***linkage zones*** relevant for planning, we truncated normalized corridors by displaying only values from zero to a species-specific ***linkage mapping cutoff***. Doing so required making decisions about cutoff values, with higher values resulting in mapped linkage zones that were wider, on average (normalized corridors will narrow when passing through high-resistance habitat because cost-weighted distance accumulates more quickly there). We chose cutoff values that would represent linkage zones of relatively uniform width across species despite significant differences between species in landscape resistance values. We chose values that produced generous linkage zone widths due to the coarse scale of the analysis and the intent that linkage zones serve not only focal species, but other species and processes as well. Wider linkage zones also reflect the uncertainty in GIS base data, resistance models, and other parameters used in our modeling process; in other words, the precision implied by mapping narrower linkages would have suggested a greater ability to identify exact locations on the landscape that are important for movement than is warranted (See Chapter 4).

Table 2.5. Example effects of per-cell resistance values on movement ability under different maximum cost-weighted distance values.

Per-cell resistance value of landscape feature (ideal conditions assigned a value of 1)	*Cost-weighted distance, in meters, accumulated by moving through one cell (resistance value x 100 m per cell)*	*Maximum Euclidean distance species can travel through each landscape feature when limited to a max cost-weighted distance of:*	
		10 km	*200 km*
1	100	10 km	200 km
2	200	5 km	100 km
5	500	2 km	40 km
10	1000	1 km	20 km
20	2000	500 m	10 km
50	5000	200 m	4 km
100	10,000	100 m	2 km
1000	50,000	20 m	400 m

To meet the above criteria, we chose linkage mapping cutoffs of 10, 25, and 75 km in cost-weighted distance. Species characterized as rapidly accumulating cost when moving through suboptimal habitat (American marten [*Martes americana*], bighorn sheep, American black bear, Canada lynx, and western gray squirrel) were assigned cutoffs of 75 km. Species characterized as capable of moving easily through suboptimal habitat (western toad and mountain goat) were assigned cutoffs of 10 km. All other focal species were assigned cutoffs of 25 km.

2.6.3. Landscape Integrity Linkage Modeling

We created four landscape integrity-based linkage maps using, respectively, the four resistance layers described in section 2.4.2. We allowed adjacent core areas within 160 km (100 mi) Euclidean distance of each other to be connected, with no maximum cost-weighted distance. We chose this conservative threshold to make as few restrictive assumptions as possible about maximum movement distances for ecological elements.

Because an identical set of core areas was used in each of the four linkage models, it was possible to additively combine them in a single composite map to identify lands that were most robust to sensitivity assumptions. To do this, we normalized each of the combined least-cost corridor rasters into 100,000 equal-area bins, then summed raster values across all connectivity models to create one composite map. To examine differences in connectivity areas identified among resistance models, we extracted each connectivity raster to include only the top 30% area (raster values <30,000) of the landscape, ranked in order of normalized least-cost distances. These four 30% connectivity zone rasters were then overlaid to show areas identified by one, two, three, or all four resistance models. Those connectivity areas associated with the greatest number of models were considered most robust to assumptions of sensitivity to human influence.

2.6.4. Network Correspondence Analysis

To identify common patterns across focal species and landscape integrity analyses, we first defined binary ***linkage networks*** based on modeling results for all 16 focal species and the medium sensitivity landscape integrity model. We defined the linkage network for each focal species (or landscape integrity) to include: (1) the HCAs (or integrity core areas), (2) the normalized least-cost corridors up to a species- or integrity-specific network cutoff, and (3) a cost-weighted distance buffer surrounding the HCAs or integrity core areas using the same cutoff value.

We then overlaid the networks and quantified the degree of overlap across them. To do this, we generated a systematic grid of points at a 2.5 km square interval across the state of Washington (*n* = 27,695). Each point in this grid was categorized as being in or out of each focal species or landscape integrity network. We assessed 3 different network cutoff values to determine whether overlap patterns were sensitive to the area that was included in the network. The network cutoff definitions for the focal species were based on the linkage mapping cutoff values (listed above in section 2.6.2), and included wide (100, 50, or 20 km), moderate (50, 25, or 10 km), and narrow (25, 13, or 5 km) cutoff ranges (Table 2.6). Network cutoffs for the landscape integrity network were based on a qualitative comparison with the focal species networks (Table 2.6).

Table 2.6. Network cutoff values (km cost-weighted distance) used to define the focal species and landscape integrity networks for this analysis.

Network	*Wide*	*Moderate*	*Narrow*
Sharp-tailed Grouse	50	25	13
Greater Sage-Grouse	50	25	13
American badger	50	25	13
Black-tailed jackrabbit	50	25	13
White-tailed jackrabbit	50	25	13
Mule deer	50	25	13
Bighorn sheep	100	50	25
Western gray squirrel	100	50	25
American black bear	100	50	25
Elk	50	25	13
Northern flying squirrel	50	25	13
Western toad	20	10	5
American marten	100	50	25
Canada lynx	100	50	25
Mountain goat	20	10	5
Wolverine	50	25	13
Landscape integrity	400	200	100

We used hierarchical cluster analysis to identify groups of species that were similar when judged by the amount that their networks overlapped with the networks of other species. We then mapped combined networks for groups of species with high degrees of overlap. Lastly, we quantified the overlap of species and landscape integrity networks by tallying the proportion of each species' network that fell within another species' network or within the landscape integrity network.

Chapter 3. Results and Discussion

This chapter describes results from focal species and landscape integrity analyses, as well as results from the integration of focal species and landscape integrity model outputs. Additional discussion can be found in subsequent chapters. Intended uses—and limitations—of our products are discussed in detail in Chapter 4, where we give guidance on interpretation and use of these products. Chapter 5 discusses our working group structure and process, which will be of interest to those involved in connectivity analysis efforts that follow ours. Finally, Chapter 6 looks ahead to future work we consider important to understanding and conserving connectivity, such as incorporating climate change, performing analyses at finer spatial scales, and validating our connectivity models.

3.1. Focal Species Overview

In this section we summarize results of focal species selection, identification of HCAs, and development of resistance surfaces, cost-weighted distance surfaces, and linkages. More detailed individual species accounts follow in Section 3.2.

3.1.1. Focal Species Selection

Sixteen species were ranked as excellent or acceptable for all of the criteria we applied. These consisted of thirteen mammals, two birds, and one amphibian (Table 3.1).

Table 3.1. Focal species selected to represent coarse-scale connectivity priorities in five broad vegetation classes. The vegetation class for which a species ranked well enough for selection is indicated with an "X." Additional vegetation classes where a species occurs are indicated with an "*".

Focal Species	*Semi-desert Habitats*	*Rocky Mt. Forests*	*Vancouverian Forests*	*Subalpine Forests*	*Alpine Habitats*
Sharp-tailed Grouse	X				
Greater Sage-Grouse	X				
American badger	X				
Black-tailed jackrabbit	X				
White-tailed jackrabbit	X				
Mule deer	X	X	*	*	*
Bighorn sheep	*	X			
Western gray squirrel		X	*		
American black bear		X	X	*	*
Elk	*	X	X	*	*
Northern flying squirrel		X	X		
Western toad		X	X	X	*
American marten		*	X	X	
Canada lynx				X	
Mountain goat		*	*	X	X
Wolverine				X	X

3.1.2. Focal Species Habitat Concentration Areas (HCAs)

In Washington, the number of HCAs identified for each species ranged from 4 for the Greater Sage-Grouse to 94 for the western toad (Table 3.2). Additionally, 131 landscape integrity core areas occurred wholly or partially in Washington. Focal species HCAs ranged in size from 24 km^2 (bighorn sheep) to 60,905 km^2 (mule deer).

Table 3.2. Number and size characteristics of focal species HCAs and landscape integrity core areas[a].

Focal species	*Number of HCAs project-wide*	*Number of HCAs Washington*	*HCA size (km^2) range*	*HCA size (km^2) mean (SD)*	*Total of all HCAs (km^2)*
Sharp-tailed Grouse	11	8	70-590	345 (195)	2761
Greater Sage-Grouse	8	4	521-3528	1428 (1428)	5711
American badger	36	16	204-1330	478 (408)	7654
Black-tailed jackrabbit	46	31	56-816	206 (187)	6372
White-tailed jackrabbit	68	38	55-2330	273 (411)	10,372
Mule deer	70	34	100-60,905	4594 (12,831)	156,186
Bighorn sheep	37	17	24-9521	767 (2270)	13,041
Western gray squirrel	34	26	50-589	196 (153)	5104
American black bear	94	27	239-7381	1966 (2218)	53,071
Elk	120	47	104-7176	1057 (1668)	49,680
Northern flying squirrel	229	41	50-7068	504 (1238)	20,648
Western toad	248	94	50-9079	420 (1044)	39,925
American marten	105	39	100-3576	535 (737)	20,865
Canada lynx	31	8	596-5916	1846 (1941)	14,769
Mountain goat	73	29	56-8023	180 (159)	5228
Wolverine	15	2	7199-16,299	11,749 (6435)	23,498
Landscape integrity[b]	349	131	41-9864	503 (1458)	65,841

[a] With the exception of "Number of HCAs project-wide," all statistics pertain to HCAs wholly or partially in Washington.
[b] Landscape Integrity medium sensitivity model.

3.1.3. Focal Species Resistance Surfaces

Across all focal species, resistance values ranged from 1–10,000, with most scores falling at the low end of that range (See Appendix B). Landscape elements assigned the highest average resistance scores included elevations over 3300 m, housing densities greater than one dwelling unit per ten acres, freeways, or urban/developed conditions. Landscape elements consistently assigned low resistance values included areas with few or no roads, low human population densities, and riparian vegetation.

3.1.4. Cost-Weighted Distance Surfaces

Cost-weighted distance maps (See Section 3.2) show the cumulative resistance—a measure of movement difficulty—encountered when moving to any point in our study area from the nearest HCA. They are particularly important because they simultaneously highlight areas that act as ***fracture zones***, suggest the best movement pathways between HCAs, and indicate the difficulty of moving between different HCA pairs (See Chapter 4 for more on interpreting our map products).

3.1.5. Focal Species Linkages

Descriptions of linkages for each focal species are provided in the individual species summaries (See Section 3.2). The number of identified linkages varied with number of HCAs (Table 3.3). The range of Euclidean distances traversed by these linkages ranged from <1 kilometer for several species up to 211 km for a wolverine linkage. Three metrics are useful for describing the quality of a linkage. The first is the cost-weighted distance, or weighted least-cost path (LCP) length. This is the total cumulative resistance encountered as an animal moves along the least-cost path, and values ranged from <1 kilometer weighted distance for western toads and white-tailed jackrabbits to 1322 km for a Canada lynx linkage. The second is the cost-weighted distance divided by the straight line or Euclidean distance, measured edge-to-edge, separating the HCA pair. The third is the cost-weighted distance divided by the non-weighted distance along the least-cost path (Table 3.3); this metric provides the average resistance encountered as animals move along the least-cost path between each HCA pair. For the second and third linkage quality metrics, an optimal linkage has a ratio equal to one. Poor quality linkages have high ratios, as seen in the high end of values for northern flying squirrel and American badger. Further discussion of these metrics and an illustration are provided in Chapter 4.

3.2. Individual Focal Species Background and Results

The focal species summaries that follow provide species-by-species presentations of model results prefaced by a general description of the conceptual basis for each model. Our focal species maps illustrate a spectrum of connectivity conditions for each species, often ranging from highly functional linkages among HCAs to complete lack of connectivity due to natural or human features that fragment habitat. Thus, close inspection of the maps can provide insights into current connectivity conditions in different parts of Washington State. The landscape patterns and the functional implications of the modeling results build progressively through the maps of HCAs, landscape resistance, cost-weighted distance, and linkages (See Appendix A for detailed species narratives).

3.2.1. A Note About Habitat Concentration Areas and GAP Distributions

We identified HCAs for each focal species based on habitat associations documented in the scientific literature and advice from species experts. For focal species that are widespread and relatively abundant, our HCAs represent the ‘best of the best habitat’ available (as for American marten). For threatened and endangered species, HCAs sometimes include suitable but currently vacant habitat within the species’ historical range (as for Sharp-tailed Grouse). We’ve included Washington State Gap Analysis Project range maps (Cassidy et al. 1997) overlaid with our HCAs for each species to illustrate the relationship between a species’ known range and our definition of HCAs. Some of our maps reflect improved knowledge of species’ distributions since the Gap Analysis Project was published in 1997. The western gray squirrel, Greater Sage-Grouse, and Sharp-tailed Grouse HCAs include areas believed to be vacant but considered important for species recovery and improved range-wide connectivity. Mountain goat HCAs do not include the Olympic Mountains where this species was introduced.

Table 3.3. Number, length and quality characteristics of focal species and landscape integrity linkages^{a}.

Focal Species	*Number of Linkages Project-wide*	*Number of Linkages WA*	*Euclidean Dist (km) mean (SD) range*	*LCP Length (km) mean (SD) range*	*Non–weighted LCP length (km) mean (SD) range*	*LCP/Euclidean mean (SD) range*	*LCP/non-weighted mean (SD) range*
Sharp–tailed Grouse	12	12	21(10) 8–40	39(19) 12–70	30(15) 9–55	2(1) 1–4	1(<1) 1–2
Greater Sage–Grouse	5	3	41(15) 30–58	106(37) 80–149	74(12) 63–87	3(2) 2–5	1(<1) 1–2
American badger	54	30	32(26) <1–84	115(84) 1–301	48(37) <1–125	35(161) 1–889	10(41) 1–228
Black–tailed jackrabbit	96	75	23(24) <1–90	67(66) 2–245	32(31) <1–113	11(45) 1–312	4(15) 1–127
White–tailed jackrabbit	131	81	27(30) <1–147	89(178) <1–1124	37(44) <1–222	6(24) 1–213	4(14) 1–128
Mule deer	148	86	19(28) <1–130	56(66) 1–241	24(35) 1–169	4(5) 1–37	3(2) 1–19
Bighorn sheep	50	22	30(34) <1–112	336(333) 1–971	38(44) <1–145	17(18) 9–94	11(7) 3–34
Western gray squirrel	40	35	10(12) <1–49	59(62) 2–199	14(18) <1–73	33(65) 1–137	10(10) 1–26
American black bear	185	44	11(10) 1–32	116(110) 4–363	12(12) 1–40	12(7) 6–51	11(4) 6–32
Elk	295	98	24(30) 1–137	80(69) 2–235	31(37) 1–166	6(5) 1–29	5(4) 1–25
Northern flying squirrel	295	49	6(7) <1–31	37(32) 2–122	9(10) <1–38	49(186) 3–1167	17(50) 2–253
Western toad	420	180	10(9) <1–36	18(14) <1–50	12(10) <1–40	3(7) 1–58	2(4) 1–34
American marten	137	53	8(7) <1–29	97(86) 4–297	9(8) <1–36	15(13) 5–100	11(5) 5–32
Canada lynx	49	13	36(39) <1–107	416(432) 7–1322	50(49) <1–134	15(7) 4–27	10(5) 3–18
Mountain goat	166	71	27(27) <1–134	38(43) <1–171	29(30) <1–151	1(1) 1–7	1(1) 1–6
Wolverine	24	4	91(90) 1–211	574–(273) 319–938	110(103) 2–244	61(110) 4–226	49(88) 4–182
Landscape integrity[b]	741	277	14(18) <1–110	870(1034) 424–6270	20(27) <1–150	97(87) 1–239	74(76) 1–266

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[a] With the exception of "Number of Linkages Project-wide," all statistics pertain to linkages wholly or partially in Washington.

[b] Landscape integrity medium sensitivity model.

3.2.2. Sharp-tailed Grouse (*Tympanuchus phasianellus*)

3.2.2.1. INTRODUCTION

Historical evidence indicates that Sharp-tailed Grouse were widely and abundantly distributed in eastern Washington (Schroeder et al. 2000b; Stinson & Schroeder 2010). Significant population declines were observed in the late 1800s and continued steadily throughout the 1900s, primarily as a result of habitat loss and degradation. The current distribution in the state encompasses about 3% of the historical range (Schroeder et al. 2000b). There are an estimated 800 Sharp-tailed Grouse in Washington distributed among seven small, isolated populations in Okanogan, Douglas, and Lincoln counties (Stinson & Schroeder 2010). Sharp-tailed Grouse are listed as Threatened in Washington and are designated a Priority Species, and their habitats Priority Habitats, by the WDFW Priority Habitats and Species Program (Hays et al. 1998b).

Sharp-tailed Grouse, photo by Marc Hallet.

Grassland habitats provide breeding and nesting areas for Sharp-tailed Grouse while deciduous trees and shrubs in upland and riparian areas provide essential food and cover in winter (Giesen & Connelly 1993). The presence of dense herbaceous vegetation and shrubs is of key importance. Plant species composition is secondary to structural characteristics of the habitat (Connelly et al. 1998). Factors important for nesting and brood-rearing habitat include vegetation density and height, and diversity of forbs and bunchgrasses (Geisen & Connelly 1993).

Sharp-tailed Grouse were selected as a focal species because their connectivity needs reflect those of wildlife in the Semi-desert vegetation class. They were considered vulnerable to loss of habitat connectivity attributed to development.

3.2.2.2. MODEL CONCEPTUAL BASIS

Habitat concentration areas were identified using WDFW distribution information for Sharp-tailed Grouse. These areas were defined using extensive surveys, active lek locations, movements of radio-marked birds, observations of birds year-round, and distribution of occupied habitat. Washington Department of Fish and Wildlife has identified the Methow Recovery Unit as having high conservation potential for re-introduction of Sharp-tailed Grouse (Stinson & Schroeder 2010). This area was also included and identified from WDFW mapping products.

To characterize landscape resistance for Sharp-tailed Grouse we used, whenever possible, documented behavior and habitat associations. When information was lacking we relied upon the professional judgment and knowledge of expert grouse biologists to score resistance values. Urban development, human population density and roads were considered major factors contributing to landscape resistance for Sharp-tailed Grouse.

Little is known about dispersal by juvenile Sharp-tailed Grouse. Gratson (1988) recorded natal dispersal for one Sharp-tailed Grouse in Wisconsin; a juvenile female nested 1.4 km from the range it used as a chick. Seasonal movement information for Sharp-tailed Grouse is limited to data collected from radio-marked birds captured at leks (traditional breeding sites) and monitored throughout the year. From spring through autumn Sharp-tailed Grouse move fairly short distances; females in Washington nested an average 1.3 km from the leks where they were captured (Schroeder 1994). Boisvert et al. (2005) monitored Sharp-tailed Grouse on Conservation Reserve Program (CRP) and mine reclamation lands in northwestern Colorado. During winter birds were a median distance of 21.5 km from lek sites where they were captured. The relatively short distances moved by Sharp-tailed Grouse in Washington may be influenced by the fragmented nature of the habitat and associated populations (M. Schroeder, personal communication).

3.2.2.3. MODEL RESULTS

Habitat Concentration Areas — Eight HCAs for Sharp-tailed Grouse are small and clustered in the north-central part of Washington in Okanogan County, within the Okanogan Valley, and in parts of northern Douglas and Lincoln Counties (Fig. 3.1). Area of HCAs ranged from 70 km^2 to 590 km^2 (Table 3.2).

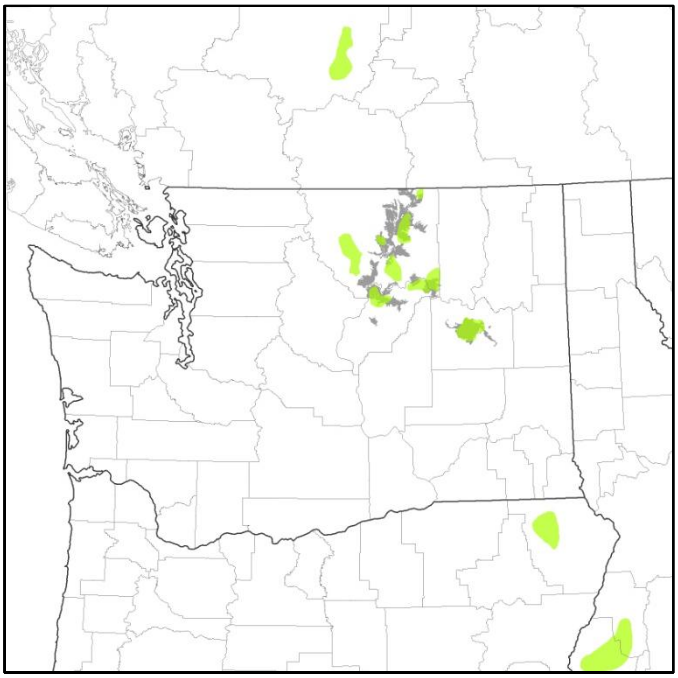


Figure 3.1. Sharp-tailed Grouse HCAs (green) and GAP distribution (gray).

Resistance Surface — The Sharp-tailed Grouse resistance surface (Fig. 3.2) shows a band of resistance due to U.S. Highway 97 running north-south through the HCA cluster within the Okanogan Valley. In general, HCAs are situated away from developed areas and high traffic-volume roads in higher elevation "islands" of habitat. Areas of least resistance tend to be fragmented and reflect the distribution of native shrubsteppe. The HCA in the Methow Valley in Okanogan County is surrounded by habitat of high resistance except for its southern border. In general, the resistance surface suggests that there are few options for additional HCAs in the state as many of the areas of low resistance are fragmented by agriculture, highways and development.

Cost-weighted Distance — There are fairly good conditions for movement among most of the centrally located HCAs in Washington (Fig. 3.3). Movement between the HCA in Lincoln County and the HCA on lands of the Colville Confederated Tribes in Okanogan County is limited to one fairly small area that skirts the Columbia River. The Methow Valley HCA is separated from the closest HCA in Okanogan County (on the Scotch Creek Wildlife Area) by an area of high resistance. Conditions for movement look relatively good among the HCAs in Douglas and Okanogan Counties. Agriculture, urban areas and highways create areas of highest resistance.

Notably, the cost-weighted distance map for Sharp-tailed Grouse has some interesting parallels with the chronology of range contraction map presented in the WDFW 2010 Sharp-tailed Grouse

Draft Recovery Plan (Stinson & Schroeder 2010). The outline of dark brown surrounding the HCAs is similar to the distribution of Sharp-tailed Grouse circa 1980 and the light gray 41–100 km cost-weighted distance extent is similar to Sharp-tailed Grouse distribution circa 1930.

Linkage Modeling — Modeled linkages between HCAs were considered when the least-cost distance between a pair of HCAs was less than 80 km (Fig. 3.4). This resulted in linkages between 12 discrete pairs of HCAs within Washington (Table 3.3). Linkage distances between HCAs were as follows: Euclidean distance (mean of 21 km [SD 10], range 8–40 km), weighted least-cost path distance (mean of 39 km [SD 19], range 12–70 km), and non-weighted least-cost path distance (mean of 30 km [SD 15], range 9–55 km).

Two linkage quality ratios were calculated for the Sharp-tailed Grouse modeling outputs: the ratio of cost-weighted distance to Euclidean distance (mean of 2.0 [SD 0.9], range 1.3–4.1) and the ratio of cost-weighted distance to least-cost path length (mean 1.3 [0.2], 1.1–1.6). The low ratio averages for linkage quality measures suggests that conditions for movement between HCAs are fairly good for Sharp-tailed Grouse. Linkage ratios were highest between HCAs separated by Highway 97 and between HCAs separated by forest.

Two of the HCAs (one in northern Okanogan County and one in Lincoln County) are peripheral and only connect to one other HCA. Disruption or increased resistance of these linkages would increase the likelihood of isolation of these HCAs. One of the HCAs connects to five others. The ***centrality*** of this particular HCA suggests that its loss or disruption would have a negative impact on a substantial portion of the population.

Most of the linkage corridors are within the movement capability of Sharp-tailed Grouse. However, each of the HCAs is occupied by relatively few birds, less than 100 individuals. Although linkages exist among the HCAs, it is not clear how movement behavior by Sharp-tailed Grouse might be influenced by low population size and past history of isolation.

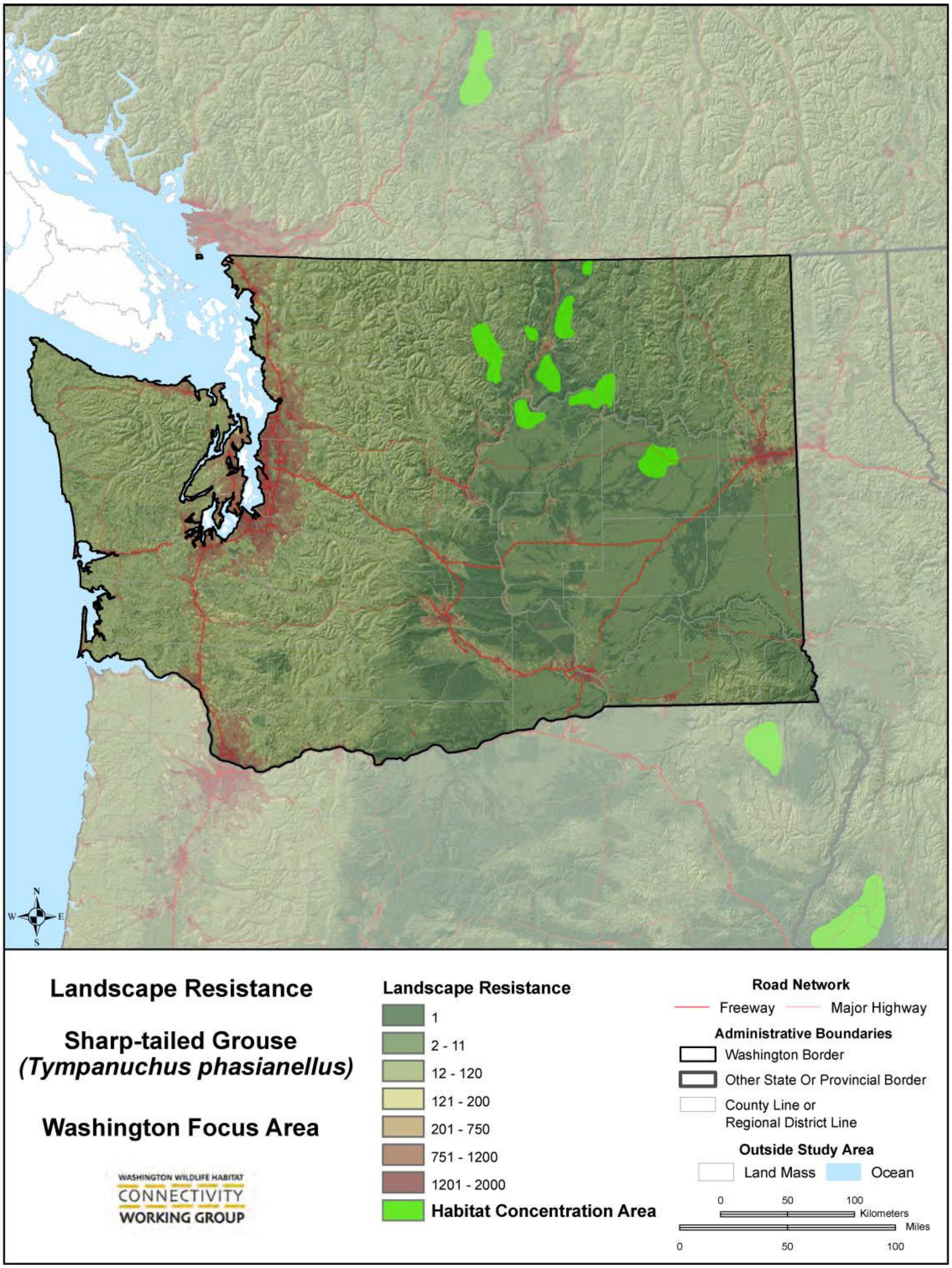


Figure 3.2. Landscape resistance for Sharp-tailed Grouse.

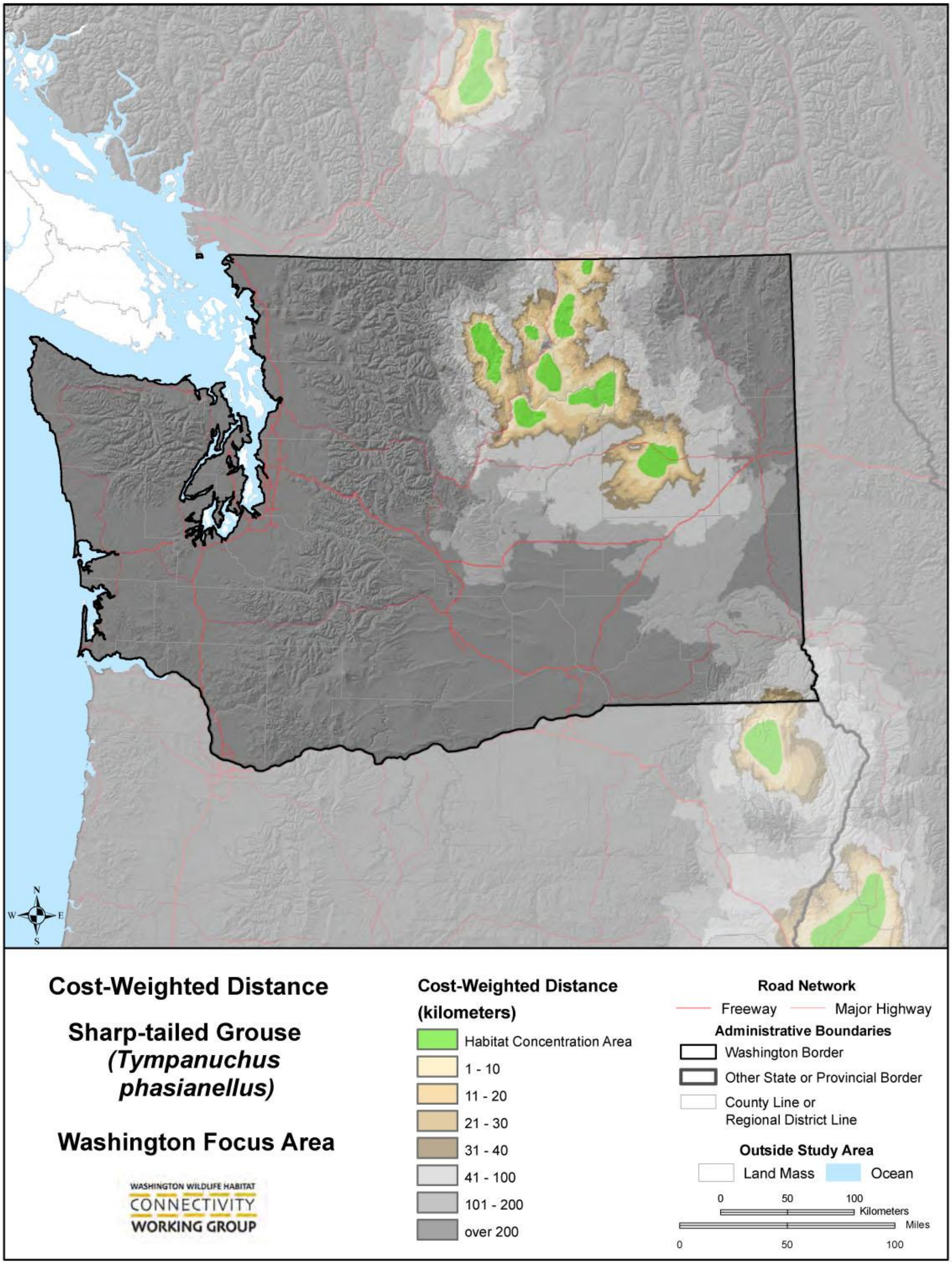


Figure 3.3. Cost-weighted distance for Sharp-tailed Grouse.

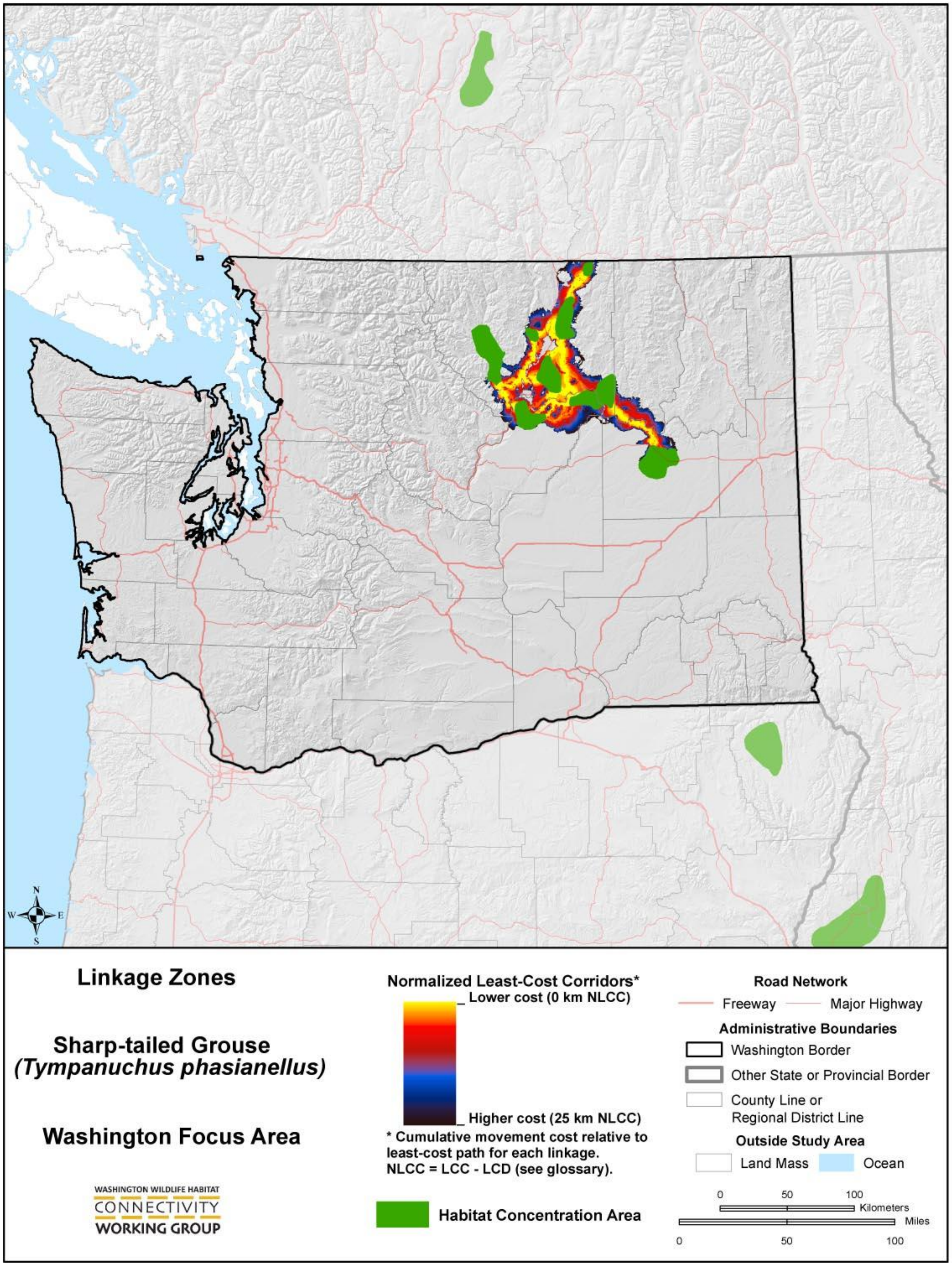


Figure 3.4. Sharp-tailed Grouse linkages.

3.2.3. Greater Sage-Grouse (*Centrocercus urophasianus*)

3.2.3.1. INTRODUCTION

Greater Sage-Grouse, photo by Rob Bennetts.

Spectacular breeding displays and dependence on sagebrush habitats make Greater Sage-Grouse icons of the West. They were once widely distributed throughout central and eastern Washington (Schroeder et al. 2000a) but declined as shrubsteppe habitat was cultivated, primarily for production of wheat. Only about 8% of the historical range in the state is occupied and the total number of birds is around 1100 (Schroeder et al. 2000a; M. Schroeder, personal communication). There are two geographically distinct populations in Washington. One population is located in the Moses Coulee area in Douglas/Grant counties and one is on the U.S. Army's Yakima Training Center (YTC) in Yakima/Kittitas counties (Schroeder et al. 2000a; Stinson et al. 2004). These populations are isolated from each other by 50 km and from populations in Oregon and Idaho by about 250 km and 350 km. Greater Sage-Grouse are listed as Threatened in the state of Washington and are considered a Priority Species by the WDFW Priority Habitats and Species Program (Hayes et al. 1998a; Stinson et al. 2004). Greater Sage-Grouse are a federal Candidate species with regard to listing under the U.S. Endangered Species Act (USFWS 2010).

Greater Sage-Grouse have large home ranges, are capable of extensive movements, and use a mosaic of habitat patch sizes within the sagebrush ecosystem. They are shrubsteppe obligate species because of their year-round dependence on sagebrush (*Artemisia* spp.) dominated habitats for food and cover (Schroeder et al. 1999). The quality of shrubsteppe habitat is critical as many uncultivated areas are not suitable because of lack of sagebrush, perennial grasses and forbs (Schroeder et al. 1999). Winter habitat for Greater Sage-Grouse consists of large stands of good quality sagebrush. Presence of sagebrush is essential for its survival, comprising roughly 100% of the winter diet (Schroeder et al. 1999).

Greater Sage-Grouse were selected as a focal species because they are a landscape species whose habitat connectivity needs reflect those of wildlife in the Semi-desert vegetation class. They were considered vulnerable to loss of habitat connectivity from three of the four main connectivity threats: (1) development, (2) roads and traffic, and (3) presence of people and domestic animals.

3.2.3.2. MODEL CONCEPTUAL BASIS

Within the assessment boundary, HCAs for Greater Sage-Grouse were mostly defined by extensive surveys; occupied areas were identified by active lek locations, movements of radio-marked birds, observations of birds year-round, and distribution of occupied habitat (Stinson et al. 2004). Additional areas recognized by WDFW as having high conservation potential for re-establishing Greater Sage-Grouse populations were also included as HCAs and delineated by WDFW management units (Stinson et al. 2004).

Recent studies have examined the impact of the human footprint on Greater Sage-Grouse habitat and population persistence (Connelly et al. 2004; Aldridge et al. 2008; Knick & Hanser 2010). Greater-sage Grouse are highly sensitive to development and disturbance from human activity.

We assigned resistance values to landscape features based on published literature of Greater Sage-Grouse habitat use, behavior and movements. When information was lacking we relied upon the professional judgment of expert reviewers to provide guidance when developing the model. Greater Sage-Grouse in Washington tend to move less than 30 km between seasonal breeding and wintering areas (Schroeder & Vander Haegen 2003). Some birds move considerably further distances. These birds are the ones important for maintaining connectivity among/between populations.

3.2.3.3. MODEL RESULTS

Habitat Concentration Areas — While there is overlap between our HCAs and the predicted GAP distribution (Fig. 3.5) they differ somewhat for a few reasons: (1) we were able to use WDFW population distribution data when identifying our HCAs, (2) Greater Sage-Grouse are known to use Conservation Reserve Program lands which are considered agricultural, and (3) shrubsteppe quality is an important factor determining habitat for Greater Sage-Grouse.

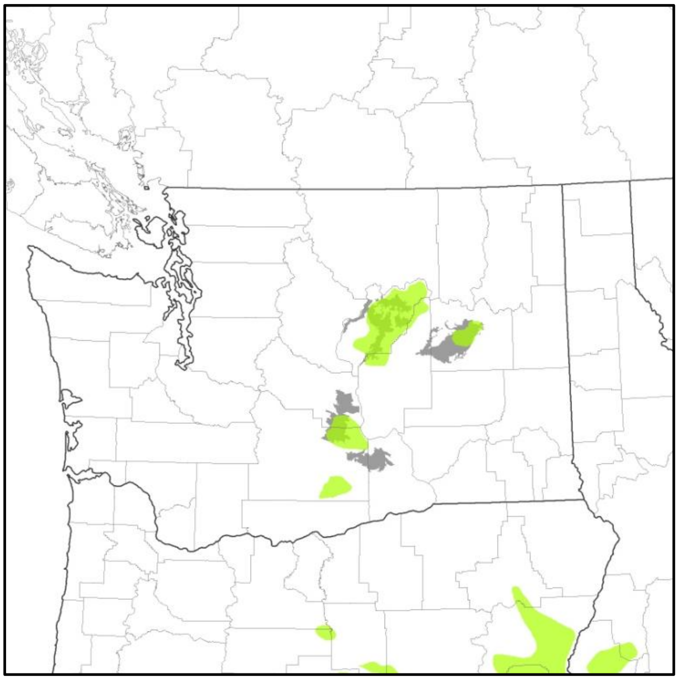


Figure 3.5. Greater Sage-Grouse HCAs (green) and GAP distribution (gray).

The HCAs in Douglas/Grant counties and on the YTC in Yakima and Kittitas counties are based on WDFW GIS distribution data of Greater Sage-Grouse populations. The HCA furthest east in Lincoln County is the Swanson Lakes Wildlife Area (SLWA) and represents the area occupied by a small re-introduced population of Greater Sage-Grouse. The most southerly HCA in Washington is located in Yakima County on Yakama Nation lands and is based on the WDFW Toppenish Ridge Greater Sage-Grouse management unit. Greater Sage-Grouse have been re-introduced to this area however there is currently no known population. All of the HCAs for Greater Sage-Grouse are situated in shrubsteppe habitats and the HCA in Douglas County also has substantial cropland in CRP. The HCAs for Greater Sage-Grouse ranged from 521 km^2 to 3528 km^2 in area.

Resistance Surface — The modeled resistance surface for Greater Sage-Grouse indicates variable conditions for movement of Greater Sage-Grouse among HCAs (Fig. 3.6). The HCA in Yakima County on Yakama Nation lands is separated from the YTC HCA by a band of high resistance due to urban development and freeway infrastructure along the route of Interstate 82 (I-82). Conditions for movement look fairly good between the YTC and Douglas/Grant HCAs however the band of low resistance between these HCAs is relatively narrow. The Columbia River marks a north-south “border” in the resistance surface between these HCAs; the area to the west of the Columbia River has lower resistance than the land to the east. Habitat west of the Columbia River is predominately shrubsteppe while east of the river is mostly agriculture.

Although I-90 creates a band of high resistance running east-west between the YTC and Grant/Douglas HCAs it is not likely an insurmountable barrier to movement. The resistance surface indicates fairly good conditions for Greater Sage-Grouse movement between the Swanson Lakes HCA and the Douglas/Grant HCA, particularly on the southern end of each HCA.

Cost-weighted Distance — Potential for movement exists among the four HCAs in Washington. Conditions for movement are probably best between the HCA in Douglas/Grant counties and the HCA in Lincoln County (Fig. 3.7), although there is an area of high resistance extending north-south between these two HCAs. The connection between the HCA in Douglas/Grant counties and the HCA in the YTC in Yakima County follows native shrubsteppe habitat (See Fig. 3.6) and is influenced by areas of high resistance to the east and west due to development, agriculture and the Columbia River, as well resistance from I-90. Interstate 82 between Yakima and Richland creates a significant barrier to movement between the YTC and Yakama Nation lands HCAs.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 200 km cost-weighted distance. This created three linkages within Washington (Fig. 3.8). Linkage distances between HCAs were as follows: Euclidean distance (mean of 41 km [SD 15], range 30–56 km), weighted least-cost path distance (mean of 106 km [SD 37], range 80–149 km), and non-weighted least-cost path distance (mean of 74 km [SD 12], range 63–87 km).

Two linkage quality ratios were calculated for the Greater Sage-Grouse modeling outputs. The ratio of cost-weighted distance to Euclidean distance (mean of 2.9 [SD 1.8], range 1.6–5.0) and the ratio of cost-weighted distance to least-cost path length (mean of 1.4 [SD 0.3], range 1.1–1.7). The ratio of cost-weighted distance to Euclidean distance indicates how “hard” it is to move between HCAs relative to how close they are. The ratio of cost-weighted distance to least-cost path length indicates the average resistance encountered moving along the optimal path between a pair of HCAs. The highest ratio values were for the linkage between the YTC HCA and the Yakama Nation HCA. The lowest ratio values were for the linkage between the YTC HCA and the HCA in Douglas/Grant counties.

The linkage between the YTC HCA and the HCA on Yakama Nation lands is highly constrained on the southern end as it passes through an area of high resistance. Local biologists have indicated that our land-cover base layer may not adequately address the increased development that has occurred in this area within the last few years. It is likely that the constrained part of the linkage, which passes through the Horse Heaven Hills area near I-82, no longer exists.

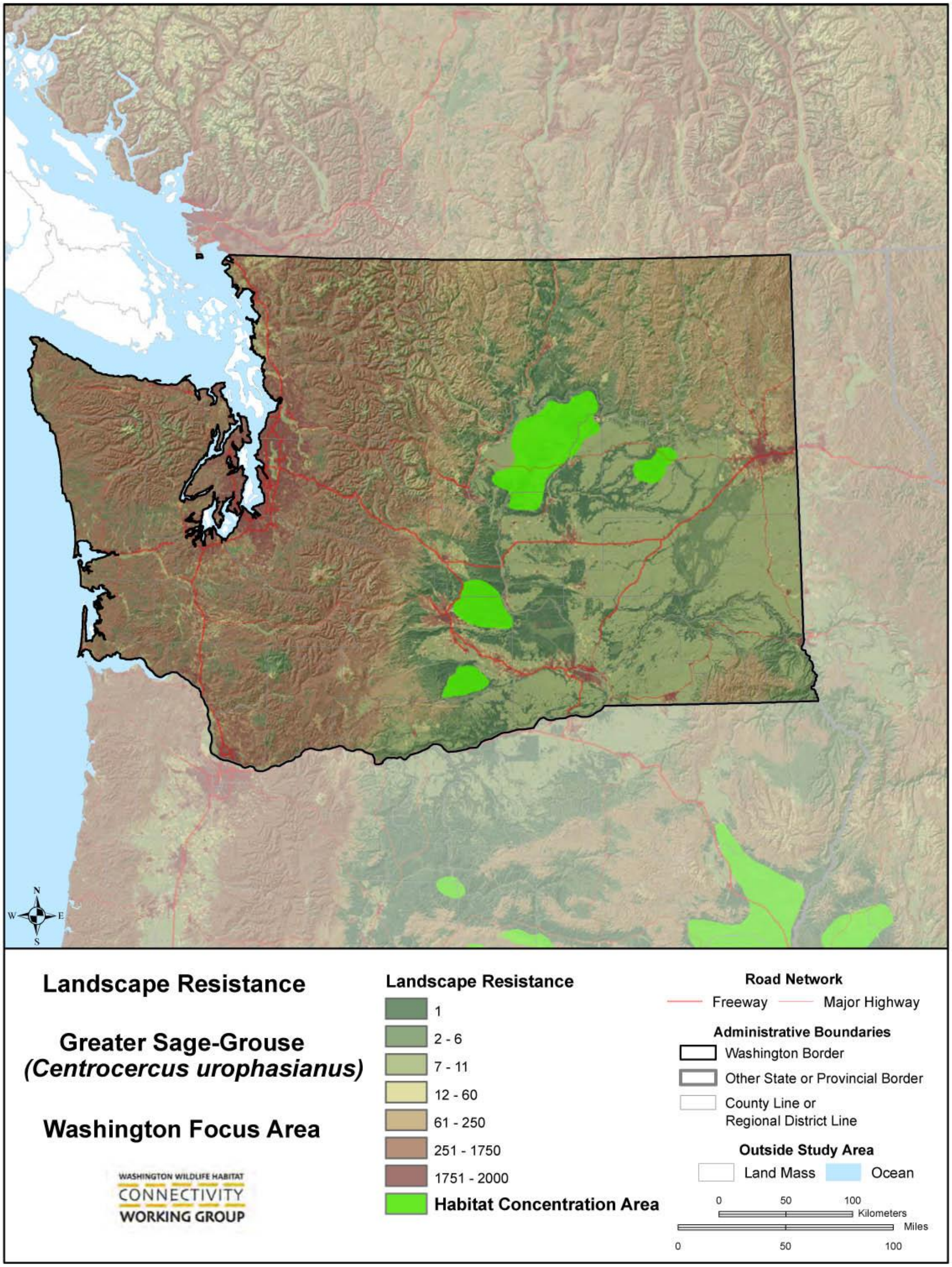


Figure 3.6. Landscape resistance for Greater Sage-Grouse.

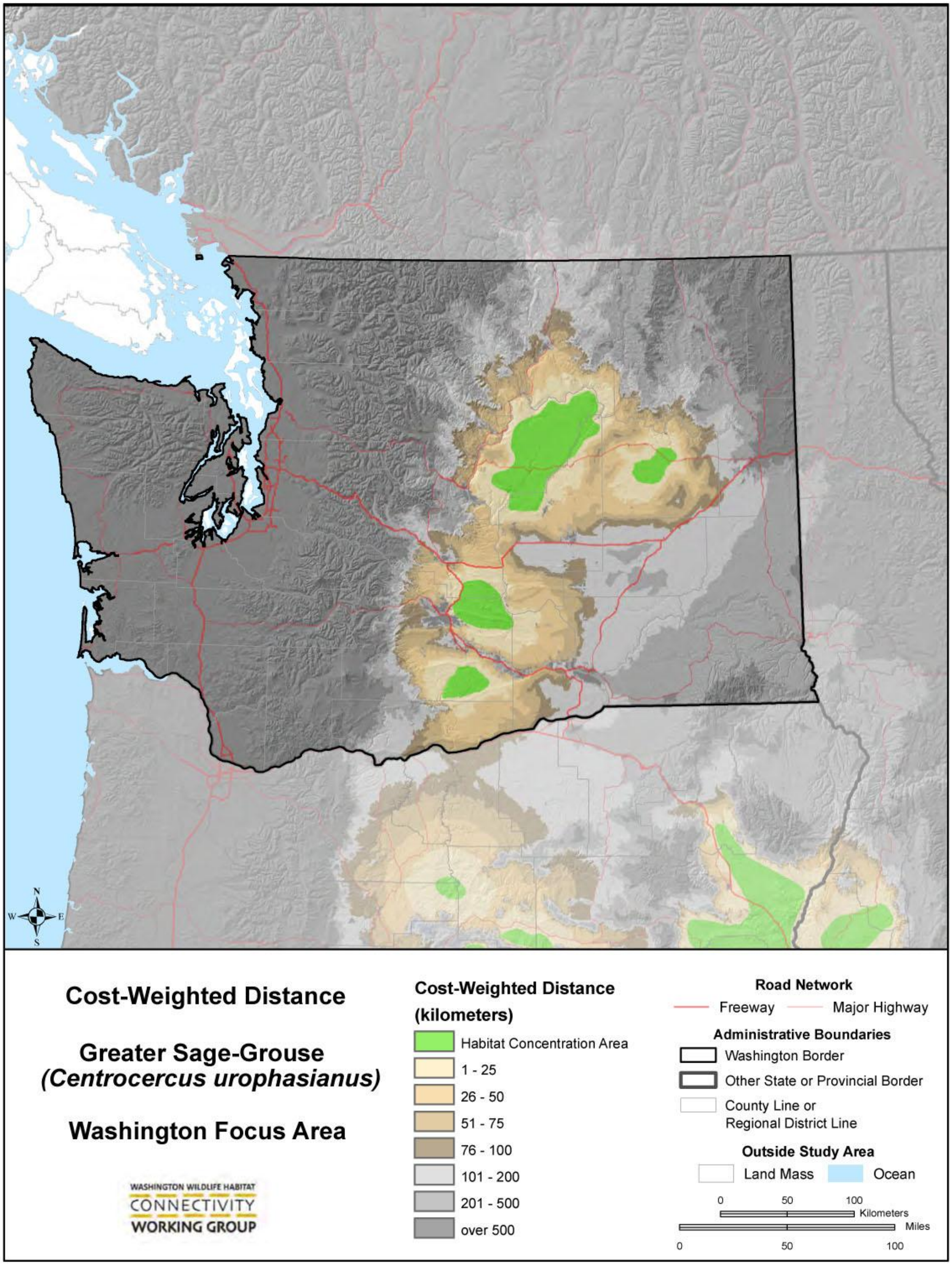


Figure 3.7. Cost-weighted distance for Greater Sage-Grouse.

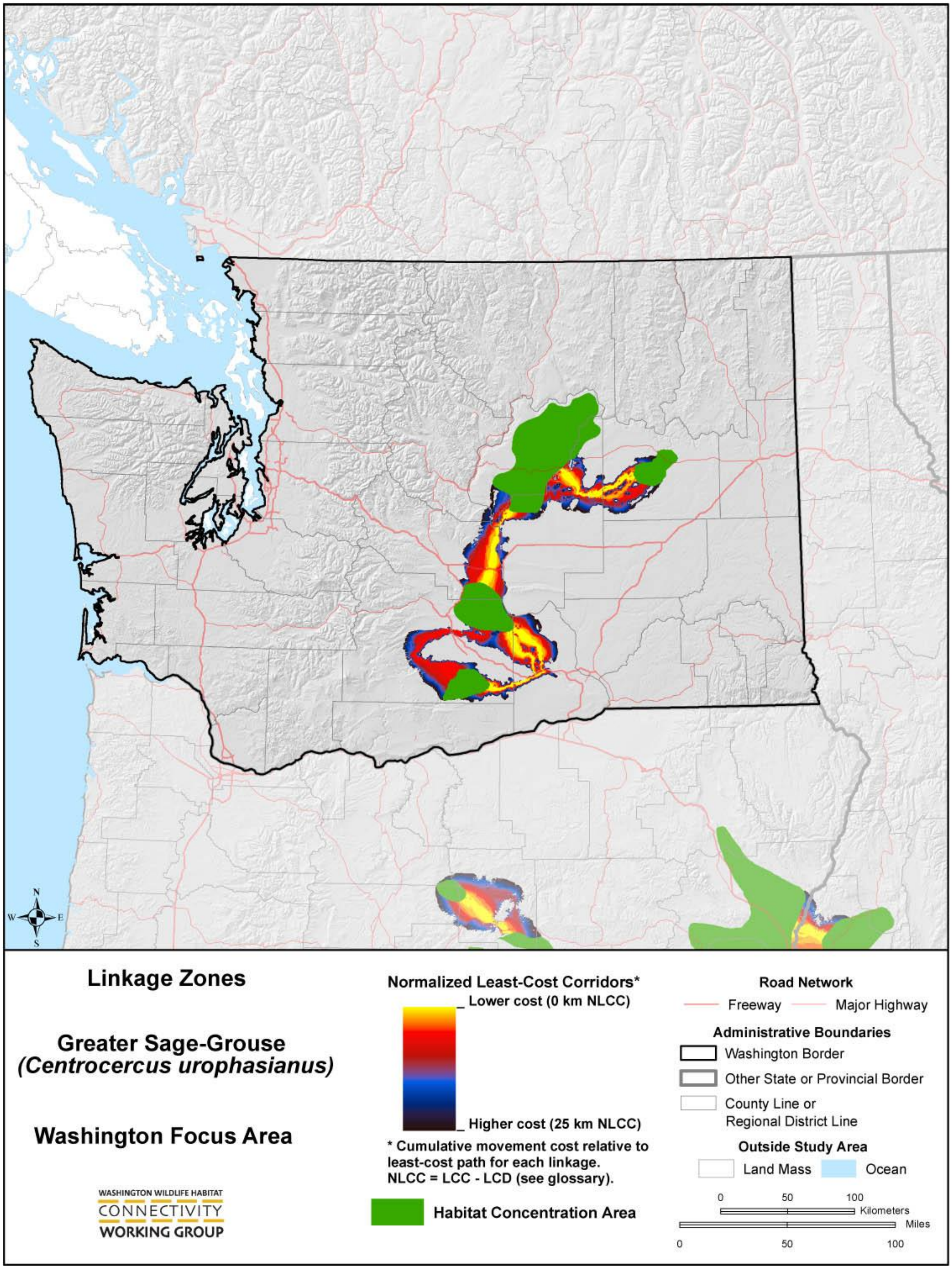


Figure 3.8. Greater Sage-Grouse linkages.

3.2.4. American Badger (*Taxidea taxus*)

3.2.4.1. INTRODUCTION

American badger, photo by Sunny Walter.

The American badger ranges from British Columbia, Canada to southern California and across the western United States. In Washington, it is an eastside species. South of Vantage (Kittitas County), its range extends up valleys penetrating the East Cascades and across the southern part of the state. North of Vantage, the western edge of its range is east of the Methow Valley in Okanogan County. In the northeast it occurs primarily in the Okanogan Highlands and in the bottoms of the major river drainages (Johnson & Cassidy 1997).

The American badger was selected as a focal species because its connectivity needs reflect those of wildlife in the Semi-desert vegetation class. Badgers are open habitat specialists that occupy shrub/grassland and occasionally open forest habitats. All recorded badger observations in the state are in dry-shrub or grassland habitat, or on the fringes of agricultural lands, with the exception of one observation in the Kettle Mountains which was likely a dispersing animal (WDFW 2010). American badgers require deep soils and adequate fossorial, or burrowing prey (Messick & Hornocker 1981). Optimal soil types are silty and sandy loams (Apps et al. 2002; Eldridge 2004; Diamond 2006). Soil conditions explain the presence and abundance of badger prey species. Thus, they are important to badgers as well (Lindzey 1976; T. Kinley, personal communication). However, badgers are capable of traversing a variety of habitats that fall outside their core habitat requirements (Messick & Hornocker 1981; Newhouse & Kinley 2000; T. Kinley, personal communication).

Badgers are vulnerable to loss of habitat connectivity from three of the four main connectivity threats: development, roads and traffic, and the presence of people and domestic animals. Although badgers are fairly tolerant of human activity, they face increased risk of mortality from vehicle traffic and persecution by people. They are listed as a Species of Greatest Conservation Need in Washington due to habitat loss and human-related threats.

3.2.4.2. MODEL CONCEPTUAL BASIS

Resistance values for landscape features were derived from descriptions in the literature of badger habitat and movements. In cases where little published information was available we relied upon the professional judgment of expert reviewers. Movement routes used by badgers are expected to be influenced by availability of rodent prey, land-cover type, and human disturbance (persecution and vehicle traffic). Factors impeding their movement throughout the landscape include vehicle traffic, urban land-uses, and human population density.

Home range size of American badgers varies from about 9 km^2 for males and 6 km^2 for females in eastern Washington (Paulson 2007) to 69 km^2 in highly fragmented habitat in British Columbia (Newhouse & Kinley 2000). In general, home range size is correlated with prey density, female availability and habitat features (Hoodicoff & Larsen 2009). The longest recorded dispersal distances for an American badger are 110 km for a juvenile male and 52 km for a juvenile female (Messick & Hornocker 1981). However, these distances are believed to be considerably less than what a badger is capable of moving (Messick & Hornocker 1981). We chose a maximum weighted distance of 301 km for linkages. This distance provides a best-fit model based on cost-weighted corridor maps and HCA modeling, as well as recorded Washington occurrence points.

3.2.4.3. MODEL RESULTS

Habitat Concentration Areas — Sixteen American badger HCAs were identified in Washington, ranging from 204 to 1330 km^2 in size (Fig. 3.9). Mean HCA size was 478 km^2; total area of all HCAs was 7654 km^2 (Table 3.2). The HCAs delineate the limits of what is considered badger habitat, from the foothills of the East Cascades, north through the Okanogan Valley, and east to the agricultural areas of eastern Adams County. Some of the shrubsteppe and grassland areas in the central Columbia Basin did not show up as HCAs because of the large minimum patch size used to identify HCAs. These areas of native habitat were intermixed with agricultural lands. American badger HCAs in most cases, include recorded occurrence points. Several sizeable HCAs are located on public lands, including WDFW wildlife areas, Yakama Tribal lands, the Yakima Training Center, and the Hanford site (which includes the Arid Lands Ecological Reserve).

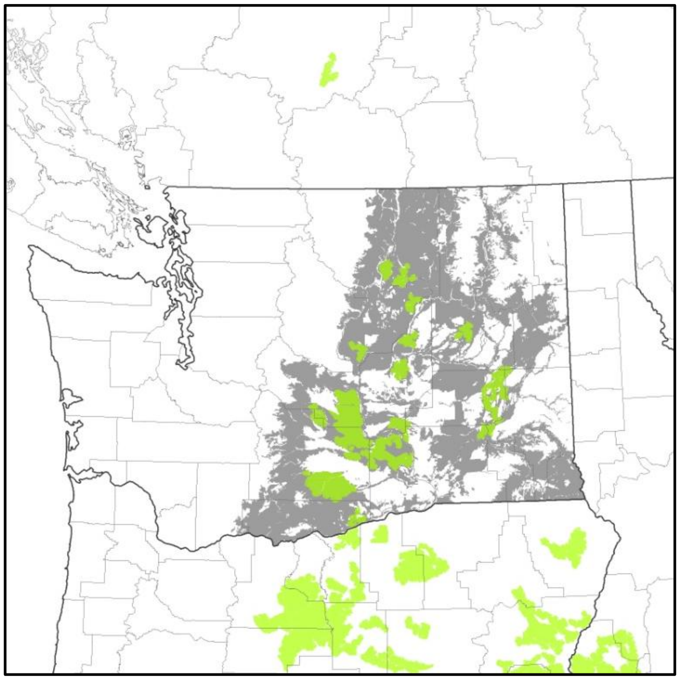


Figure 3.9. American badger HCAs (green) and GAP distribution (gray).

Resistance Surface — The resistance surface for badgers (Fig. 3.10) demonstrates relatively free badger movement throughout their range with the exception of urban areas. Interstate 90 and the Columbia River impose increased resistance to badger movements but are not impermeable barriers for badgers, which will cross highways and swim across rivers.

Cost-weighted Distance — The badger cost-weighted distance map provides a view of the full range of areas the model indicates as most suitable for badger movements away from HCAs (Fig. 3.11). This map is most useful for understanding the full range of badger movement through landscapes beyond least-cost corridors produced by the linkage model output.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 301 km. This resulted in linkages being modeled between 30 discrete pairs of HCAs in Washington (Fig. 3.12). Least-cost distances for these 30 linkages ranged from 1 km to 301 km with a mean of 115 km, while Euclidean distances ranged from <1 km to 84 km with a mean of 32 km). The ratio represented by the least-cost distance divided by the Euclidean distance had a range of 1 to 889 with a mean of 35 (Table 3.3). The results of the linkage model for badgers generally showed strong connections throughout the HCA matrix. Many corridors run through public lands that may be managed for long-term habitat protection. The major interruption to connectivity occurs at I-90 between Vantage and Kittitas, which separates two HCAs that otherwise would have been combined.

Some other ***pinch points*** occur in corridors running: (1) just northwest of the Potholes Reservoir where the corridor squeezes between I-90 and irrigated agriculture; (2) north/south along the Grand Coulee, where it is constrained by the Columbia River on one side and development on the other; and (3) along the Wahluke Slope, where it winds between agricultural lands and developed lands. Because the minimum patch size for the HCAs is large, smaller patches of suitable and occupied habitat, as well as the linkages connecting them to others, were not accounted for.

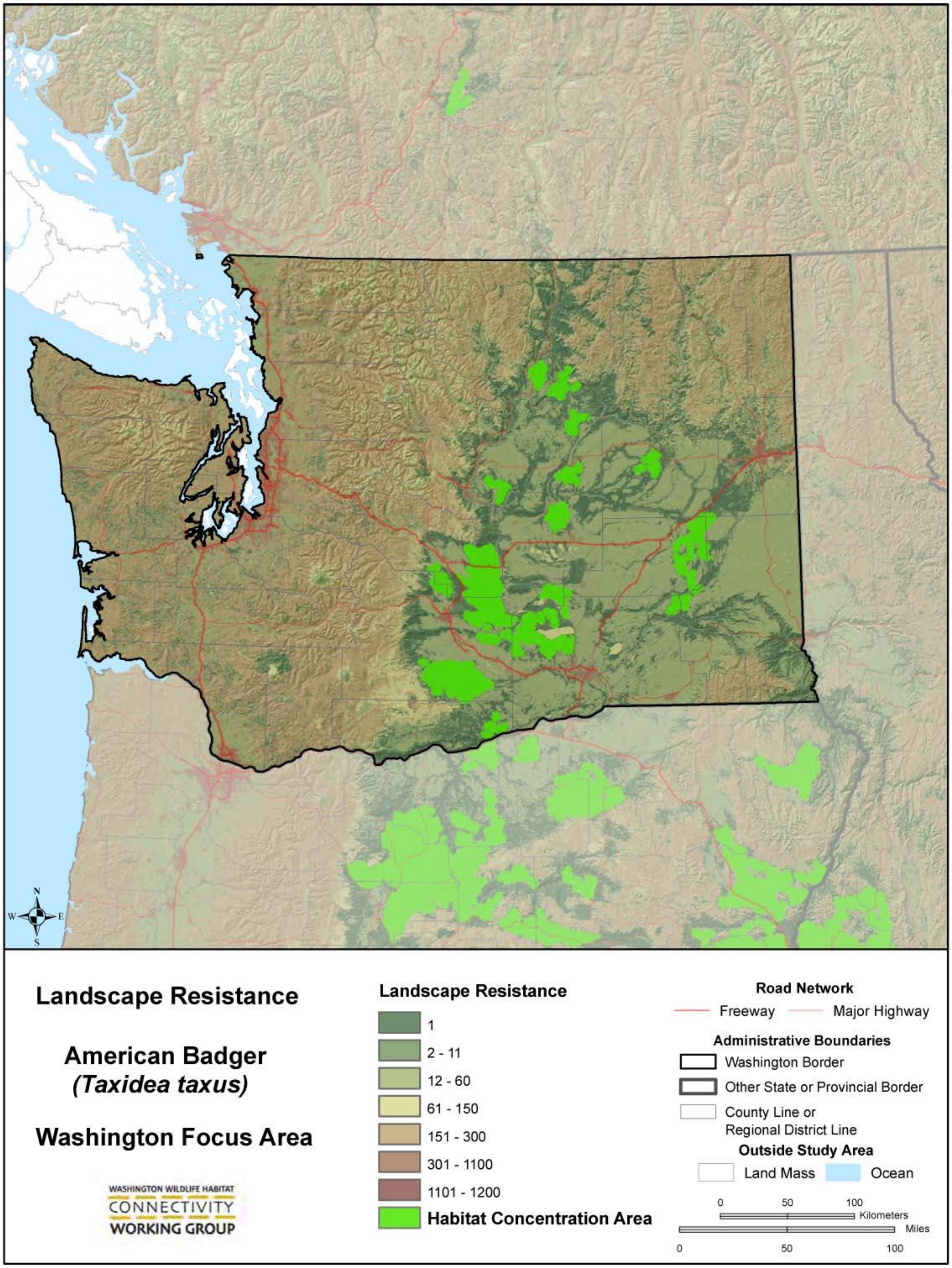


Figure 3.10. Landscape resistance for American badgers.

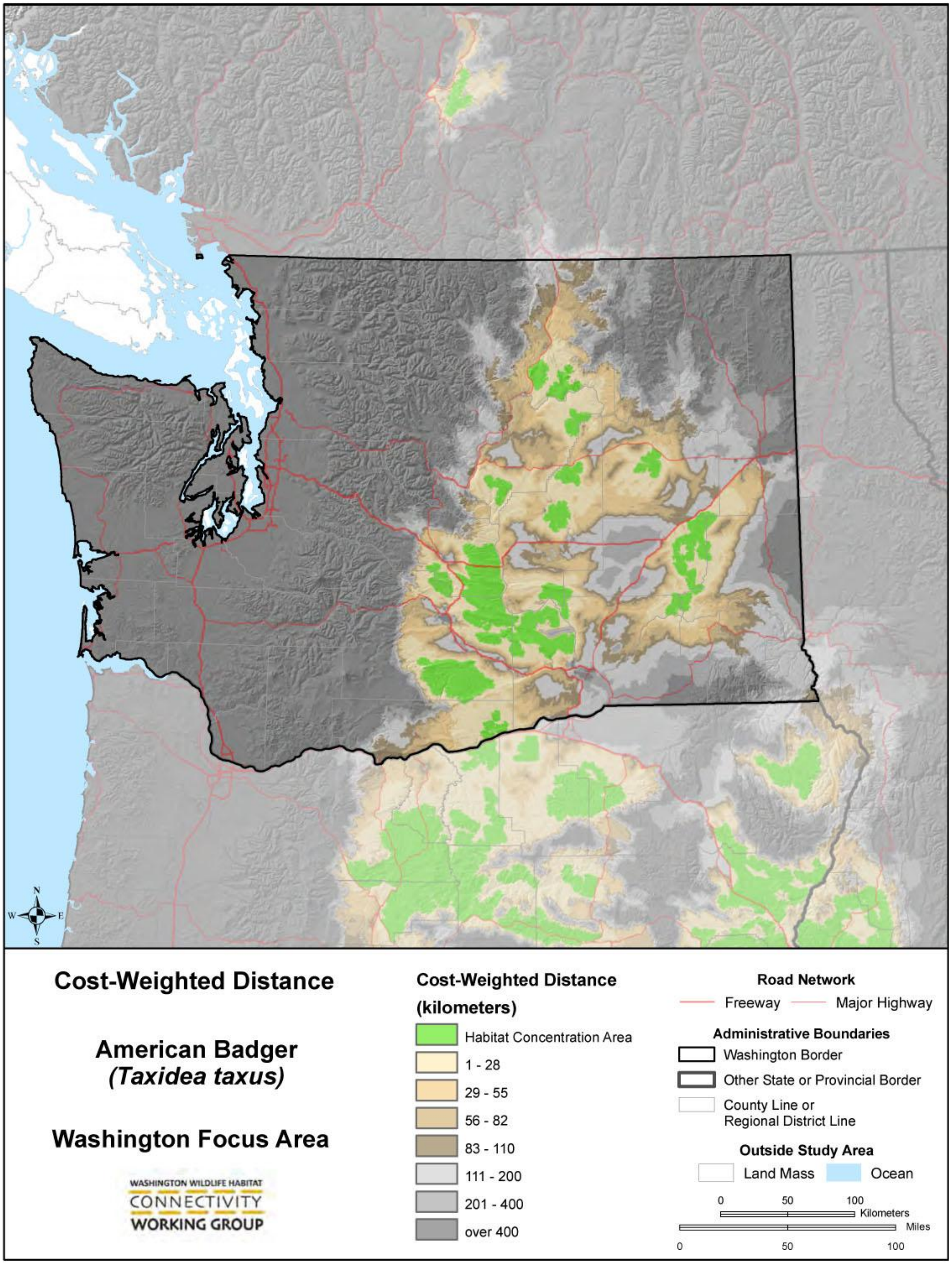


Figure 3.11. Cost-weighted distance for American badgers.

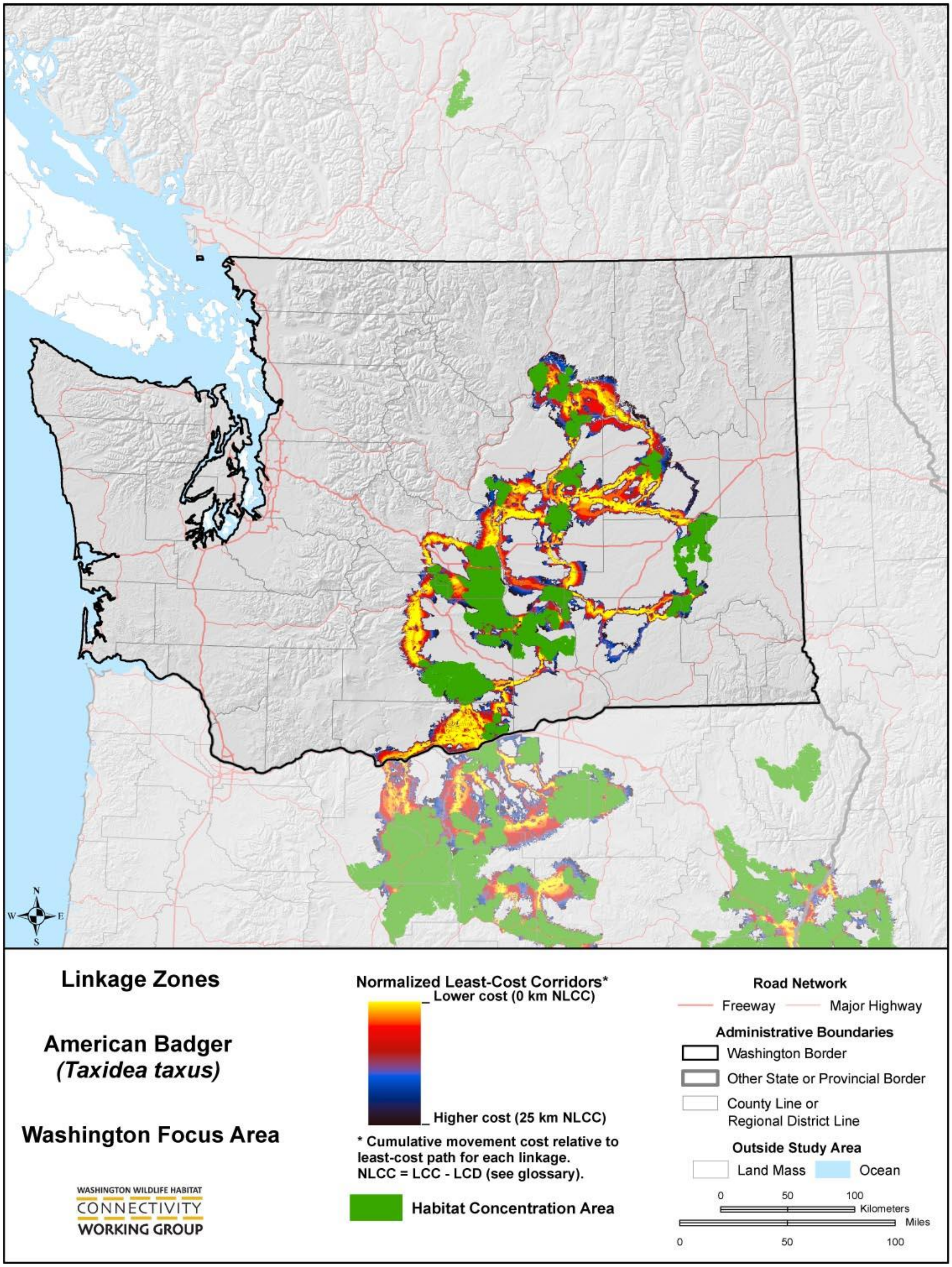


Figure 3.12. American badger linkages.

3.2.5. Black-tailed Jackrabbit (*Lepus californicus*)

3.2.5.1. INTRODUCTION

Black-tailed jackrabbit, photo by Mike Schroeder.

The black-tailed jackrabbit is the most common jackrabbit in the western U.S. (Flinders & Chapman 2003). Their range extends from southern-central Washington to South Dakota and southward into Baja California and well into south-central Mexico (Chapman & Flux 1990). They also have been successfully introduced into various eastern states. In central Washington, east of the Cascade Mountains, black-tailed jackrabbit distribution is concentrated in the arid Columbia Plateau shrubsteppe and grassland habitats, and extending south into Oregon. Areas used by black-tailed jackrabbits include sagebrush and rabbitbrush (*Chrysothamnus* sp.) dominated habitats as well as areas of mixed grassland and shrub (Johnson & Cassidy 1997). They tend to occupy areas with more shrubs and less grass than white-tailed jackrabbits and are more tolerant of grazing by livestock (Best 1996). Their diet varies seasonally, consisting of a higher percentage of shrubs in winter, forbs in spring, and mostly grasses with almost no shrub ingestion in summer (Grant 1987). Black-tailed jackrabbits are generally nocturnal and solitary (Flinders & Chapman 2003). Population monitoring is a challenge as no reliable census method exists for all population levels.

Black-tailed jackrabbits are highly mobile. Size of home range varies from 20–300 ha (Lechleitner 1958; Harestad & Bunnell 1979; Smith 1990). The literature suggests that no regular seasonal migration occurs; however, most recorded large movements are between fall and winter ranges and winter and spring ranges (Rusch 1965; Grant 1987; Smith et al. 2002). Grant (1987) reported a black-tailed jackrabbit moving about 57 km during early winter; in this study, distances travelled averaged 16.2 km with a range of 2.2–57.3 km. Early observations in Washington indicate that this species moved a distance of forty miles from 1908–1912, colonizing the area from western Walla Walla up to Grant County (Couch 1927).

The black-tailed jackrabbit was selected as a focal species because its connectivity needs reflect those of wildlife in the Semi-desert vegetation class. They are vulnerable to loss of habitat connectivity from all four major connectivity threats: clearing and vegetation removal, development, roads and traffic, and the presence of people and domestic animals. Additionally, they are at considerable risk for increased mortality from vehicle traffic, persecution, and harassment by pets. The black-tailed jackrabbit is listed as a Species of Greatest Conservation Need in Washington due to habitat loss and human-related threats.

3.2.5.2. MODEL CONCEPTUAL BASIS

Due to lack of studies, published literature, and occurrence data for black-tailed jackrabbits, the core habitat in Washington was not well defined. Habitat concentration areas were therefore modeled based on habitat suitability. Grid cells were either designated as habitat (resistance values equal to 1) or non-habitat (resistance values >1), based on assigned resistance values. A GIS moving window analysis was then applied to generate a habitat density surface, with each cell representing the proportion of habitat around it. Habitat concentration areas were defined as areas that were at least 50 km^2 and composed of cells that had ≥75% good habitat (resistance value of 1) within 2 km.

Resistance values were derived from habitat descriptions from the literature, with shrubsteppe habitat assigned the lowest values. Resistance parameter values for non-habitat conditions such as agricultural lands, developed landscapes, and roads were based on expert opinion.

3.2.5.3. MODEL RESULTS

Habitat Concentration Areas — The 31 black-tailed jackrabbit HCAs are located throughout the Columbia Plateau shrubsteppe habitat in Washington, from the Columbia River north, with the northern most HCA modeled in Okanogan County (Fig. 3.13; Table 3.2). The modeling process resulted in HCAs occurring outside of the historical range of black-tailed jackrabbits, specifically within the Okanogan Highlands. These HCAs were retained on the statewide map due to the availability of suitable habitat in sufficient quantities to support black-tailed jackrabbits. The most sizeable HCAs are located on the Hanford Reach National Monument, Yakama Tribal Lands, YTC, WDFW Swanson Lakes Wildlife Area and on other state and federal public lands throughout the historical extent of the Columbia Plateau where larger tracts of shrubsteppe lands still exist.

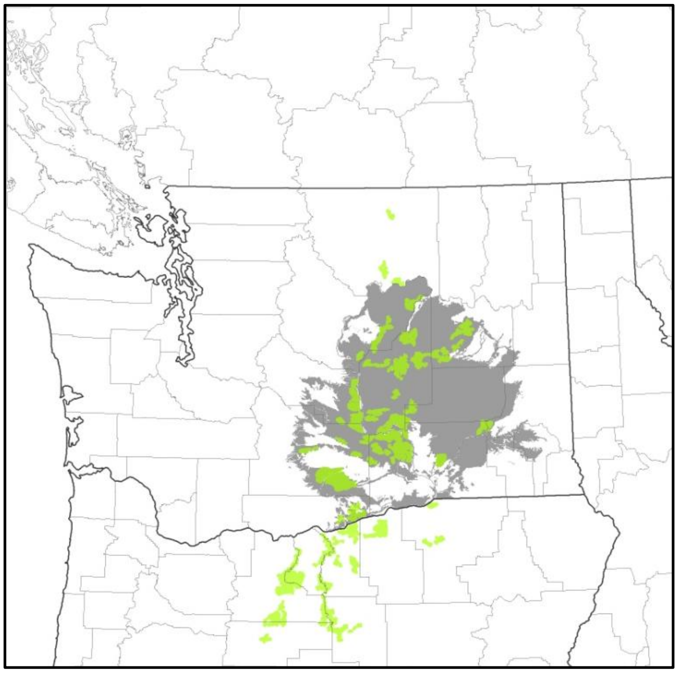


Figure 3.13. Black-tailed jackrabbit HCAs (green) and GAP distribution (gray).

Resistance Surface — The black-tailed jackrabbit resistance surface indicates good conditions for movement within their distributional range east of the Cascades in shrubsteppe dominated habitat (Fig. 3.14). The resistance values were used as representative of habitat values and matched up relatively well with known occurrence data for jackrabbits. While roads are assigned resistance values derived from the road type and distance, jackrabbit movement itself is not deterred by the presence of roads, though jackrabbits are definitely at risk from mortality associated with vehicles.

Cost-weighted Distance — The cost-weighted distance map (Fig. 3.15) illustrates the full range of areas suitable for movement between HCAs. Black-tailed jackrabbit HCAs appear highly connected (i.e., the cost-weighted distance between them is low) within the available shrubsteppe habitat in the Columbia Plateau.

Linkage Modeling — Linkages were modeled between 75 discrete pairs of HCAs within or partially within Washington. Least-cost distances between these 75 linkages ranged from 1 to 90km (1 to 90 km Euclidean distance). The Euclidean to cost-weighted ratio ranged from 1 to 312 (Table 3.3).

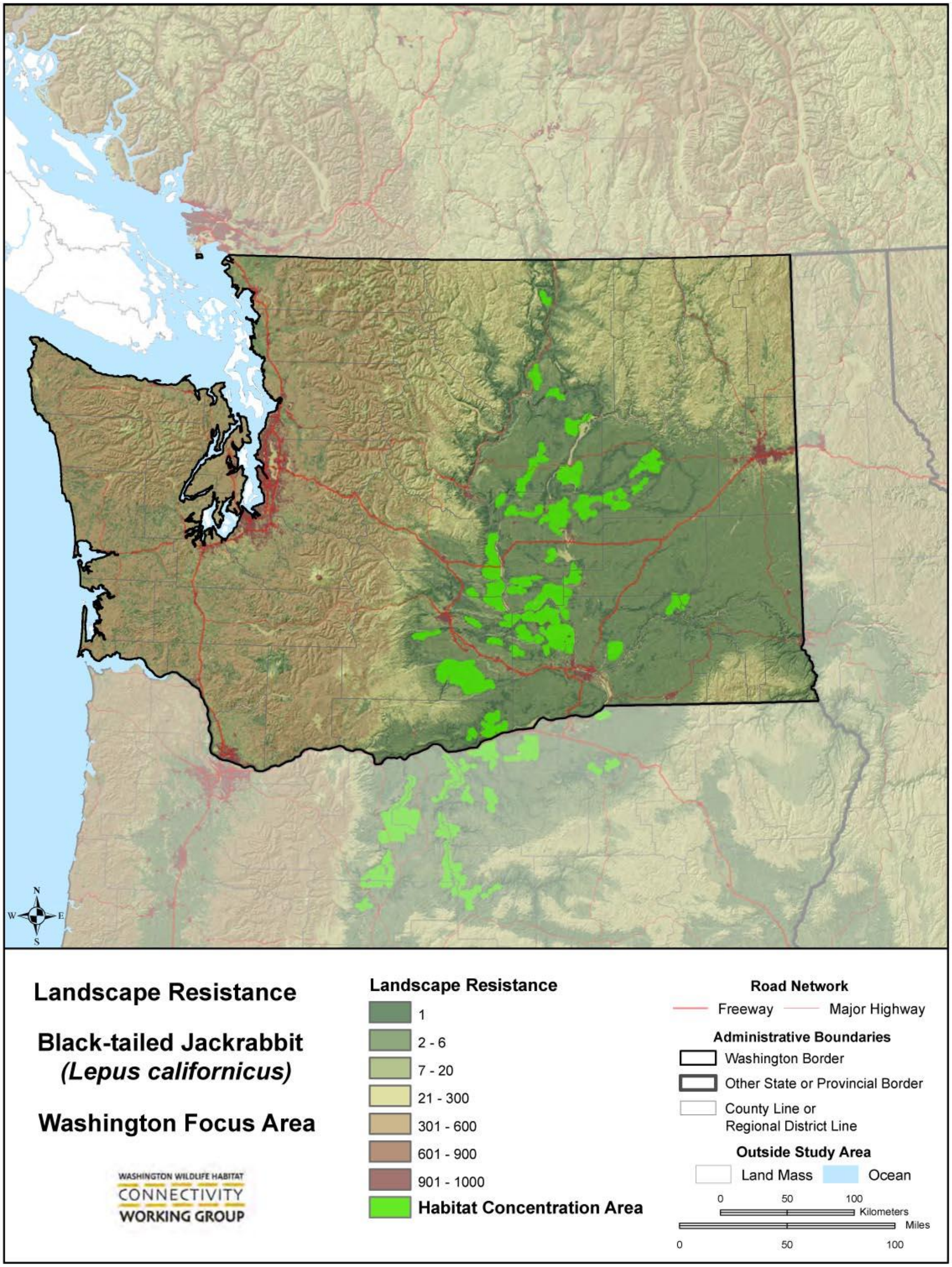


Figure 3.14. Landscape resistance for black-tailed jackrabbits.

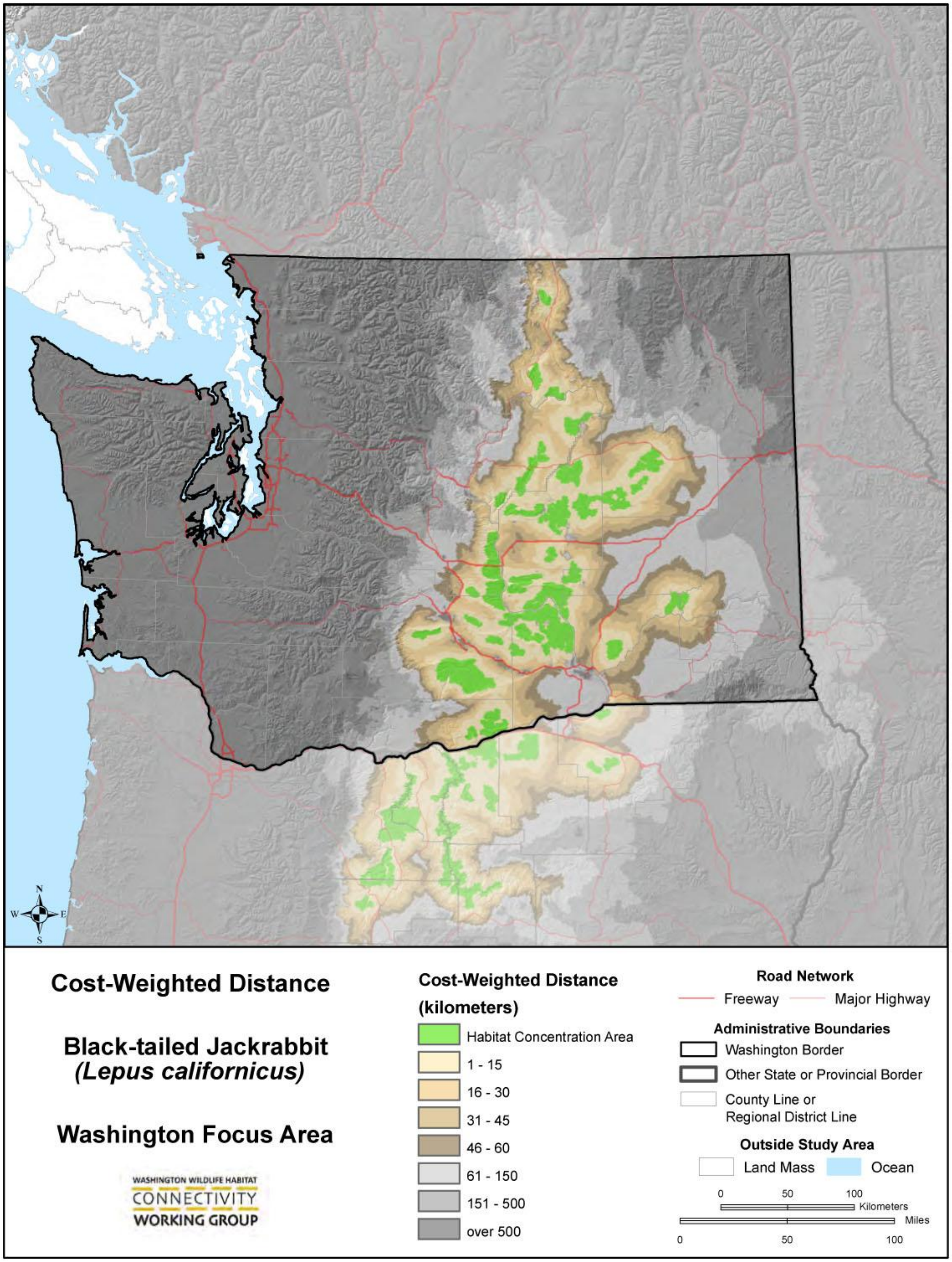


Figure 3.15. Cost-weighted distance for black-tailed jackrabbits.

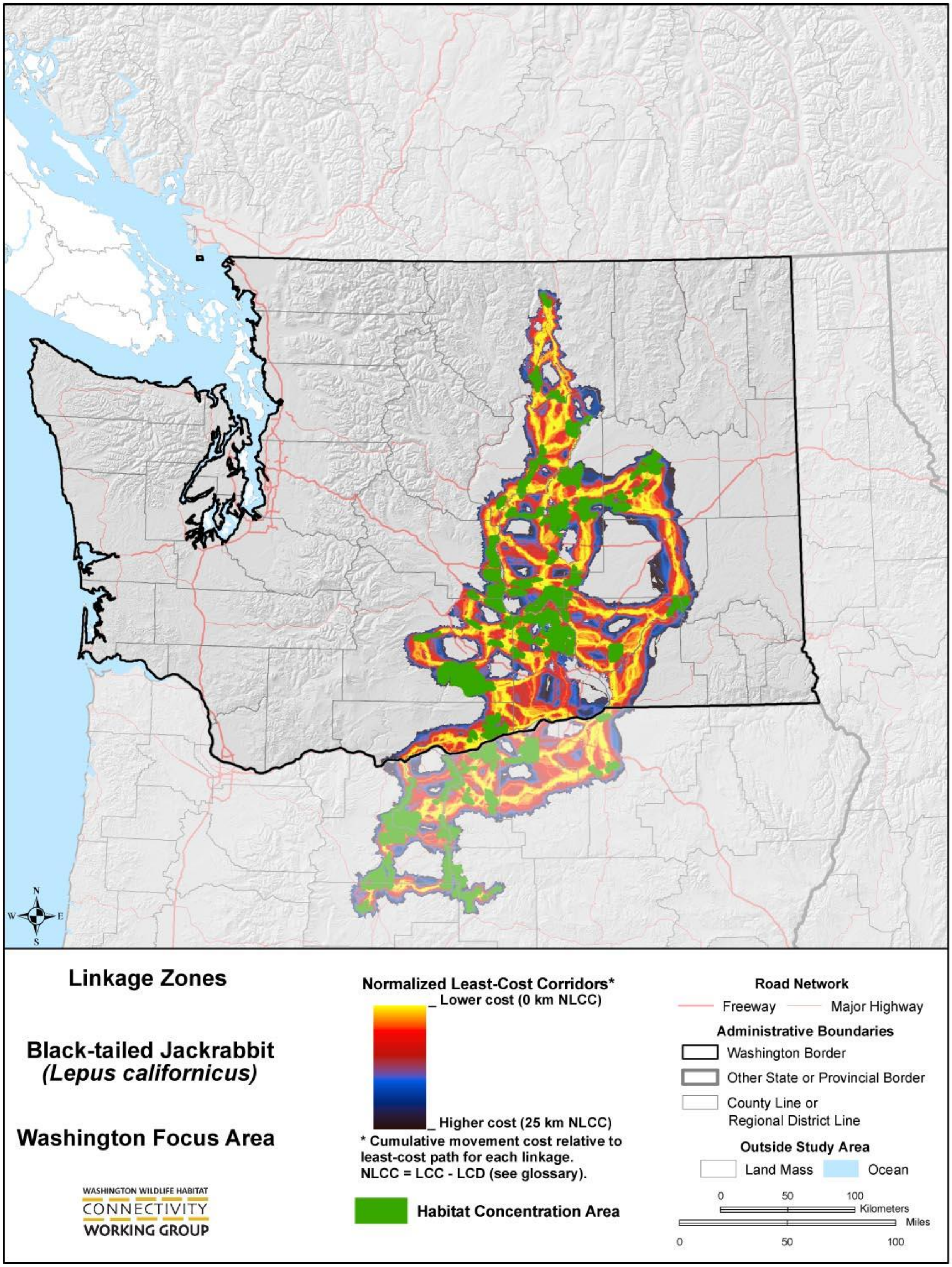


Figure 3.16. Black-tailed jackrabbit linkages.

3.2.6. White-tailed Jackrabbit (*Lepus townsendii*)

3.2.6.1. INTRODUCTION

White-tailed jackrabbit, photo by Doug Backlund.

The white-tailed jackrabbit is an ecologically important species affecting habitats and serving as prey for a wide variety of raptors and mammalian predators (Flinders & Chapman 2003). Its range extends from the prairies of the mid-western states and Canadian provinces westward to the Rocky Mountains, Cascades and Sierra Nevada mountain ranges and southward to the northern borders of Utah and New Mexico. Most populations are declining due to factors such as, habitat loss, degradation, fragmentation, competition with black-tailed jackrabbits, and unregulated hunting (Flinders & Chapman 2003). In Washington, it is found throughout the arid Columbia Plateau. White-tailed jackrabbits are largely nocturnal which makes population monitoring a challenge; no reliable census method exists for all population levels. The white-tailed jackrabbit is listed as a Washington State Candidate species.

In parts of its historical range, where cultivation, drought or overgrazing have affected the habitat, white-tailed jackrabbits have been replaced by black-tailed jackrabbits (Armstrong 1972). In areas where the two species overlap they use different habitats: black-tailed jackrabbits occur primarily in sagebrush habitats with open grass while white-tailed jackrabbits are most common in bunchgrass habitats with less shrub cover (Anthony 1913; Couch 1927). White-tailed jackrabbits generally prefer more open habitat than black-tailed jackrabbits; and in Washington they occur at somewhat higher elevations, in habitats such as grassy hills and plateaus (Johnson & Cassidy 1997). Dalquest (1948) found white-tailed jackrabbits on arid, hilly bunchgrass sites during the summer and in lower sagebrush valleys during winter. Dalquest (1948) also noted that as bunchgrass decreased due to overgrazing so did numbers of white-tailed jackrabbits.

The white-tailed jackrabbit was selected as a focal species because its connectivity needs reflect those of other species in the Semi-desert vegetation class. White-tailed jackrabbits scored high for all four major connectivity threats: clearing and vegetation removal, development, roads and traffic, and the presence of people and domestic animals. White-tailed jackrabbits are at considerable risk for increased mortality from vehicle traffic, persecution, and harassment by pets.

3.2.6.2. MODEL CONCEPTUAL BASIS

Resistance values for landscape features were derived from descriptions in the literature of white-tailed jackrabbit habitat and seasonal movements. In cases where little published information was available we relied upon the professional judgment of expert reviewers. Urban land-use and roads were considered top factors impeding movement of white-tailed jackrabbits through suitable landscape.

Due to a lack of scientific studies and occurrence data, core habitat areas for white-tailed jackrabbits were not well defined. We modeled habitat concentration areas (HCAs) based on habitat suitability whereby grid cells in a moving window were designated as either habitat or non-habitat based on resistance values assigned to landscape features for the white-tailed jackrabbit; resistances values of 1 were selected as white-tailed jackrabbit habitat while those greater than 1 were designated as non-habitat. We then calculated the proportion of habitat within a circular moving window while passing over the resistance surface. To establish the size of the moving window we used literature describing patterns of white-tailed jackrabbit movement. Home range of the white-tail is reported as 2 to 3 km in diameter (Seton 1928; Jackson 1961), but information is scant. We used a home range of 2 km in the model. A habitat density threshold (proportion of the moving window that is white-tailed jackrabbit habitat) of 85% was applied. Habitat areas were then expanded outwards up to a total cost-weighted distance equal to a home-range movement radius of 2.0 km. This had the effect of joining nearby habitat cells if the intervening landscape supported within-home range connectivity. Small habitat patches less than 50 km^2 were eliminated because they were unlikely to support a viable population of jackrabbits.

3.2.6.3 MODEL RESULTS

Habitat Concentration Areas — The 38 white-tailed jackrabbit HCAs are located throughout the Columbia Plateau grassland and shrubsteppe habitat (Fig. 3.17). White-tailed jackrabbits tend to occur at higher elevations than the black-tailed jackrabbits, and their distribution extends up the Okanogan drainage into B.C. The most sizeable HCAs are located on the Hanford Reach National Monument, Yakama Reservation, Yakima Training Center, WDFW Swanson Lakes Wildlife Area in Lincoln County and on other State and Federal public lands throughout the historical extent of the Columbia Basin, where larger tracts of grassland and shrubsteppe lands still exist.

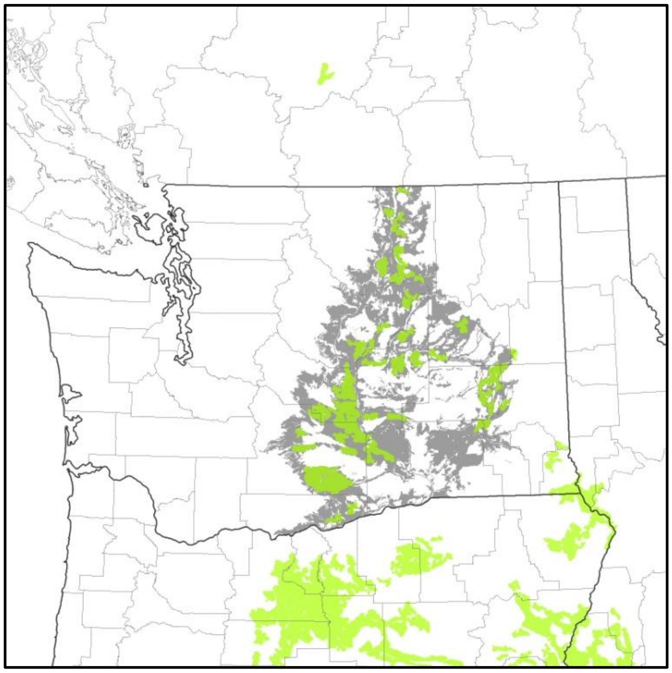


Figure 3.17. White-tailed jackrabbit HCAs (green) and GAP distribution (gray).

Resistance Surface — The white-tailed jackrabbit resistance surface indicates good conditions for movement within their distributional range east of the Cascades in grassland shrub-dominated habitat (Fig. 3.18). While centerlines of roads, particularly major highways, are assigned the highest resistance values, jackrabbit movement is not deterred by the presence of roads. The resistance values were used as representative of habitat values and matched up relatively well with known occurrence data for jackrabbits.

Cost-weighted Distance — The white-tailed jackrabbit cost-weighted distance map illustrates the full range of areas suitable for movement between HCAs (Fig. 3.19). Looking at the map, white-tailed jackrabbit HCAs appear highly connected (i.e., the cost-weighted distance between them is low) within the available shrubsteppe and grassland habitat in the Columbia Plateau.

Linkage Modeling — Linkages were modeled between 81 discrete pairs of HCAs within or partially within Washington. Least-cost distances for these 81 linkages ranged from <1 to 147 km (Table 3.3). The Euclidean to cost-weighted ratio ranged from 1 to 213 km. The results of the least-cost corridor model for white-tailed jackrabbit show strong connections throughout the HCA matrix; corridors are often associated with shrubsteppe habitats (Fig. 3.20). Corridors from HCAs in southeastern Washington follow the Snake River drainage. Connections in eastern Washington between the lower Rock Creek drainage and the Potholes follow patchy areas of shrubsteppe cover. Corridors between HCAs flow around areas of cultivated cropland.

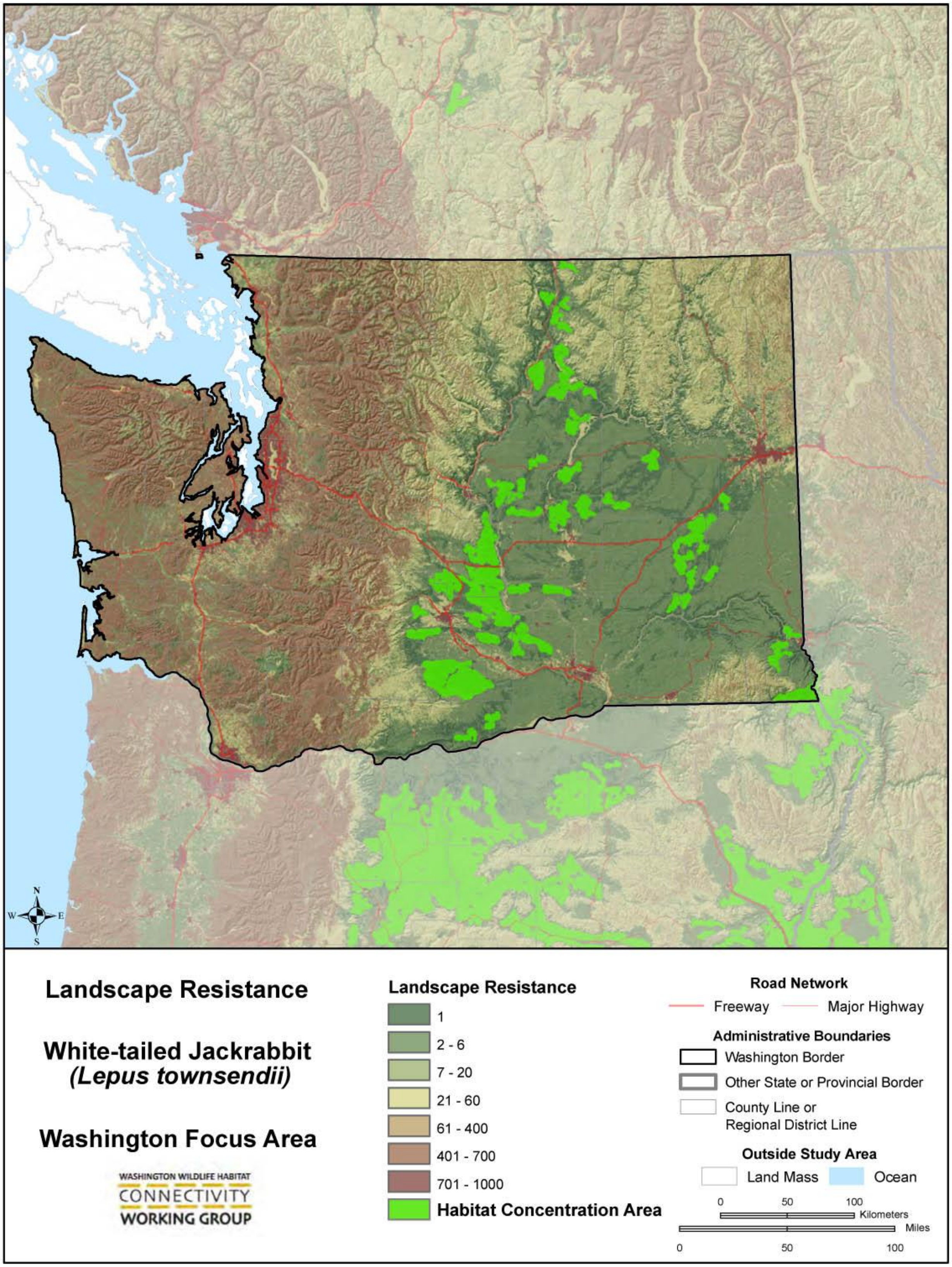


Figure 3.18. Landscape resistance for white-tailed jackrabbits.

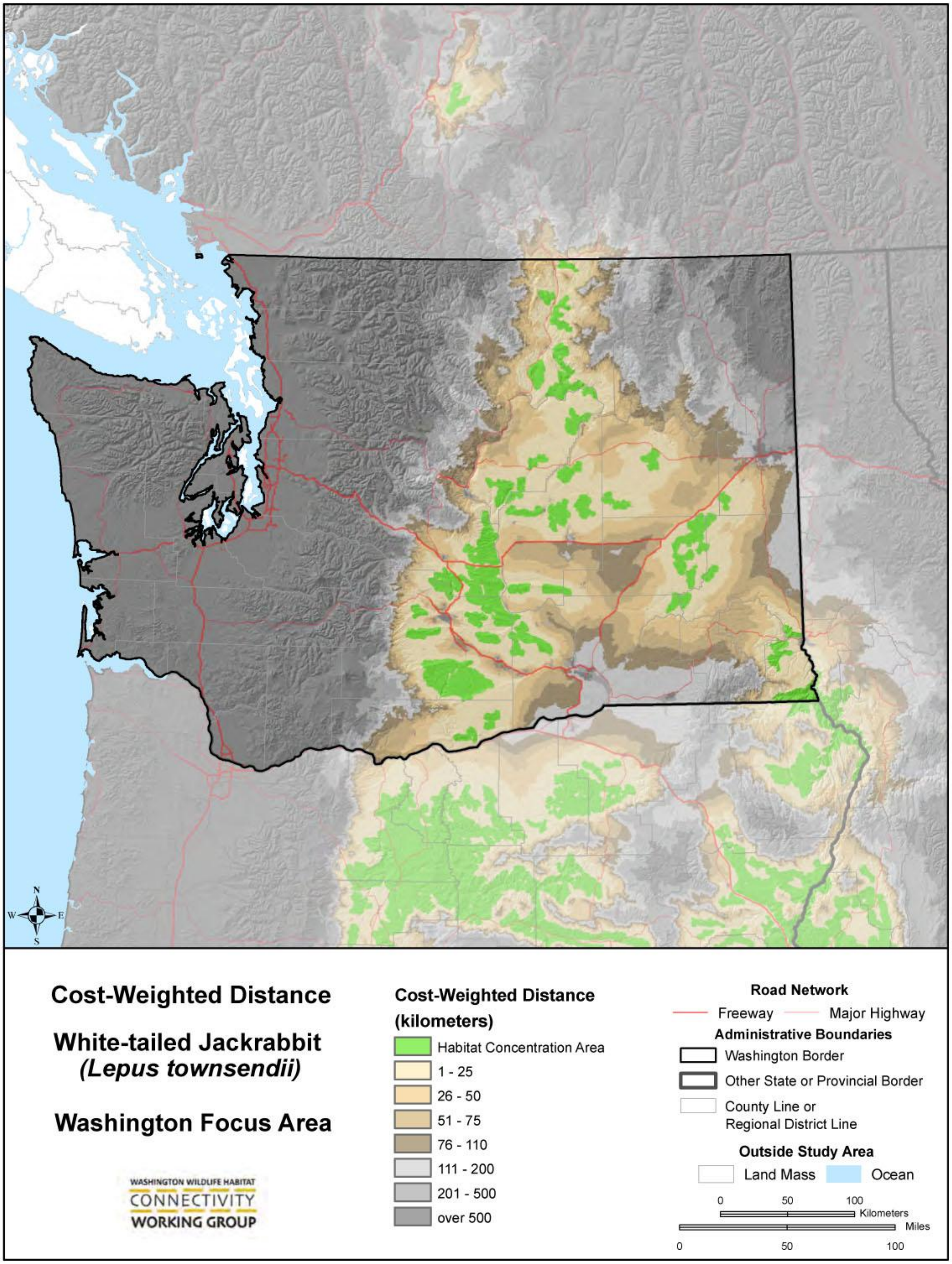


Figure 3.19. Cost-weighted distance for white-tailed jackrabbits.

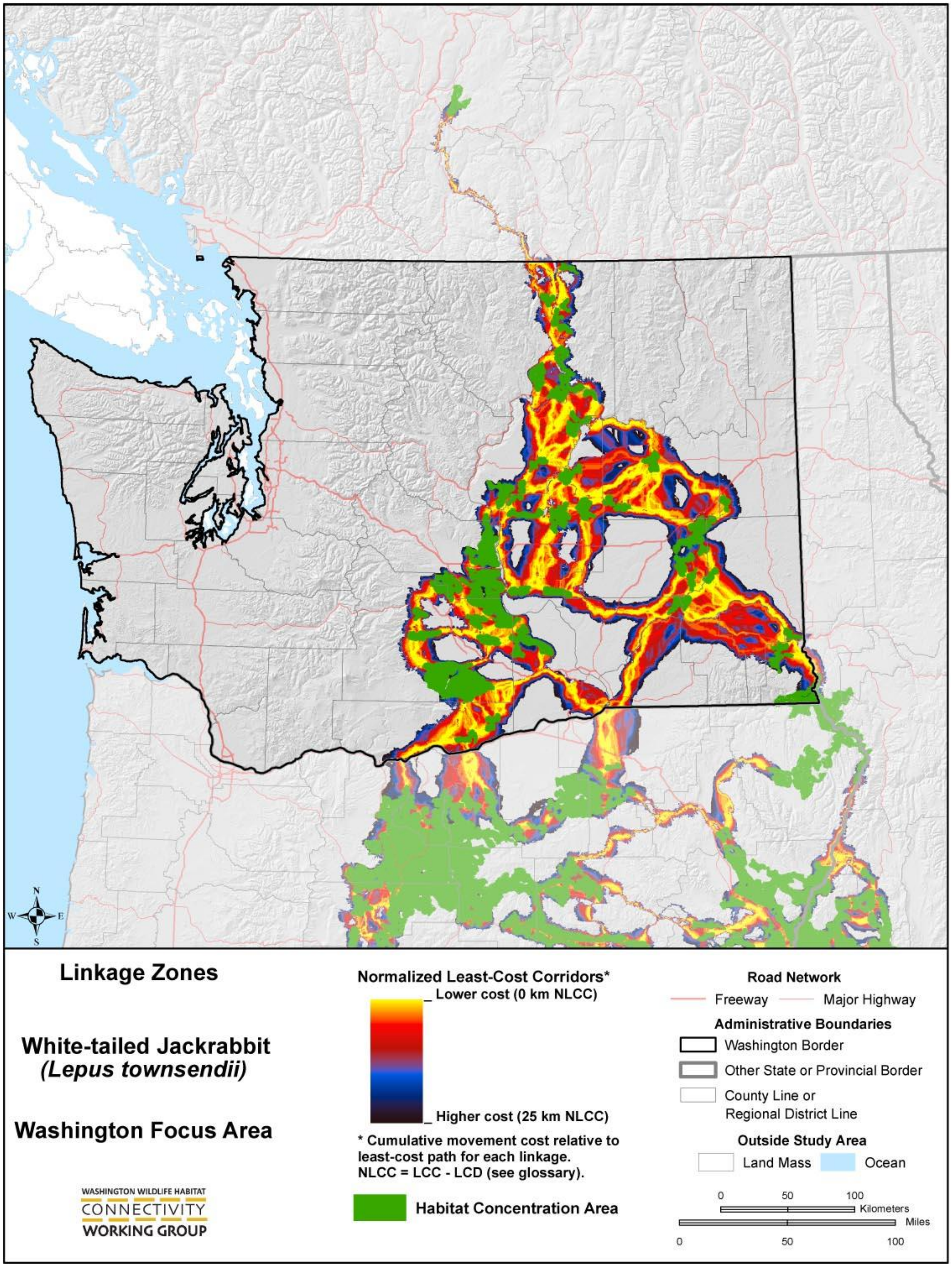


Figure 3.20. White-tailed jackrabbit linkages.

3.2.7. Mule Deer (*Odocoileus hemionus*)

3.2.7.1. INTRODUCTION


Black-tailed deer, photo by Kelly McAllister.

Mule deer are found throughout much of western North America, extending as far east as Nebraska, Kansas, and western Texas. In Washington, two subspecies of mule deer are recognized: black-tailed deer (*Odocoileus hemionus columbianus*), found primarily west of the crest of the Cascade Mountains, and Rocky Mountain mule deer (*Odocoileus hemionus hemionus*), which are widespread east of the crest of the Cascades. Only the larger agricultural blocks of the Columbia Plateau fail to support robust populations, due to a lack of adequate forest or shrub cover (Johnson & Cassidy 1997).

Mule deer are important members of the wildlife community, serving a number of key ecological functions as herbivores and prey for large carnivores such as cougars (*Felis concolor*) and wolves (*Canis lupus*). Some local populations are migratory, exploiting productive mountain meadow habitat in summer but retreating to low-elevation valleys in winter. As such, migratory mule deer often move long distances on a seasonal basis. Mule deer were selected as good representatives of connectivity needs in the Semi-desert and Northern Rocky Mountain Forest vegetation classes.

3.2.7.2. MODEL CONCEPTUAL BASIS

Mule deer require a mosaic of habitat types of different age classes to meet their life history requirements. They use forest, woodland, brush, and meadow habitats, reaching their highest densities in open pine forests, riparian strips within arid and agricultural lands, and along edges of meadows and grasslands. They also occur in open scrub, young chaparral, and low-elevation coniferous forests. A variety of brush cover and tree thickets interspersed with meadows and shrubby areas are important for food and cover. Thick cover can provide escape from predators, shade in the summer, or shelter from wind, rain and snow. Varying slopes and topographic relief are important for providing shade. Fawning occurs in moderately dense shrub, forest, riparian or meadow edge cover. Meadows are particularly important as fawning habitat.

Habitat concentration areas were identified based on habitat suitability scores that were used to build the GIS resistance surface. Apparently suitable habitat was eliminated from consideration if it fell outside of documented mule deer range (North American Mule Deer Foundation, unpublished data). A GIS moving window analysis was used to identify areas with the highest concentrations of suitable habitat. Only patches of 100 km^2 or greater were retained as HCAs.

The GIS moving window analysis used movement data from published research. Home range estimates vary from 39 ha to 3379 ha. Harestad and Bunnell (1979) calculated mean home range from several studies as 285 ha. Doe and fawn groups have smaller home ranges, averaging 100–300 ha, but can vary from 50 to 500 ha. Bucks usually have larger home ranges and are known to wander greater distances. A recent study of 5 different sites throughout California recorded home range sizes from 49 to 1138 ha.

Where deer are seasonally nomadic, winter and summer home ranges tend to largely overlap in consecutive years. Elevational migrations are observed in mountainous regions in response to extreme weather events in winter, or needs for shade or perennial water in summer. Distances travelled between winter and summer ranges vary from 8.6 to 29.8 km. Robinette (1966) observed natal dispersal distances ranging from 97 to 217 km.

3.2.7.3. MODEL RESULTS

Habitat Concentration Areas — Seventy mule deer HCAs were identified in the entire project area of which 34 were wholly or partially in Washington. The Washington HCAs ranged from 100 to 60,905 km^2 in size (Fig. 3.21; Table 3.2). Mule deer HCAs are extensive over much of the project area. However, landscapes within the arid Columbia Plateau and urbanized Puget Trough had few HCAs. Much of the Idaho Panhandle and extreme northeastern Washington were not included in an HCA because they were not mapped as significant mule deer range by the Mule Deer Foundation.

Resistance Surface — The mule deer resistance surface indicates good conditions for deer movements in all of the more mountainous regions of the project area as well as some areas of the Columbia Plateau where native shrub cover is plentiful (Fig. 3.22). Heavily urbanized areas and busy road corridors contributed to barriers.

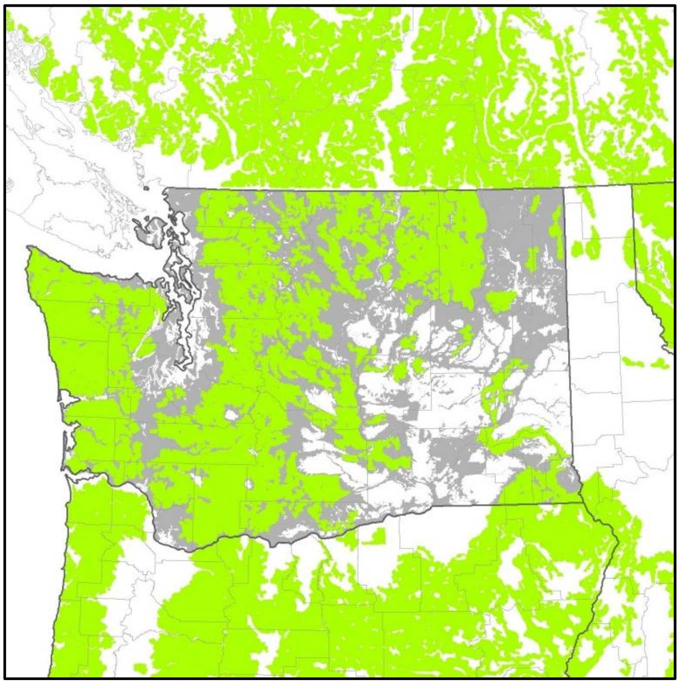


Figure 3.21. Mule deer HCAs (green) and GAP distribution (gray).

Cost-Weighted Distance — The mule deer cost-weighted distance map indicates that connectivity is good throughout much of the project area (Fig. 3.23). Movement between HCAs appears reasonably likely even in the arid Columbia Plateau where HCAs tend to be more widely separated.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 250 km. This resulted in linkages being modeled between 86 discrete pairs of HCAs wholly or partially in Washington (Fig. 3.24). Straight-line Euclidean distances between HCAs ranged from <1 to 130 km. Weighted least-cost distances for these 86 linkages ranged from 1 to 241 km.

In western Washington, the more significant linkages included a corridor connecting the Olympic Mountains with the Tahuya Peninsula. This linkage follows the south shore of Hood Canal from the Skokomish River to the Belfair vicinity. Others link Fort Lewis and the Vail Tree Farm to the Capital Forest, following paths that cross several busy highways, including I-5. Another important linkage across I-5 was identified north of the Toutle River. Eastern Washington's linkages include several that link identified HCAs in Klickitat County. These linkages are associated with Rock Creek, Alder Creek and Pine Creek. Other important corridors correspond with Moses Coulee and East Foster Creek and the breaks of the Columbia River near Chelan. Modeled corridors cross I-90 both east and west of Sprague Lake. Several HCAs in the high elevations of Pend Oreille and Steven’s Counties, and adjacent areas in British Columbia and Idaho, are joined by modeled corridors. In southeastern Washington, the Tucannon and Snake Rivers contribute to a linkage that connects to an extensive arid-lands HCA associated with Cow Creek to the Blue Mountains.

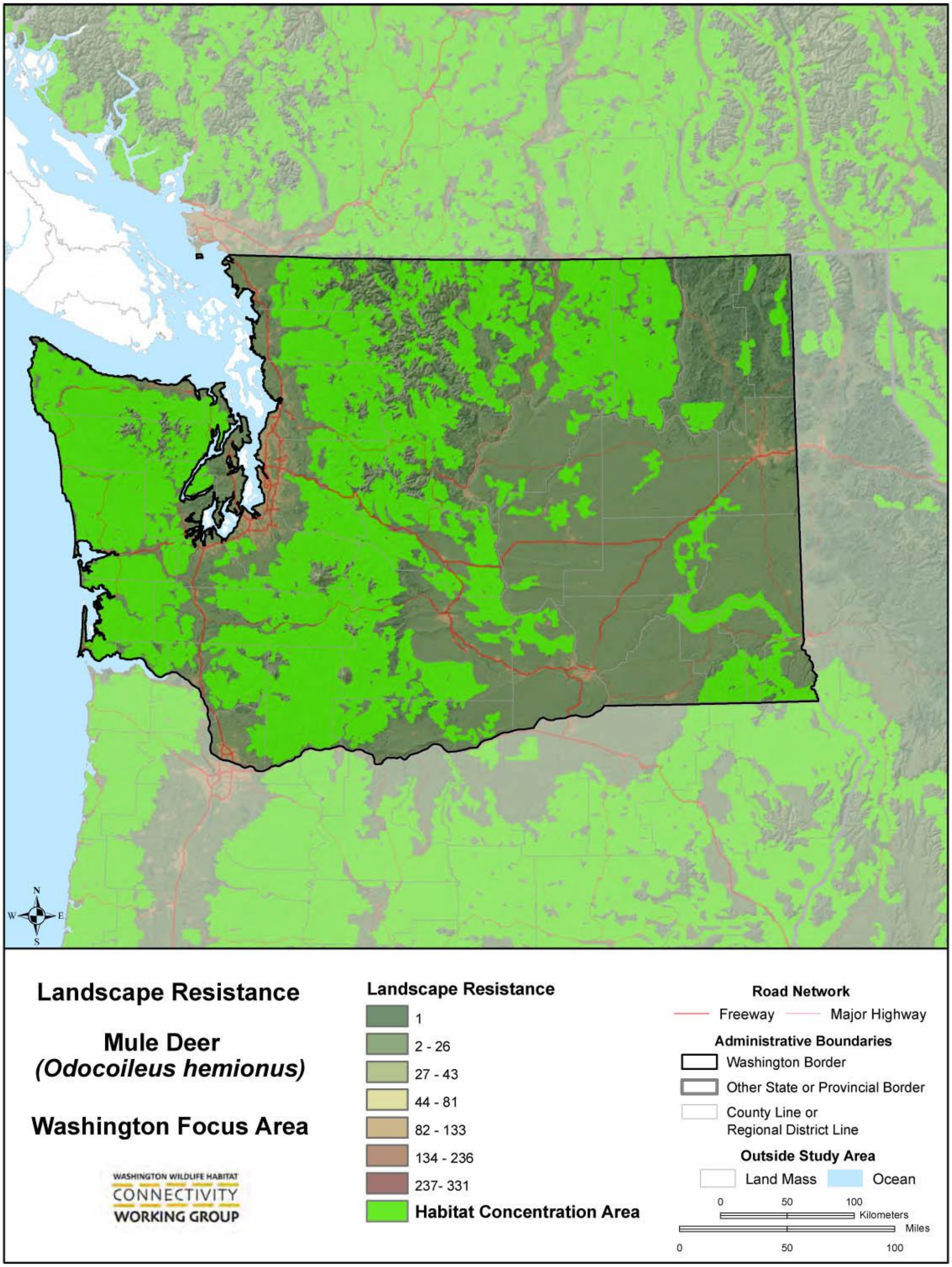


Figure 3.22. Landscape resistance for mule deer.

Figure 3.23. Cost-weighted distance for mule deer.

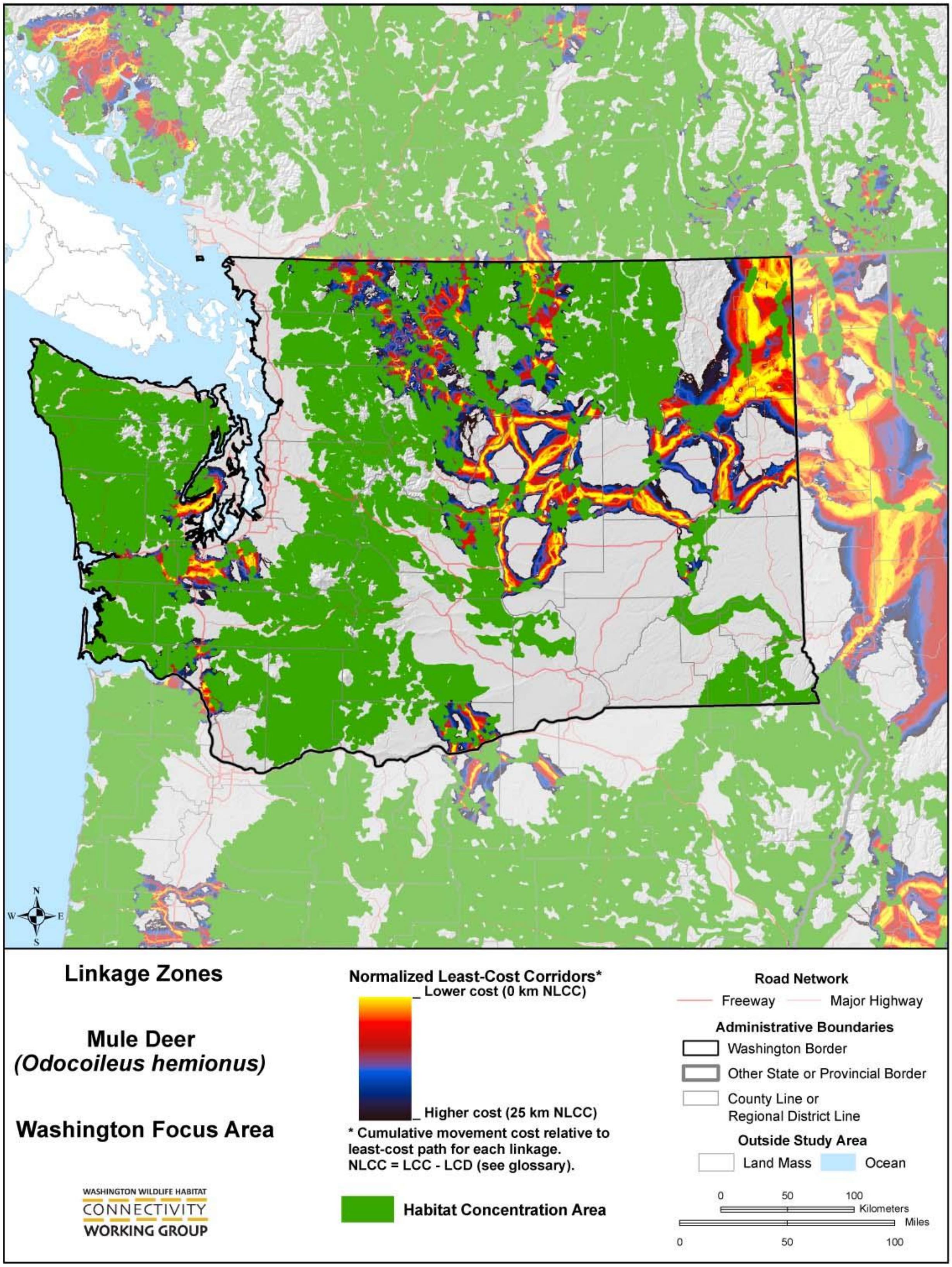


Figure 3.24. Mule deer linkages.

3.2.8. Bighorn Sheep (*Ovis canadensis*)

3.2.8.1. INTRODUCTION

Bighorn sheep have a history of active management in Washington State. The species was extirpated from the state and had to be re-introduced. Most of the herds were gone before 1900. The last known survivors, on Chopaka Mountain, died in 1925 (Johnson 1999a). Historically, bighorn sheep occurred on the eastern slopes of the Cascades from the Canadian border south to the Columbia River and in the Selkirk Mountains. Bighorn sheep were extirpated from the Selkirks by the late 1800s (Johnson 1999b).

Bighorn sheep, photo by Mike Schroeder.

As a result of considerable efforts to re-establish populations, bighorn sheep are now distributed across eastern Washington in 19 herds, each with a limited geographic range. There are approximately 1000–1500 bighorn sheep statewide. Bighorn sheep were selected as a focal species to represent the Rocky Mountain Forests vegetation class.

3.2.8.2. MODEL CONCEPTUAL BASIS

Habitat concentration areas for bighorn sheep were identified using a GIS layer of herd ranges compiled for the western U.S. and Canada. Herd ranges and HCAs were limited to south-central British Columbia, eastern Washington, northern and central Idaho, and the Blue Mountains in northeastern Oregon and southeastern Washington. A total of 37 HCAs were identified within the project area.

Dispersal rates in female bighorn sheep have been reported to be very low (Festa-Bianchet 1991; Jorgenson et al. 1997). Epps et al. (2005) reported that the distance between populations of bighorn sheep appeared to be a prevailing natural barrier, as evidenced by the strong correlation between genetic diversity and gene flow with distance. They estimated a “barrier effect distance” to be about 40 km.

3.2.8.3. MODEL RESULTS

Habitat Concentration Areas — Thirty-seven HCAs were identified within the project areas, 17 were wholly or partially within Washington. The HCAs covered about 13,041 km^2 and ranged in size from 24 km^2 to 9521 km^2 (Fig. 3.25).

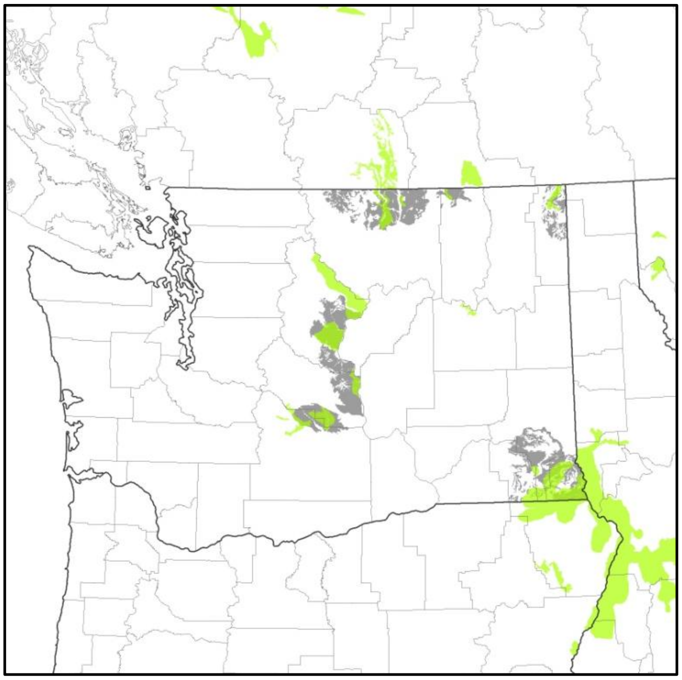


Figure 3.25. Bighorn sheep HCAs (green) and GAP distribution (gray).

Resistance Surface — The bighorn sheep resistance surface indicates limited conditions for bighorn movements in the project area (Fig. 3.26).

Cost-weighted Distance — There are a number of gaps between the HCAs as bighorn sheep populations are generally not well connected (Fig. 3.27). Barriers to connectivity include highways, roads, trails, and areas of human disturbance.

Linkage Modeling — Linkages were modeled where the least-cost distance between a pair of HCAs was less than 1000 km. This resulted in 22 linkages being modeled between HCAs (Fig. 3.28). The mean Euclidean distance of the linkages was 30 km and ranged from <1 to 112 km. The mean cost-weighted distance of the linkages was 336 km and the ratio of cost-weighted to Euclidean distance ranged from 9 to 94.

Linkages occur between bighorn sheep populations in the Tieton, Mount Clemens, and Umtanum herds. However these populations are likely isolated from populations further north. Linkages occur between bighorn sheep in the Chelan Butte and Lake Chelan herds. Linkages also occur between the Tucannon River/Wooten and Cottonwood Creek herds in the Blue Mountains. The Quilomene, Swakane, Lincoln Cliffs, and Vulcan Mountains herds are isolated and the potential linkages are intended to identify areas where finer-scale modeling will be important to determine the feasibility of providing habitat connectivity. It may also be useful in determining where future bighorn sheep re-introductions could occur to facilitate ***metapopulation*** function.

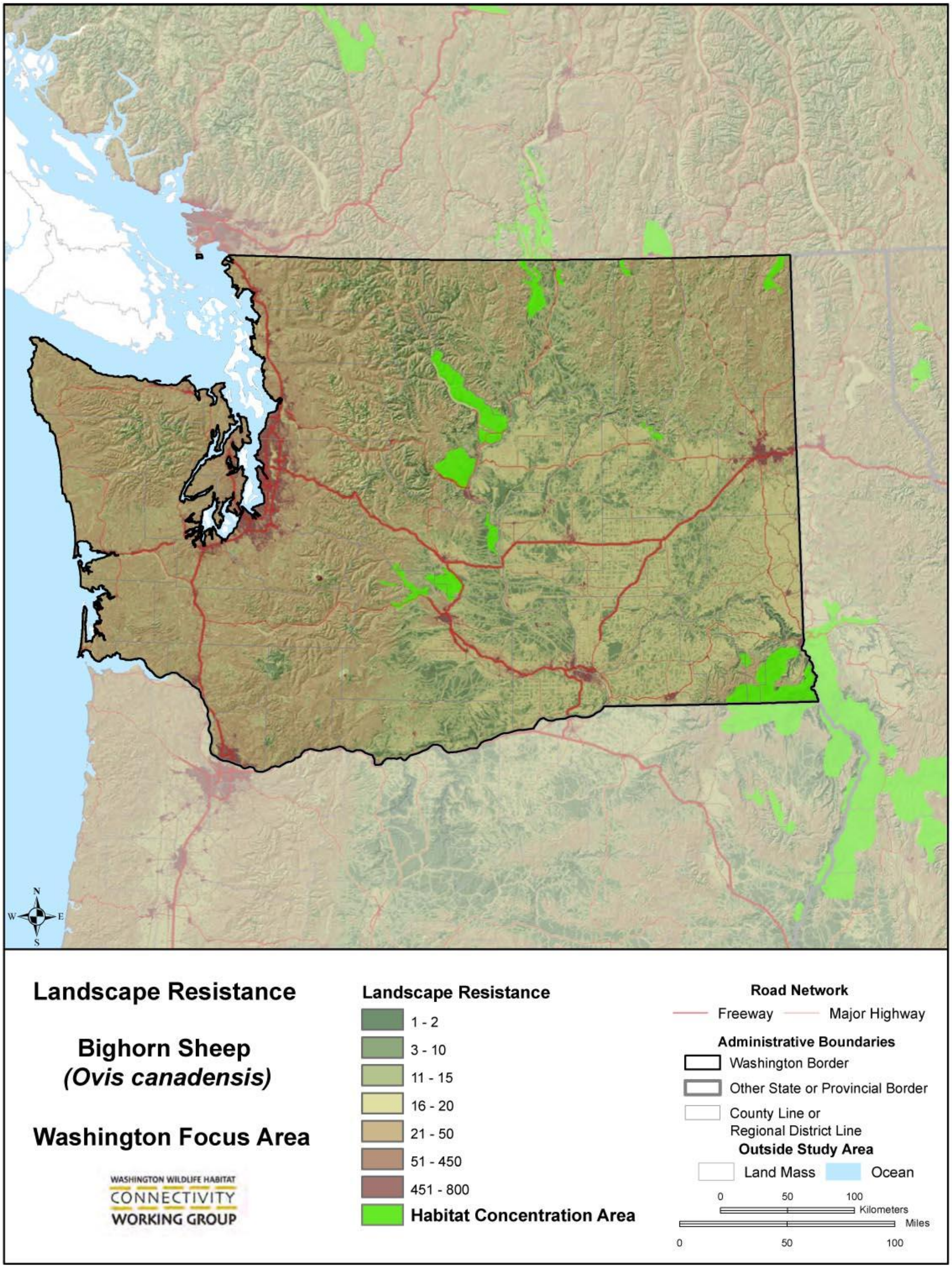


Figure 3.26. Landscape resistance for bighorn sheep.

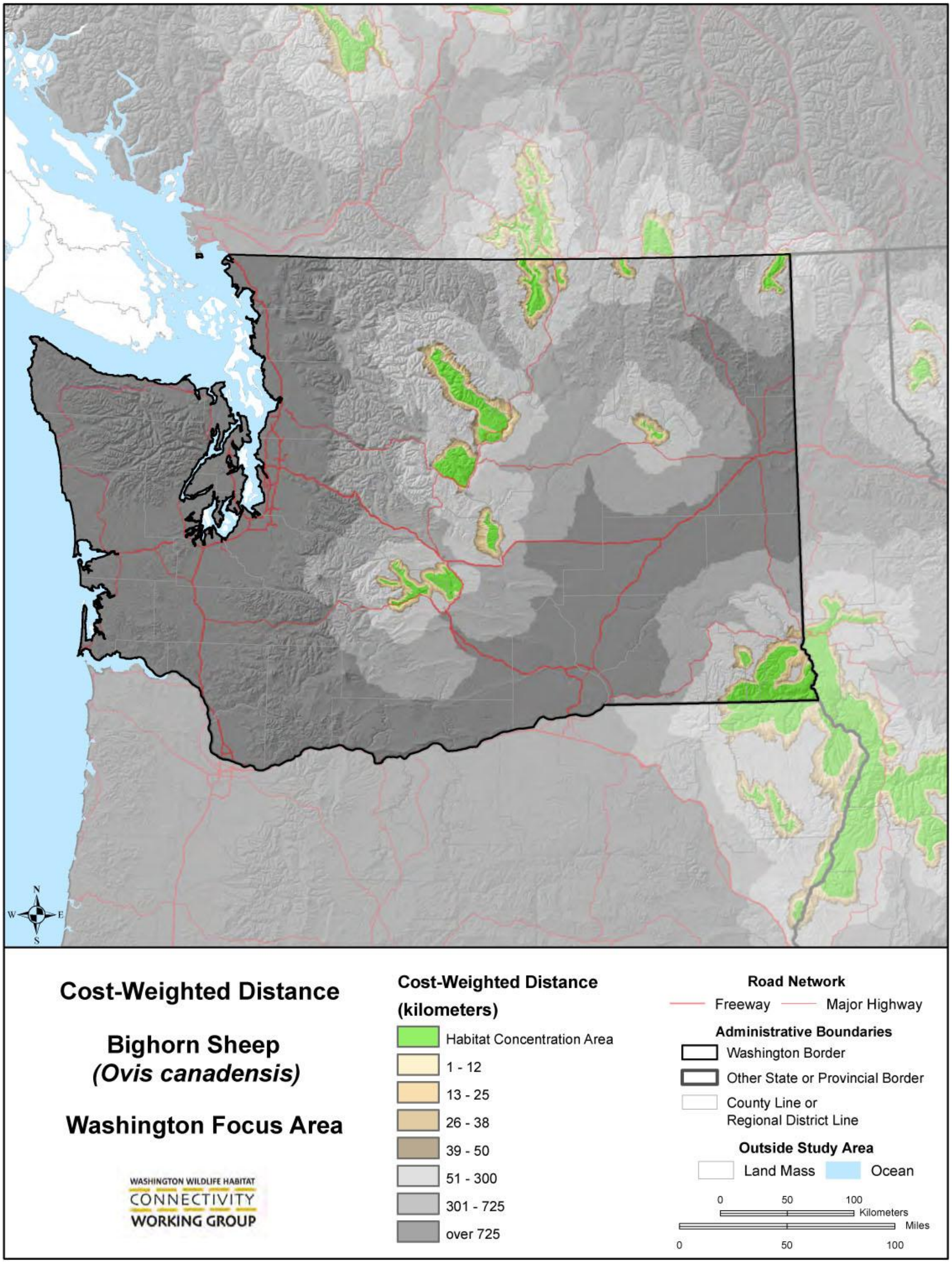


Figure 3.27. Cost-weighted distance for bighorn sheep.

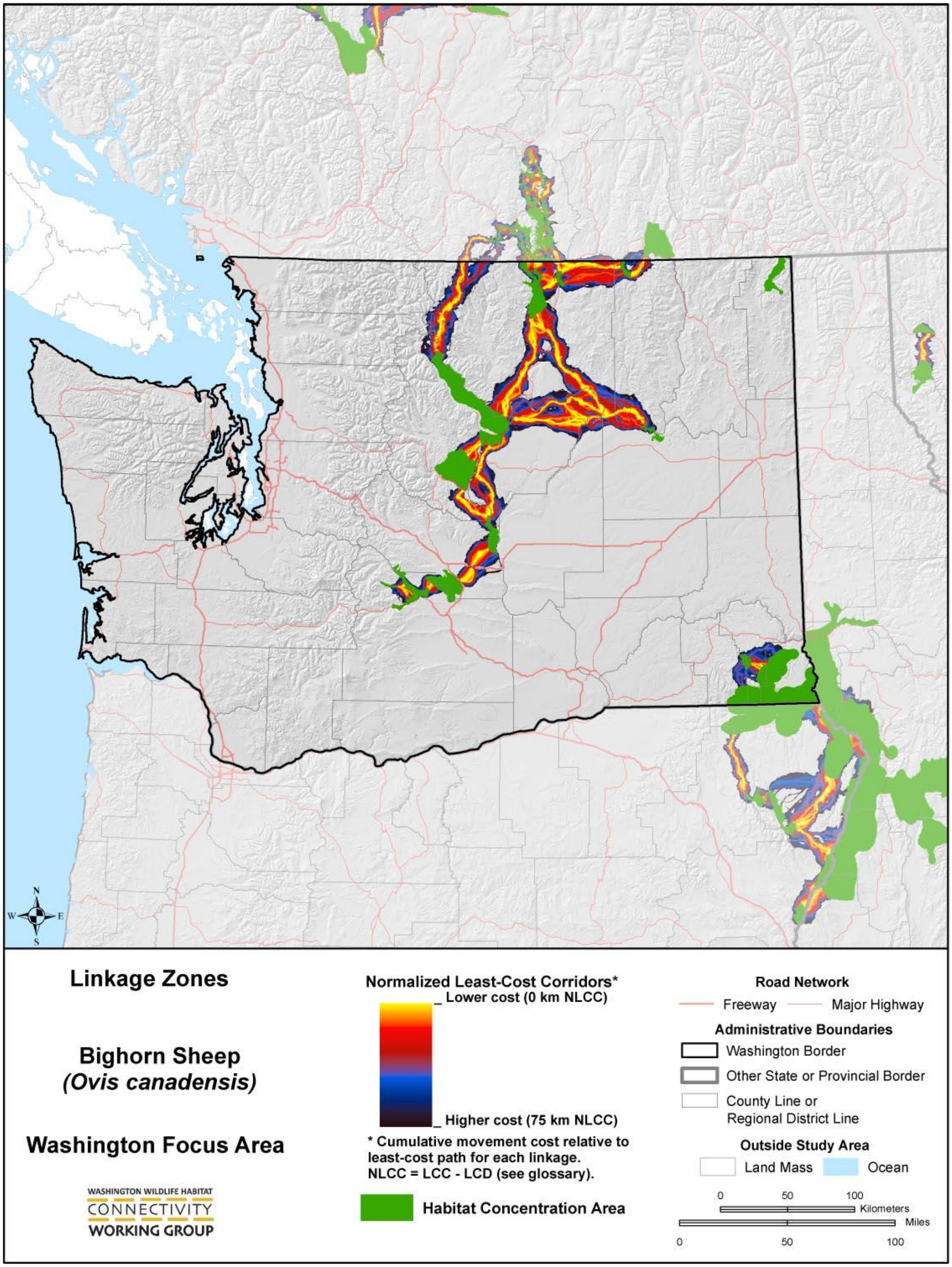


Figure 3.28. Bighorn sheep linkages.

3.2.9. Western Gray Squirrel (*Sciurus griseus*)

3.2.9.1. INTRODUCTION

Western gray squirrel, photo by Rod Gilbert.

The western gray squirrel is Washington's largest native tree squirrel. Washington State lists this squirrel among the state's Threatened species. Its numbers and geographic range have diminished and, in much of its western Washington range, it has been replaced by the non-native eastern gray squirrel (*S. carolinensis*). Western gray squirrels range from north-central Washington south to the southern border of California. Within Washington, their range consists of three geographically distinct areas: South Puget Sound (primarily Joint Base Lewis-McChord), Klickitat County extending into Yakima County, and the Lake Chelan and Methow Valley region.

The western gray squirrel was selected as a focal species because it is a good representative of wildlife habitat connectivity needs within the Rocky Mountain Forests vegetation class. The species was considered vulnerable to loss of habitat connectivity from all four overarching connectivity threats: land clearing and vegetation removal, development, roads and traffic, and the presence of people and domestic animals. Western gray squirrels inhabit mast-producing conifer-hardwood forest types such as, in Washington, transitional forests of ponderosa pine (*Pinus ponderosa*), Oregon white oak (*Quercus garryana*), Douglas-fir (*Pseudotsuga menziesii*), and various riparian tree species. Most occupied forest habitats contain pine or oak, though the presence of both is not essential. Suitable conditions are often found close to edges between forest and grass or shrub-dominated landscapes. In these areas fire often contributes to a sparse or open understory and may be influential in maintaining the vigor of mast-bearing trees and shrubs.

3.2.9.2. MODEL CONCEPTUAL BASIS

Habitat concentration areas were identified from known occupied habitat, areas with concentrations of ponderosa pine or Oregon white oak forests, within the historical range of the species. A GIS moving window analysis was applied to identify areas with the greatest concentrations of suitable habitat.

Resistance parameters were derived, primarily, from literature describing suitable habitat characteristics and, therefore, forested conditions received the lowest resistance values. Resistance parameters for non-habitat conditions such as roads, agriculture, and developed areas were based on professional judgment and vetted with experts attending a workshop in Cle Elum, Washington on 10 November 2009.

To establish the size of the GIS moving window used to identify HCAs, available information on western gray squirrel movement scale was used. Western gray squirrels regularly move 4–5 km in brief time intervals. Juveniles have been tracked dispersing an average of 2862 m from their natal site (Vander Haegen et al. 2005). The longest recorded movement distance was noted for an adult squirrel fitted with a radio collar in Chelan County. This animal moved 19.2 km in a two-week time span (M. Vander Haegen, personal communication).

3.2.9.3. MODEL RESULTS

Habitat Concentration Areas — Western gray squirrel HCAs were identified in concentrations of habitat that included the three widely separated populations at South Puget Sound, Klickitat/Yakima, and Methow/Chelan. Additional areas of concentrated oak or ponderosa pine forest were identified along the eastern foothills of the Cascade Mountains where forests begin to give way to shrubsteppe environments (Fig. 3.29). A total of 26 HCAs, wholly or partially within Washington, were identified. Some of these HCAs are not known to be occupied by western gray squirrels, including those identified on the Colockum Wildlife Area and in the Entiat and Chelan Mountains.

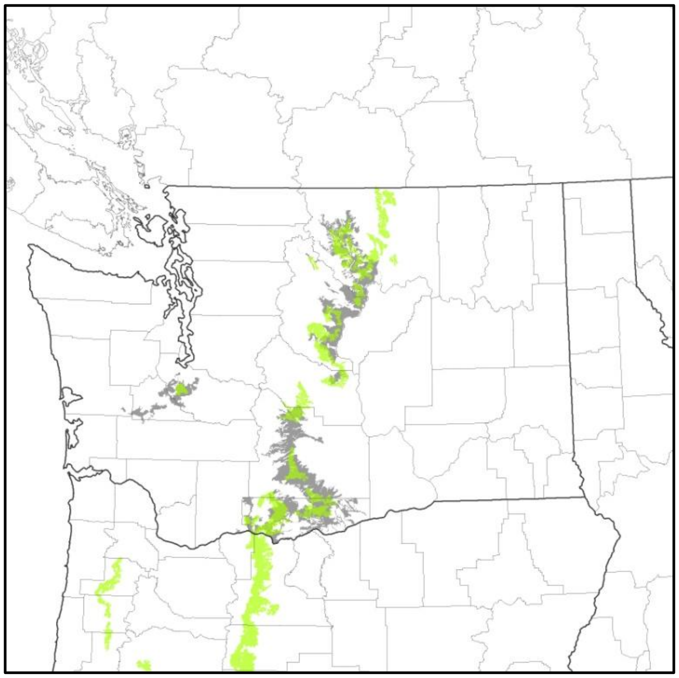


Figure 3.29. Western gray squirrel HCAs (green) and GAP distribution (gray).

Resistance Surface — The western gray squirrel resistance surface (Fig. 3.30) indicates good conditions for squirrel movements along the north-south axis of the Cascade Mountain foothills, particularly in riparian corridors. The South Puget Sound HCA is surrounded by largely impermeable conditions suggesting that this population may remain isolated from all others for the foreseeable future.

Cost-weighted Distance — The western gray squirrel cost-weighted distance map shows reasonably good conditions for animals to move between HCAs in Klickitat County and those on the Yakama Nation lands (Fig. 3.31). However, conditions deteriorate further north, on Cowiche Mountain and the south side of the Tieton River and U.S. Highway 12. Further north, the Kittitas Valley is another formidable barrier, with the best conditions for squirrels occurring at the western end of the valley. U.S. Highway 2, near Cashmere, and Lake Chelan are the remaining significant barriers to connectivity along the north-south axis of the east slope Cascade Mountains.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 200 km (well beyond the dispersal capability of individual squirrels but potentially achievable over multiple generations by squirrels that live in a corridor). For linkages wholly or partially within Washington, this resulted in linkages being modeled between 35 discrete pairs of HCAs (Fig. 3.32). Least-cost distances for these 35 linkages ranged from 2 to 199 km. Linkage quality metrics indicate that connections between HCAs are sometimes many times more costly than the closest straight line route, with ratios up to 137. Along the least costly path, least-cost to non-weighted distance ratios were less severe, reaching 26 at the upper extreme, with an average of 10.

The South Puget Sound HCA was beyond the maximum cutoff for linking to any other western gray squirrel HCA and, for all practical purposes, will remain isolated. The model suggests that presently unoccupied habitat north of State Route 410 could be linked to squirrel populations to the south via a corridor that cuts across the Oak Creek Wildlife Area west of Naches. Another corridor, further north, crosses I-90 west of Thorp and makes a connection to potentially suitable habitat on the Colockum Wildlife Area. Additional linkages are identified crossing U.S. Highway 2 west of Cashmere and through the Entiat Mountains between Tillicum Creek and Mosquito Ridge. The last major barriers to connecting the squirrel population in the Klickitat/Yakima region with the squirrel population in the Chelan/Methow region, is Lake Chelan and the developed area around the town of Chelan. The model indicates the best opportunities for connecting populations through the Lake Chelan area are paths that skirt the Columbia River at the lower end of the lake and that follow closely along the shoreline at the upper end.

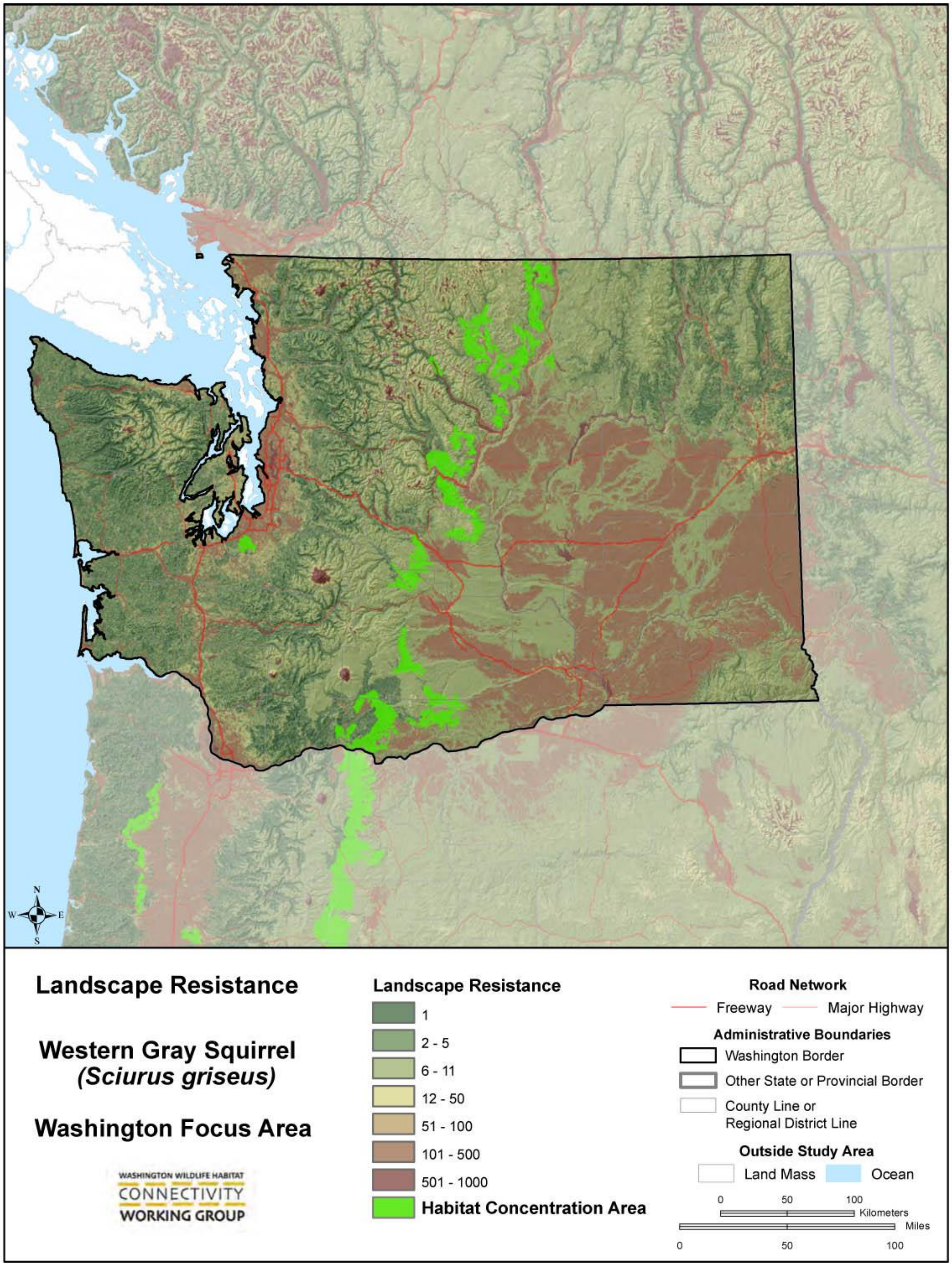


Figure 3.30. Landscape resistance for western gray squirrels.

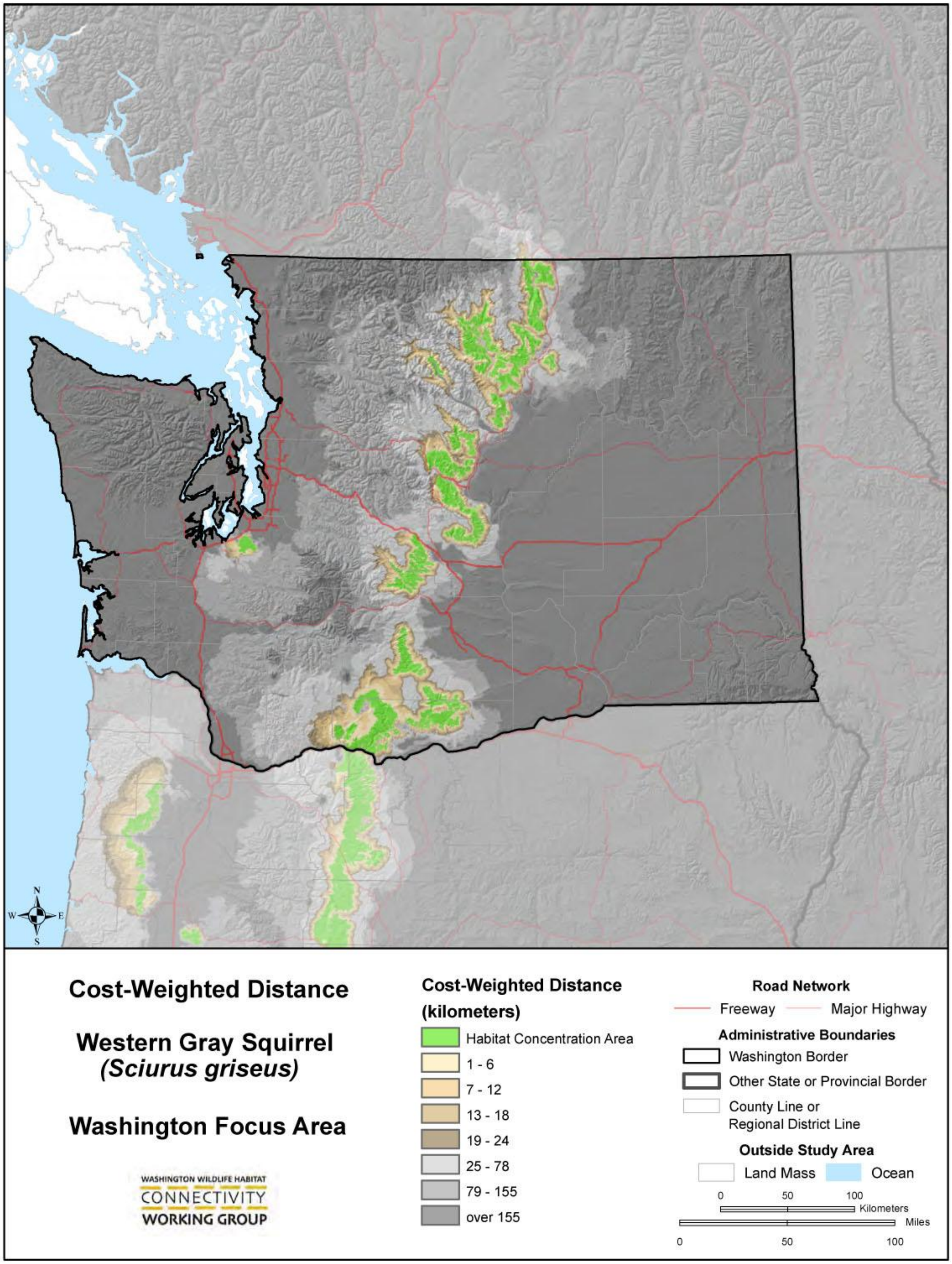


Figure 3.31. Cost-weighted distance for western gray squirrels.

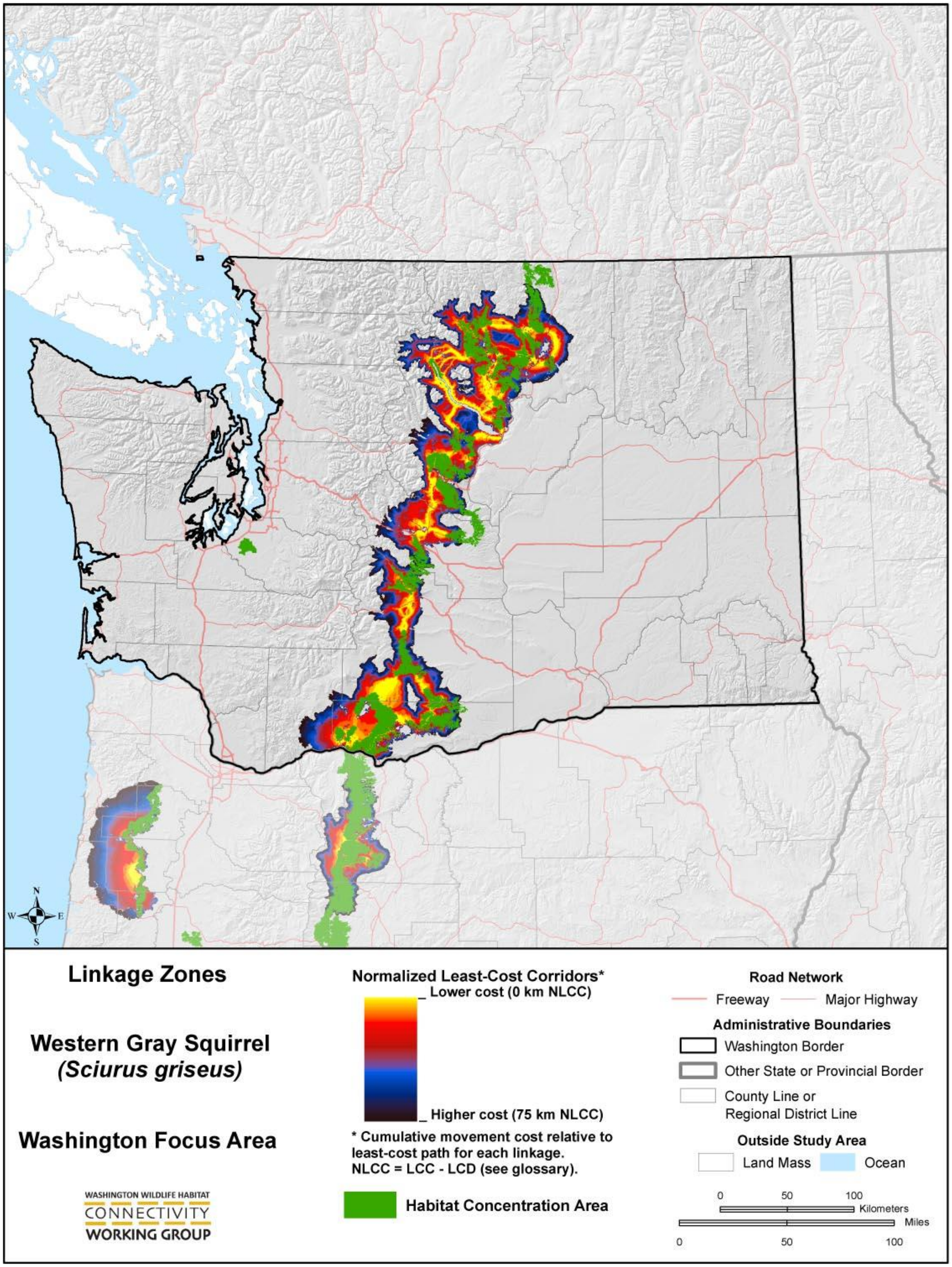


Figure 3.32. Western gray squirrel linkages.

3.2.10. American Black Bear (*Ursus americanus*)

3.2.10.1. INTRODUCTION

Black bear, photo courtesy of USFWS.

Throughout North America, American black bears are symbolic of wild environments (Hummel et al. 1991). They seldom get along well in areas with lots of people; not because they can't, but often because they aren't allowed to. Despite conflicts with humans, the species is very successful and currently occupies much of its historical range in the project area. American black bears were selected as a focal species due to their broad distribution within the assessment area, association with forested habitats, and wide-ranging space-use patterns.

American black bears have large home ranges and exhibit relatively high sensitivity to landscape fragmentation (Beier & Noss 1998). Cushman et al. (2009) evaluated the potential for American black bears to be used as a surrogate for the federally Threatened grizzly bear (*Ursus arctos*) in the identification of regional conservation corridors. They found considerable overlap in areas identified as important corridors for American black bears when compared to areas that others identified as important "linkage zones" for grizzly bears (Mietz 1994; Sandstrom 1996; Waller & Servheen 2005).

3.2.10.2. MODEL CONCEPTUAL BASIS

Habitat concentration areas were identified using a resistance value of ≤6, a home range radius of 2.6 km, a moving window threshold of 0.5, and a minimum patch size of 200 km^2. Habitat concentration areas were areas of at least 200 km^2 (roughly equivalent to average female home range size [see Appendix A] and multiplied by 10, which equals 214 km^2) composed of forest or higher elevation non-forest habitats, with distances from main open roads (paved or Forest Service Level 3, 4 or 5) of at least 500 m.

Information from published habitat connectivity models (Singleton et al. 2002; Cushman et al. 2006) was modified with local research on resource selection (Koehler & Pierce 2003; Lyons et al. 2003; Gaines et al. 2005) to derive resistance values.

3.2.10.3. MODEL RESULTS

Habitat Concentration Areas — There are 27 HCAs well distributed throughout the known distribution of American black bears within the project area (Fig. 3.33). Habitat concentration areas for American black bears cover 53,071 km^2 of the assessment area and range in size from 239 km^2 to 7381 km^2. Areas that are within the distribution of American black bears but are not included within HCAs include southwestern Washington where high concentrations of human activities, such as roads, resulted in high resistance values. Other notable gaps in the distribution of HCAs occurs along the Okanogan and Upper Columbia River valleys where a combination of low-elevation dry vegetation types, rivers, highways, and other human activities precluded inclusion within an HCA. These patterns are relatively consistent with those presented for the general forest carnivore model by Singleton et al. (2002) and represent a reasonable approximation of the distribution of high quality habitat for American black bears across the project area.

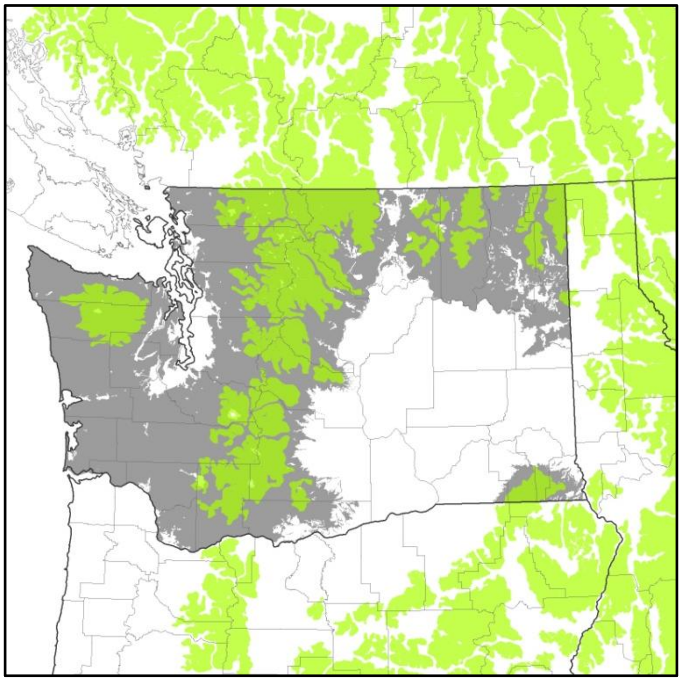


Figure 3.33. American black bear HCAs (green) and GAP distribution (gray).

Resistance Surface — The American black bear resistance surface generally indicates that good conditions for black bear movements occur throughout their habitat in the project area. Human development and natural factors such as low elevations and dry habitats contributed to barriers (Fig. 3.34).

Cost-weighted Distance — The American black bear cost-weighted distance map indicates that connectivity is good throughout much of the project area, with the exception of the Puget Trough, southwestern Washington, and the arid lands of the Columbia Plateau (Fig. 3.35).

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 400 km. This resulted in 44 linkages being modeled between HCAs (Fig. 3.36). The mean Euclidean distance of the linkages was 11 km and ranged from 1 to 32 km. The mean cost-weighted distance was 116 km and the ratio of cost-weighted/Euclidean distance ranged from 6 to 51 km.

The HCAs that occur along the Cascade Mountains extend from south-central British Columbia to the central Cascades of Oregon. In general there is a relatively high level of connectivity north-south throughout the Cascades due to sizeable areas of wilderness, national parks, national forests, state wildlife areas, and other public lands. However, there are some interruptions in this pattern that are important for consideration in conservation planning. A noticeable gap in north-south habitat connectivity for American black bears occurs along the Columbia River Gorge where a combination of human (highways, dams, trains, towns) and natural factors (low-elevation dry habitats) interact. Another gap in habitat connectivity occurs along the I-90 corridor where efforts are currently underway to improve habitat connectivity for a wide array of terrestrial and aquatic species. Finally, careful planning along the Highway 2 corridor and finer-scale linkage modeling will be important to conserve or enhance this linkage.

Our modeling effort did not yield a potential habitat corridor for American black bears between the Olympic and Cascades Mountains. Singleton et al. (2002) modeled a linkage through southwestern Washington between the Olympic and Cascade Mountains, but based on the actual and weighted distance concluded that the southwest Washington landscape is an effective barrier for forest carnivores. Another east-west potential linkage was modeled in Oregon between Redmond and Madras. This potential linkage includes public lands such as the Crooked River National Grassland and Ochoco National Forest. It is bisected by Highways 97 and 26. This is the only potential linkage within the project area that could connect the Cascades with the Blue Mountains. It is unknown whether this potential linkage currently functions to provide connectivity for American black bears. Finer-scale linkage modeling will be needed to better determine the function of this linkage.

Potential linkages were also modeled between the North Cascades and the Selkirk Mountains across northeastern Washington. This area has been identified as important for connecting populations of carnivores that occur in the Rocky Mountains and the Cascades Mountains (Singleton et al. 2002; Singleton et al. 2004). The valleys associated with the Okanogan, Upper Columbia, and Pend Oreille Rivers occur within the potential linkages between HCAs in this area. Along these valley bottoms occur towns, highways, and agricultural lands. Public lands, mostly the Okanogan and Colville National Forests, may function as stepping-stone habitats and increase the ***permeability*** of this landscape for bears and other carnivores (Singleton et al. 2002; Singleton et al. 2004). Finer-scale linkage modeling would be useful in identifying locations where potential linkages could be conserved or enhanced.

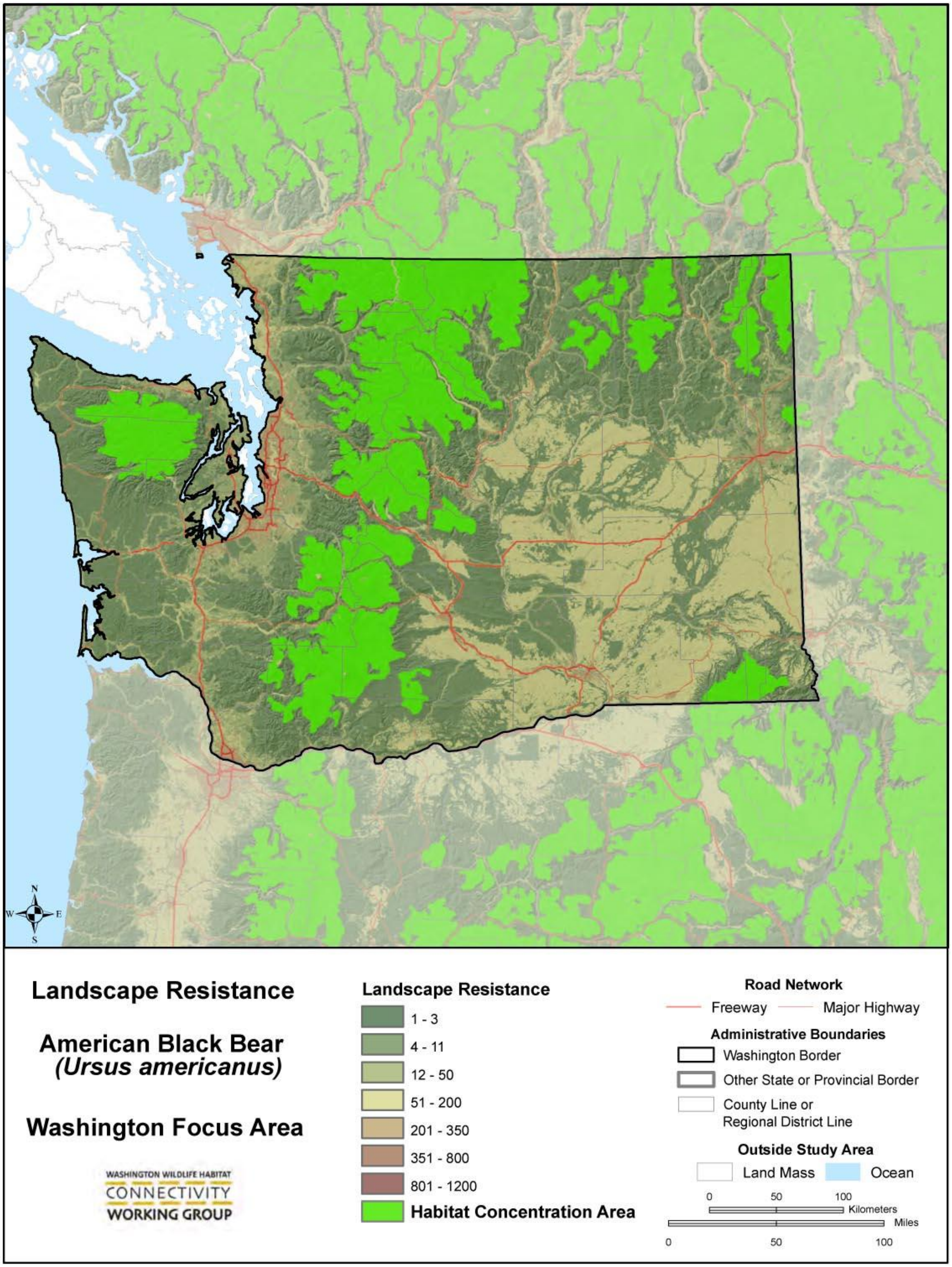


Figure 3.34. Landscape resistance for American black bears.

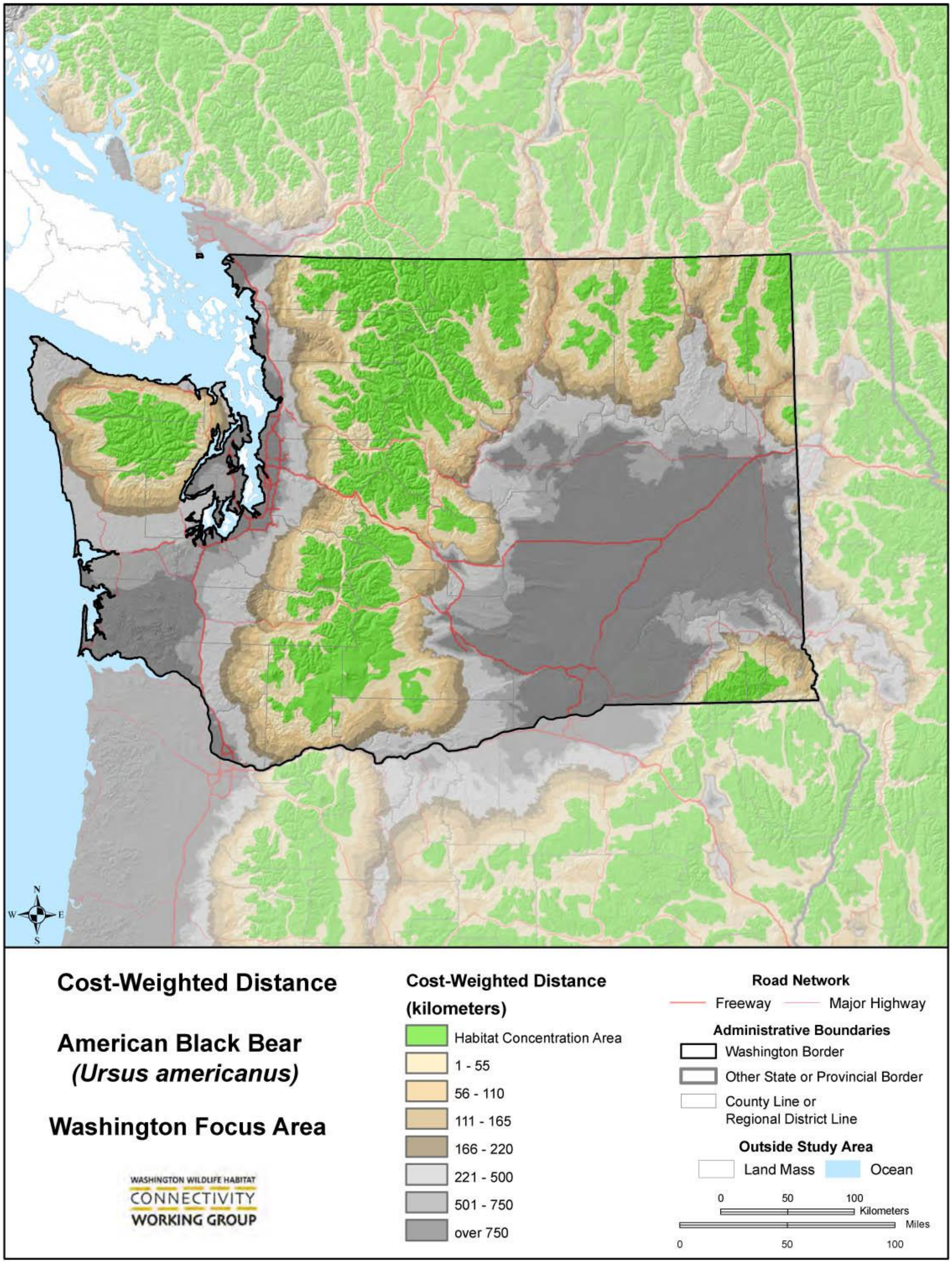


Figure 3.35. Cost-weighted distance for American black bears.

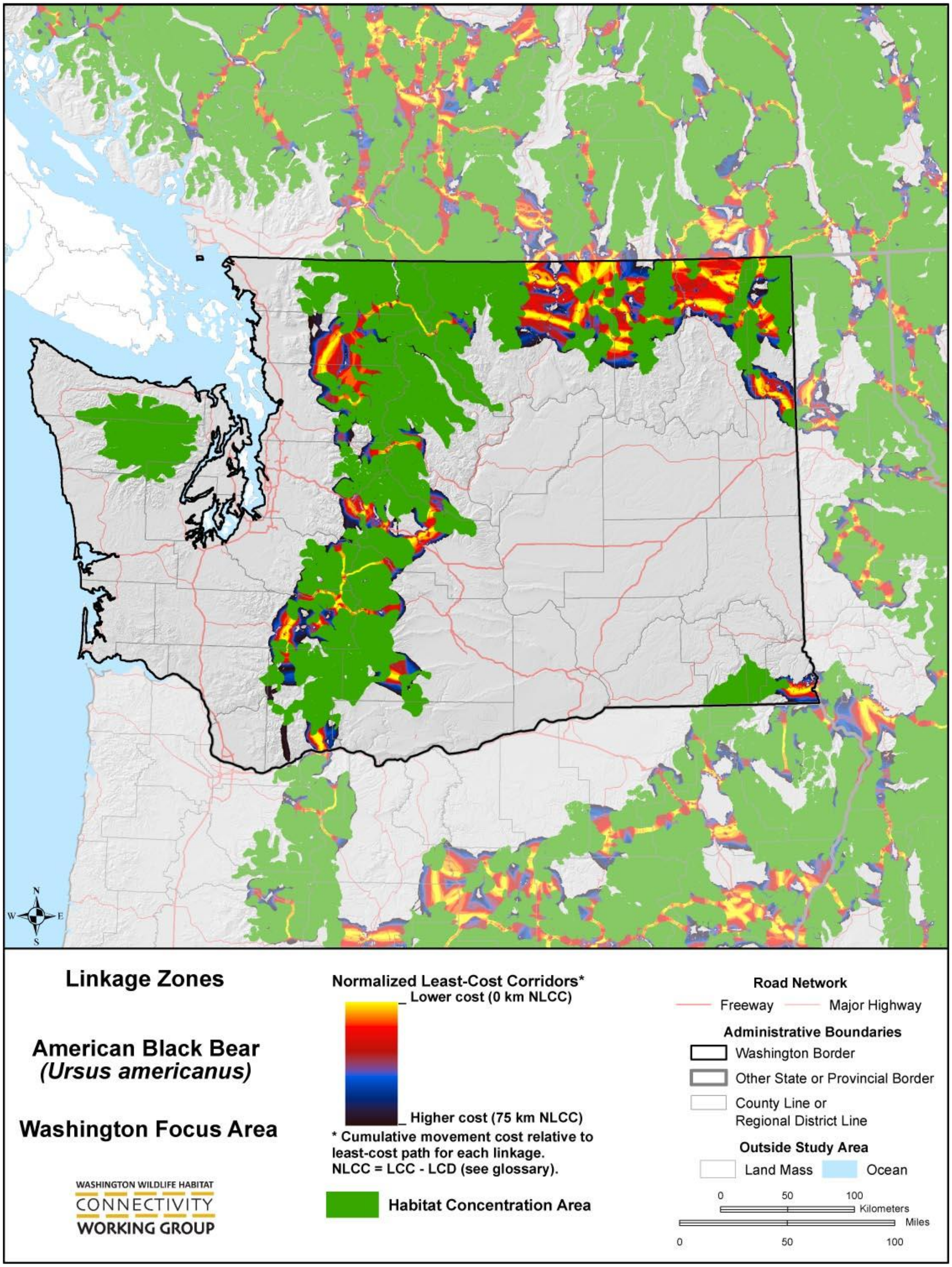


Figure 3.36. American black bear linkages.

3.2.11. Elk (*Cervus elaphus*)

3.2.11.1. INTRODUCTION

Elk, photo by Kelly McAllister.

Elk are among the more visible and culturally important wildlife in Washington State. There are avidly pursued by hunters and highly valued by Native American Tribes for subsistence and ceremonial uses. Elk also figure prominently in damage to private property, primarily agricultural crops and fencing. Simply viewing elk is considered a privilege by many. Their value and the nature of their interactions with people are multi-faceted. In Washington, elk are classified as a big game animal. One population, the Nooksack elk population, is a Species of Greatest Conservation Need.

Elk are additionally important as members of the wildlife community, serving a number of key ecological functions as herbivores and prey for large carnivores such as cougars and wolves. In the Pacific Northwest, elk are common to abundant in most mountainous regions and are present in many low-lying valleys, particularly during winter. The only extensive areas with few to no elk are the arid desert regions. Elk are associated with a wide variety of habitat conditions including forest habitats spanning the full range of moisture conditions and even shrubsteppe environments where there are no trees within the herd's range. In general, though, elk are associated with open woodlands or a mosaic of mature forest, meadow, and early successional forest conditions. They avoid dense, unbroken forests, largely due to a lack of adequate forage. Elk can be found in coniferous swamps, clear cuts, aspen-hardwood forests, and coniferous-hardwood forests. They are found over a wide range of elevations. In our project area, they occur from sea level to nearly 3000 m, with the highest elevations occupied seasonally, when snowpack allows.

Some local populations are migratory, exploiting productive mountain meadow-habitat in summer but retreating to low-elevation valleys in winter. As such, migratory elk often move long distances on a seasonal basis. Telemetry studies of the migratory Yakima elk herd (S. McCorquodale, personal communication) indicate that the average distance between winter and summer home ranges is about 30 km. Most of the Yakima elk had winter and summer activity centers that were separated by ~25–40 km. Maximum distances between winter and summer activity centers were in the range of 70–80 km. Elk are known to move as much as 100 km between seasonally important habitats (Boyce 1991).

3.2.11.2. MODEL CONCEPTUAL BASIS

The Department of Fish and Wildlife's Landscape Priority Habitats and Species Project characterized elk as having high sensitivity to the effects of roads and development. Elk are known to be affected by development, roads and traffic, and the presence of people and domestic animals.

Elk HCAs were largely identified based on vegetative cover conditions that indicated adequate forage and cover within the typical daily movement range of an individual elk. Areas outside of documented elk range were eliminated from consideration as were highway corridors and areas of human population density greater than one dwelling unit per 40 acres.

To characterize the suitability of the landscape for elk movements, resistance parameters were developed from descriptions of optimal elk habitat conditions and features of the landscape that are avoided. Since road avoidance is a recurring theme in the elk literature, this aspect of elk behavior was built into the model.

While there is ample information on elk habitat associations and preference, there is little published information on conditions suitable for elk movements, with the exception of research in Arizona to determine the barrier effect of highways (Dodd et al. 2007). Scoring resistance for landscape attributes that fell short of documented preferred conditions was based on professional judgment with the knowledge that elk will move through a wide variety of conditions that offer little or nothing in the form of security cover or forage.

3.2.11.3. MODEL RESULTS

Habitat Concentration Areas — Elk HCAs are well-distributed throughout the project area but considerably less extensive than known elk range (Fig. 3.37). Some areas with significant numbers of elk (for example, the Willapa Bay area) were not included in HCAs due to high road densities. Elk numbers are sometimes high in areas where human population densities or agricultural land uses make it difficult for the numbers to be sustained over time. These areas were not included in HCAs.

Resistance Surface — The elk resistance surface indicates good conditions for elk movements throughout much of the project area, with the exception of most of the arid Columbia Plateau and all areas affected by extensive development or conveying busy roads (Fig. 3.38).

Cost-weighted Distance — The elk cost-weighted distance map provides a view of the full range of areas most suitable for elk movements away from HCAs (Fig. 3.39). This map is most useful for understanding the full range of elk movement landscapes beyond least-cost corridors produced by the linkage model output.

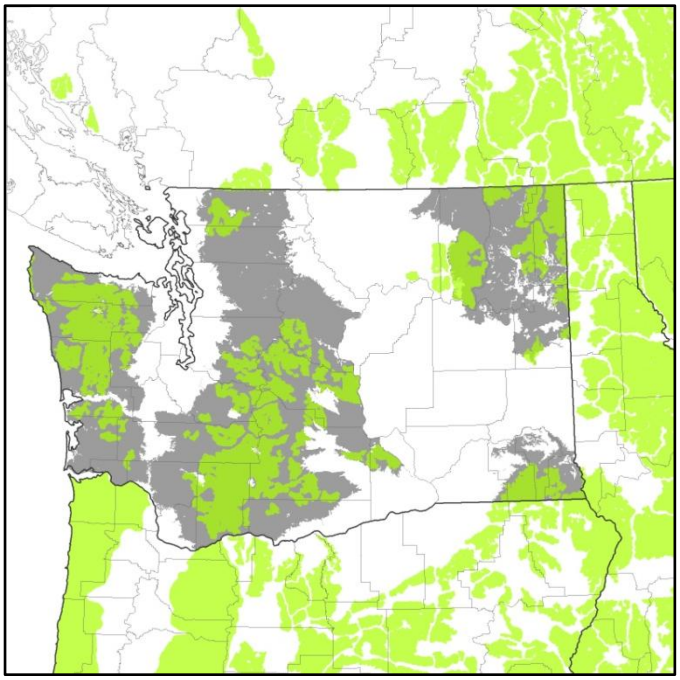


Figure 3.37. Elk HCAs (green) and GAP distribution (gray).

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 250 km. This resulted in linkages being modeled between 98 discrete pairs of HCAs (Fig. 3.40). Straight-line, Euclidean, distances between HCAs ranged from 1 to 137 km. Weighted least-cost distances between HCAs averaged 80 km with a range from 2 to 235 km.

There are a number of large gaps or significant interruptions between HCAs for elk. The I-5-Puget Trough fracture is one of them. Here, substantial development and the state's busiest interstate threaten to isolate coastal elk from those of the interior Cascade Mountains. Linkage model outputs suggest several locations where conserving or restoring conditions suitable for elk movements could serve to keep populations connected. Similar, though perhaps less severe, interruptions to connectivity occur in the Chehalis bottomlands, where U.S. Highway 12 connects Olympia with Grays Harbor, and in the Cascade Mountains, where I-90 passes west to east. In the Chehalis bottomlands, outputs from the models indicate where to look to maintain a corridor between the Olympics and the Willapa Hills. Good locations for maintaining connectivity in the Cascade Mountains are indicated between North Bend and Snoqualmie Pass. Unfortunately, the best identified corridor across I-90 on the east slope of the Cascades is currently blocked by a fence constructed for the purpose of preventing elk movements onto the interstate and into agricultural lands where they are likely to damage private property.

Model outputs suggest the central and north Cascade Mountains provides ample suitable conditions for connecting elk of the south Cascades with elk in the Nooksack herd of Whatcom and Skagit Counties. Multiple linkages are also suggested as connections between elk in British Columbia and those in the U.S., including those in and around lands managed by the Colville Confederated Tribes. Similarly, elk associated with the Arid Lands Ecology Reserve on the Hanford Department of Energy site might be well served by conserving suitable conditions for movements to and from the Colockum Wildlife Area and Cascade foothills areas of the upper Yakima River drainage.

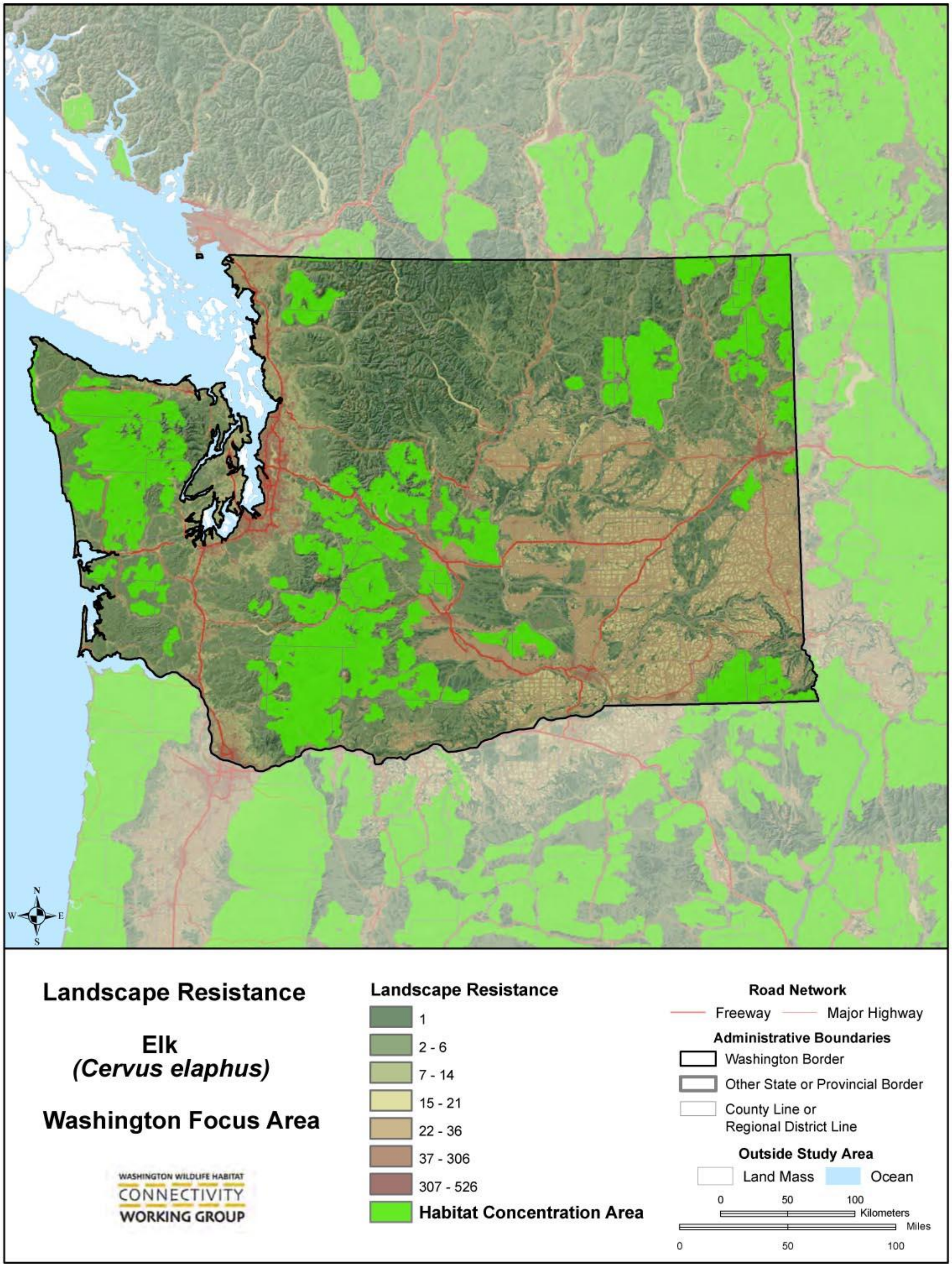


Figure 3.38. Landscape resistance for elk.

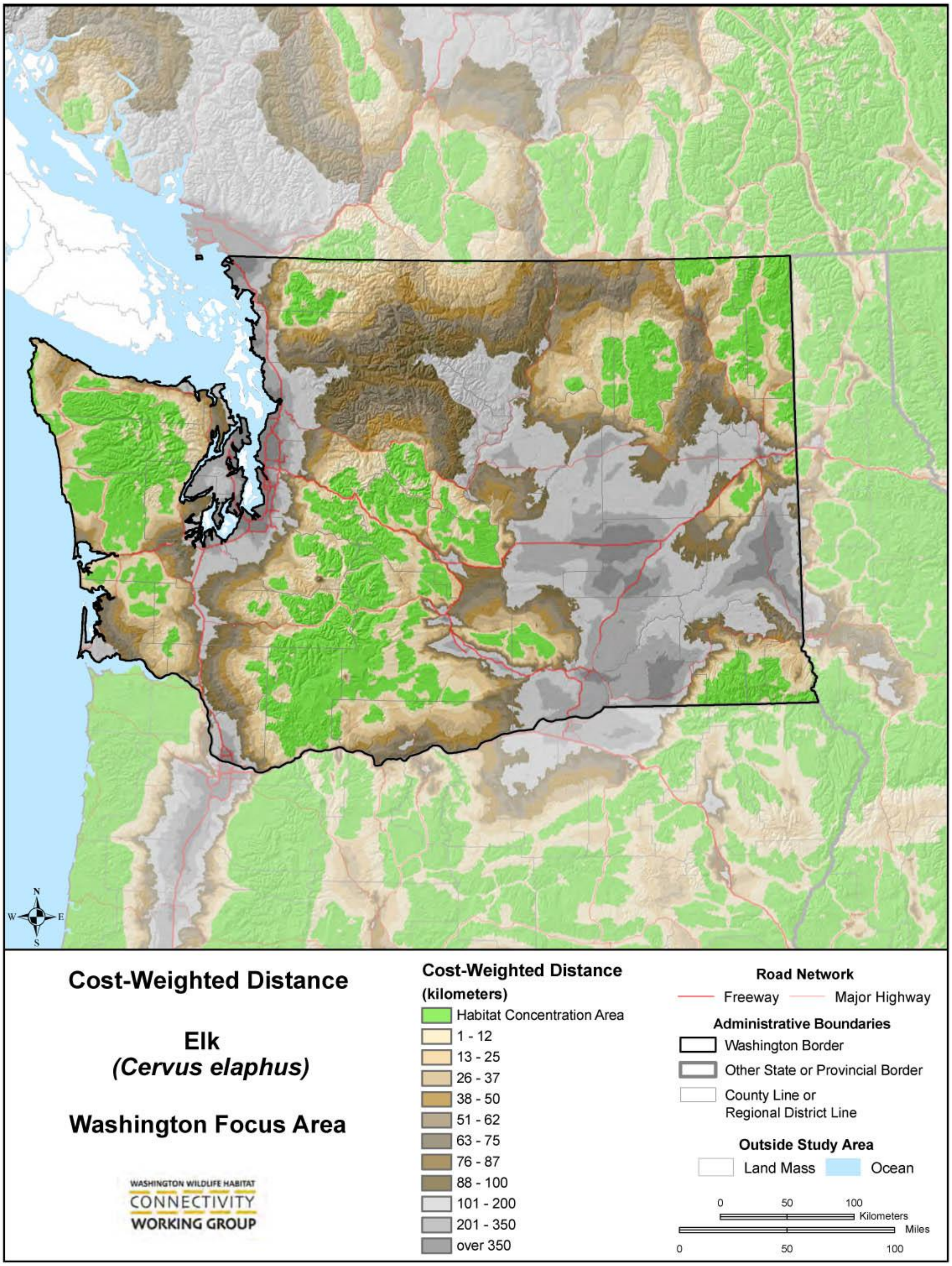
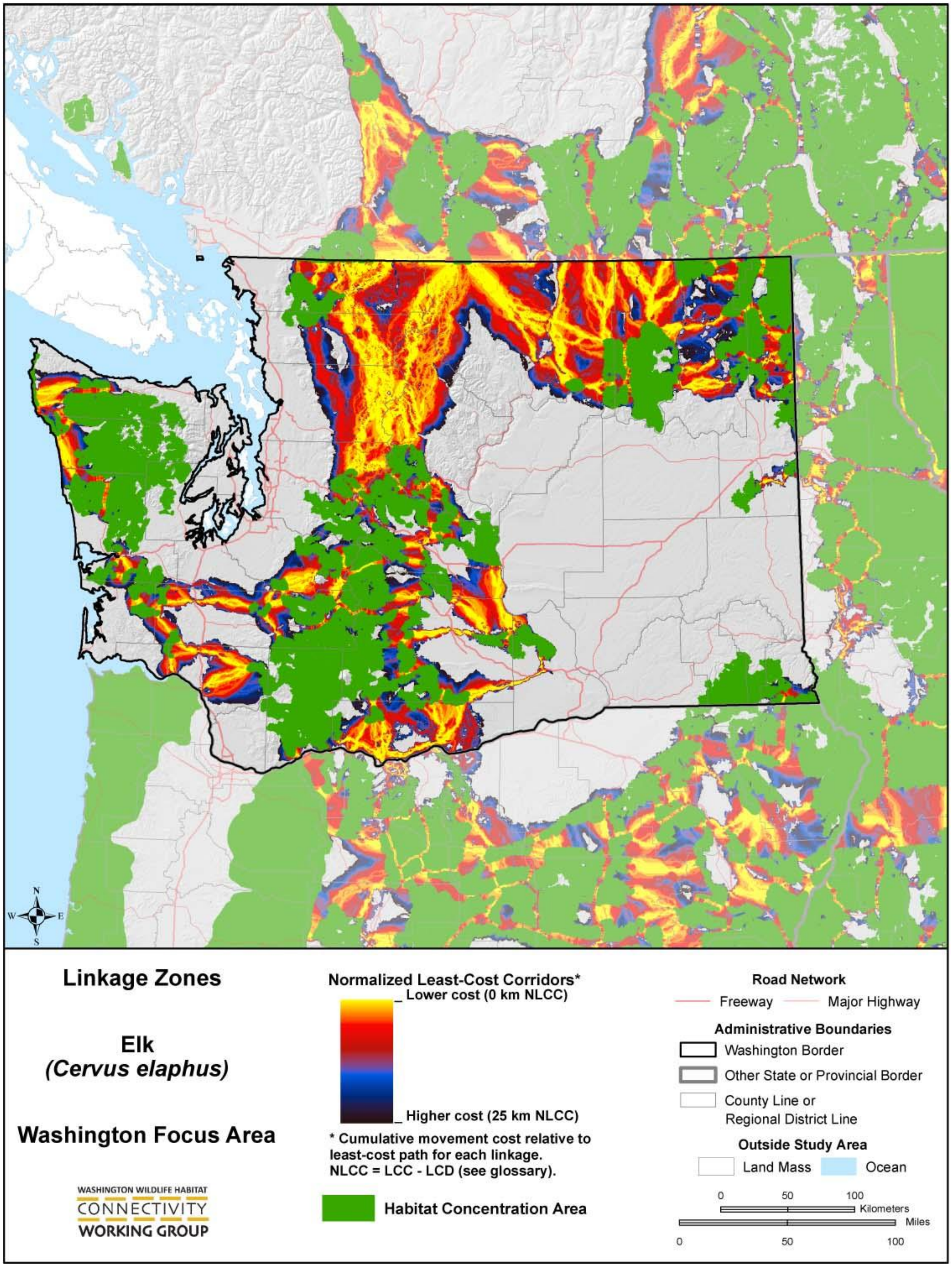


Figure 3.39. Cost-weighted distance for elk.



Linkage Zones

Elk
(Cervus elaphus)

Washington Focus Area

* Cumulative movement cost relative to least-cost path for each linkage.
NLCC = LCC - LCD (see glossary).

Figure 3.40. Elk linkages.

3.2.12. Northern Flying Squirrel (*Glaucomys sabrinus*)

3.2.12.1. INTRODUCTION

Northern flying squirrel, photo courtesy of WDFW.

Northern Flying Squirrels play a critical role in the ecology of Pacific Northwest forests. They are important in the diet of Northern Spotted Owls (*Strix occidentalis*). They also help disperse fungal spores (underground fungi are a major part of their diet) that aid trees in their absorption of nutrients from the soil. In Washington, the northern flying squirrel occurs in all coniferous and mixed forest types within its range. It is absent from the San Juan Islands, as well as Guemes, Cypress, and Lummi Islands, and does not occur in conifer 'islands' in the Palouse. Interestingly, it has adapted to urban areas in Washington; populations occur in the cities of Walla Walla, Seattle, Dayton, and Tacoma (Johnson & Cassidy 1997).

The northern flying squirrel was selected as a focal species because it is a good representative of wildlife connectivity habitat needs within the Vancouverian and Rocky Mountain Forest classifications. Flying squirrels are vulnerable to loss of habitat connectivity from all four of the main connectivity threats: land clearing and vegetation removal, development, roads and traffic, and people and domestic animals.

Forests that support high densities of northern flying squirrels are generally characterized as having dense multi-layered mid and over-story canopies, low to moderate amounts of understory, and few canopy gaps (Wilson 2010). These characteristics are typically found in mature and old-growth forests but can also be found in some younger forests (Rosenberg & Anthony 1992; Buck & Woodworth 2008). Older forests that lack one or more of these characteristics have been found to support few or no squirrels (Carey 1995; Wilson 2010). Across its range, squirrel abundance has been associated with large-diameter trees, large snags, coarse-woody debris (particularly decayed logs), and fungi (Carey et al. 1999; Smith 2007). These associations may have more to do with the structural complexity of a forest than a specific need for these individual components (Wilson 2010).

3.2.12.2. MODEL CONCEPTUAL BASIS

We used published literature and input from expert reviewers to develop resistance surfaces used to evaluate dispersal habitat suitability and HCAs. Riparian and forested areas with >70% canopy cover were assigned the lowest resistance values; agriculture, sparsely vegetated, grass and shrub-dominated habitats the highest.

Home range size of northern flying squirrels in the Pacific Northwest varies from 2.5–5.8 ha and tends to be influenced by forest structure and composition (Martin & Anthony 1999; Lehmkuhl 2006). Dispersal rate and distance for northern flying squirrels may depend on population density in a given source site and on habitat quality, however few studies address this topic. In a study in Alaska, northern flying squirrel juveniles dispersed 0.8–1.1 km in a landscape of complex old growth islands in the Tongass National Forest; some juveniles moved 1–2 km and readily crossed two-lane roads. One juvenile moved about 7 km in 48 hrs however it is unclear whether this was a dispersal or circuit movement (Smith et al. 2010). The largest home range documented is 11.2 ha in unlogged coniferous forest in Canada (Holloway & Malcolm 2007). Dispersal events for northern flying squirrels likely reflect a slow, generational progression across the landscape. Corridor width and a dense multi-layered canopy may be key factors affecting how far and how safely an individual squirrel can disperse (T. Wilson, personal communication).

3.2.12.3. MODEL RESULTS

Habitat Concentration Areas — Forty-one northern flying squirrel HCAs were identified for Washington, ranging from 50 to 7068 km^2 in size, with a mean of 504 km^2. Northern flying squirrel HCAs are patchy and elongated, and generally follow higher altitude, north-slope drainages and valleys (Fig. 3.41). The total area of all HCAs was 20,648 km^2 (Table 3.2). HCAs on the Olympic Peninsula are largely centered in the Olympic National Park. Others follow relatively undisturbed areas along the North and South Cascades, with a rather wide gap at I-90 and above Keechelus, Kachess, and Cle Elum Lakes, resuming to the south around Mount Rainier. In the northeastern part of Washington, HCAs are scattered, few and far between. Southeast Washington, in the Blue Mountains, an especially convoluted HCA follows the Wenaha Tucannon Wilderness into the Umatilla National Forest.

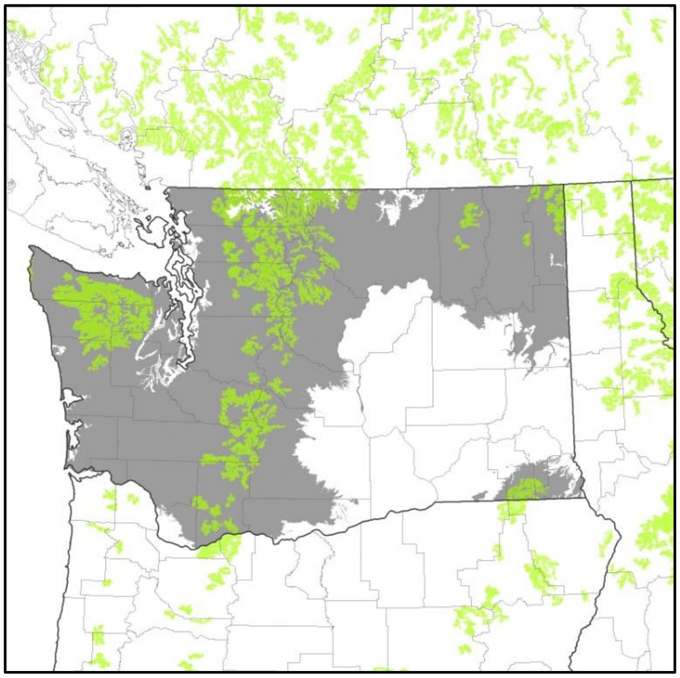


Figure 3.41. Northern flying squirrel HCAs (green) and GAP distribution (gray).

A number of HCAs for this model may no longer represent core squirrel habitat. The vegetation layer used in the model dates from 2001 and, since then, forestry activity has altered the landscape. For example, one HCA, located just south of Olympic National Park, has been heavily clear-cut. The number and extent of HCAs in the northeastern part of the state are probably under-represented due to the minimum size requirements of the HCA identification model, and recent changes in the landscape.

Resistance Surface — The northern flying squirrel resistance surface shows reasonable conditions for squirrel movements throughout the species' range in the project area, with the exception of the arid Columbia Plateau and all areas affected by extensive development, heavy forestry, or road systems. However, some areas shown on the map as low resistance (e.g., the Willapa Hills) are currently poorly suited to squirrel occupation and movement, due to recent timber harvest (Fig. 3.42).

Cost-weighted Distance — The northern flying squirrel cost-weighted distance map provides a view of the full range of areas most suitable for squirrel movements away from HCAs (Fig.

3.43). This map is most useful for understanding the full range of squirrel movement landscapes beyond least-cost corridors produced by the linkage model output.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 126 km. This maximum distance was chosen based on a subjective evaluation of the pairs of HCAs we wanted to link and takes into account slow, multi-generational dispersal over fragmented landscapes to depict the most viable linkages likely to be functional over coming decades. This resulted in linkages being modeled between 49 discrete pairs of HCAs within or partially within Washington (Fig. 3.44). Least-cost distances for these 49 linkages ranged from 2 km to 122 km with a mean of 37 km, while Euclidean distances ranged from <1 km to 31 km. The ratio represented by the least-cost distance divided by the Euclidean distance had a range of 3 to 1167 with a mean of 49 (Table 3.3). This ratio is an indication of corridor quality, and can be thought of as representing the additional cost of moving along a corridor composed of less than optimal dispersal habitat (e.g. a corridor with a ratio of 2.0 would be, conceptually, twice as difficult to traverse per unit distance than a corridor consisting entirely of optimal dispersal habitat, which would have a ratio of 1.0).

Corridors provide fairly good linkages throughout the North Cascades and South Cascades; however, I-90 poses a significant interruption. On the Olympic Peninsula, two very strong corridors connect HCAs on Olympic National Park lands across the Olympic Experimental State Forest. Two corridors also join the large Olympic National Park HCA to a small one to the south, located in the Olympic National Forest. In the northeastern part of Washington, HCAs are scattered and few. A cluster exists in Pend Oreille County, but these have few linkages; pinch points occur at Sullivan Lake and along Box Canyon Dam. No linkages appear in the Blue Mountains HCA; despite its fractured appearance, it is a single connected HCA.

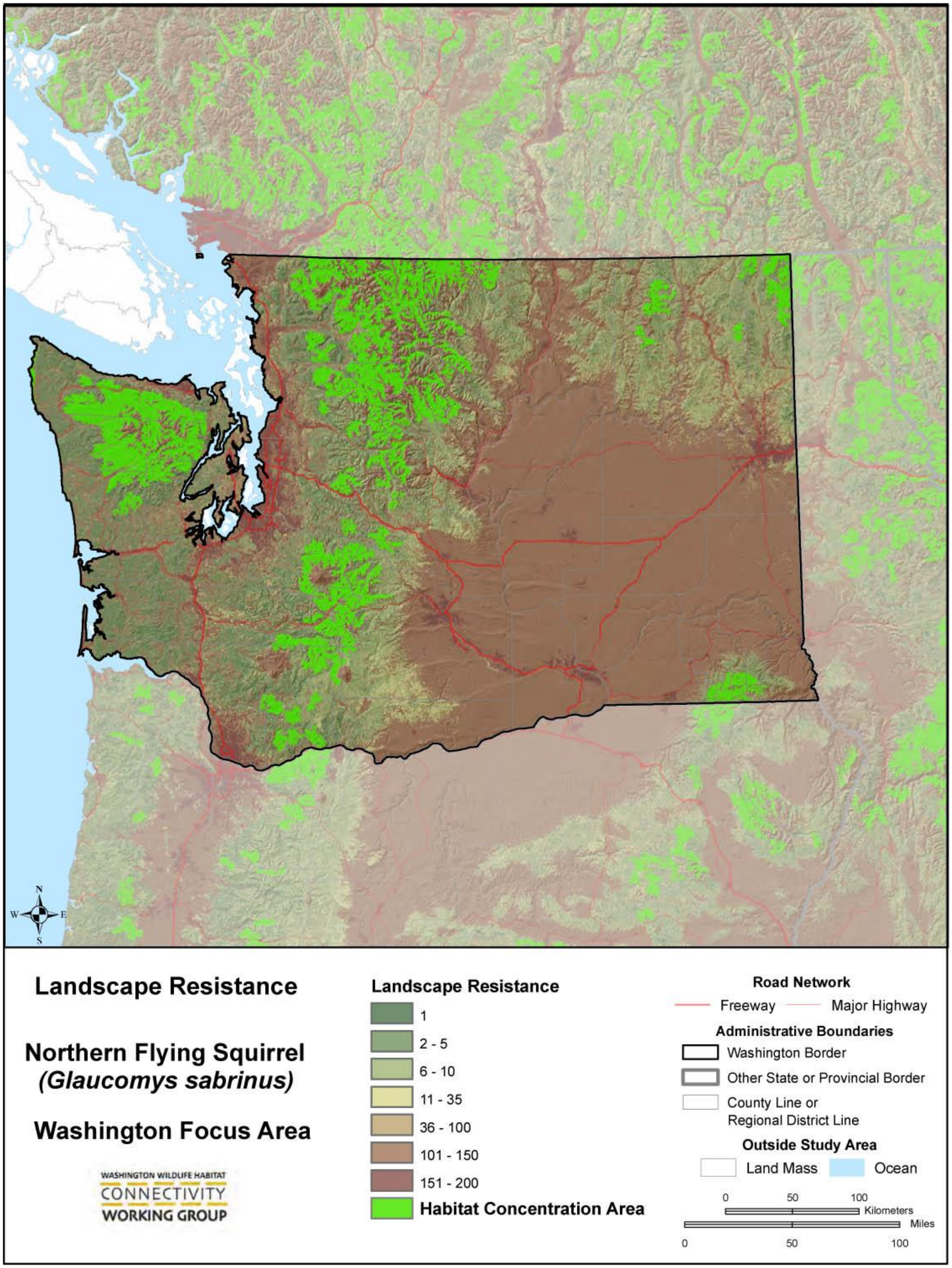


Figure 3.42. Landscape resistance for northern flying squirrels.

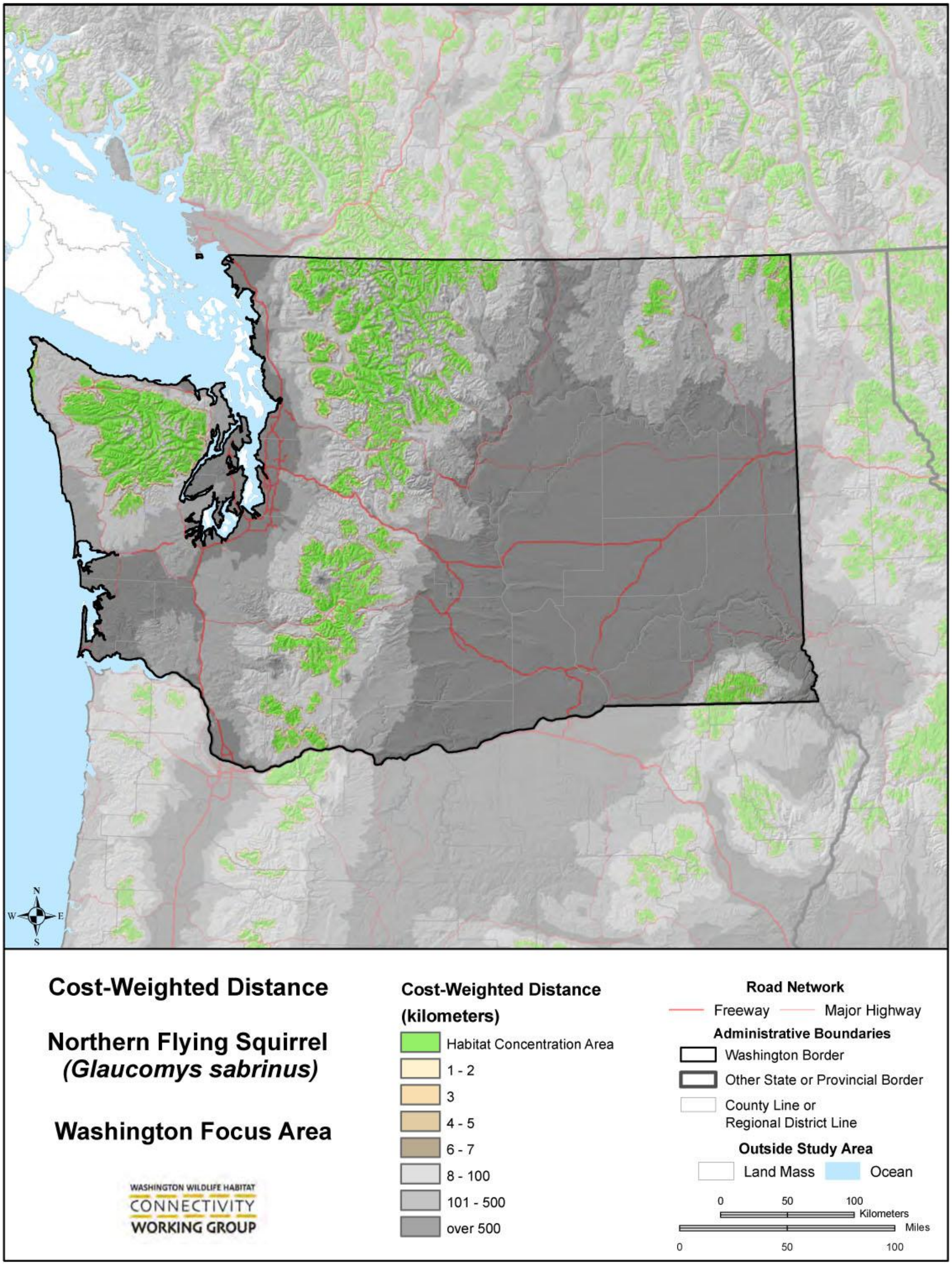


Figure 3.43. Cost-weighted distance for northern flying squirrels.

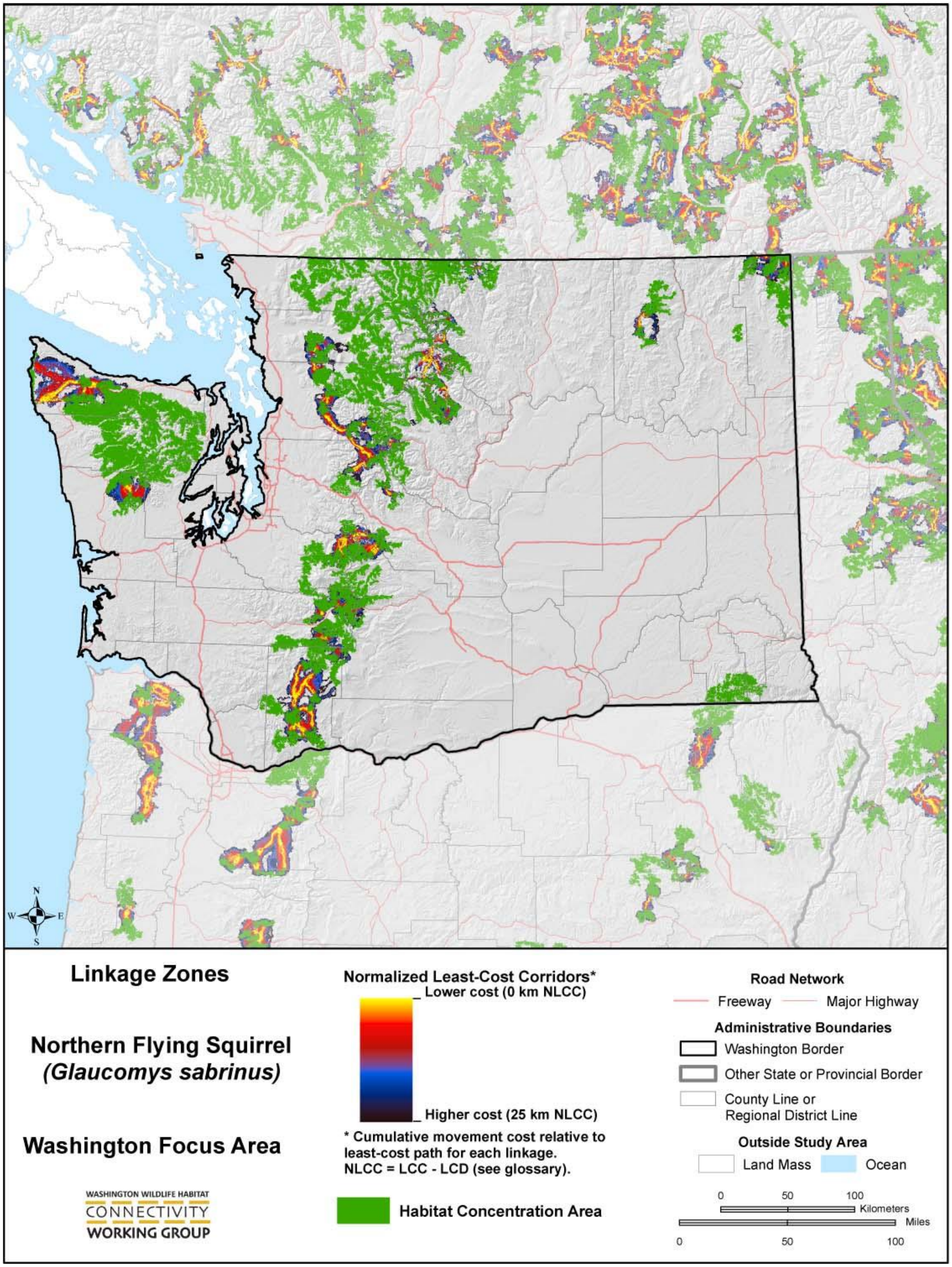


Figure 3.44. Northern flying squirrel linkages.

3.2.13. Western Toad (*Anaxyrus boreas*)

3.2.13.1. INTRODUCTION

Western toad, photo by Joanne Schuett-Hames.

Western toads are pond-breeding amphibians that move during the year to access aquatic breeding areas as well as terrestrial habitats. Seasonal movements of 1 to 3 km appear to be common (Bartelt et al. 2004; Bull 2006; Lynch 2006; Deguise 2007), and movement of 13 km in less than one month has been documented (Schmetterling & Young 2008). The reliance on aquatic habitats that occur in association with terrestrial habitats makes the toads important as an umbrella species for other pond-breeding amphibians with similar life history needs. Western toads are found across much of Washington from low to high elevations with the exception of much of the non-forested arid lands in eastern Washington (Leonard et al. 1993). The toad populations have been declining, for instance, in the Puget Sound Region, and in Mount Rainier National Park (Leonard et al. 1993; Adams [date unknown]). This species has a state conservation status of Candidate and nationally is a federal Species of Concern.

Populations of pond-breeding amphibians such as the western toad operate at multiple scales. These scales are: (1) the individual breeding pool or stream, (2) the breeding pool or stream with surrounding upland habitat, (3) neighboring breeding locations and upland habitat, and 4) clusters of neighboring populations in a regional framework where the focus is on long-term connectivity of metapopulations at a regional scale (after Compton et al. 2007). The latter scale is the focus for this statewide modeling effort.

Western toads were selected as a focal species because they are a good representative of habitat connectivity needs of wildlife with similar life history needs in the three forest vegetation classes (Rocky Mountain, Vancouverian, and Subalpine Forests; Table 3.1). In addition, the toad's broad coverage across the landscape, reliance on connectivity between populations, and in particular, its association with wetlands and aquatic systems led to inclusion in the statewide analysis.

3.2.13.2. MODEL CONCEPTUAL BASIS

Estimates of landscape resistance to dispersal were derived from expert opinion and literature regarding western toad movement and habitat characteristics. Road traffic, human population density, and urban land use are top factors impacting ***landscape permeability*** for this species and relevant GIS factors were given the highest resistance values.

We modeled western toad HCAs through steps that began with identification of potential breeding habitat based on wetlands, river, and waters data layers. We classified breeding habitat as having a value of 1 and all other areas as having a value of 0. We next ran a 2 km moving window to calculate the average proportion of breeding habitat within the window; this step begins the linking of breeding areas to complementary terrestrial habitats. We then removed any habitat grid cells where the breeding habitat density was <0.05, thus eliminating areas where breeding habitat was scarce. We ran a 2 km cost-weighted distance out from the remaining breeding habitat to link neighboring populations. This became our preliminary HCA map. We completed our map by removing small HCAs (<50 km^2), and HCAs in eastern Washington shown to be outside of the western toad range based on Dvornich et al. (1997).

3.2.13.3. MODEL RESULTS

Habitat Concentration Areas — We identified a total of 248 western toad HCAs across much of the toads range within Washington as well as into British Columbia, Idaho, Oregon, and Montana: 94 of the HCAs are within or intersect Washington (Fig. 3.45; Table 3.2). Within Washington the Olympic Peninsula encompasses the densest HCA pattern; HCAs are also scattered through the Willapa Hills, the Cascade Mountain Range, the upper Columbia River and Pend Oreille River valleys, and along portions of the Snake River and Blue Mountains in southeast Washington. The HCAs are convoluted shapes that tend to follow river valleys, other large water features such as Lake Roosevelt, and areas of dense wetlands and streams. Washington includes toad HCAs that span boundaries with all neighboring jurisdictions.

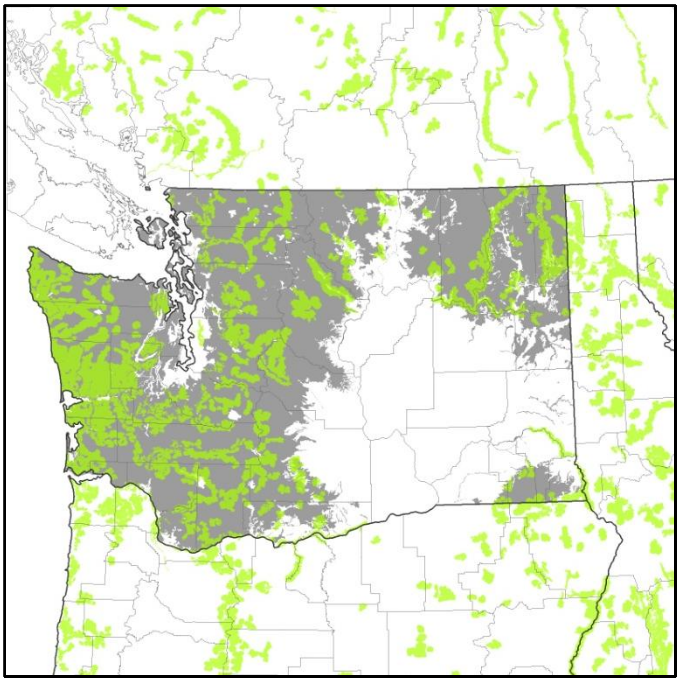


Figure 3.45. Western toad HCAs (green) and GAP distribution (gray).

Notably, few HCAs were identified in highly developed areas such as much of the Puget Sound region, and HCAs were fragmented by freeways and major highways. The Salish Sea islands are inhabited by western toads but were not within our study boundaries, and thus do not have HCAs. In addition, a lack of consistent wetland, water, and riparian data layers across boundaries with neighboring states and British Columbia has likely reduced the accuracy of HCA patterns across our borders.

We found the toad HCA sizes and extents to be highly sensitive to breeding habitat density values. Lower values provided substantially more habitat in HCAs and conversely more stringent values collapsed down the sizes and extent of the HCAs. We chose to use the value of ≥0.05 which produced a result where many known toad location points and known population areas were included, but such that discrete HCAs would be an effective size for linkage modeling.

Resistance Surface — The western toad resistance surface results (Fig. 3.46) within the toad distribution area broadly parallel the HCA results. Areas of least resistance tend to occur outside of developed areas and away from highway corridors.

Road traffic is among the most significant factors affecting survival of anurans including toads (van Gelder 1973; Heine 1987; Hels & Buchwald 2001; Lynch 2006). In this model we intentionally applied small values to secondary highways and local roads resistance factors. Had we done otherwise the coarse road data we used for this statewide scale analysis would have indicated much of the landscape as inhospitable. At finer scales of modeling, obtaining and using road layers that include traffic data will provide greater options for this factor and should allow for enhanced model performance.

Cost-weighted Distance — The western toad cost-weighted distance map (Fig. 3.47) indicates all areas within a 20 km cost-weighted distance of HCAs in brown colors. These areas are likely to be accessible to toads; thus there appears to be a very high level of accessibility across much of the toad's range in Washington, and across borders to Oregon, Idaho, and British Columbia. Within Washington only three HCAs appear to be isolated. Two are in the Puget Sound region: freeways and high use roads, urban/developed lands, and agriculture are factors in this isolation. The third isolated HCA is in north-central Washington, east of the Okanogan River. Our map layers may be under-representing good habitat in this area and future efforts should more carefully consider layer accuracy.

Linkage Modeling — We modeled linkages when the least-cost distance between a pair of HCAs was ≤50 km cost-weighted distance. This provided 420 linkages across the full mapped area, of which 180 were fully within Washington or spanned between Washington and neighboring jurisdictions (Fig. 3.48; Table 3.3). Within Washington linkages were mapped to all but the two isolated HCAs within the Puget Sound region.

Considering all 180 linkages within or spanning Washington, the ranges in linkage lengths were: Euclidean distance, 0–36 km (mean of 10 km [SD 9]); least-cost path distance, 0–40 km (mean of 12 km [SD 10]); and 0–50 km (mean of 18 km [SD 14]; Table 3.3). Generally, the larger extents of these ranges appear reasonable for a species such as the western toad which may be a ***linkage dweller***, i.e., a species that can disperse between habitat areas by living and dispersing through a linkage over the course of multiple generations.

The western toad linkage modeling outputs include ratios for two combinations of linkage measurements, the cost-weighted distance to Euclidean distance (range 1–58, mean of 3 [SD 7]), and the cost-weighted distance to least-cost path distance (range 1–34, mean of 2 [SD 4]; Table 3.3). In particular, low means for both ratios appear to indicate many toad linkages are generally hospitable for movement.

Cost-weighted distance to least-cost path ratios for the Washington western toad linkages were ≤2 for 79% (n = 143) of linkages, and ≤3 for 96% (n = 173) of linkages providing an indication that a majority of the linkages are likely favorable to movement by toads. Another 2% (n = 3) of linkages had ratios >3 to 10, and 2 incurred extremely high ratios of >10 to 35. While on-the-ground assessment is necessary to clarify the relationship of these ratios to the ability of toads to successfully move through the linkage areas, the range of ratios appears to include excellent to poor conditions, and may reflect a range of conservation needs from maintaining good conditions to restoring degraded conditions.

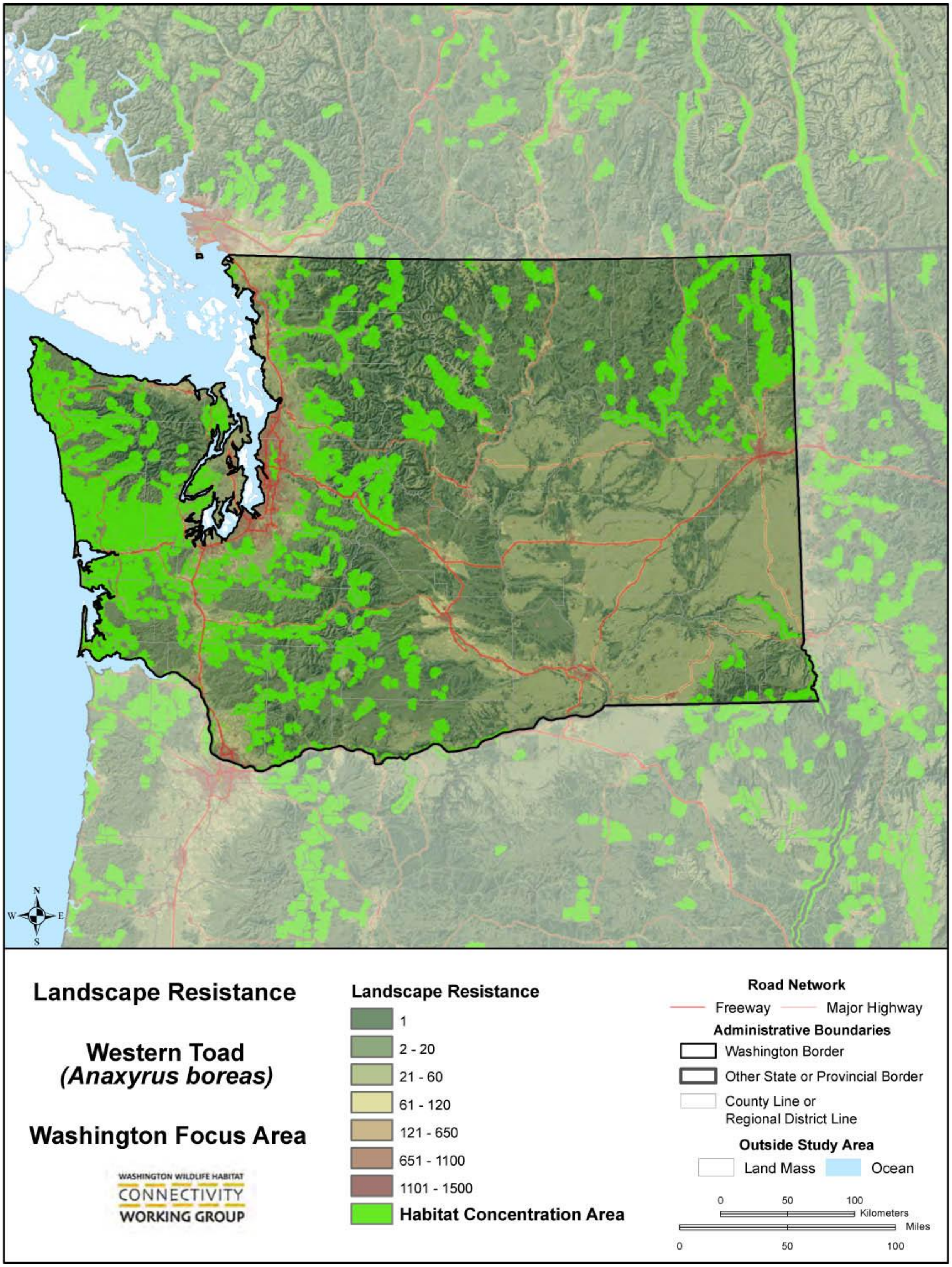


Figure 3.46. Landscape resistance for western toads.

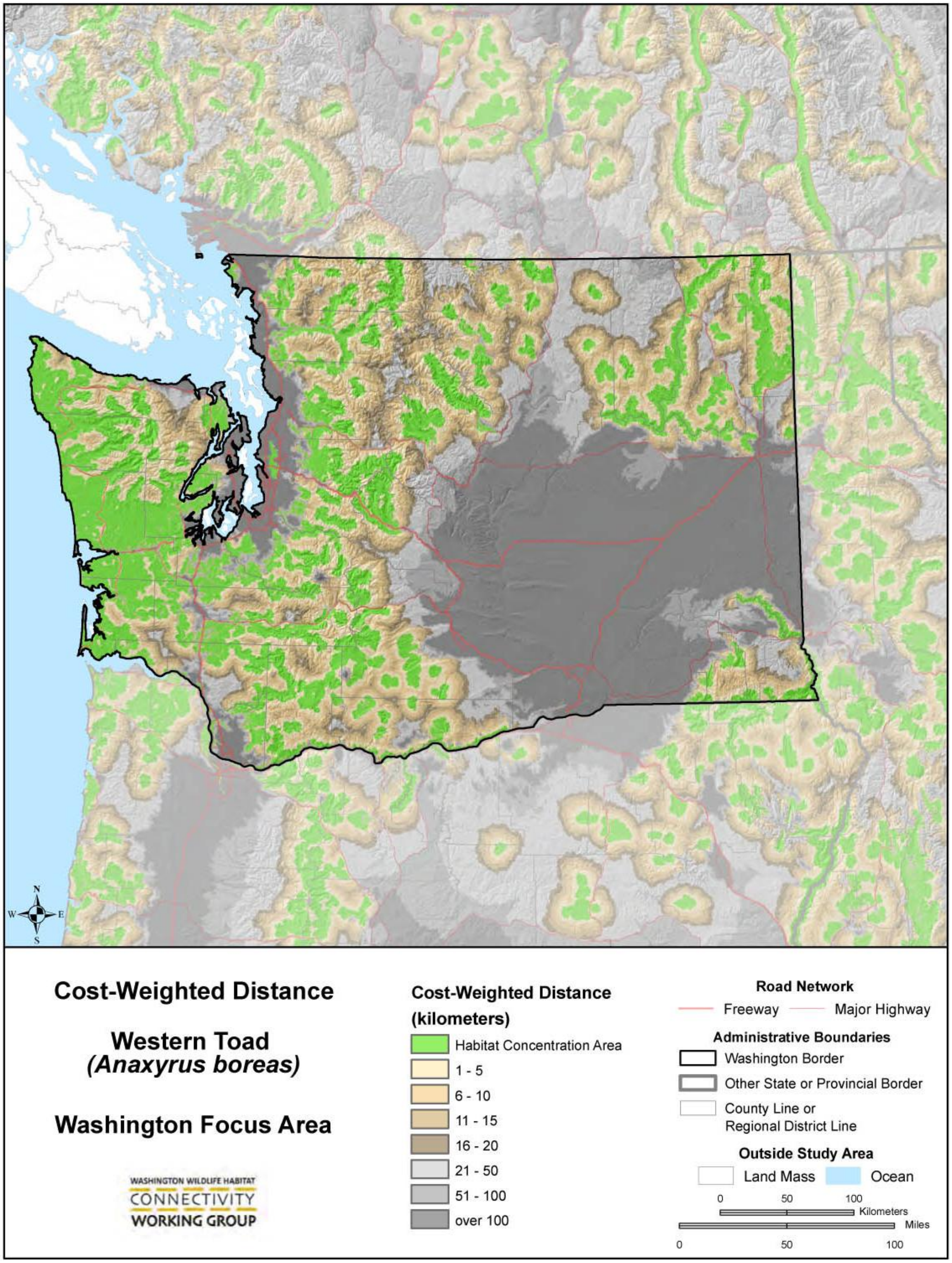


Figure 3.47. Cost-weighted distance for western toads.

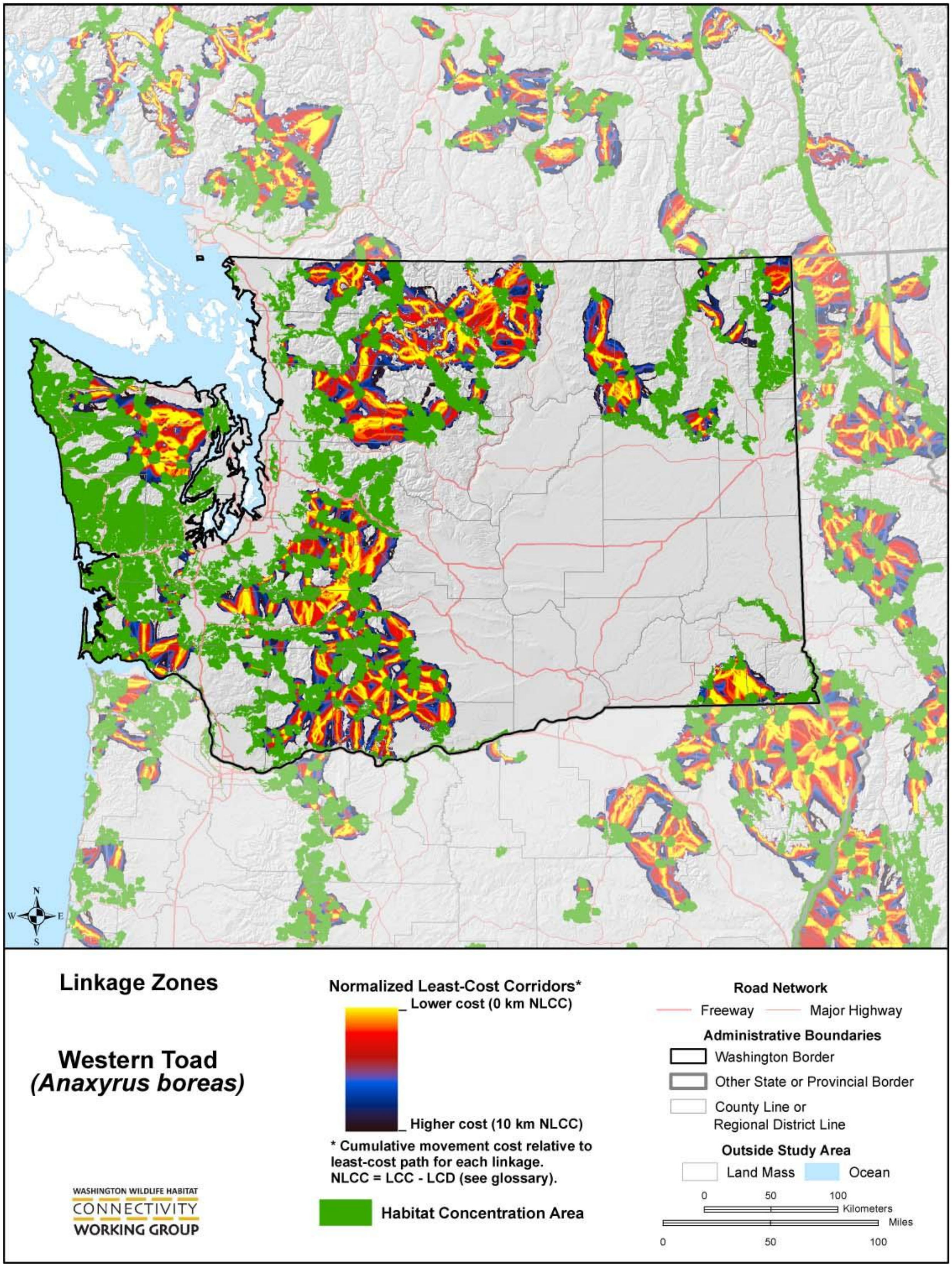


Figure 3.48. Western toad linkages.

3.2.14. American Marten (*Martes americana*)

3.2.14.1. INTRODUCTION

American marten, photo courtesy of WDFW.

American marten are a boreal species with a relatively wide distribution across the forested portions of the assessment area (Johnson & Cassidy 1997), though observations are relatively rare within the lower elevation dry forests of eastern Washington (Bull et al. 2005; Munzing & Gaines 2008). The presence of abundant snags and coarse woody debris is an important feature of the habitat, especially in winter, as it provides access to prey beneath the snow and resting places (Bull & Heater 2000).

Marten prefer riparian habitats throughout their range (Martin 1987; Buskirk et al. 1989; Anthony et al. 2003) and habitats near water (Bull et al. 2005). Percentage of the landscape in openings, such as forest clear cuts, is a primary factor in determining habitat quality; home range quality decreases as percentage of openings exceeds 25% (Hargis & Bissonette 1997; Hargis et al. 1999). Marten population reductions of 67% were reported following removal of 60% of timber (Soutiere 1979), and 90% with 90% timber removal (Thompson 1994). Trapping is a major source of mortality for marten especially in forested areas with road development (Hodgman et al. 1994; Thompson 1994).

The American marten was selected as a focal species for the Subalpine and Vancouverian Forest vegetation classes because of its relatively wide distribution and association with late-successional (mature and old-growth) forests. This species is considered vulnerable to loss of habitat connectivity from two of the four overarching connectivity threats: development, and roads and traffic. Marten are a species of management focus on national forest lands (USDA-FS 2006) and are considered a Species of Greatest Conservation Need in Washington State (WDFW 2005).

3.2.14.2. MODEL CONCEPTUAL BASIS

Habitat concentration areas for American marten were identified using late-successional forest excluding low-elevation dry forests of eastern Washington and in the Blue Mountains (Bull et al. 2005; Munzing & Gaines 2008), and areas that are >50 m from a road. Bull & Heater (2001) presents the best home range estimates for marten in the assessment area. They reported marten home range sizes of 27.2 km^2 for males and 14.2 km^2 for females. The minimum area for a marten HCA was determined by multiplying the female home range by 10 to equal 140 km^2. The resistance value cutoff was ≤8. Within home range movement distance (female) was 5 km based on dispersal and home range information.

Resistance parameters were derived, primarily, from literature describing marten habitat associations and behavior. In cases where information was lacking, we relied upon the professional judgment of species experts to score values. Wet forest and wetland vegetation types were assigned the lowest resistance values; urban areas, water bodies, and freeway roads the highest.

Snyder and Bissonette (1987) reported limited use by marten of patches <15 ha. Patches used by resident marten were 18 times larger (median = 27 ha) than patches that were not used (median = 1.5 ha) and were closer to adjacent forest preserves (Chapin et al. 1998). Median size of largest forest patch in marten home ranges was 150 ha for females and 247 ha for males (Chapin et al. 1998). Potvin et al. (2000) recommended that uncut forest patches be >100 ha to maximize core area and to minimize edge.

3.2.14.3. MODEL RESULTS

Habitat Concentration Areas — We identified 39 HCAs (Fig. 3.49) that were well distributed throughout the known and modeled habitat distribution for marten within or partially within Washington (Johnson & Cassidy 1997). Habitat concentration areas covered about 20,865 km^2 of the project area and ranged in size from 100 km^2 to 3576 km^2.

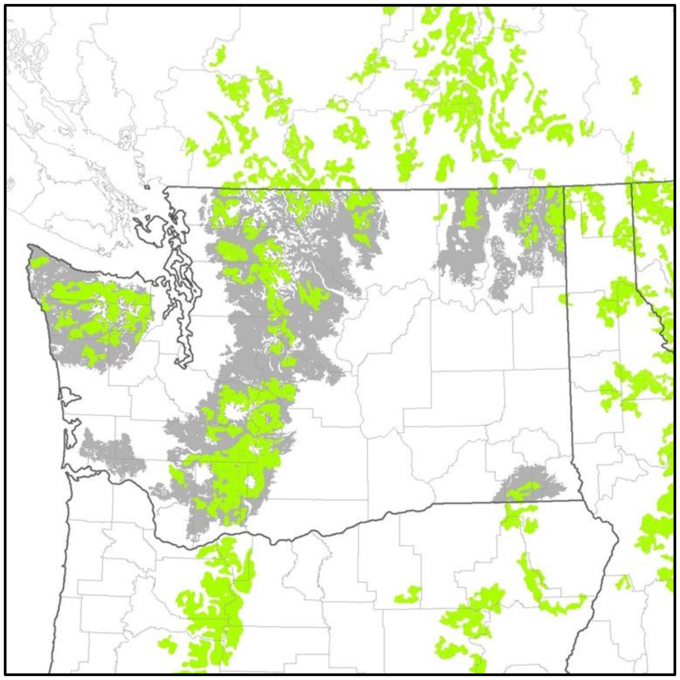


Figure 3.49. American marten HCAs (green) and GAP distribution (gray).

Resistance Surface — The American marten resistance surface for the project area indicates relatively good connectivity throughout most of its range (Fig. 3.50). Natural (low-elevation forests, grasslands and shrublands) and human created features (highways, dams, towns, and railways) contribute to areas of high resistance.

Cost-weighted Distance — The American marten cost-weighted distance map indicates that connectivity in the project area is reasonable for marten movements along the North Cascades/South Cascades with the exception of I-90, and throughout the Olympic Peninsula with the exception of U.S. Highway 101 (Fig. 3.51). The I-5 corridor and associated human development poses a potential barrier between the Olympic Peninsula and the southern Cascades HCAs. Connections between HCAs in the northeastern part of the state are patchy. The Blue Mountains HCA is surrounded by largely impermeable conditions suggesting that this population will remain isolated from all others in the project area.

Linkage Modeling — Linkages were modeled when the least-cost distance between a pair of HCAs was less than 300 km (Fig. 3.52). This resulted in 53 linkages, in Washington, between HCAs. The mean Euclidean distance of the linkages was 8 km and ranged from <1 to 29 km. The mean cost-weighted distance was 97 km and the ratio of cost-weighted/Euclidean distance ranged from 5 to 100.

The distribution of HCAs and their associated potential linkages resulted in seven hypothetical metapopulations of marten across the project area. These include the Olympics in which there were potential linkages between HCAs but no linkages to HCAs in the Cascades. There were three areas in the Cascades that appeared as hypothetical metapopulations, one occurring in the Cascades of Oregon, separated from HCAs in southern Washington by natural (low-elevation forests, grasslands, and shrublands) and human created features (highways, dams, towns, and railways). Another hypothetical metapopulation was identified in the southern Cascades of Washington. These HCAs are separated from those in the North Cascades by I-90, indicating the importance of efforts to restore habitat connectivity. Habitat concentration areas in the North Cascades include those in north-central Washington and south-central British Columbia. Potential linkages between HCAs across the Highway 2 corridor will be important to consider at a finer scale. Additionally, there are potential linkages across gaps in HCAs from the head of Lake Chelan westward across the North Cascades, likely a result of high elevation mountains and glaciers.

The HCAs in south-central British Columbia showed linkages to each other and to the Kettle Range in Washington. The HCAs in this area are separated from HCAs in the North Cascades by the Okanogan Valley to the west and HCAs in northeastern Washington by the Upper Columbia River.

Habitat concentration areas in northeast Washington have potential linkages to northern and central Idaho. Habitat concentration areas in the Blue Mountains of southeastern Washington and northeastern Oregon showed some linkages but are largely isolated from each other.

Figure 3.50. Landscape resistance for American marten.

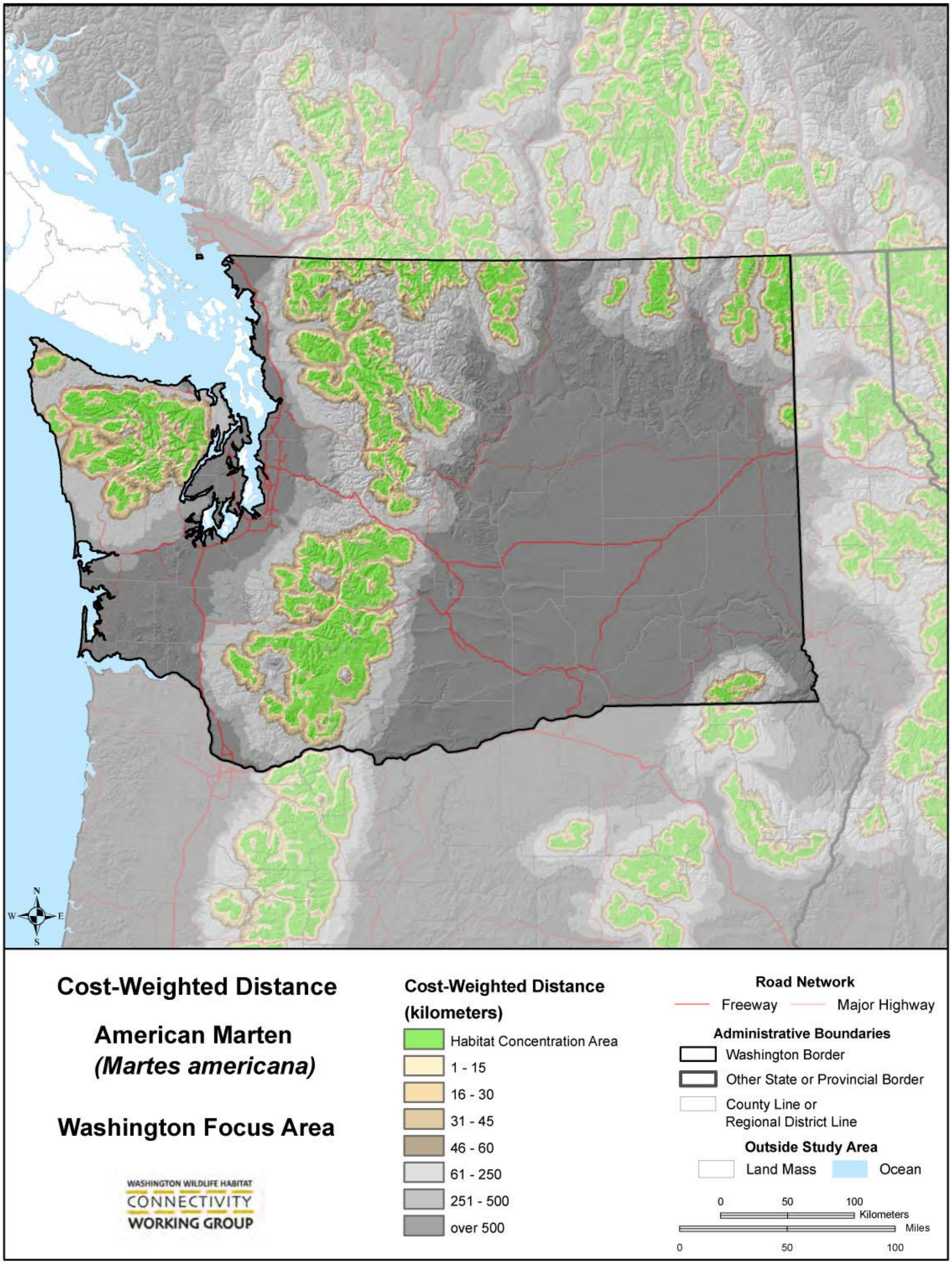


Figure 3.51. Cost-weighted distance for American marten.

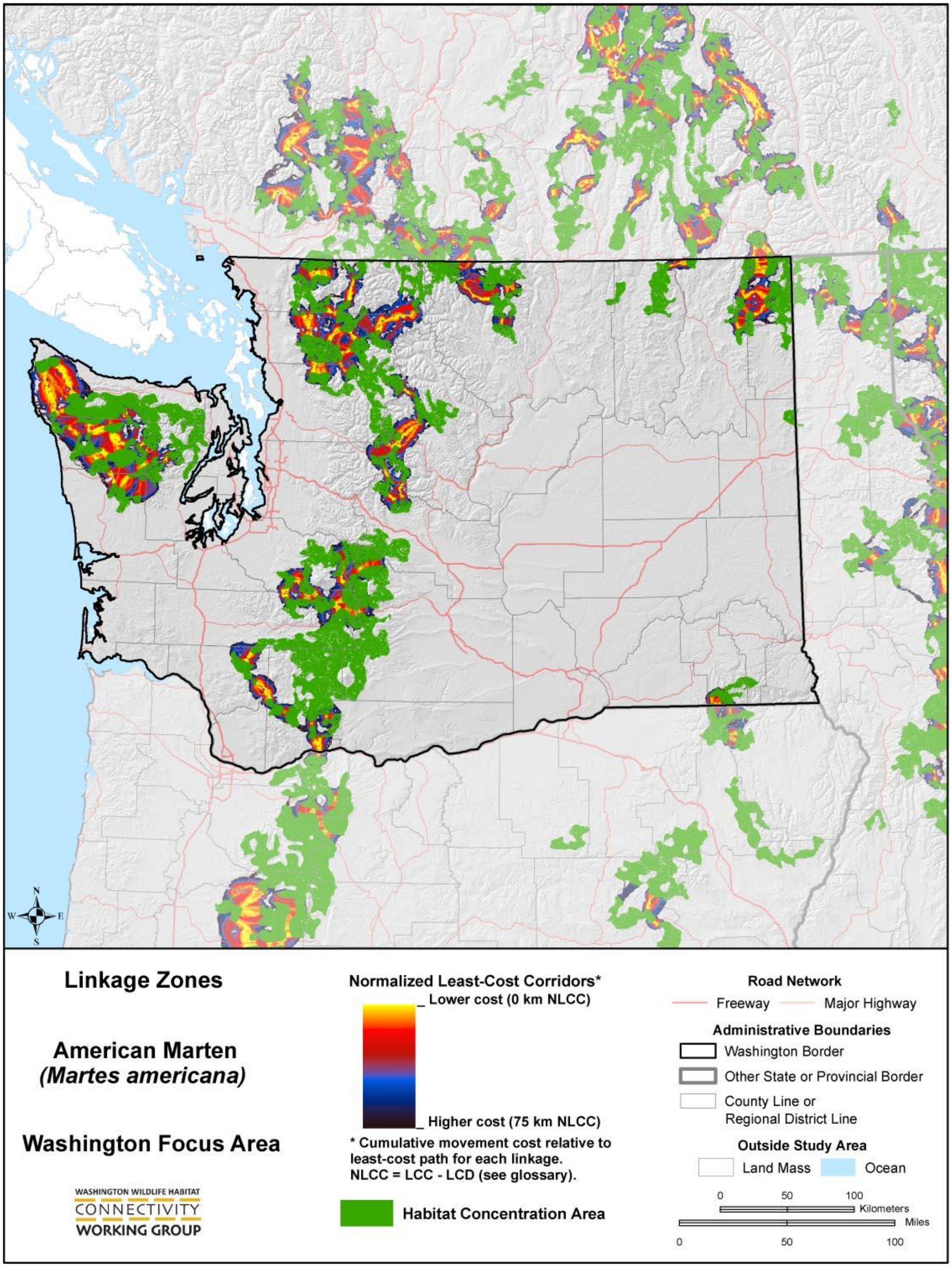


Figure 3.52. American marten linkages.

3.2.15. Canada Lynx (*Lynx canadensis*)

3.2.15.1. INTRODUCTION

Canada lynx occur in most boreal forest habitats in North America, including the upper elevation coniferous forests of the Rocky Mountains and Cascade Ranges (Aubry et al. 2000). In Washington, Canada lynx are primarily found in high-elevation forests in the north-central and northeast parts of the state including areas in Okanogan, Chelan, Ferry, Stevens, and Pend Oreille counties (Stinson 2001). The distribution of Canada lynx within the state has been stratified into core, secondary and peripheral habitat areas based on known records of their occurrences (USFWS 2005). The Canada lynx is state and federally listed as a Threatened Species.

Canada lynx, photo courtesy of WDFW.

The Canada lynx was selected as a focal species for the Subalpine Forest vegetation class due to its association with boreal forests (Koehler & Aubry 1994; Aubry et al. 2000; Koehler et al. 2008; Maletzke et al. 2008). Canada lynx were considered vulnerable to loss of habitat connectivity from all four major connectivity threats: land clearing and vegetation removal, development, roads and traffic, and the presence of people and domestic animals.

Key habitat components include foraging habitat for Canada lynx where understory stem densities and structure provide forage and cover for snowshoe hare (*Lepus americanus*), a major prey species (Koehler 1990; Agee 2000; Hodges 2000). In Washington, Canada lynx select for Engelmann spruce (*Picea englemanni*) and subalpine forest, moderate canopy cover, flat to moderate slopes, and relatively high elevations. They select against Douglas-fir and ponderosa pine forest, forest openings, recent burns, sparse canopy and understory, and relatively steep slopes (Koehler et al. 2008; Maletzke et al. 2008). Throughout their range, Canada lynx are absent or uncommon in dense, wet forests along the Pacific coast (Aubry et al. 2000).

3.2.15.2. MODEL CONCEPTUAL BASIS

We used published literature and input from expert reviewers to develop resistance surfaces used to evaluate dispersal habitat suitability. This spatial information was then used to identify concentrations of high quality Canada lynx habitat referred to as habitat concentration areas (HCAs). The distribution of HCAs within the U.S. portion of the assessment area was constrained by the location of core and secondary areas identified by the USFWS (2005), which were based on Canada lynx distribution. We calculated a weighted average home-range size of 60.4 km^2 (data for female Canada lynx; Brainerd 1985; Brittell et al. 1989; Koehler 1990; Apps 2000; Squires & Laurion 2000). We used the following criteria to identify HCAs for Canada lynx: a resistance value <8, home range radius of 4.4 km, minimum patch size of 400 km^2 and a habitat threshold of 0.5.

Intra-home range movements vary seasonally and depend on the availability of prey, mainly snowshoe hare. Daily movement distances range 2.6–10 km (Parker et al. 1983; Ward & Krebs 1985). Movements of 15–40 km beyond home-range boundaries have been documented in

Montana (Squires & Laurion 2000). However, this type of movement was not documented in a study in north-central Washington (Koehler 1990). In more northerly habitats Canada lynx can move up to 1000 km during periods of prey scarcity (Mech 1980; Slough & Mowat 1996; Poole 1997).

3.2.15.3. MODEL RESULTS

Habitat Concentration Areas — Thirty-one HCAs were identified for Canada lynx within the northern and eastern portions of the project area; 8 HCAs were wholly or partially within Washington (Fig. 3.53). These occurred within core and secondary areas identified for Canada lynx recovery (USFWS 2005) and within the highest quality Canada lynx habitat in the remainder of the project area. Habitat concentration areas covered a total of 14,769 km^2 of the project area and ranged in size from 596 km^2 to 5916 km^2. Habitat concentration areas occurred primarily within the North Cascades, Kettle Range, and Selkirk Mountains. The pattern of HCAs for Canada lynx are similar to those identified by Singleton et al. (2002) except that we constrained the distribution of HCAs by the core and secondary areas (as described above).

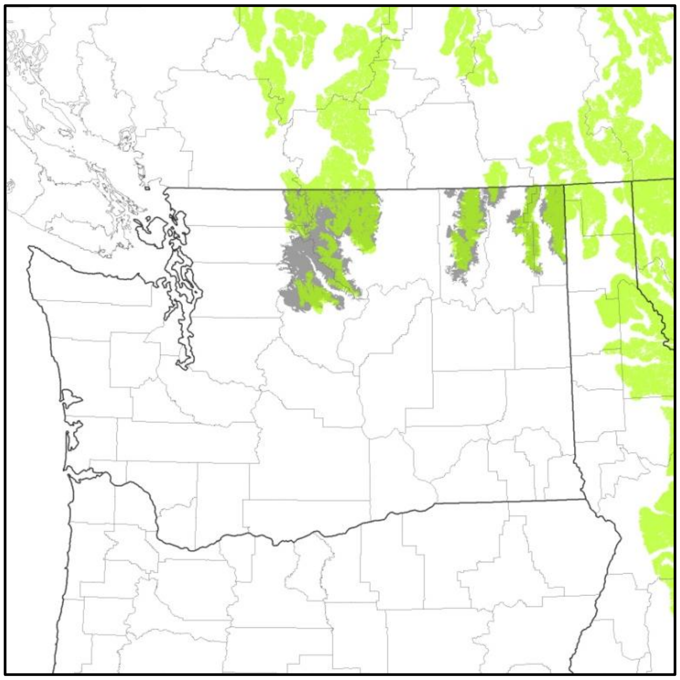


Figure 3.53. Canada lynx HCAs (green) and GAP distribution (gray).

Resistance Surface — The Canada lynx resistance surface generally indicates limited conditions for movements throughout the project area (Fig. 3.54). Human activities and low-elevation forest along the Okanogan River, Upper Columbia River, and Pend Oreille River valleys constitute the main barriers for connectivity.

Cost-weighted Distance — The Canada lynx cost-weighted distance map indicates that connectivity of habitats north-south is relatively good (Fig. 3.55). However, gaps exist between the southernmost HCAs where the distribution of Canada lynx habitat becomes more naturally fragmented.

Linkage Modeling — Potential linkages were modeled for Canada lynx when the least-cost distance between a pair of HCAs was <1350 km (Fig. 3.56). This resulted in 13 potential linkages between pairs of HCAs within or partially within Washington. The mean Euclidean distance of the linkages was 36 km and ranged <1–107 km. The mean cost-weighted length of the linkages was 416 km and the ratio of cost-weighted/Euclidean distance ranged from 4 to 27.

The connectivity of habitats for Canada Lynx north-south is relatively good. However, gaps exist between the southernmost HCAs where the distribution of Canada lynx habitat becomes more naturally fragmented. In addition, gaps in HCAs occur along the Similkameen River valley and along the Fraser and Thompson River valleys. These river valleys contain low-elevation forests and human activities. Similar results were found by Singleton et al. (2002).

The east-west connectivity between the North Cascades, Kettle Range, and Selkirk Mountains is interrupted by the Okanogan River, Upper Columbia River, and Pend Oreille River valleys which include low-elevation forests and human activities. The upper elevation forests associated with the Kettle Range and Selkirk Range may provide important stepping-stone habitats that could increase the permeability of the landscapes between the Rocky Mountains and the North Cascades. Our assessment shows relatively long and narrow linkages across the Okanogan Valley on the U.S. side, and long but broader linkages in British Columbia. It is interesting to note that several of the linkages identified in Singleton et al. (2002) for Canada lynx are also identified in this assessment (e.g., the potential linkage across the Okanogan Valley near the town of Riverside). These potential linkages are likely important for the long-term conservation of Canada lynx (Singleton et al. 2002; Schwartz et al. 2002) and a finer-scale assessment will be important to identify specific areas for the restoration or maintenance of these linkages.

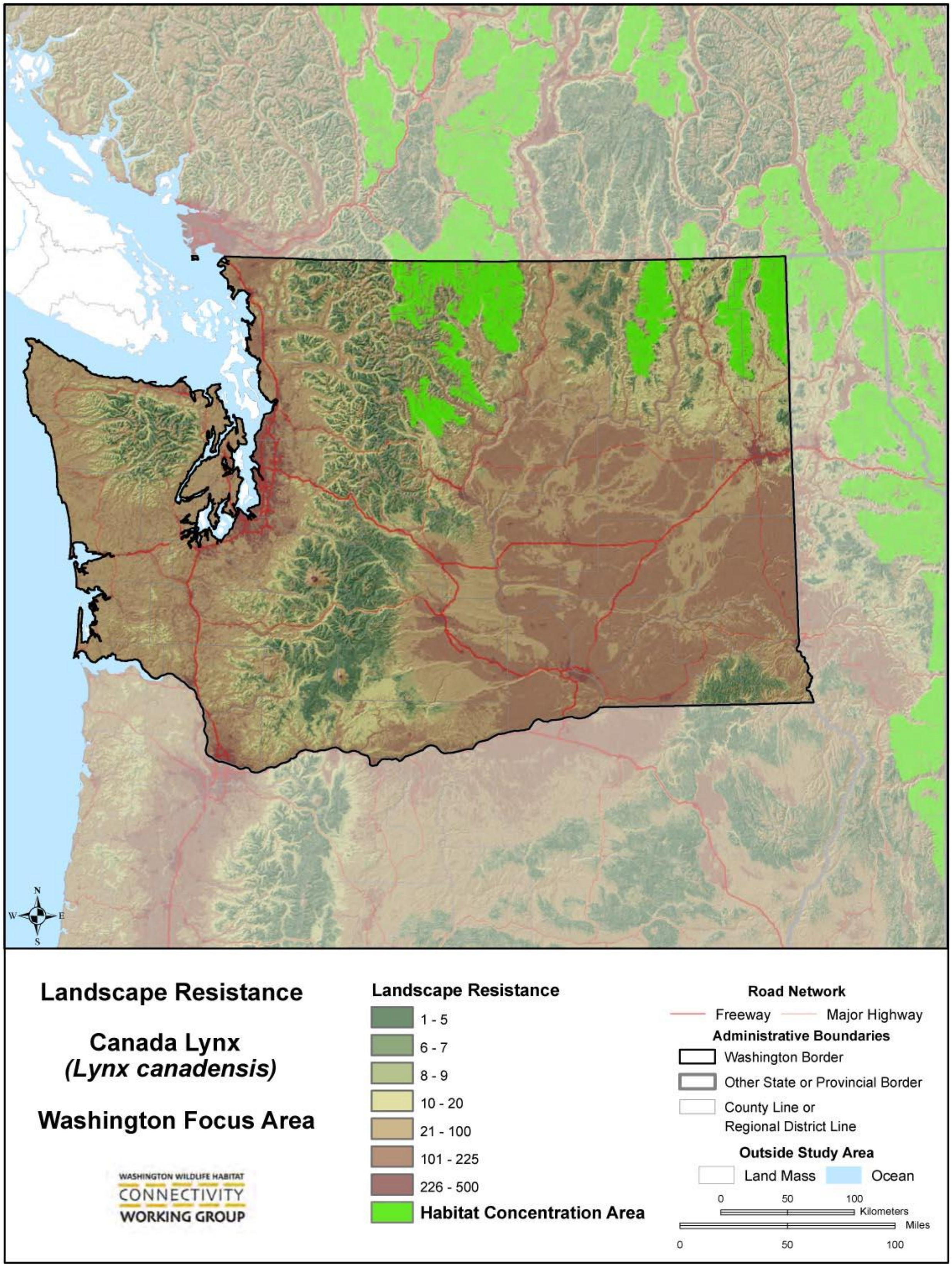


Figure 3.54. Landscape resistance for Canada lynx.

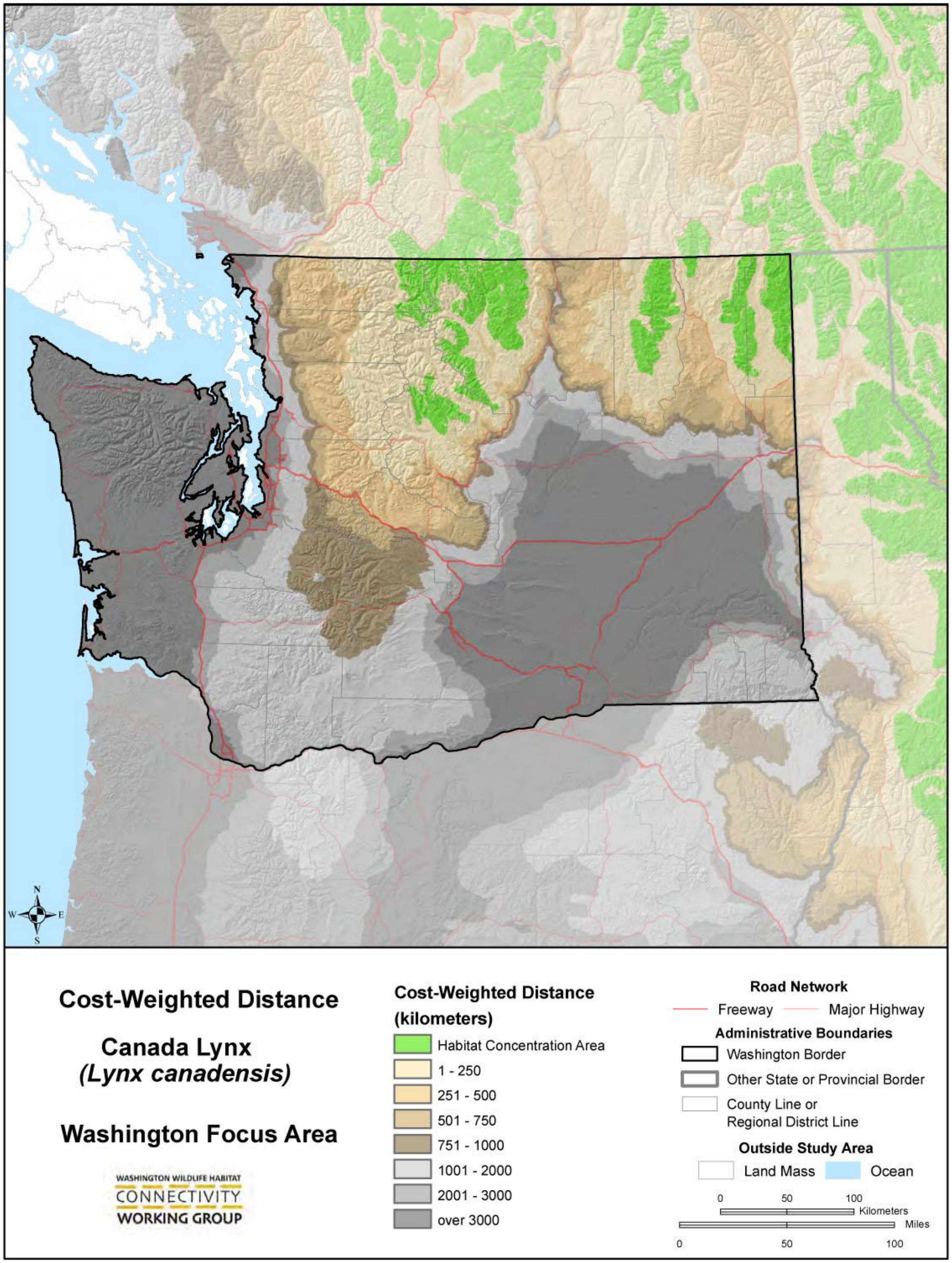


Figure 3.55. Cost-weighted distance for Canada lynx.

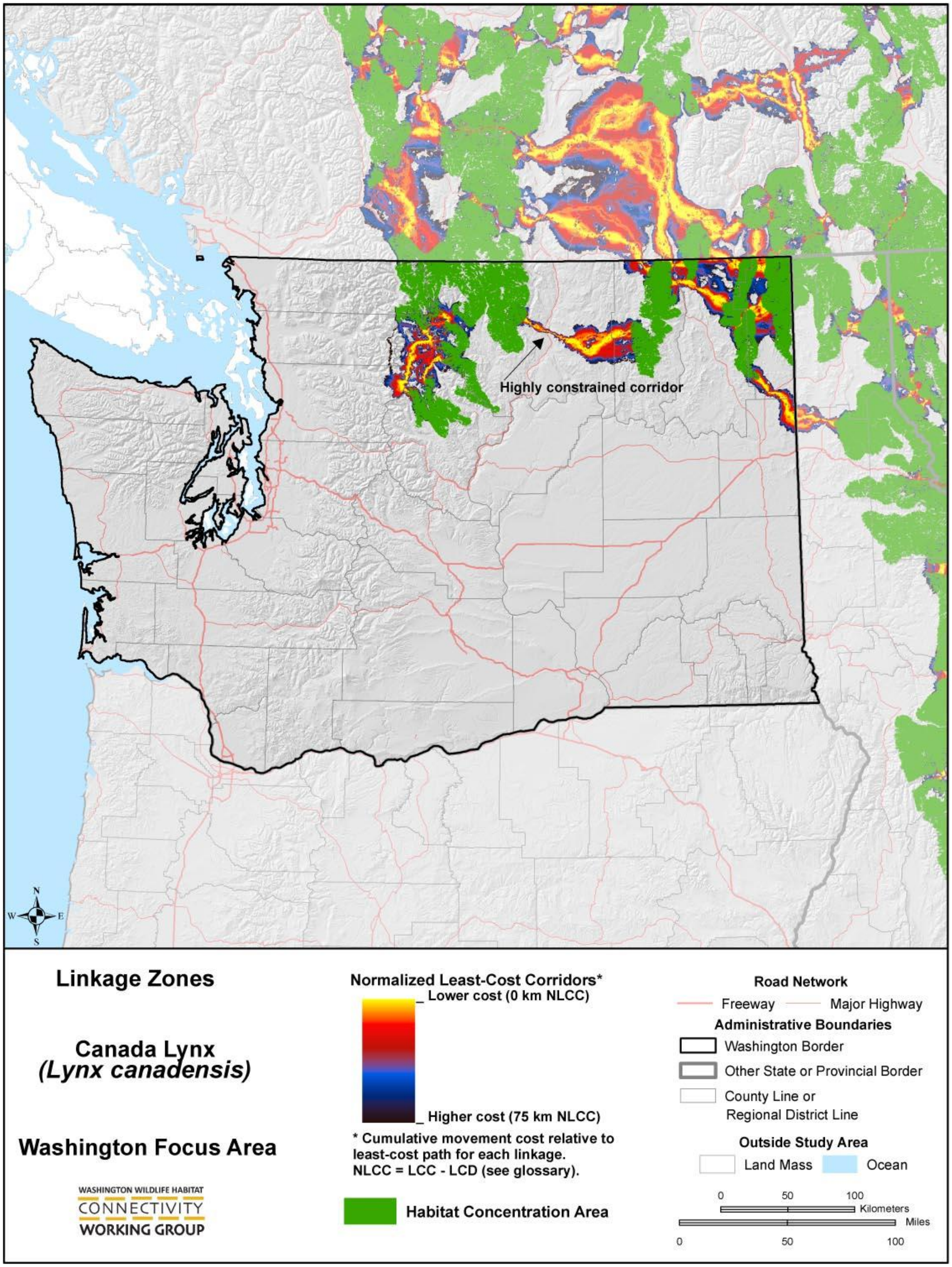


Figure 3.56. Canada lynx linkages.

3.2.16. Mountain Goat (*Oreamnos americanus*)

3.2.16.1. INTRODUCTION

Mountain goat, photo by Cliff Rice.

Mountain goats live in some of the most inhospitable alpine and subalpine terrain in North America where they are associated with cliffs or rocky ledges on which they depend to escape predators (Côté & Festa-Bianchet 2003). In Washington, the native population of mountain goats numbered about 8500 in 1961 (excluding populations in Mount Rainier National Park and Yakama Nation lands). Numbers have declined over the past several decades to about 2500 individuals. Although harvest of mountain goats is now strictly limited some areas of formerly occupied range in the state remain sparsely populated. Populations in Washington are patchily distributed among islands of habitat that are linked together by dispersal. Mountain goats are capable of long-distance movement (>50 km) through areas of relatively poor habitat (Fielder & Keesee 1988). Recent studies describing habitat (Wells 2006), genetic structure, and gene flow (Shirk et al. 2010) reveal that connectivity between mountain goat populations in the north and south Cascades is greatly reduced due to the effect of I-90.

Mountain goats were selected as a focal species because their habitat connectivity needs are representative of wildlife in the Subalpine Forests and Alpine vegetation classes. They were considered vulnerable to loss of habitat connectivity from three of the four main connectivity threats: development, roads and traffic, and the presence of people and domestic animals

3.2.16.2. MODEL CONCEPTUAL BASIS

Mountain goat HCAs for Washington were defined by aerial surveys and expert knowledge of populations in the state. Habitat concentration areas for portions of British Columbia, Idaho, Oregon, and Montana that fell within the study area were also identified by surveys. Resistance values were derived from published literature; where information was lacking we relied on the professional judgment of expert reviewers. Aside from I-90, primarily geographic distance but also highways, urban and agricultural areas, very high and low elevations, and bodies of water reduce ***landscape connectivity*** for this species (Shirk et al. 2010). Mountain goats are sensitive to human-caused disturbances in the landscape such as roads and development and avoid populated areas.

3.2.16.3. MODEL RESULTS

Habitat Concentration Areas — Most mountain goat HCAs exist within large cores of remote mountainous terrain that are less impacted by anthropogenic landscape changes relative to the lower elevations of the Puget Trough and Columbia Basin (Fig. 3.57). This reflects the adaptation of mountain goats to habitats generally devoid of high human population densities or expansive anthropogenic landscape changes. However, lowland areas and mountain passes between HCAs, in some cases, have been modified in ways that profoundly influence habitat connectivity. HCAs for this species form three large clusters representing the population of Washington, the Coast Range of British Columbia, and the interior North American population of the Rockies. The Olympic peninsula, which is inhabited by a sizeable non-native mountain goat population, was not considered an HCA in this study.

Resistance Surface — The mountain goat resistance surface was parameterized based on a study linking elevation, land cover, and roads to mountain goat gene flow in the Cascade Range, Washington (Shirk et al. 2010; Fig. 3.58). Based on this study, mountain goats appear capable of efficiently dispersing through lower elevation forested environments unless major roads, water bodies, and high human population densities are present. This is reflected in the resistance surface, where large cores of mountainous habitat have very low resistance while major roads, large lakes, and urban areas offer high resistance. We assigned resistance due to human population density entirely to the housing density (acres per dwelling unit) rather than the urban class of the land cover layer.

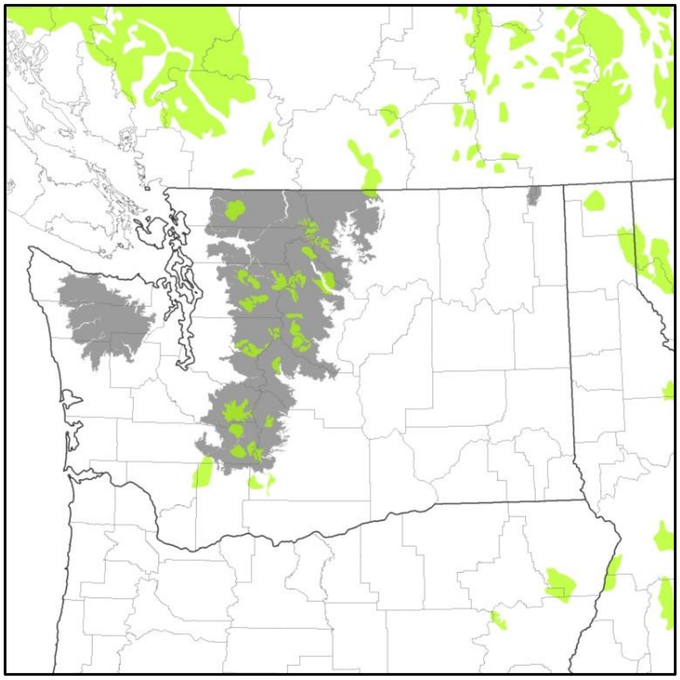


Figure 3.57. Mountain goat HCAs (green) and GAP distribution (gray).

Cost-weighted Distance — Habitat concentration areas appear highly connected (i.e., the cost-weighted distance between them is low) within the north and south Cascades (Fig. 3.59). Due to the very high resistance of I-90, the cost-weighted distance increases rapidly when crossing this major transportation corridor. This is congruent with the observation that mountain goats in the Cascade Range form two genetic sub-populations clearly delineated by I-90. A similarly strong barrier appears to rapidly increase cost-weighted distance when crossing the Fraser Valley between the Washington Cascade Range and Coast Range of British Columbia. Resistance due to a combination of distance, roads, and development in the Okanogan Valley also increase the cost-weighted distance between the interior North American population in the Rockies and the Washington Cascade mountain goat population.

Linkage Modeling — Linkages between mountain goat HCAs were limited to cost-weighted distances of less than 217 km. This criterion yielded a total of 166 linkages (71 within Washington) between the 73 mountain goat HCAs (29 within Washington) forming a large regional network (Fig. 3.60). The length and quality of linkages varied considerably across the study area. Linkage cost-weighted distances ranged from 0.3 km to 197 km (mean of 41 km [SD 47]). In Euclidean distance, linkages ranged from 0.2 km to 169 km (mean of 29 km [SD 31]). These values differ slightly from the linkage statistics reported in Table 3.3 because they summarize linkages across the full study area rather than Washington alone.

The ratio of the linkage Euclidean distance to cost-weighted distance ranged from 1 to 7 (mean of 1 [SD 1]; Table 3.3). This ratio is an indication of linkage quality, and can be thought of as a multiplier representing the additional cost of moving along a linkage due to suboptimal dispersal habitat (e.g. a linkage with a ratio of 2.0 would be, on average, twice as difficult to traverse per unit distance than a linkage consisting entirely of optimal dispersal habitat, which would have a ratio of 1.0).

Most of the mountain goat HCAs within the study area are in large cores of remote mountainous terrain that are less affected by anthropogenic landscape changes relative to the lower elevations of the Puget Trough and Columbia Basin. An exception occurs where major highways bisect the range. Empirical genetic data indicates that I-90 fragments the Washington mountain goat population into two distinct subpopulations (Shirk et al. 2010). This sharp boundary is reflected in the linkage models that connect HCAs on either side of I-90. For these connections, the cost-weighted distance is greater than 150 km, yet the Euclidean distance between these HCAs is only 43 km. This disparity can be quantified by taking the ratio of the Euclidean linkage length to the cost-weighted distance, which in the case of linkages crossing I-90 is 3.5 or greater. By comparison, most HCAs within the large cores of remote mountainous habitat have a ratio approaching 1:1 (the ratio which would occur if the entire linkage was in optimal dispersal habitat).

Major fracture zones occur across I-90, the Fraser Valley, and the Okanogan Valley. In addition to the fracture zone across I-90, the mountain goat linkage models predict similar fracture zones coinciding with other major highways. The connection which spans the Fraser River valley between the north Cascades and the Coast Range of British Columbia, for example, has a total cost-weighted distance of 189 km and a Euclidean to cost-weighted distance ratio of 4.5. This linkage crosses the Trans-Canada highway, a major river, agricultural lands, and areas with high human population density. It also becomes restricted to a narrow pinch point in the vicinity of Hope, B.C.

The connection between the North Cascades and the western sub-ranges of the Rockies involves several stepping-stone HCAs. Among these, the more northerly of two linkages spanning the Canadian portion of the Okanogan Valley appears costly according to our model (though not on par with the I-90 or Fraser Valley linkages) due to a combination of high human population density, significant water bodies, and highways. This linkage has a total cost-weighted distance of 56 km and a ratio of 2.1. It is also significantly constrained by a pinch point in the vicinity of Penticton, B.C. An alternative but longer route (96 km cost-weighted distance) exists to the south, but the distance ratio of 1.2 suggests it is comparatively more favorable to dispersal per unit of Euclidean distance. This more southerly route crosses the Okanogan in the vicinity of Oliver, British Columbia.

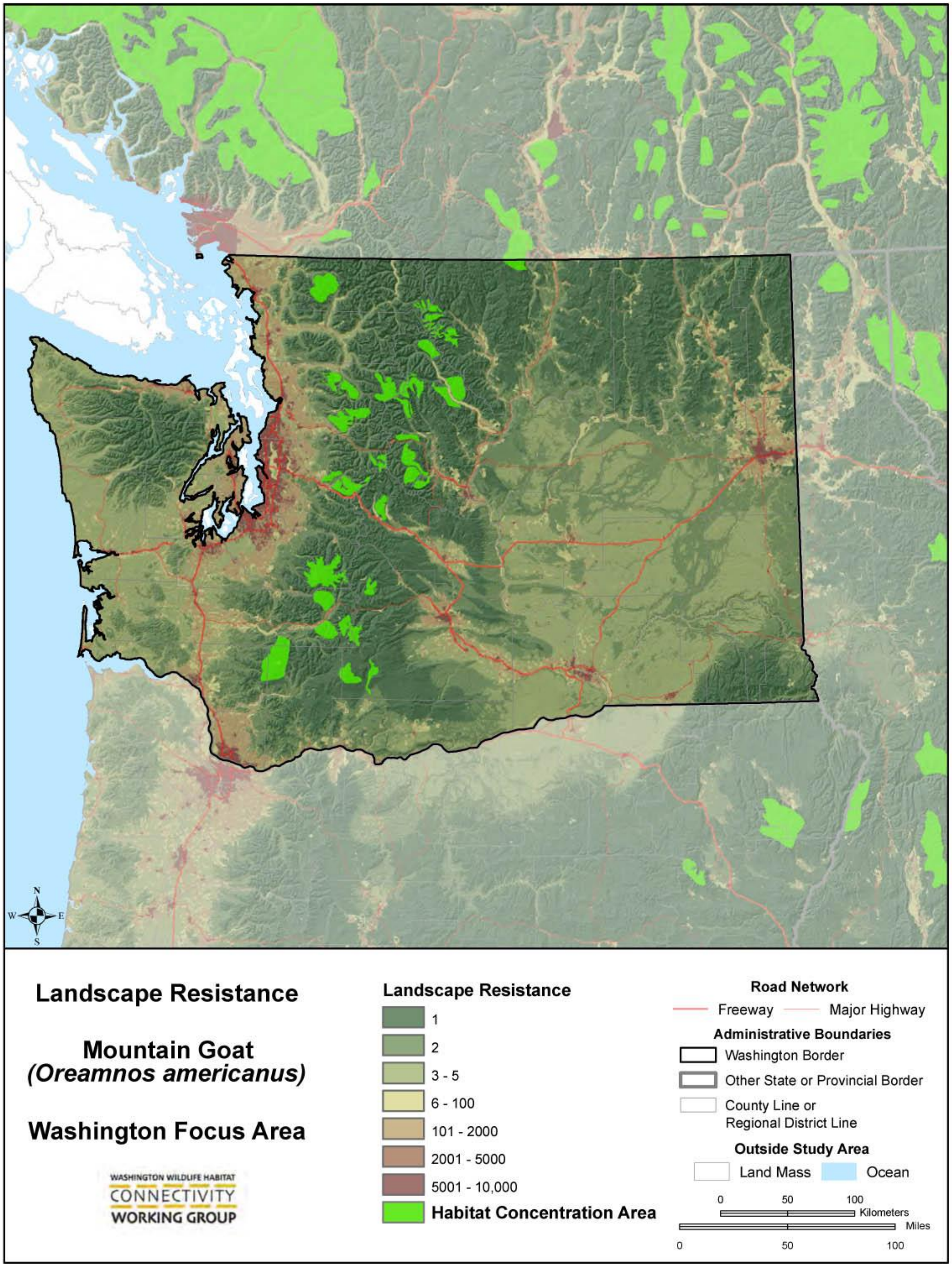


Figure 3.58. Landscape resistance for mountain goats.

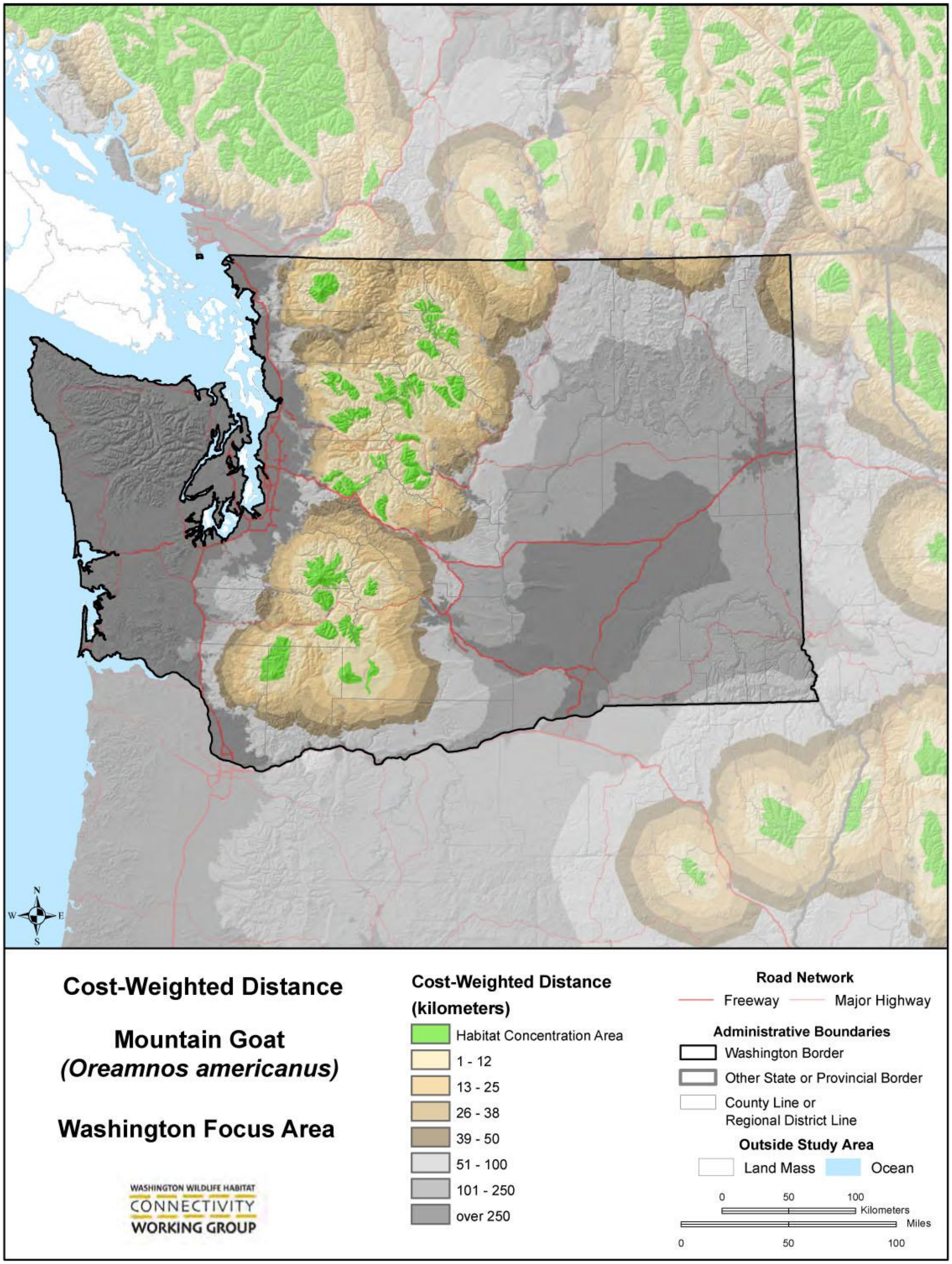


Figure 3.59. Cost-weighted distance for mountain goats.

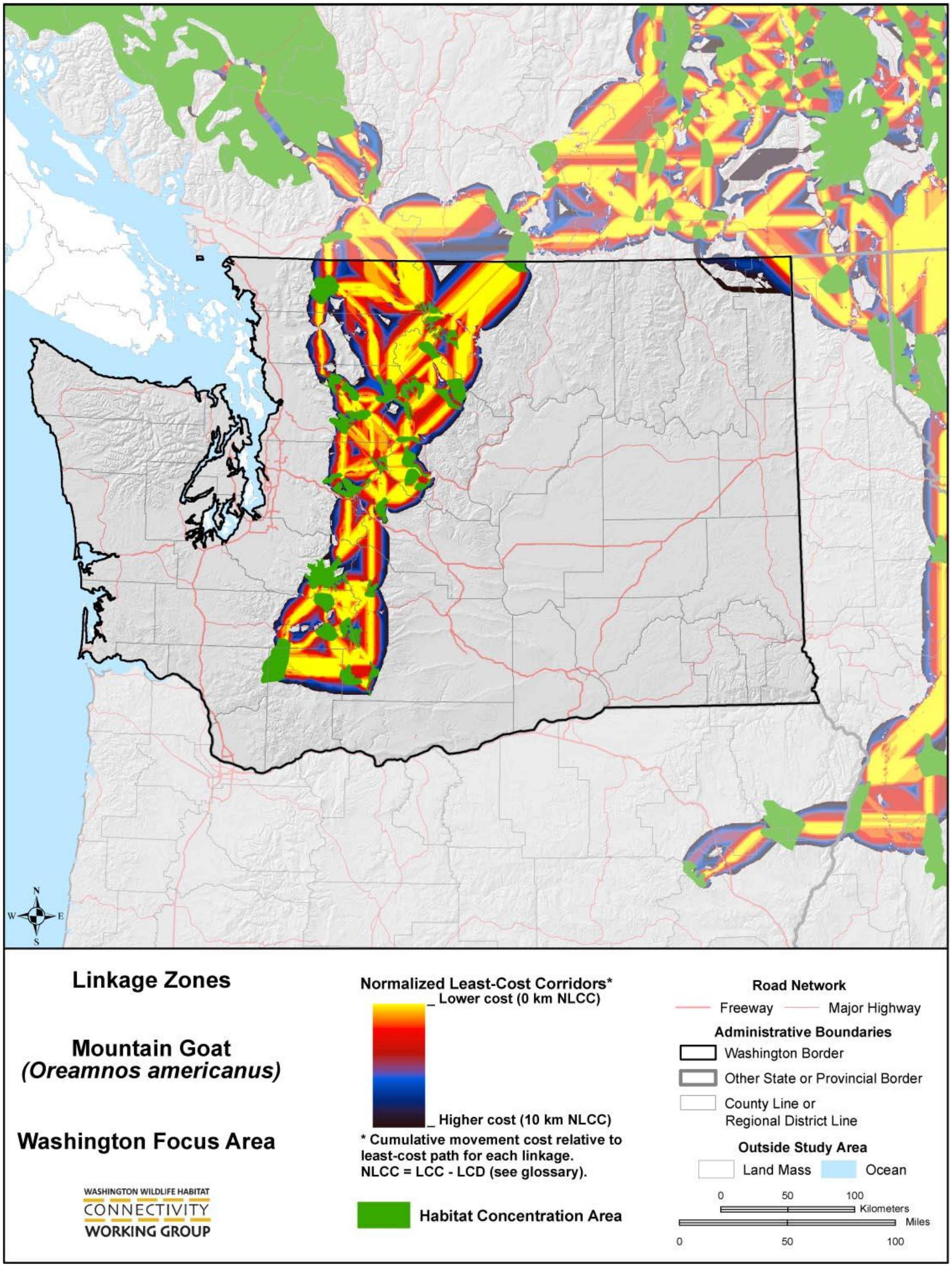


Figure 3.60. Mountain goat linkages.

3.2.17. Wolverine (*Gulo gulo*)

3.2.17.1. INTRODUCTION


Wolverine, photo by Anna Yu.

At far northern latitudes, wolverine habitat occurs virtually everywhere, but in Washington, the subalpine life-zone necessary for wolverine presence is restricted to a high-elevation band, resulting in a naturally fragmented distribution (Copeland & Yates 2008). Populations in the Cascades and Rocky Mountains have been described as peninsular extensions of a more widespread population in Canada (Banci 1994). In Washington, Oregon, and Idaho, wolverine sightings suggest the species' current distribution is clustered in the Cascade Ranges of Washington and Oregon, and the northern Rocky Mountains of Idaho (Edelmann & Copeland 1999). The pattern of wolverine distribution in Washington has varied through time. Before 1919, wolverine presence was reported often in the Cascade Range and northern parts of Washington State (Johnson 1977). From 1919 to 1959 reports were rare, but increasing reports in the 1960s and 1970s suggested re-colonization was occurring (Johnson 1977). Wolverines have not been reliably reported from the Olympic Peninsula and coastal areas to the south (Johnson 1977). Recent work suggests breeding is occurring in the North Cascades of Washington (Rohrer et al. 2008).

Wolverines are predators and scavengers that currently reproduce only in isolated, high-elevation habitats within our analysis area. Although wolverines seem to prefer to move through higher elevation areas (Copeland & Yates 2008; Schwartz et al. 2009; Copeland et al. 2010) they show a remarkable capacity for long-distance dispersal across a variety of forested and unforested habitat types. Wolverines also avoid human developments within their home ranges (May et al. 2006) and during dispersal (Packila et al. 2007). Thus the wolverine represents breeding habitat specialists that are sensitive to human disturbance and dispersal habitat generalists that are highly mobile. The wolverine tends to have large spatial requirements, making it well suited for evaluating landscape permeability at large extents and coarse scales such as this statewide assessment (Begley & Long 2009).

We selected the wolverine as a focal species to represent species that breed in subalpine and alpine habitats. The wolverine rated "excellent" for all selection criteria as a representative of the Subalpine Forests and Alpine vegetation classes. The association between wolverines and areas of persistent spring snow cover suggests the wolverine is also representative of species sensitive to climate changes that influence snow depth and persistence (Brodie & Post 2010; Copeland et al. 2010). Finally, the wolverine is a rare carnivore that is a candidate for listing under the Endangered Species Act. It is currently a Species of Concern in Washington State.

3.2.17.2. MODEL CONCEPTUAL BASIS

We derived estimates of landscape resistance to wolverine dispersal from the literature, especially past efforts to model wolverine habitat quality and connectivity. We also used results from telemetry studies and genetic analyses to infer the relative resistance of different landscape features. Because our inferences about landscape resistance were primarily based on professional judgment, and were only circumstantially supported by data or observations, we generally assigned resistance coefficients in bins that corresponded to low, medium, and high levels of resistance.

We delineated wolverine HCAs using a model that combined low cumulative landscape resistance with spring snow depth. Our evaluation criteria for candidate spatial models of HCAs included: (1) conformance with known activity areas of radio-collared wolverines in the North Cascades of Washington, (2) concordance between our proposed HCAs and areas found to be high quality habitat in previous modeling efforts, and (3) the degree to which our proposed HCA models captured patches of concentrated sighting records. We developed the GIS layer describing spring snow depth using data from the Snow Data Assimilation System (SNODAS) and a broader effort to estimate monthly snow depth across North America (Brown et al. 2003). To be included in an HCA, areas had to have an average snow depth on May 1 that was greater than 1 m and a cumulative resistance score of 10 or less, considering the full suite of layers we used to estimate landscape resistance.

To identify areas with concentrated habitat, we used a circular moving window analysis. We considered the average home-range diameter (19.42 km) of a female wolverine to reflect a typical within-territory movement distance. We merged habitat areas that were less than this distance apart. We found it challenging to determine a minimum size for HCAs. The difficulties were largely associated with an inherent conflict: should we emphasize the role of smaller patches of habitat that could serve as stepping stones for dispersing wolverines (about 100 km^2) or focus on larger patches of high quality habitat that were more likely to sustain populations of wolverines through time (10,000 km^2). We compromised at a smallish patch size of 400 km^2 that we felt was appropriate for both of the focal species in our analysis that are wide-ranging carnivores (wolverine and Canada lynx).

3.2.17.3. MODEL RESULTS

Habitat Concentration Areas — Modeling produced a network of 15 HCAs across the analysis area (Fig. 3.61). HCAs were concentrated in three groups: (1) the Coast Range of British Columbia, northwest of the Lillooet River; (2) the Cascade Range from Manning Provincial Park south to I-90, and from I-90 south to the Mount Adams area; and (3) in the Selkirk and Purcell Mountains of British Columbia. More isolated HCAs were located in the Monashee Mountains of British Columbia, in the Rocky Mountains of Idaho and Montana, and in the Wallowa Mountains and the Oregon Cascades near Mount Hood. In the Cascade Range, HCAs overlapped well with the GAP model of potential wolverine distribution (Johnson & Cassidy

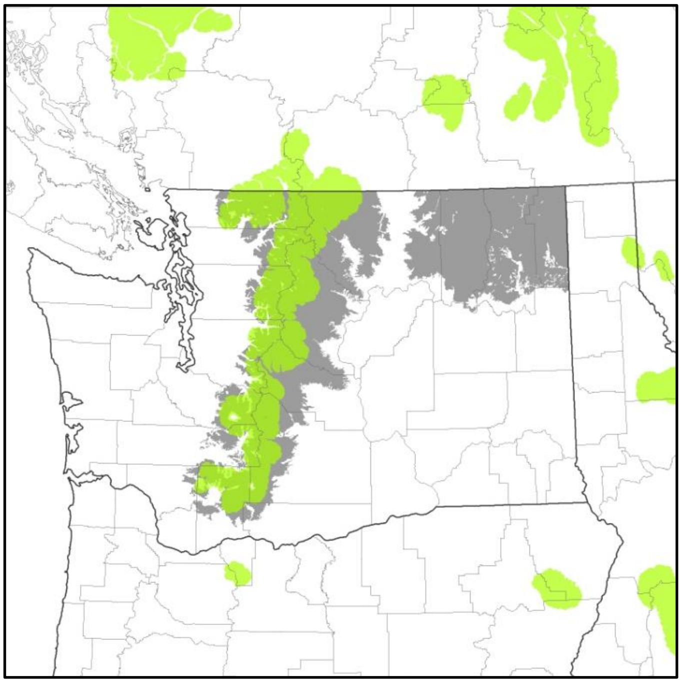


Figure 3.61. Wolverine HCAs (green) and GAP distribution (gray).

1997). HCAs generally cover less area, because they are focused on deep-snow areas near the crest (Fig. 3.61). In northeastern Washington, however, GAP modeling indicated a large area of potential wolverine habitat, but our analysis did not produce any HCAs. This divergence results from the lack of spring snow cover in large enough patches to meet our HCA criteria.

Resistance Surface — Our assignment of resistance values to different landscape features generated a resistance surface in which much of the undeveloped, forested, landscape had low resistance for wolverine dispersal (Fig. 3.62). Densely developed areas, agricultural lands, open water, volcanic peaks, and freeways and major roads were features we assigned a high level of resistance. This resulted in a pattern is which lowland areas and valley bottoms typically had moderate to high resistance, and mountainous areas had low resistance.

Cost-weighted Distance — The combination of high wolverine mobility and apparent willingness to traverse a variety of natural cover types enable wolverines to access most of the analysis area (Fig. 3.63). Cumulative resistance of highly developed areas in the Puget Trough and areas of intensive agriculture on the Columbia Plateau are likely to preclude wolverine dispersal through these areas. River valleys with residential development, transportation infrastructure, open water, and agriculture, such as the Okanogan River valley, represent areas where cost-weighted distance accumulates rapidly. Opportunities for crossing these valley bottoms is likely limited only to remnant patches of natural habitat aligned perpendicular to the long axis of the valley. Mountain passes with transportation infrastructure show a similar pattern of rapid accumulation of cost-weighted distance.

Linkage Modeling — Using 1500 km as the threshold of maximum cost-weighted distance for linkages led to all HCAs in the analysis area being linked (Fig. 3.64). These linkages form an arch that extends from Mount Hood in Oregon, up the Cascade Range of Washington, across southern British Columbia to the Monashee, Selkirk, and Purcell Mountains, and then back south along the Rocky Mountains between Idaho and Montana. A spur links the northwest Cascades to the Coast Range of British Columbia. This overall pattern suggests that existing linkages in the Cascade and Rocky Mountains are relatively good, while the linkage between them is tenuous.

Four linkages were mapped that exceeded 150 km in Euclidean distance. Two of these linkages extend from the Monashee and Selkirk Mountains in British Columbia to the Cabinet Mountains on the border between Idaho and Montana (Euclidean distances of 211 and 168 km). The remaining two long linkages connect an HCA located south of I-90 in the St. Joe portion of the Idaho Panhandle National Forest to an HCA east of McCall, Idaho, and another HCA in the Wallowa Mountains of Oregon (Euclidean distances of 167 and 197 km). We display these linkages to err on the side of inclusiveness, to highlight areas with tenuous linkages, and to acknowledge the remarkable dispersal capacity of wolverines. In the case of linkages from St. Joe to the south, additional shorter linkages may be available to the east (Brock et al. 2007), but the boundary of our analysis area prevented these from being displayed.

Considering all 24 linkages we identified among HCAs, the mean linkage length was 82 km in Euclidean distance and 476 km in cost-weighted distance. Thus, most linkages in the analysis area are on the high end of dispersal distances typical of wolverines. The longest linkage we mapped, from the Monashee Mountains to the Cabinet Mountains, was 211 km long in Euclidean distance and only 938 km in cost-weighted distance, a ratio of about 4.5. This low ratio suggests that habitat with relatively low resistance to wolverine dispersal is available throughout this long linkage. In contrast, the linkage across I-90 in the Cascade Mountains is only 1.4 km in Euclidean distance, but has a cost-weighted distance of 319 km. This high ratio of cost-weighted distance to Euclidean distance (226) reflects the high resistance to wolverine movement of an interstate highway with high traffic volume.

The mean ratio of cost-weighted distances to straight-line Euclidean distances between HCAs was about 10, when the anomalous I-90 linkage was excluded. Similarly, the mean ratio of cost-weighted distances to the non-weighted distance of the least-cost path was about 7. Both ratios suggest that wolverines have access to relatively direct routes that also have relatively high habitat suitability when moving among HCAs. Transportation infrastructure and associated development resulted in linear zones that increased resistance and led to more circuitous linkages.

Our estimates of resistance associated with major highways led to most of State Highway 2 across the Cascade Range being modeled as an obstacle to wolverine movement. In some locations, however, the combination of a narrow highway right-of-way with adjacent, low-resistance habitat resulted in our modeling approach annealing habitat north and south of Highway 2 into one large HCA. These habitat linkages are limited, but the resolution of the maps presented here is not fine enough to clearly display these linkages or to show that the highway is mostly a narrow, linear discontinuity in the HCA. We believe our modeling of the Highway 2 corridor is a reasonable representation of current conditions. The right-of-way is currently about 50 m wide and nighttime traffic volumes are relatively light, suggesting that there may be opportunities for wolverines to cross at select locations with relatively low risk of being deterred by traffic or harmed in a collision. Increases in traffic volume or expansion of the right-of-way could make Highway 2 much more resistant to wolverine movements. Several other major roads in our analysis area likewise have the potential to increase resistance in wolverine linkages.

Wolverine habitat is not as well connected in the Rocky Mountains as it is in the Cascade Mountains. In the Cascade Range, increased resistance is confined to areas around major highways and freeways crossing the range, especially I-90, which bisects the range into northern and southern HCAs. We expect that wildlife crossing structures currently being built as part of I-90 expansion near Snoqualmie Pass will improve connectivity across this freeway. In the Rocky Mountains, transboundary linkages between British Columbia and Idaho and Montana are relatively long and confined by a combination of developed valley bottoms, reservoirs, highways, and active forestry. Additional connections may be available east of our analysis area, but within our area, increased patchiness of persistent spring snow and more widely distributed resistance factors contribute to more fragmentation of wolverine habitat in the Rocky Mountains relative to the Cascade Range.

Other noteworthy impediments to wolverine dispersal in our analysis area include the Okanogan River valley and the Fraser River valley in southern British Columbia, and the Columbia River. We believe that the linkage between the Cascade and Rocky mountains in southern British Columbia is important to the persistence and expansion of the wolverine population in Washington State. This connection is tightly constrained to a narrow band of low resistance habitat across the Okanogan River valley north of Osoyoos, indicating a tenuous linkage that is unlikely to support high rates of successful dispersal. The Fraser River valley similarly constrains an otherwise relatively robust linkage between the Cascade Range and the Coast Range. This is another linkage that likely has important demographic consequences for the wolverine population in Washington. The recent detection of a wolverine that was trapped in the Washington Cascades at a location in the Lilooet Range, west of the Fraser River (C. Raley, personal communication), suggests this linkage is still functional. The Columbia River is a substantial barrier to movement between the Washington Cascade Range and an HCA around Mount Hood in Oregon. Our linkage modeling suggests that a relatively narrow corridor of low resistance habitat converges on the Columbia near Hood River, Oregon.

Given the association of wolverines with persistent spring snow and cool temperatures, climate change is likely to constrain both HCAs and linkages for wolverines in the future. We suspect these changes could lead to future discontinuities in wolverine habitat in the Cascade Range, further fragmentation of habitat in the Rocky Mountains, and northward shift of habitat in British Columbia.

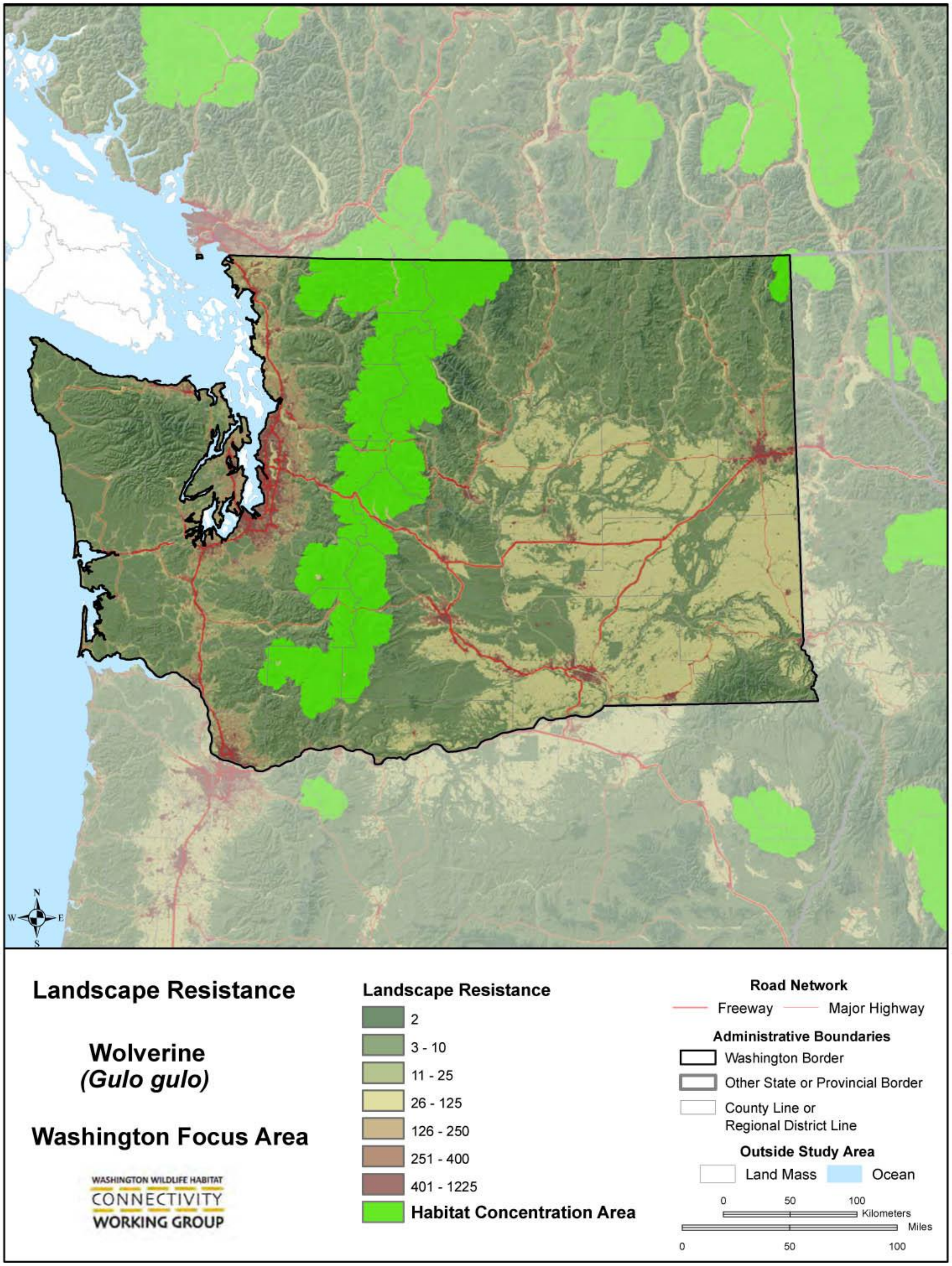


Figure 3.62. Landscape resistance for wolverines.

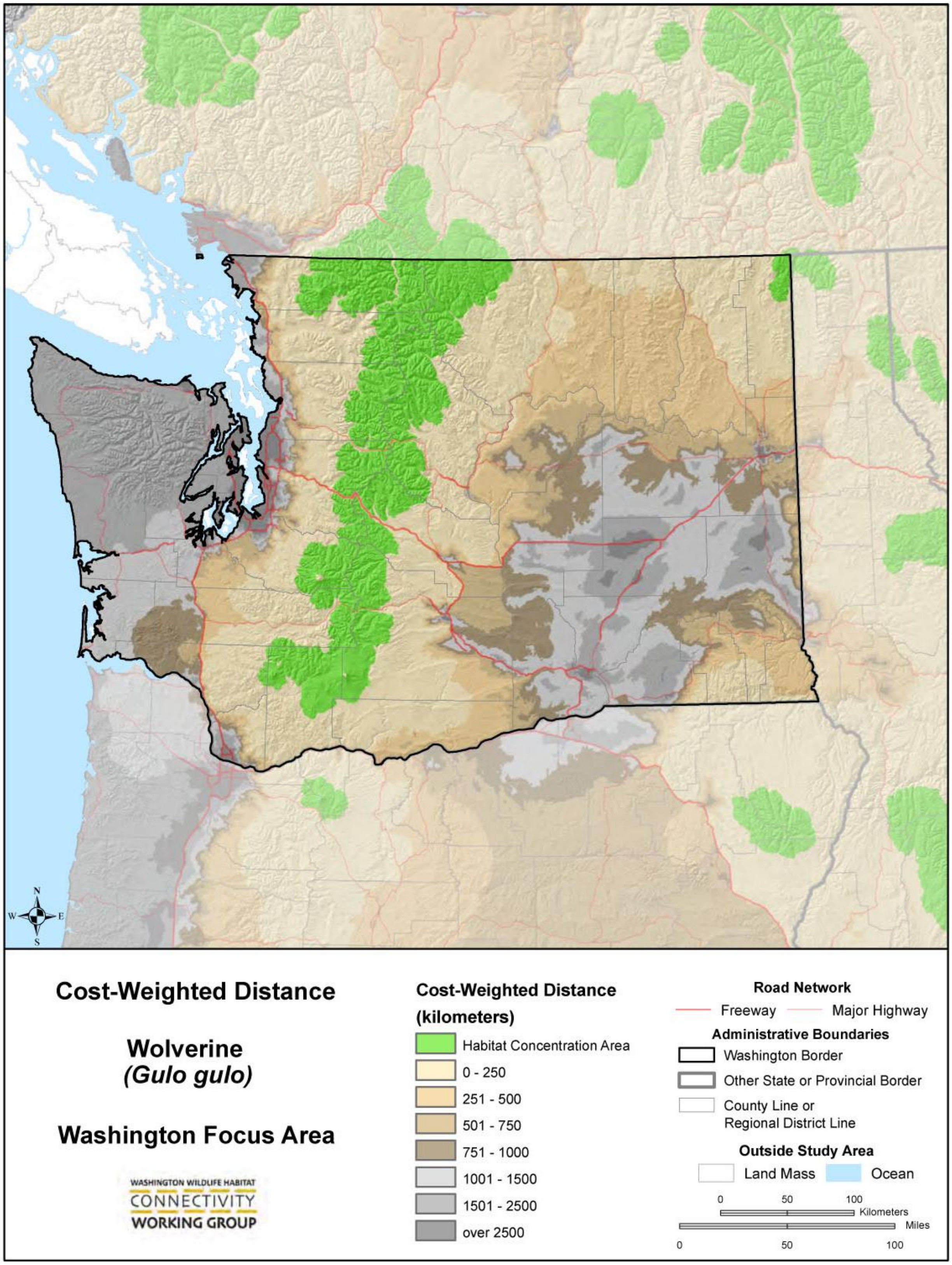


Figure 3.63. Cost-weighted distance for wolverines.

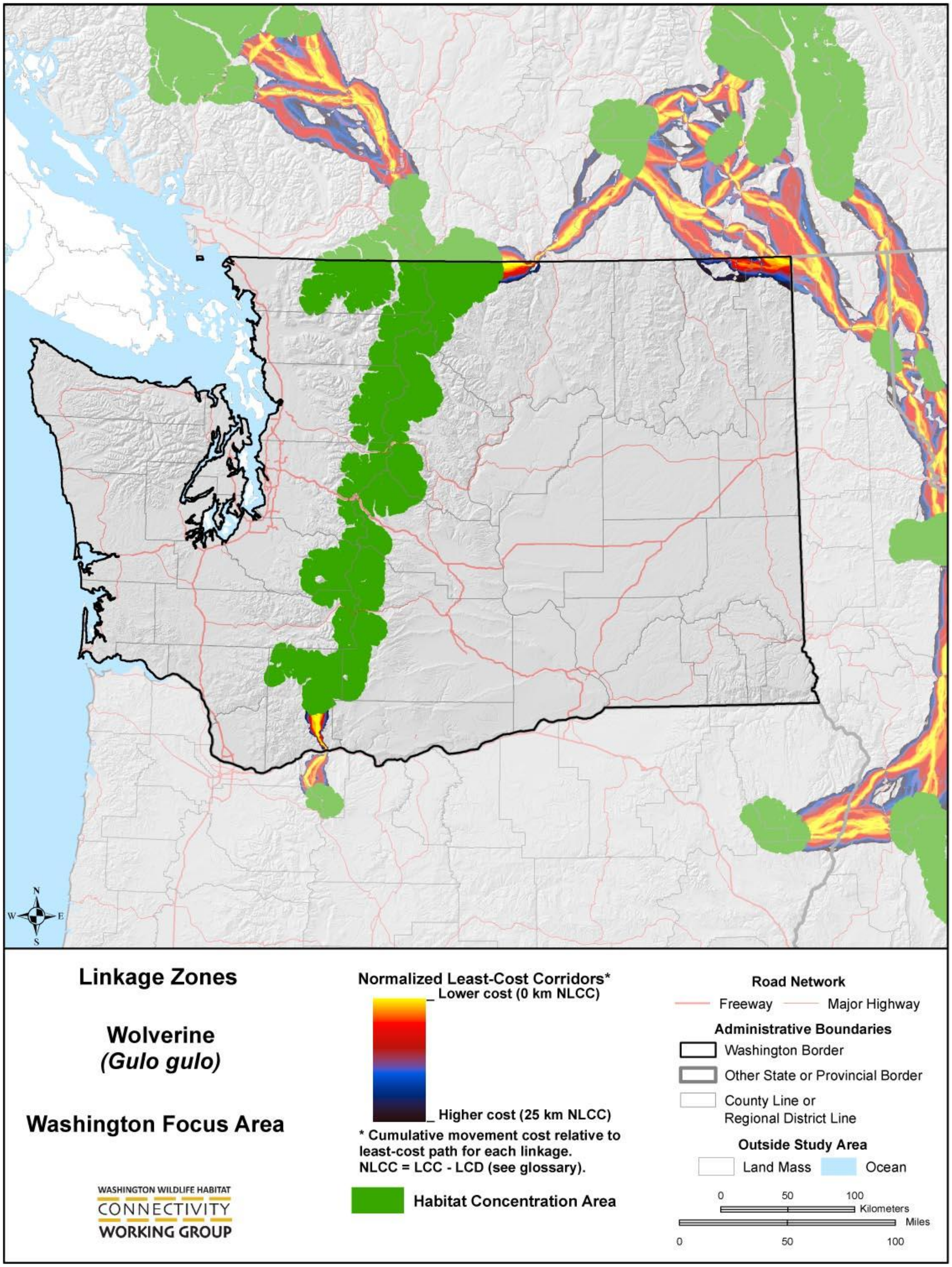


Figure 3.64. Wolverine linkages.

3.3. Landscape Integrity Results

The areas identified as having the highest levels of landscape integrity in Washington were located in the Cascade and Olympic Mountains (Fig. 3.65). Areas where integrity was consistently low or where high integrity lands were severely fragmented were found in the Puget Sound lowlands, the arid lands of the Columbia Plateau, and in southwestern Washington.

3.3.1. Landscape Integrity Core Areas

Our map of landscape integrity core areas (Fig. 3.66) shows the distribution of large, contiguous blocks of land with high integrity scores. The largest core areas show a high degree of overlap with large blocks of public and tribal ownership: in Washington, these large core areas cover much of the Olympic Mountains and North Cascades, along with significant portions of Washington's central and south Cascades. Other reasonably large core areas, wholly or partially within Washington, corresponded with the Selkirk Mountains in the northeast corner of the state, Yakama Nation lands in south-central Washington, and the Blue Mountains in the southeast corner of the state. Smaller core areas were well-distributed in the western Columbia Plateau ecoregion. A few significant core areas were identified in the Willapa Hills of southwest Washington, much of northeastern Washington, and the eastern half of the Columbia Plateau ecoregion. The Puget Trough was poorly represented by core areas, with a few small core areas identified along the foothills of the Cascades, Kitsap Peninsula and Fort Lewis Military Reservation. All of the GAP protected lands with status codes 1 & 2 that met minimum size requirements of 10,000 ac (4047 ha) were captured in our core area network (USGS 2010).

3.3.2. Landscape Integrity Linkages

As described in Section 2.4.2, we modeled landscape integrity linkages using four different resistance surfaces, representing varying levels of resistance associated with different ecological sensitivity to human-induced changes on the landscape. The resulting four connectivity maps identified similar linkage networks, despite their differing cost surfaces (Fig. 3.67). Because linkage locations are largely determined by the locations of core areas, areas with many small core areas in close proximity have many short linkages, as seen in north-central Washington and north-central Oregon. There are few linkages within the Puget Trough and Willamette Basin regions, as well as in southeastern Washington, corresponding to few or no core areas in these regions. However, these core-devoid regions are crossed by longer linkages, such as those connecting the Coast Range to the Cascades in northern Oregon and southern Washington, or those connecting the clusters of core areas in the Columbia Plateau.

The models of low, medium, and high sensitivity to human influences differed in several respects. All models used the same 349 core areas, but because we discarded linkages that passed through intermediate core areas (See Appendix D), the number of linkages varied between models (Fig. 3.67; Appendix E). Because it had the lowest resistance values, the low sensitivity model tended to identify broader, more direct linkages, while the high sensitivity model linkages tended to be more constrained, tracing narrow routes through areas of least human impact.

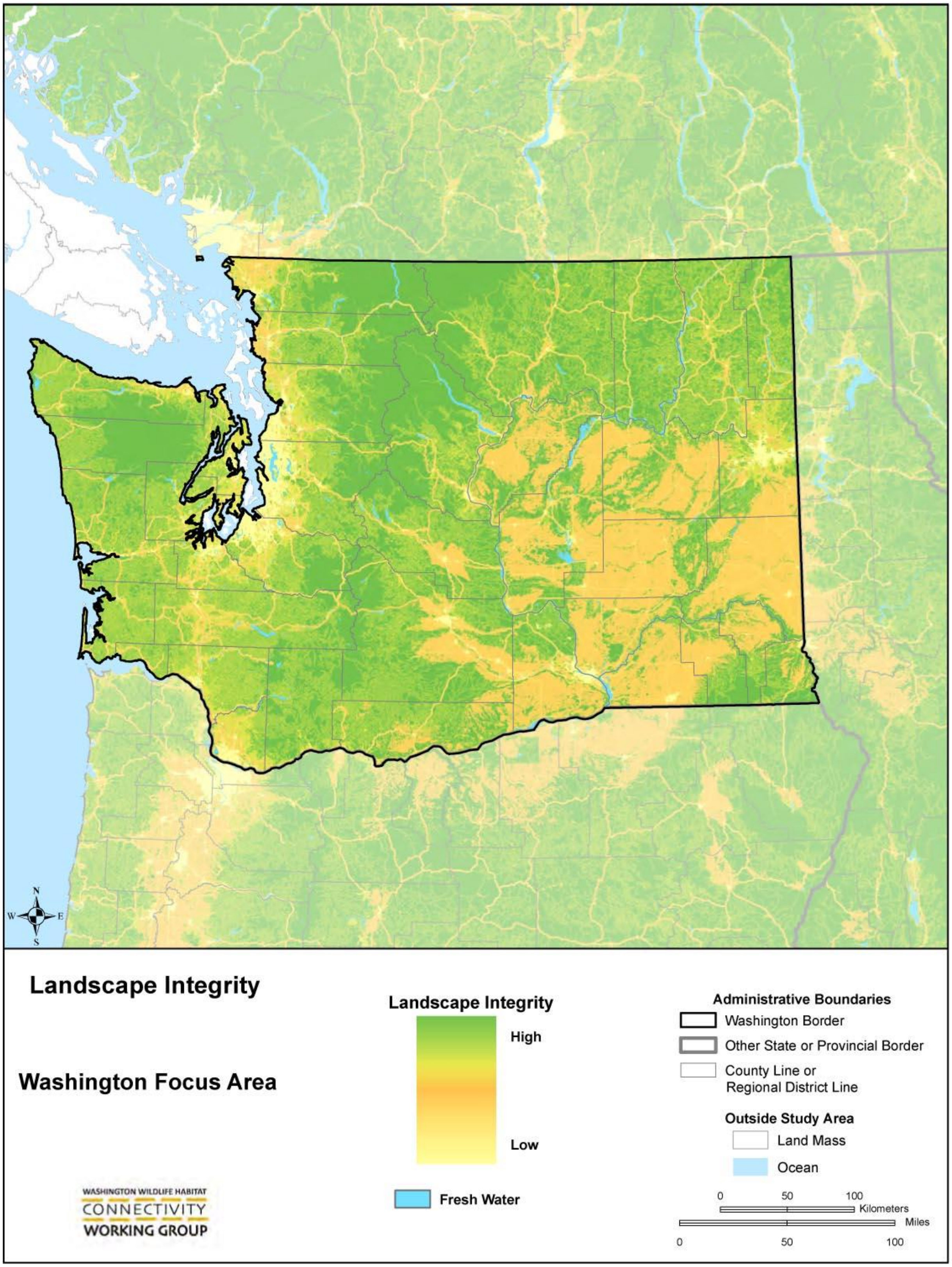


Figure 3.65. Landscape integrity map. Areas of highest landscape integrity have the least human footprint (e.g., natural land-covers, low housing density, and minimum roads).

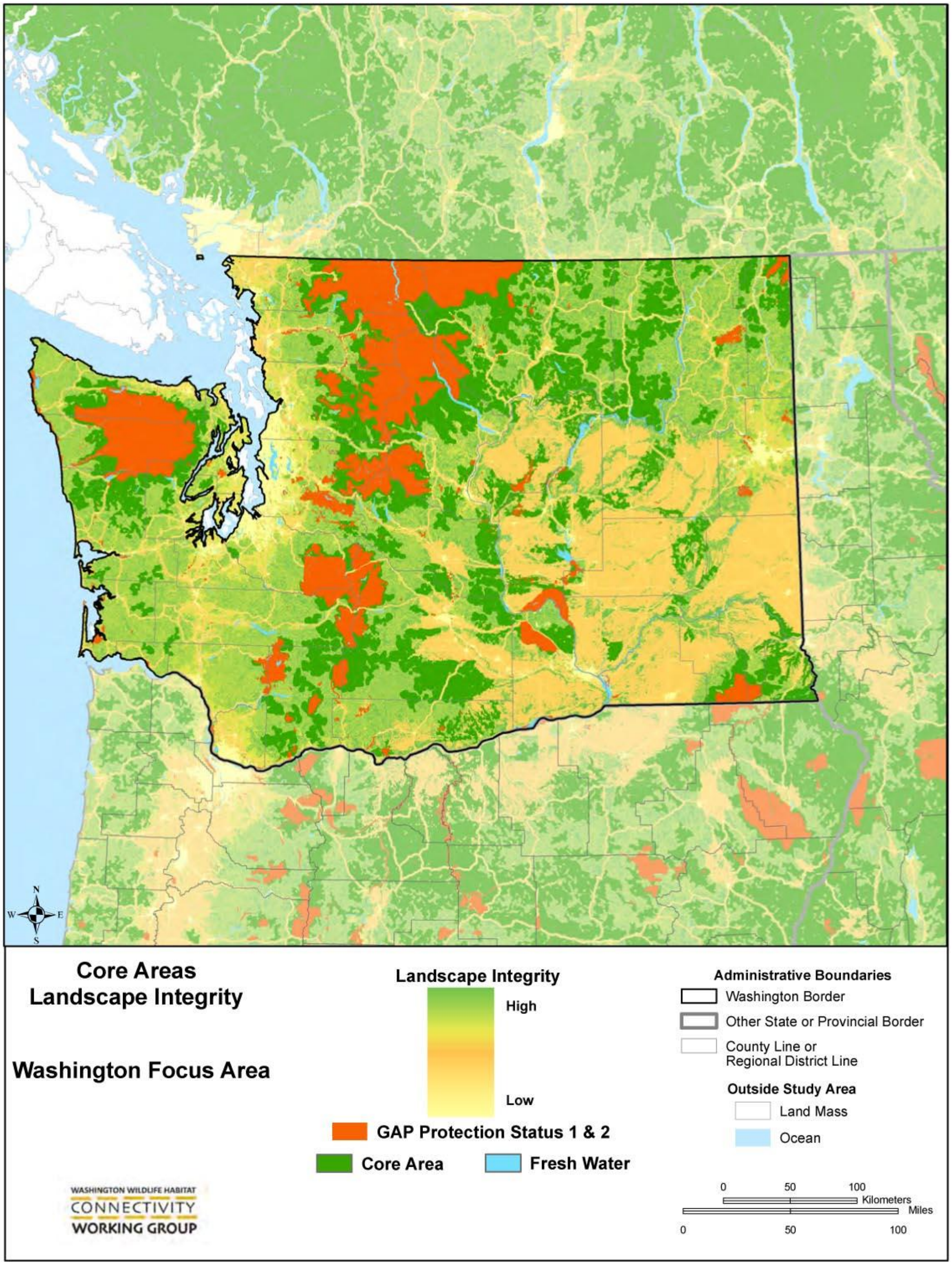


Figure 3.66. Landscape integrity core areas. Core areas were defined by large areas of high landscape integrity values (0.9). All core areas were equal to or larger than 10,000 acres (4047 ha) with local road density ≤10% in all ecoregions, except in Pacific Northwest Coast and Willamette Valley – Puget Trough – Georgia Basin, where local road density thresholds were 20% and 30% respectively.

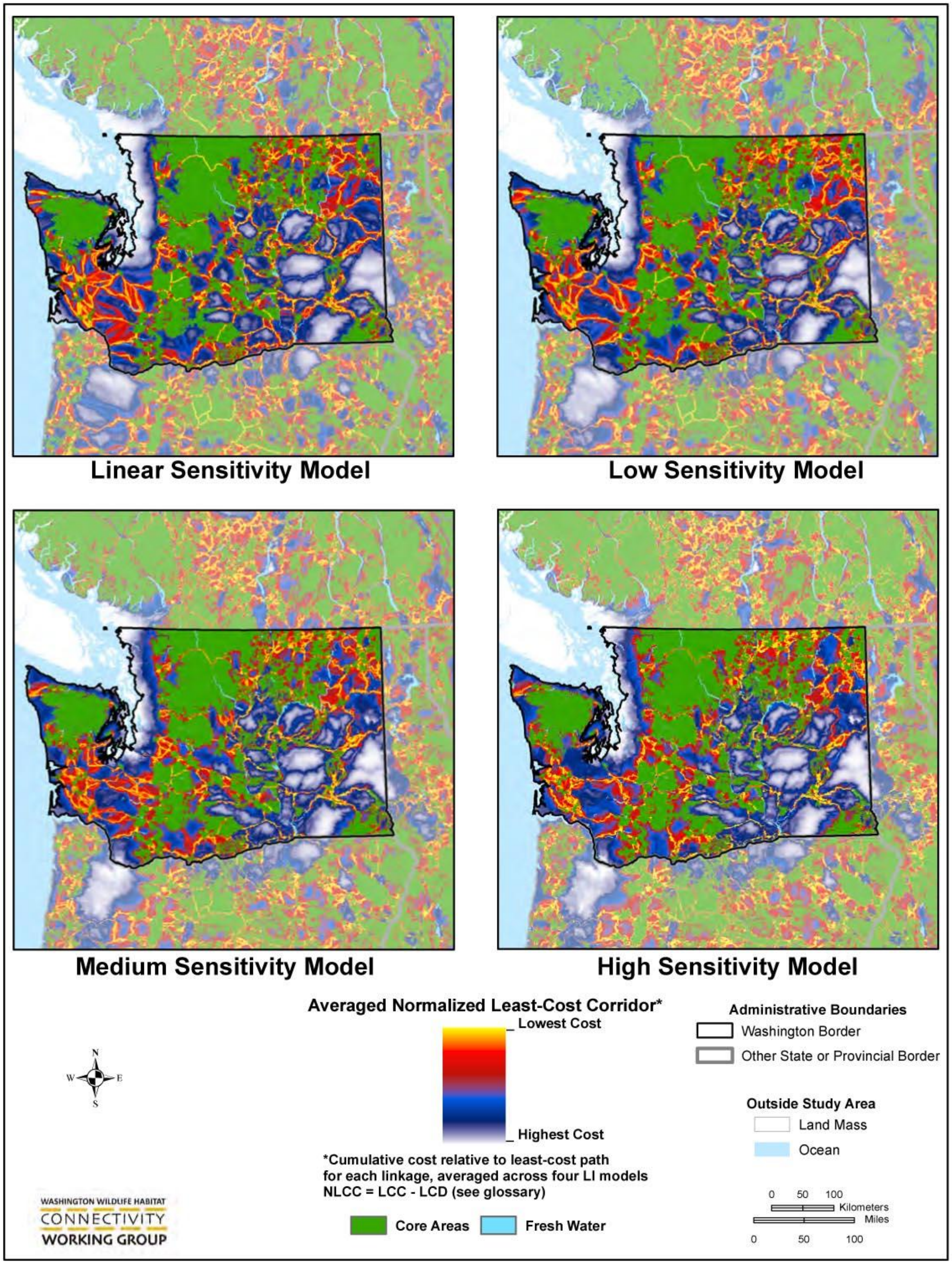


Figure 3.67. Landscape integrity linkage maps derived from four resistance models. Cost values indicate relative ease of movement within each linkage.

The overall composite landscape connectivity map (See Section 2.6.3) identified areas important for connectivity when all sensitivity models were considered. Areas with high linkage values (low normalized least-cost corridor scores) on the composite map had high linkage values for all four models, and areas with lowest linkage values had low values for all four models (Fig. 3.68).

A few patterns emerged from comparing connectivity values across the four resistance models. First, most linkages were similar across all four models. In general, there was more contrast in connectivity values associated with higher-sensitivity models than lower-sensitivity models, where more lands were identified with moderate connectivity values. In some areas, linkage locations differed significantly among the models (e.g., Fig. 3.69). Lower sensitivity models resulted in multiple pathways with similar cost-weighted distance values between core areas. Higher sensitivity models tended to restrict the number and width of corridors between core areas to only those with the highest landscape integrity values. The composite model identified areas that were important to all sensitivity models (Fig. 3.70).

Overlaying the best 30% of each connectivity map (i.e., the 30% with the lowest normalized least-cost distances for each sensitivity model) revealed that most (61%) of these were shared among three or four models (Fig. 3.71). Areas associated with only a single model accounted for 22% of the best 30% of the connectivity landscape; 16% of the linkage network was important for two models.

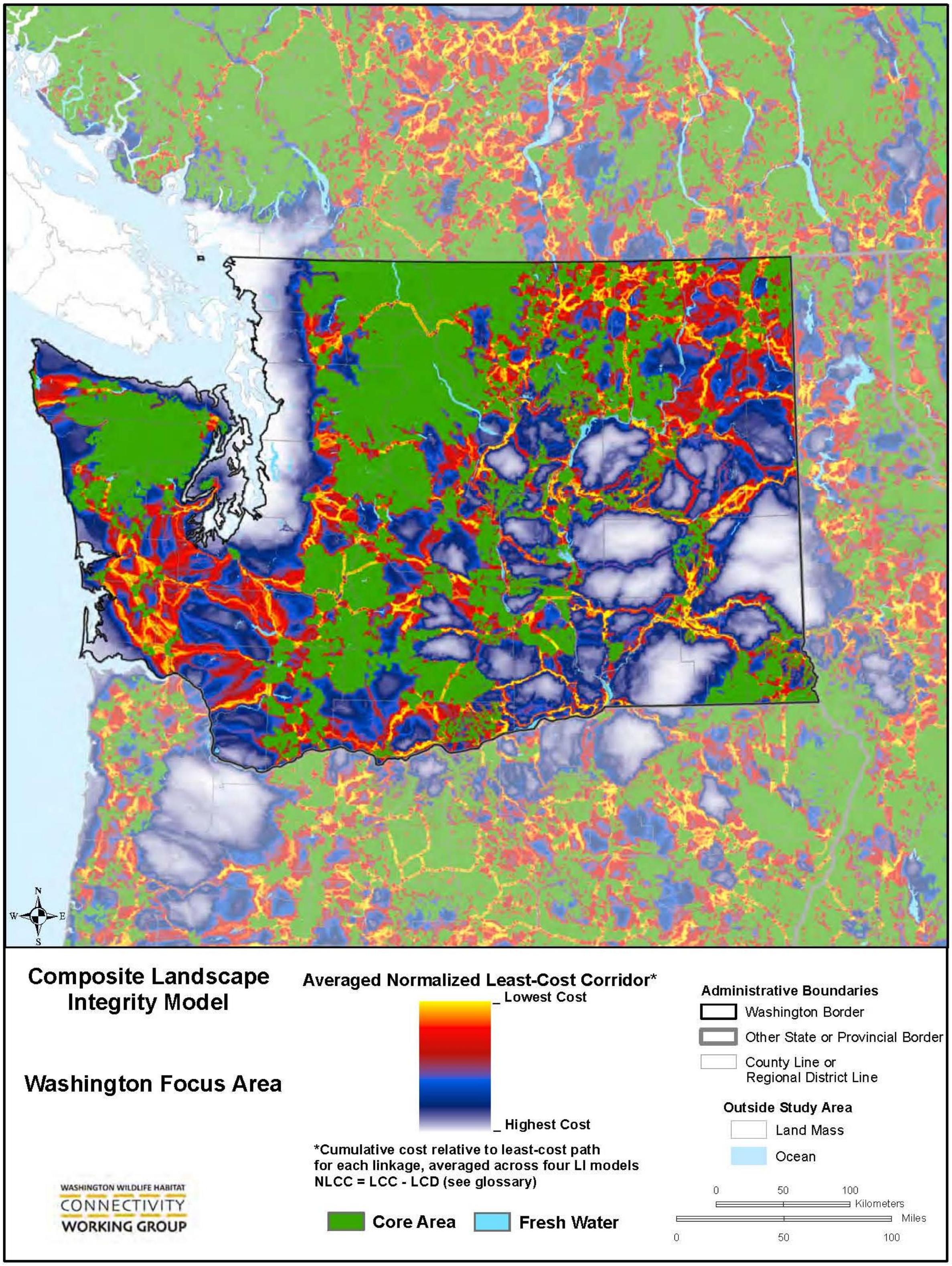


Figure 3.68. Composite landscape integrity linkage map which combines four sensitivity models. Cost values indicate relative ease of movement within each linkage.

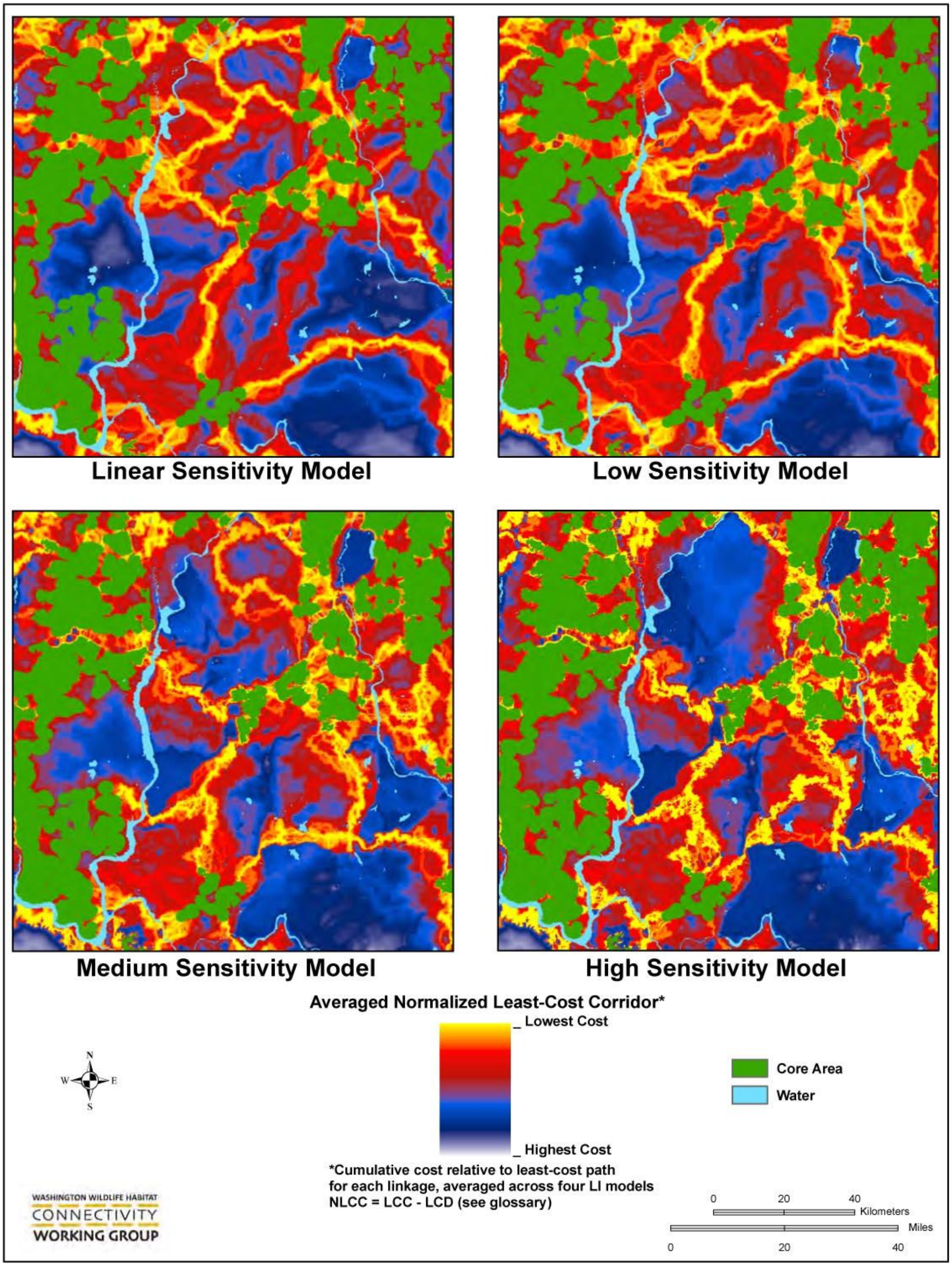


Figure 3.69. Landscape integrity connectivity areas in Kettle Falls/Republic area in northeastern Washington. These maps compare four different resistance models, representing a range of ecological flow sensitivity to human-altered landscapes.

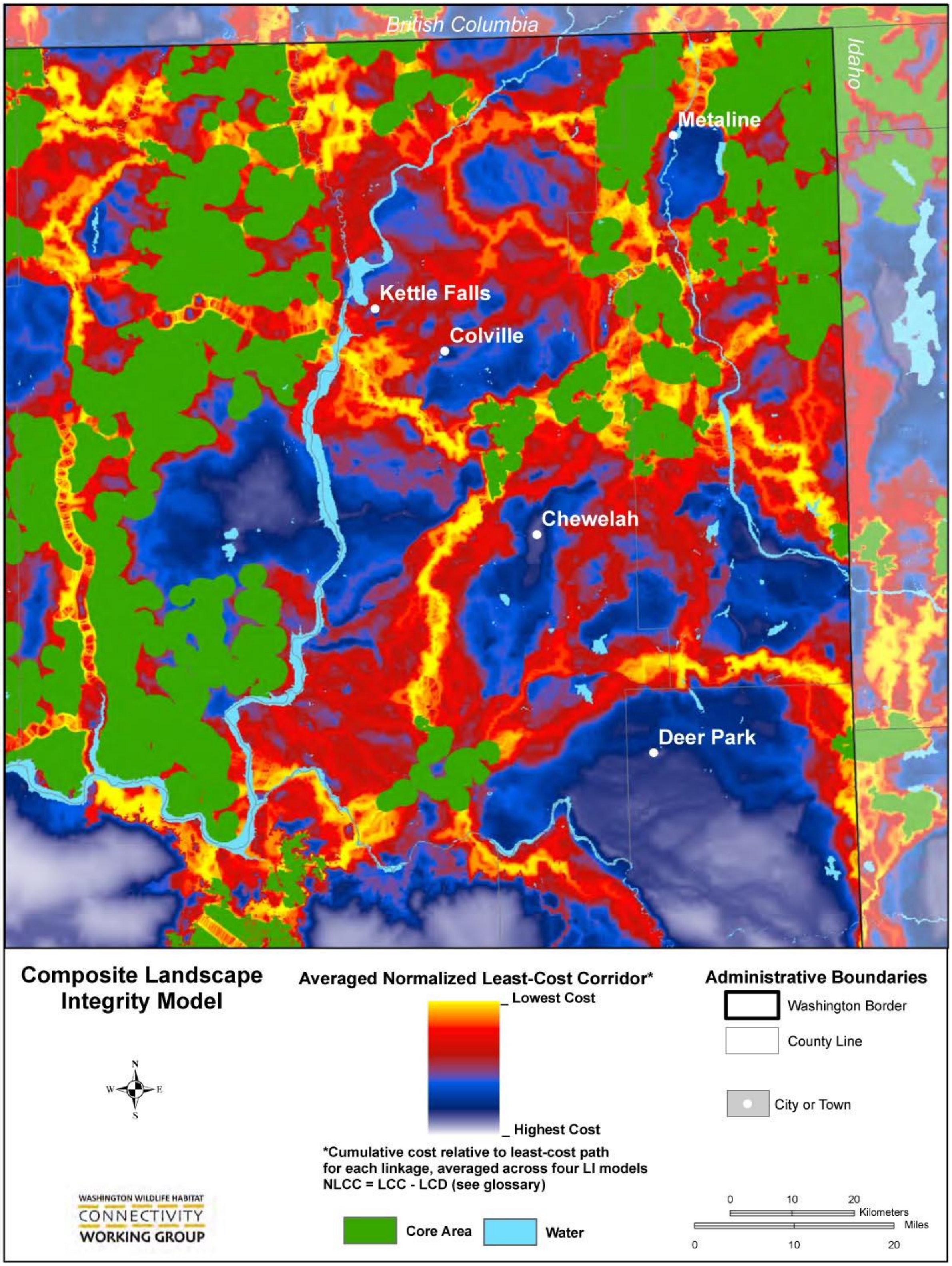


Figure 3.70. Composite landscape integrity connectivity areas in Kettle Falls/Republic area in northeastern Washington. This map is a composite of four different resistance models, representing a range of ecological flow sensitivity to human-altered landscapes.

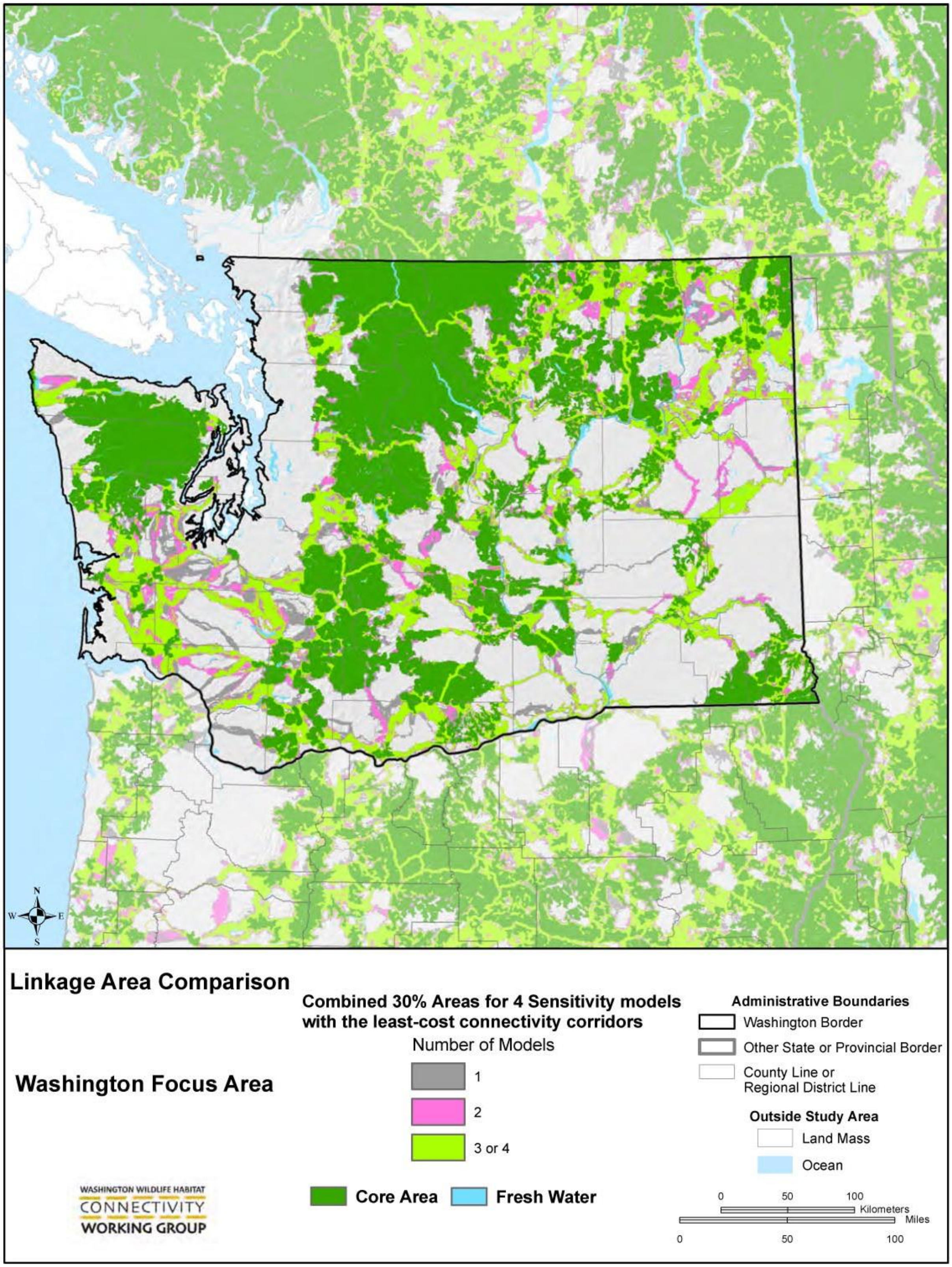


Figure 3.71. Comparison of linkage areas important for wildlife connectivity among four different models representing different sensitivities (linear, low, med, high) to human-altered landscapes.

3.4. Integration of Focal Species and Landscape Integrity Networks

Landscape integrity results were both concordant with, and complementary to, the focal species results. For example, both landscape integrity and focal species analyses revealed a strong pattern of habitat fragmentation in the Columbia Plateau ecoregion. These analyses also identified an extensive and widely distributed array of natural core areas that can form the base for future conservation of arid lands wildlife. Functional connectivity for many arid lands species may still occur, but it is unlikely to be resilient to much additional fragmentation. One way the landscape integrity results complemented the focal species results was that they were 'wall-to-wall,' allowing comparison of connectivity conditions across our entire study area in a single map.

Our systematic sampling across Washington allowed us to quantify the level of overlap between the focal species and landscape integrity networks. Overlap patterns were very similar between the wide, moderate, and narrow networks (See Section 2.6.4), so we only include the results for the narrow network here. The degree of overlap between the narrow linkage networks ranged from 0.9% of the black bear network falling within the Greater Sage-Grouse network, to 99.6% of the flying squirrel network falling within the mule deer network (Table 3.4). The degree of overlap between the landscape integrity network and the focal species networks ranged from 98.5% of the flying squirrel network falling within the landscape integrity network, to 69.1% of the Greater Sage-Grouse network falling within the landscape integrity network (Table 3.4).

Our results also indicated a high level of correspondence between the landscape integrity network and the union of all 16 focal species networks. The landscape integrity network captured 87% of the area that was within more than two focal species networks (Table 3.5).

Table 3.4. Network correspondence between narrow focal species (by code*) and medium sensitivity landscape integrity networks. Table entries show proportions of each row network contained within each column network; for example, 70% of the western toad network falls within the elk network. LI_LCC represents landscape integrity network.

	ANBO	CEEL	CEUR	GLSA	GUGU	LECA	LETO	LYCA	MAAM	ODHE	ORAM	OVCA	SCGR	TATA	TYPH	URAM	LI_LCC
ANBO	1	0.7	0.01	0.31	0.23	0.02	0.04	0.11	0.32	0.94	0.24	0.05	0.12	0.02	0.03	0.47	0.76
CEEL	0.59	1	0.04	0.33	0.28	0.06	0.12	0.15	0.36	0.94	0.26	0.06	0.13	0.08	0.04	0.58	0.88
CEUR	0.08	0.34	1	0.04	0.04	0.66	0.75	0.04	0.04	0.75	0.04	0.06	0.07	0.61	0.29	0.04	0.69
GLSA	0.74	0.91	0.02	1	0.49	0.02	0.02	0.21	0.77	1	0.46	0.05	0.06	0.02	0.02	0.86	0.99
GUGU	0.67	0.96	0.02	0.6	1	0.02	0.02	0.21	0.6	0.99	0.76	0.03	0.08	0.02	0.02	0.98	0.98
LECA	0.07	0.27	0.39	0.03	0.03	1	0.78	0.03	0.03	0.7	0.03	0.05	0.05	0.58	0.13	0.03	0.69
LETO	0.11	0.43	0.33	0.02	0.02	0.59	1	0.02	0.02	0.8	0.02	0.11	0.1	0.59	0.17	0.05	0.76
LYCA	0.54	0.82	0.03	0.43	0.34	0.03	0.03	1	0.48	0.98	0.37	0.09	0.18	0.03	0.04	0.97	0.95
MAAM	0.69	0.92	0.01	0.71	0.45	0.01	0.01	0.22	1	0.99	0.39	0.03	0.06	0.01	0.01	0.85	0.93
ODHE	0.54	0.64	0.06	0.25	0.2	0.1	0.16	0.12	0.27	1	0.19	0.05	0.12	0.11	0.05	0.43	0.76
ORAM	0.72	0.9	0.02	0.58	0.78	0.02	0.02	0.23	0.53	0.98	1	0.06	0.11	0.02	0.03	0.95	0.98
OVCA	0.43	0.62	0.09	0.18	0.09	0.12	0.35	0.18	0.13	0.87	0.17	1	0.38	0.16	0.1	0.41	0.87
SCGR	0.54	0.65	0.04	0.1	0.12	0.06	0.14	0.17	0.12	0.94	0.17	0.18	1	0.1	0.13	0.43	0.78
TATA	0.09	0.42	0.42	0.03	0.03	0.68	0.9	0.03	0.03	0.86	0.03	0.08	0.11	1	0.18	0.04	0.84
TYPH	0.26	0.46	0.4	0.06	0.06	0.31	0.51	0.08	0.06	0.84	0.08	0.1	0.27	0.36	1	0.17	0.84
URAM	0.62	0.91	0.01	0.49	0.45	0.01	0.02	0.27	0.52	0.98	0.43	0.06	0.13	0.01	0.02	1	0.95
LI_LCC	0.53	0.72	0.07	0.29	0.23	0.12	0.18	0.14	0.3	0.91	0.23	0.07	0.12	0.13	0.06	0.5	1

*Species codes: ANBO = western toad; CEEL = elk; CEUR = Greater Sage-Grouse; GLSA = northern flying squirrel; GUGU = wolverine; LECA = black-tailed jackrabbit; LETO = white-tailed jackrabbit; LYCA = Canada lynx; MAAM = American marten; ODHE = mule deer; ORAM = mountain goat; OVCA = bighorn sheep; SGCR = western gray squirrel; TATA = American badger; TYPH = Sharp-tailed Grouse; and URAM = American black bear.

Table 3.5. Proportion of sample points within focal species and medium sensitivity landscape integrity networks. Table entries show sample point proportions that are in or out of the landscape integrity network; and varying numbers of focal species networks.

	Number of focal species										
	0	1	2	3	4	5	6	7	8	9	10
Out of LI network	0.2	0.08	0.07	0.04	0.02	0.01	0	0	0	0	0
In LI network	0.01	0.03	0.05	0.1	0.09	0.09	0.1	0.06	0.04	0.01	0

The hierarchical cluster analysis dendrogram for all of the focal species and landscape integrity networks indicates that splitting the networks into three groups captured much of the variation in the data. The scree plot further supports the conclusion that much of the variation in spatial concordance is explained by clustering into three groups (Figure 3.72). The trio of focal species groups with similar linkage network patterns were the shrubsteppe associates (Sharp-tailed Grouse, Greater Sage-Grouse, black-tailed jackrabbit, white-tailed jackrabbit, American badger), the montane associates (Canada lynx, wolverine, mountain goat, black bear, northern flying squirrel, American marten), and the generalists (western toad, mule deer, elk, bighorn sheep, western gray squirrel). The landscape integrity network (LI_LCC) consistently clustered with the generalists and was most similar to the mule deer network.

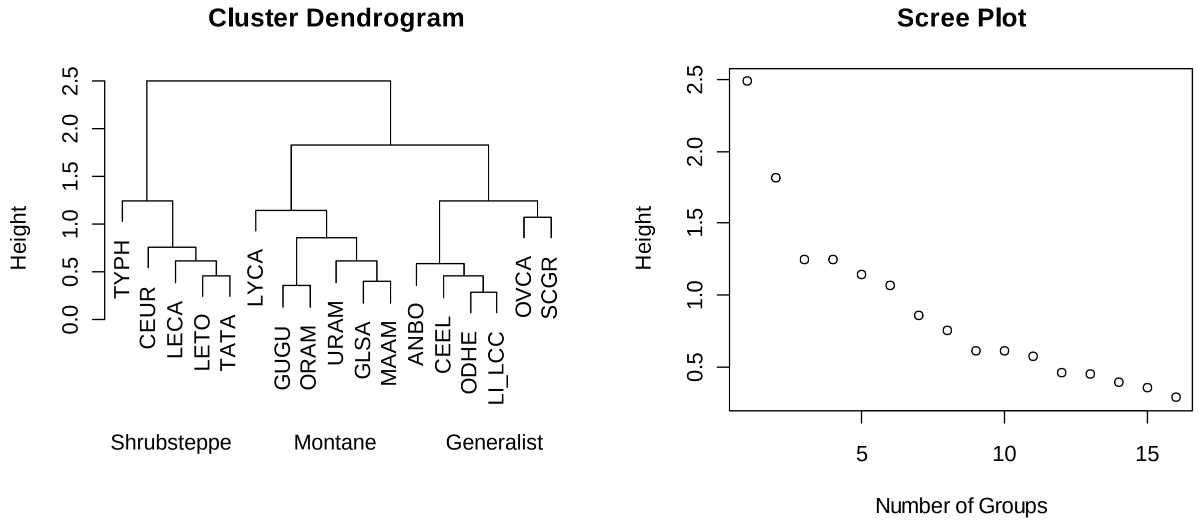


Figure 3.72. Hierarchical cluster analysis dendrogram showing three guilds, and scree plot.

3.4.1. Connected Landscapes Networks – Overviews by Species Guild

The results of this project are best represented by the maps and output data layers, in their entirety (See Chapter 4). The geographic coverage is vast, the range of species and landscape integrity is broad, and patterns in any individual map are relatively complex. However, there is value in comparing and contrasting the networks produced for focal species guilds and landscape integrity models.

The networks for the three identified species guilds were distinctly different. The networks for the generalist and montane species guilds are generally broadly connected, with the interruptions fitting the traditional view of “fracture zones,” i.e., linear features that pose significant barriers to animal movement (Figs. 3.73 and 3.74). In contrast, the network representing the shrubsteppe species guild looks more like a series of broad linkages connecting isolated blocks of intact natural habitat (Fig. 3.75). Reflecting these differences, the results that follow highlight features of fracture zones and linkages among the three guilds.

Networks in the range of the generalist species guild — Relatively broad, well-connected landscapes typified much of the generalist species network (Fig. 3.73). A few important interruptions to the network were associated with fracture zones that were sometimes heavily developed and traversed by busy highways. Some of the more important fracture zones were associated with I-5 between Olympia and Vancouver, the Chehalis River bottomlands along U.S.

12, I-90 between North Bend and Cle Elum, the Methow River bottomlands between Winthrop and Twisp, U.S. 97 between Okanogan and the Canadian border, State Route 395 and the Colville River valley from Deer Park to Kettle Falls, and U.S. 12 from Morton to Naches.

Networks in the range of the montane species guild — In the more mountainous and forested regions of the state, where fragmentation from human-created barriers was less extensive and often confined to relatively narrow linear areas, the montane species networks were almost entirely represented within the landscape integrity network (Fig. 3.74). The identified narrow fracture zones often have similar conditions on both sides, and modeled corridors for focal species and landscape integrity varied in their selected crossing locations. In the Canadian Rocky Mountains ecoregion in the northeast corner of Washington State, linkage overlaps often reflected the most suitable lands, in private ownership, providing connectivity between blocks of publicly-owned or Native American Tribal lands that were strongly represented in multiple species' HCAs and the landscape integrity network.

Networks in the range of the shrubsteppe species guild — The range of the shrubsteppe focal species guild corresponds with the Columbia Plateau ecoregion and the semi-arid vegetation class used for focal species selection. This is a distinctive region within Washington, with arid conditions resulting in vegetation, wildlife communities, and land uses that are unlike most of the rest of the state. Natural vegetation communities and their associated wildlife are more extensively fragmented here as well (Fig. 3.75). The remaining sizeable blocks of native vegetation and limited human footprint contribute to a well-defined linkage network. This pattern is apparent in both focal species and landscape integrity networks. A prominent feature of the shrubsteppe species network is a south-to-north tending complex of linkages and HCAs that results from our models suggest is suitable for either four or five of the region's focal species (Fig. 3.76). This linkage network starts, on the south end, in the Horse Heaven Hills and the Yakama Indian Reservation. From the Prosser vicinity, it tends north through the Rattlesnake Hills and the Yakima Training Center, then follows the west bank of the Columbia River, broadly, to a river-crossing point that lands on the east side of the Columbia at the mouth of Moses Coulee. Moving east, the network forks, one leg continuing east and northeast to Swanson Lakes, and the other following the west side of Banks Lake north to East Foster Creek, then up the Okanogan Valley to the town of Okanogan. While portions of this network represent the best conditions available for animals to move through, conditions for many species may still be quite poor. However, this is undoubtedly an important network for maintaining connectivity for many species. A significant portion of this network is composed of channeled scablands, with soils too shallow for productive farming. Significantly, this network extends almost from the southern border of Washington to its northern border, providing connectivity that may be important to the shifting ranges of plants and animals as climate changes.

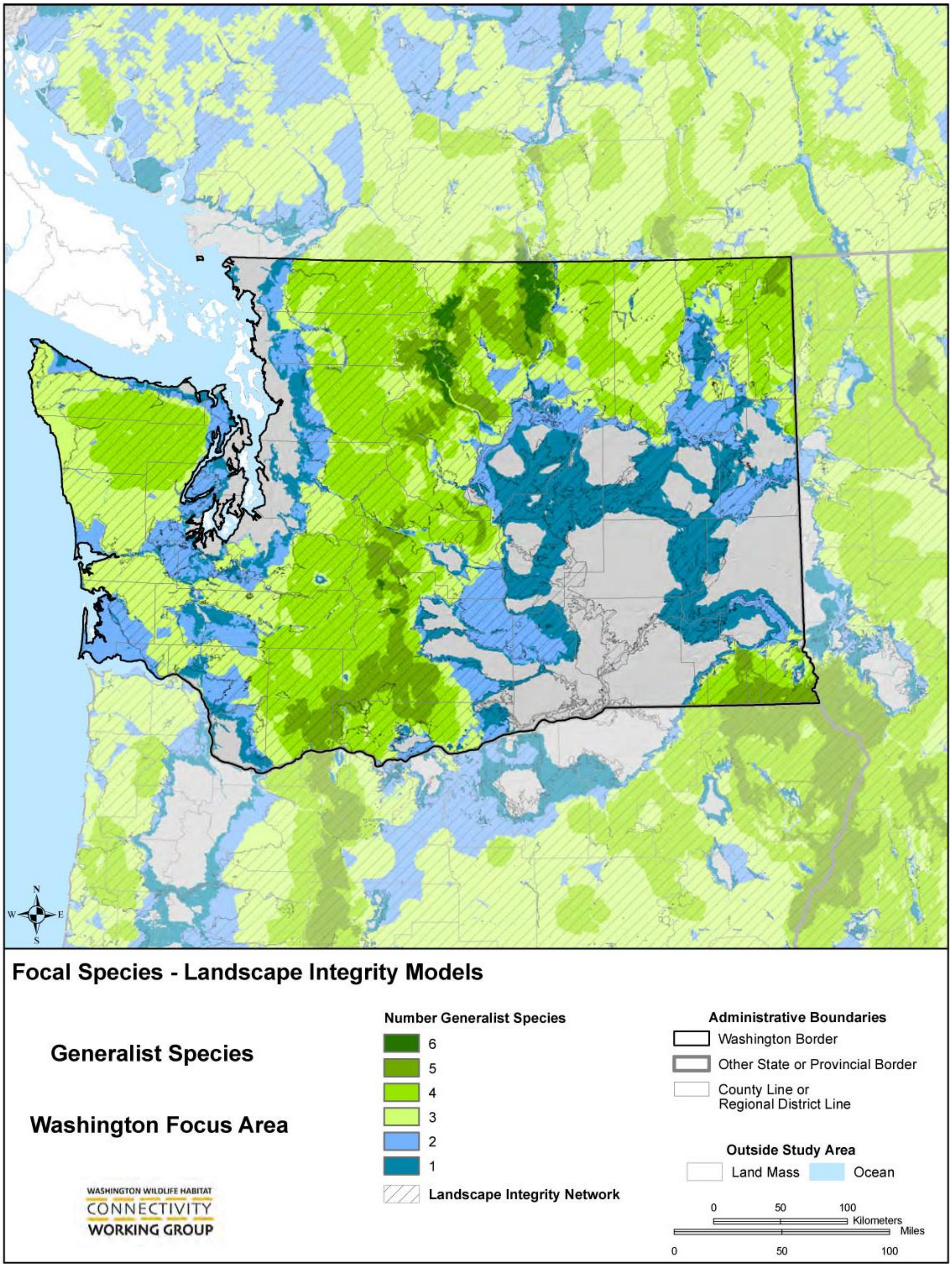


Figure 3.73. Composite focal species and landscape integrity map for generalist connectivity guild. Includes species that can inhabit a variety of habitats such as mule deer and western toads.

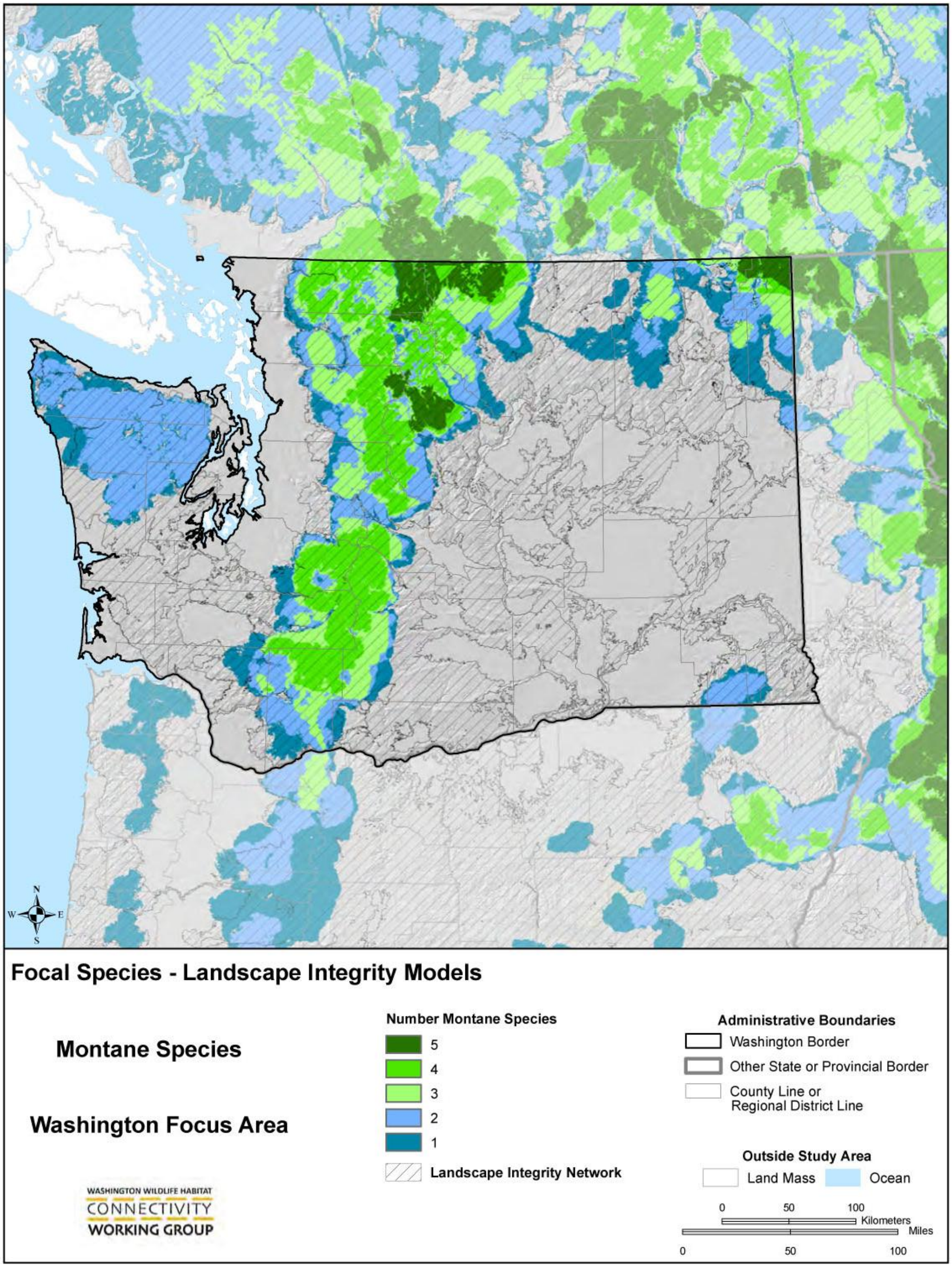


Figure 3.74. Composite focal species and landscape integrity map for montane connectivity guild. Includes species found in forests and mountainous areas such as American black bears and wolverines.

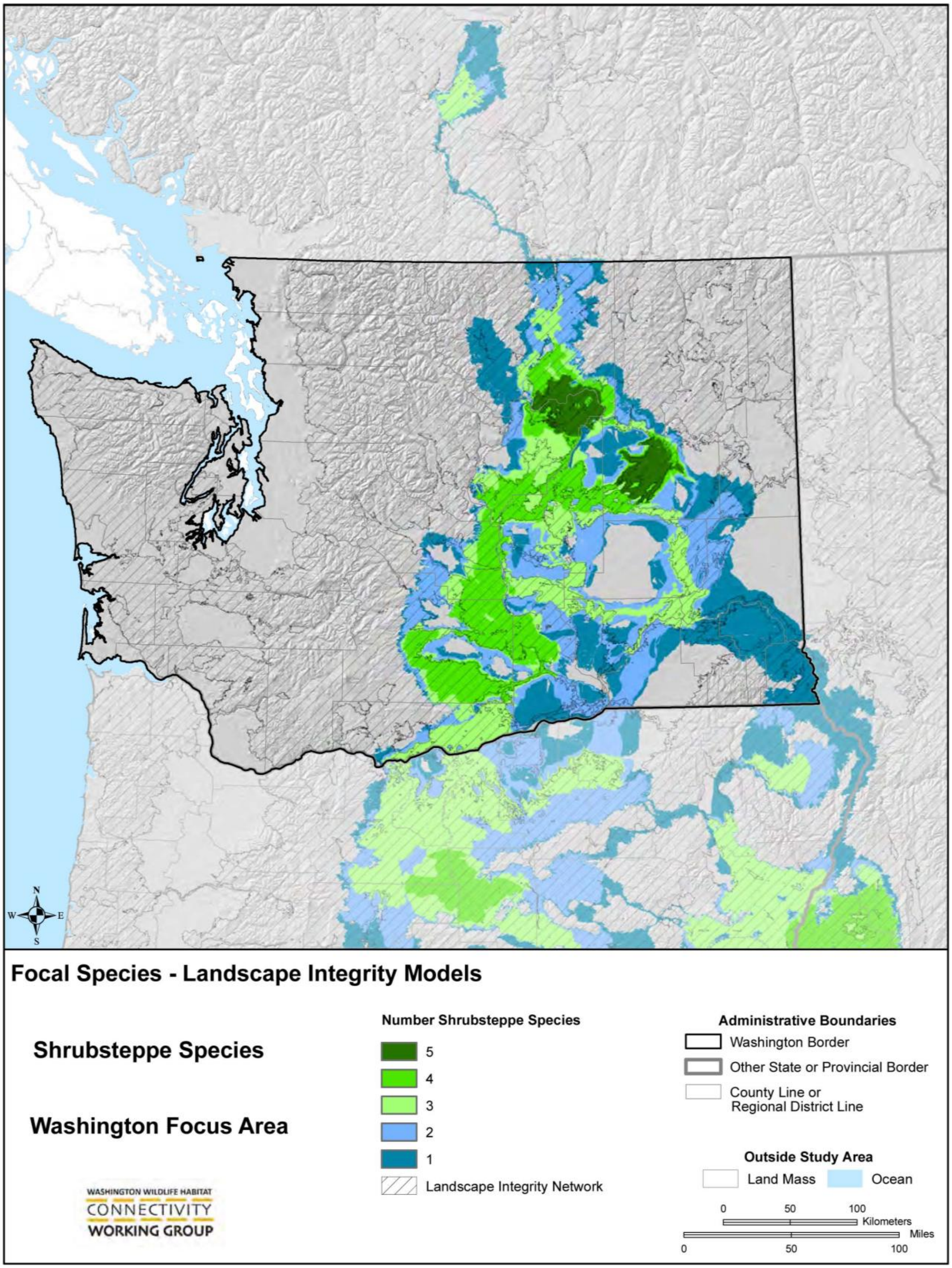


Figure 3.75. Composite focal species and landscape integrity map for shrubsteppe connectivity guild. Includes arid lands species such as American badgers and white-tailed jackrabbits.

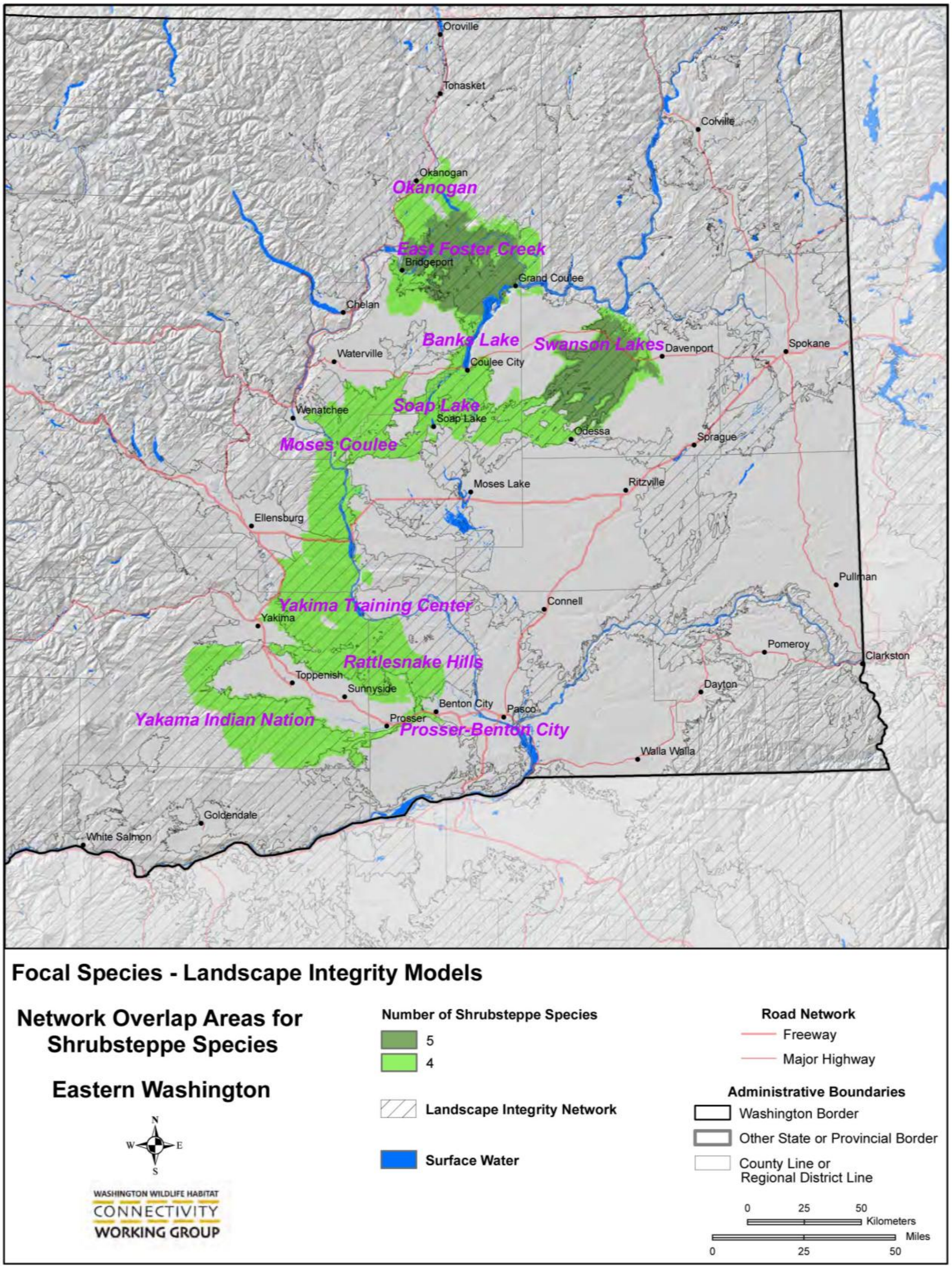


Figure 3.76. Shrubsteppe species and landscape integrity networks with overlap of four to five focal species shown in green.

3.4.2. Identifying Linkages for Broader Arrays of Species

We intended our analyses to identify areas important for a broad array of species and ecological processes. We designed our modeling approaches accordingly; for example, our focal species selection process was designed to identify those species that could serve as conservation umbrellas (Roberge & Angelstam 2004; Beier et al. 2008), representing the connectivity needs of a diverse suite of species.

Our network correspondence analyses revealed that focal species could be grouped into three major connectivity guilds (generalist, montane, and shrubsteppe), within which there is substantial network overlap (Fig. 3.72, Table 3.4). Further examination of linkage networks should help us understand how well these linkage networks serve non-focal species as well. We need to know, for example, if portions of networks identified for multiple focal species have greater ecological value than portions identified for a single species.

We included landscape integrity analyses in part to evaluate their ability to cost-effectively identify networks that are important for many species while requiring fewer data and resources than focal species models (Chapter 2). Such approaches (e.g., Spencer et al. 2010) are relatively new and there is a critical need to understand how well they perform relative to more arduous focal species-based approaches. Thus far, the quantitative comparisons between our focal species and landscape integrity results are limited to correspondence and cluster analyses of one landscape integrity network with all focal species networks. The landscape integrity network showed a high degree of overlap with most of the focal species linkage networks, containing between 69% (black-tailed jackrabbit and Greater Sage-Grouse) to 99% (for northern flying squirrel) of individual species' networks. This promising result must be balanced with the fact that the medium sensitivity landscape integrity network we used for comparison covers 58% of our project area (Figs. 3.73–3.75). More detailed analyses are needed to fully understand how conservation plans based on integrity compare with those based on focal species. We invite and eagerly anticipate such analyses, which should strengthen future connectivity modeling efforts. We briefly discuss plans for pursuing such analyses in Chapter 6.

3.4.3. Linkages to Lands Outside of Washington

Connections to important habitat blocks beyond Washington's borders sometimes met the needs of multiple species. Some of the readily apparent network connections across state borders were associated with:

1) The Selkirk Mountains linkage to British Columbia.

2) The Kettle River Range into the Granby River area, a connection to British Columbia.

3) The Similkameen/Chopaka Mountain connection west of the Okanogan River valley, a connection to British Columbia.

4) The Pasayten Wilderness connection to British Columbia.

5) The North Cascades National Park connection to Manning Provincial Park in British Columbia.

6) The Colville National Forest linkage south through Mount Spokane and to the Idaho Panhandle.

7) The linkage to the Idaho Panhandle from the Lamont & Turnbull National Wildlife Refuge, extending east into Idaho just south of Spokane.

8) The linkage from Washington's Blue Mountains to Oregon and Idaho along the Grand Rhonde and Snake Rivers.

9) The shrubsteppe species linkage between Washington and Oregon, just east of the big bend of the Columbia River and south of Wallula.

3.5. Key Findings

The statewide analysis confirmed many of the patterns that spurred the formation of the WHCWG. For example, habitat connectivity is clearly compromised in areas with extensive urban development and agriculture, such as the Puget Trough-Willamette Valley ecoregion in western Washington and the Columbia Plateau ecoregion in eastern Washington. I-5 and associated development between Olympia and the Columbia River create a substantial barrier to east-west movement of wildlife. Similarly, I-90 creates a major disruption to north-south wildlife movement in the Snoqualmie Pass area, which has been recognized by WSDOT as a priority for implementing wildlife-friendly crossing structures. Many important habitat areas and connecting landscapes are found on public lands, such as those in the Cascade and Olympic Mountains. Private lands also contribute important habitat areas, and frequently help link wildlife habitats on public lands.

More importantly, the analysis also yielded new insights, which should both inform connectivity conservation efforts in Washington and advance best practices for connectivity assessments elsewhere. Below we briefly summarize some of our major findings:

- Two different analysis approaches (focal species and landscape integrity) identified broadly consistent habitat connectivity patterns in Washington. Initial quantitative comparisons of these approaches is promising; more detailed analyses are needed to fully understand how conservation plans based on integrity would compare with those based on focal species. Nonetheless, the landscape integrity approach can complement individual species-based approaches by providing seamless, 'wall-to-wall' connectivity maps across large regions.

- Synthesis of the focal species modeling results highlighted three distinct linkage networks: the generalist species network, montane species network, and the shrubsteppe species network. Within each network, there was considerable overlap in habitat areas and linkages across species. This finding should facilitate future efforts to plan for multiple species conservation.

- Previously undocumented patterns of potential habitat connectivity for shrubsteppe species within the Columbia Basin were highlighted in this analysis. We believe these should be a priority for further attention due to the heavily fragmented nature of the area.

Similarly, the potential importance of the Okanogan Valley was highlighted because it provides habitat connectivity values for all three linkage networks described above.

- We identified broad-scale landscape patterns that may provide the best opportunities for restoring habitat connectivity in several areas where it has been highly compromised, such as along I-5 south of Olympia.

- Additional work is needed in southwestern Washington to adequately map connectivity patterns due to the complex patterns of land ownership and land use history (including an emphasis on commercial timber production) in that area.

- Automation of our core area and linkage modeling methods facilitated collaboration between modelers and focal species experts, and fostered iterative model development. We will be releasing our GIS tools (See Appendix D) following publication of this report. Other lessons relevant to best practices for connectivity assessments are discussed in Chapter 5.

Chapter 4. Using the Statewide Connectivity Analysis

This statewide analysis provides the foundation of a three-tier connectivity analysis and planning framework which includes: (1) the statewide connectivity maps and products presented in this document and associated future web-based products, (2) future ecoregional connectivity maps, and (3) future detailed local ***linkage designs*** (Fig. 1.3). Importantly, this statewide analysis is not a plan and does not set priorities. It is a science-based document that provides information that can be used—in conjunction with other sources of information—to support conservation planning and prioritization efforts. Our products must be used carefully, and correctly interpreting our results particularly with respect to the coarse scale of our statewide-plus analyses, is critical to using them effectively. Some strengths and limitations of this analysis are as follows:

STATEWIDE CONNECTIVITY ANALYSIS STRENGTHS

- Serves as a resource for informing, implementing, and coordinating broad-scale connectivity conservation within Washington State and across our borders to neighboring jurisdictions.
- Highlights regional-scale landscapes in Washington State and neighboring jurisdictions that are important core habitats or linkages for wildlife. These landscapes allow us to prioritize where to look more closely with further analysis, field information, and local expertise and knowledge to ensure our state maintains a connected network of wildlife habitats.
- Creates a foundation for building future analyses that can provide priorities among linkages at finer scales such as ecoregions.
- Yields a foundation for analyses that address specific conservation challenges such as climate change, population growth, and energy development.
- Provides a broad-scale context for planning areas of smaller extent.
- Complements other broad-scale conservation maps.
- Provides information to help organizations incorporate connectivity into conservation efforts while meeting their own organizational needs and priorities.

STATEWIDE CONNECTIVITY ANALYSIS LIMITATIONS

- The broad-scale nature of the data and models means that not all important habitat areas and linkages have been mapped; additional detail and regional and local expertise are needed to ensure local connectivity needs are addressed.

- Habitat areas and linkages must be refined at a finer scale and/or validated through field research to create implementable linkage designs.

In this chapter we describe how to interpret and use our products, and how future analyses will build upon them. We also include a section on additional resources that may be of assistance to users of this statewide analysis.

4.1. How Base Data Affect Our Products: Scale and Age of Spatial Data Layers

The various base maps we used for modeling form the foundations of our analyses. All spatial data sets, especially those that cover such a broad geographic extent, have errors in them. Acquaint yourself with the base data for areas you are interested in: our base maps are described briefly in section 2.2, and in more detail in Appendix C. More importantly, comparing the data with other sources of information, such as aerial photography or Google Earth, can give one a good sense of their accuracy at different scales (Fig. 4.1).

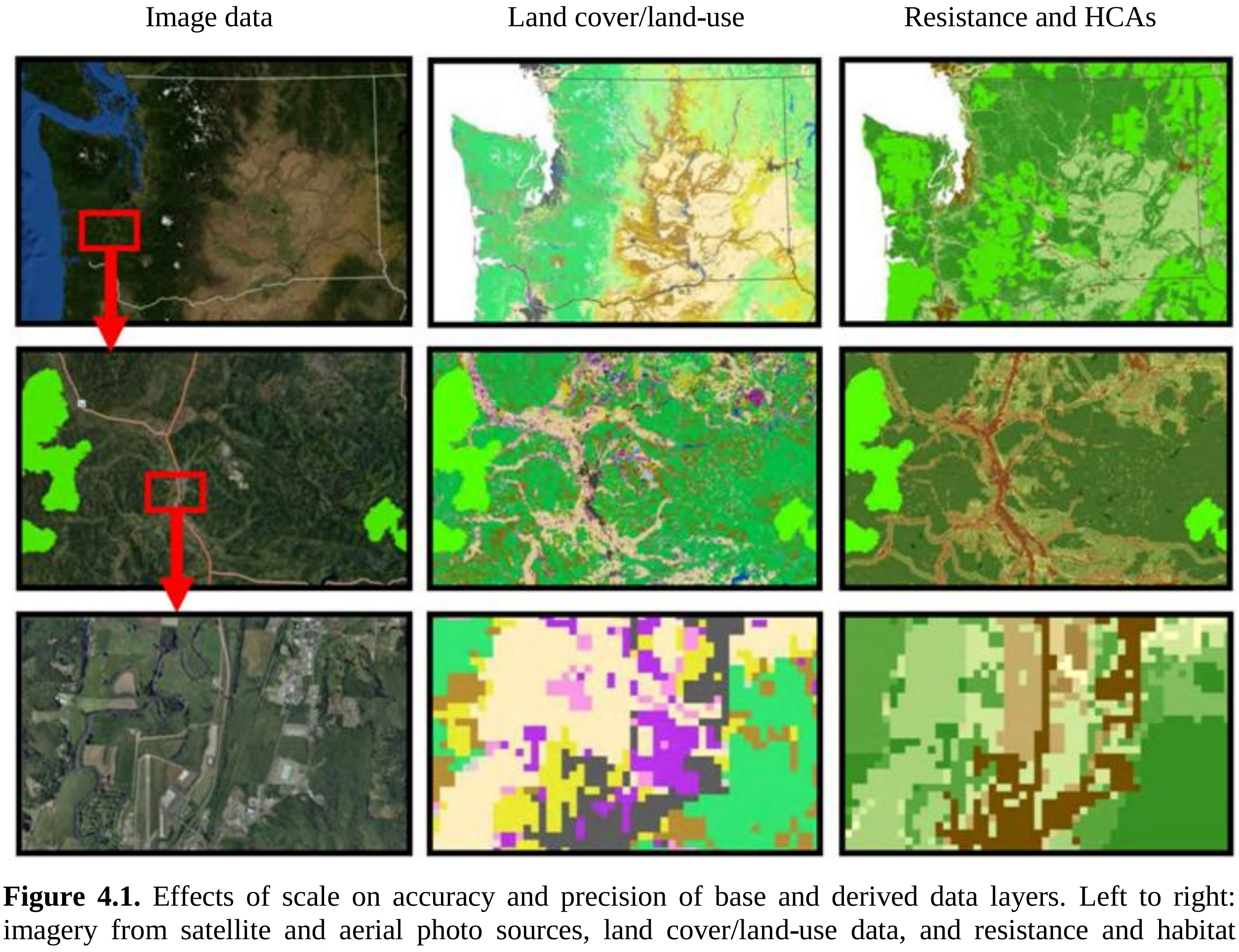


Figure 4.1. Effects of scale on accuracy and precision of base and derived data layers. Left to right: imagery from satellite and aerial photo sources, land cover/land-use data, and resistance and habitat concentration areas layers for elk. Top to bottom: statewide extent and increasingly smaller extents. Red boxes in top two rows show zoom extent for the next row. Our base maps capture reasonable levels of detail when viewed at the extents depicted in the top two rows. When zoomed to the extent in the bottom row (Chehalis-Centralia airport area), the limitations of the data become evident.

The coarse grain of the data layers used in our analyses limits the resolving power of all of our modeled outputs. We did not include important features that affect connectivity, such as power lines and fences, or details such as different crop types that are more or less suitable for wildlife movement. The broad extent of our statewide-plus analysis made it impossible to include this level of detail.

Our data sources in many cases won't include recent features on the landscape because the data are based on information that can be several years old (See Appendix C for dates of origin for data used to develop these layers). For example, GAP and LANDFIRE data are based on satellite imagery acquired between 1999 and 2003. That means if clear-cut logging has created gaps in northern flying squirrel habitat in the last 7 years, those gaps won't be reflected in our habitat concentration area (HCA) maps. Other new features on the landscape, such as wind farms, have also been missed by our models and would need to be considered separately in planning efforts.

4.2. Cost-Weighted Distance Maps: A Key Product

Our linkage maps tend to attract the most attention, but we urge readers to look closely at our cost-weighted distance maps. These show the cumulative cost—a measure of movement difficulty—that it would take for wildlife to move to any point in our study area from the nearest HCA.

Cost-weighted distance maps actually contain the same information as our linkage maps (a linkage map is created by adding the cost-weighted distances from the two HCAs it connects), plus something more. Cost-weighted distance maps allow you to compare the relative difficulty of moving through different linkages.

For example, a linkage connecting HCAs at the far ends of box 1 in Figure 4.2 would incur less cost (even though it is longer) than a linkage traversing box 2. Box 2 also includes a fracture zone, i.e., it passes through an area with significantly reduced permeability and would need considerable attention to serve as a reliable linkage. In a single map, you can see how isolated different parts of the landscape are from the nearest HCA, how isolated HCAs are from each other, and where some of the best movement routes between HCAs are likely to be. Linkage statistics (section 4.3.3; Appendix E) can also be used to estimate the degree of isolation between HCAs.

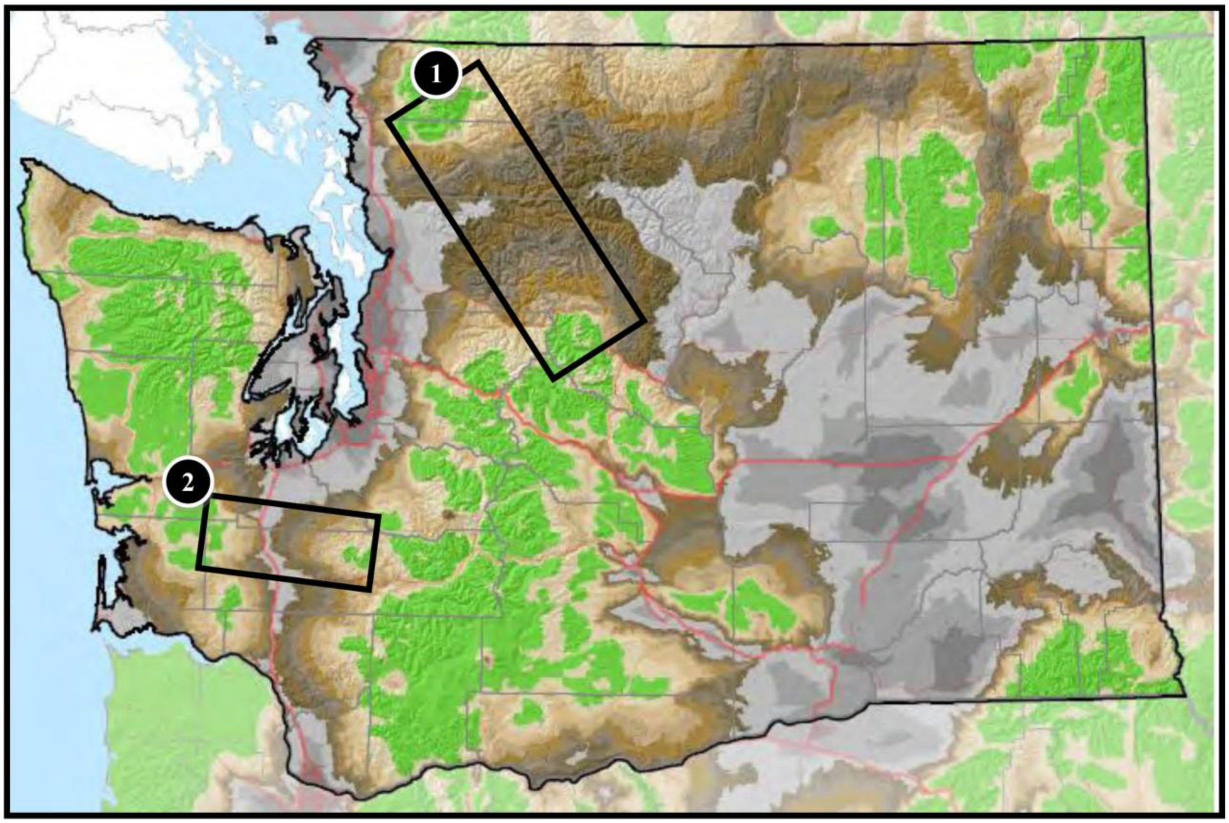


Figure 4.2. Cost-weighted distance map for elk. Even though box 1 spans a larger distance, the higher permeability of habitat means the length of this box is predicted to be easier and safer for elk to traverse than box 2, which spans a fracture zone.

This extra information comes at the expense of some detail: in other words, these maps have more of a fuzzy look to them than our linkage maps. This isn't necessarily a bad thing; in the opinion of our modeling team, this "broad-brush" appearance probably best conveys: (1) the broad array of paths animals will likely use as they attempt to move across the landscape, (2) spatial uncertainty associated with base data resolution, and (3) uncertainty associated with modeling how wildlife species perceive and respond to features that contribute resistance to the landscape.

4.3. Linkage Maps

Our linkage maps reflect our best estimates of potential movement pathway locations between adjacent HCAs given our data sources and models. As such, they provide powerful tools to support connectivity conservation planning.

These linkage maps can also be misused, because they appear to provide easy answers to connectivity conservation questions. They do not. In reality, they must be used with extra care because they are especially sensitive to our modeling assumptions and errors in our data layers. But they are valuable when used with a clear understanding of our models and data sources, and when combined with other conservation maps and additional information (such as from aerial photography, road kill records, or other field data).

We do not suggest that all mapped linkages should be conserved or even that all are important; some linkages may be impractical, and there may be other ways to keep habitat areas connected rather than focusing on direct linkages between them. Conversely, unmapped linkages may also be important, especially at more local scales or for species or systems that we didn't consider.

4.3.1. What Linkages Represent

A mapped linkage zone is not a known migration pathway. It depicts the easiest *modeled* movement routes between neighboring pairs of HCAs. Its existence, characteristics, and location are all dependent on the coarse-scale data layers that were available to us, our models of habitat suitability (reflected in our HCA maps), our models of dispersal habitat suitability (reflected in our resistance maps), and other factors such as our knowledge of maximum dispersal distances for each species (which informed maximum linkage lengths).

The map in Figure 4.3 shows dozens of linkages, all of differing lengths, qualities, and permeability to movement. Putting all linkages for a whole region on one map with one color scheme means yellow areas (the best portion of each linkage) can be in very good or very poor condition. For example, movement routes along ideal (yellow) pathways vary in cumulative cost-weighted distance by a factor of 10. Some routes are predicted to be as easy to traverse as moving through 2 km of ideal habitat, while others are predicted to be as difficult as moving 235 km, and include the crossing of highways and other hazards. Yet, each linkage has a central yellow band, indicating the best modeled movement pathway *for that linkage*. The important point is that one cannot compare *between* linkages using this map. Cost-weighted distance maps (See previous section and Fig. 4.2) and linkage statistics (See Appendix E and Fig. 4.4) must be used for this purpose.

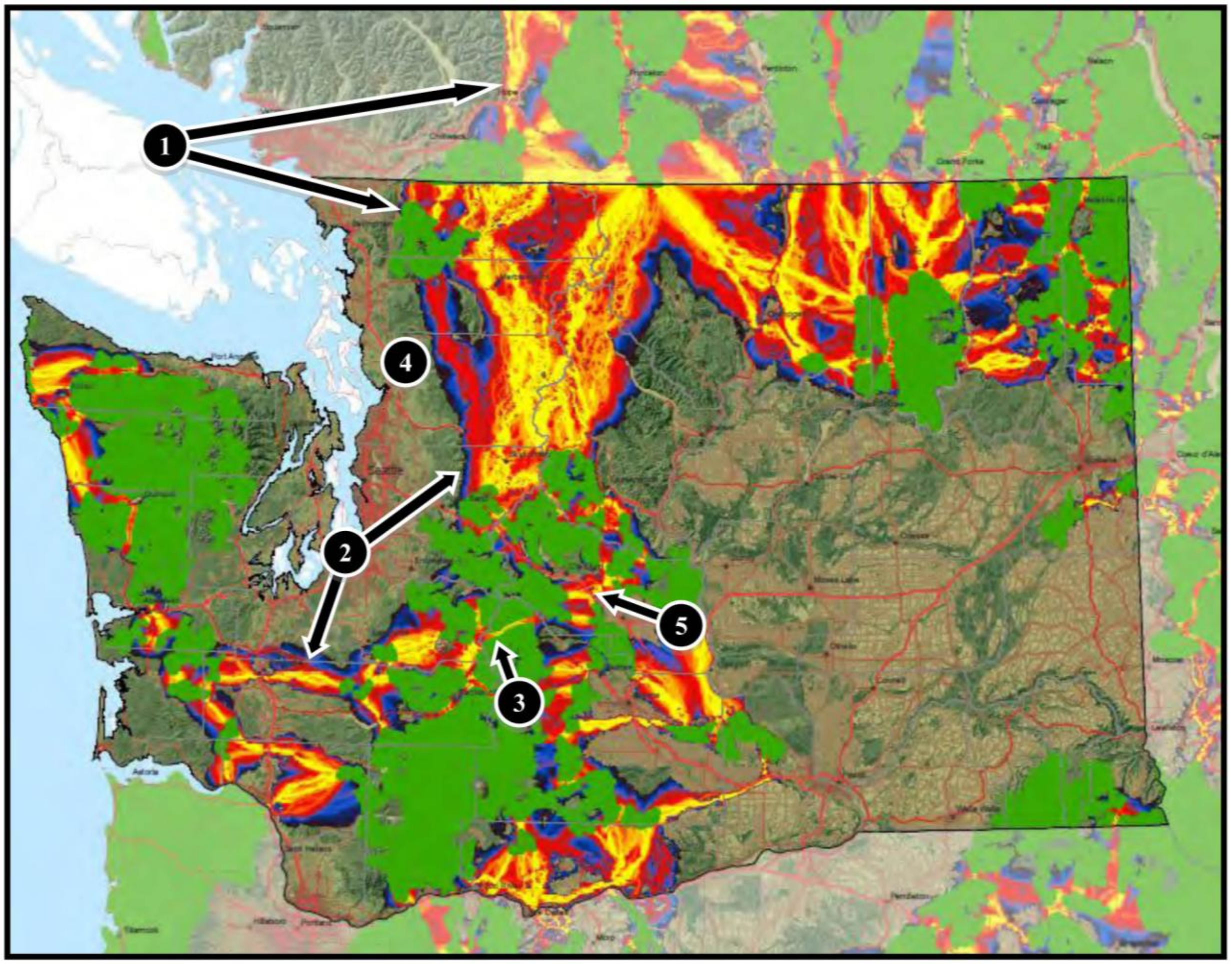


Figure 4.3. Linkage map for elk. See section 4.3.2 for points illustrated by item numbers.

4.3.2. Interpreting Individual Linkages

There are several points to be aware of when interpreting individual linkages. The items that follow are illustrated with corresponding numbers in Fig. 4.3.

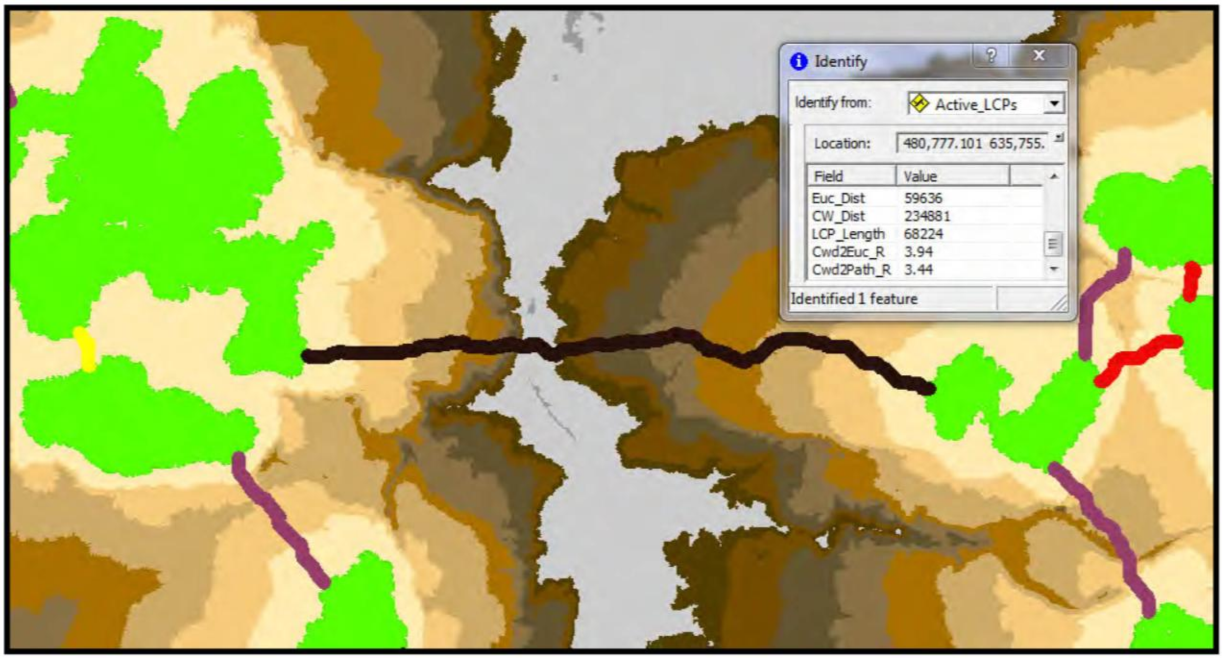
- *Item 1. Confidence in map products inside vs. outside Washington State.* For many cases, we were able to find better datasets within Washington State than outside its borders (due in part to the fact that we had easier access to spatial data for Washington than for other jurisdictions). As a result, some of our data, particularly for local roads, were considerably more reliable inside Washington than outside. We thus have higher confidence in our modeled map results within Washington than for the rest of our project area.

- *Item 2. Wide vs. narrow linkages*. Wider linkages don't mean that more area is needed to conserve connectivity, they simply mean there are many options for movement that incur similar movement costs and risks. Normalized least-cost corridors typically become wider in high-quality movement habitat because resistances are low and cost accumulates more slowly there. The wider linkage identified by item 2 passes through low resistance habitat in the North Cascades. The narrower linkage navigates through areas with significant barriers and hazards along I-5 near Centralia, where conservation options are more limited.

- *Item 3. Wide yellow bands when two HCAs are separated along a broad front by a narrow, linear barrier.* When two HCAs are separated by a narrow barrier (like a highway), they are often connected by a linkage that is very wide and yellow along much of its width. This is a result of normalizing linkages so that they can be mapped with the same color scheme. For elk, any portion of a linkage that can be traversed while accumulating less than ~2 km extra cost-weighted distance relative to that accumulated along the easiest path will display as yellow. But in these very short, wide linkage zones, 2 km is a considerable extra distance, in some cases doubling the cost accumulated relative to the easiest route. Finer-scale analyses would be needed to determine where the best conservation options exist.

- *Item 4. Secondary corridors (independent stringers).* Recall that we mapped linkages with normalized least-cost corridor values up to a species-specific cutoff value (See section 2.6.2). In many cases, entirely independent corridors fell within this cutoff value. These should be given extra consideration because they may provide greater redundancy—alternative pathways—than the red and blue fringes of least-cost (yellow) corridors. Often these fringes represent nothing more than cases where it is relatively easy for an animal to take a short detour from the least-cost path into a fringe area and back again before continuing its journey. The key point is that the potential to provide a functionally independent linkage is clearer for secondary corridors than for fringe areas. Independent, redundant connections can be important in ensuring connectivity plans are robust to uncertainty in underlying data, species models, or habitat loss due to unpredictable events like wildfires (Moilanen et al. 2006; O'Hanley et al. 2007; Pinto & Keitt 2009).

- *Item 5. Important features we couldn't map.* We were surprised by the mapped elk linkage predicted to cross I-90 between Cle Elum and Ellensburg. If this was an important movement route, we'd expect higher numbers of elk to be killed on this stretch of road than have been recorded by Washington State Department of Transportation (WSDOT). More elk are killed on segments of I-90 that are upslope from this segment (towards Cle Elum) than on this segment. A little investigating revealed that an elk fence had been constructed along this segment in the 1970s, presumably because elk were moving through this area and creating hazards for drivers. Features like fences are too detailed to map at statewide scales, but are nonetheless important to consider when developing detailed connectivity conservation plans.



Identify from: Active_LCPs

Location: 480,777.101 635,755.

Field	Value
Euc_Dist	59636
CW_Dist	234881
LCP_Length	68224
Cwd2Euc_R	3.94
Cwd2Path_R	3.44

Identified 1 feature

Figure 4.4. Cost-weighted distance surface and linkage statistics for elk linkages in Centralia area (See Fig. 4.1, middle row for approximate location). Here, least-cost path lines are used as placeholders for modeled linkages, and are colored to reflect cost-weighted distances for corresponding linkages (warmer colors are shorter in cost-weighted distance). Euclidean distances (Euc_Dist in query table) are the straight-line edge-to-edge distances between HCAs. Cost-weighted distances (CW_Dist) measure the total cost accumulated walking along the least-cost path. Least-cost path lengths (LCP_Length) are the actual (un-weighted) distance traveled walking along the least-cost path. The black linkage passing through the Centralia area connects HCAs that are 59.6 km apart, has a total un-weighted length of 68.2 km, but accumulates nearly 235 km of cost along that length because of barriers. Linkage quality information can be found in Appendix E.

4.3.3. Linkage Statistics

In addition to linkage maps, we provide basic statistics describing linkages (Appendix E). For each linkage, these include the Euclidean (straight-line edge-to-edge) distance between HCAs the linkage connects, the cost-weighted distance measured along the easiest movement route (i.e., the total cost accumulated walking along the least-cost path), and the un-weighted length of the least-cost path (i.e., the actual distance traveled walking along the least-cost path). Examples of each are shown in Fig 4.4. We also provide informative quality metrics, including a ratio of cost-weighted distance to Euclidean distance and cost-weighted distance to the length of the least-cost path.

Note that least-cost paths are calculated and mapped in Appendix E only to provide identifiable placeholders for each linkage, and to provide estimates of relative linkage quality. Given the limitations of our models and our base data (See section 4.1, Figs. 4.1 and 4.5), these 1-grid-cell-wide routes are not meaningful for planning purposes.

4.3.4. Limitations of Linkage Maps

WHAT OUR LINKAGES ARE CONNECTING

Remember that our habitat concentration area (HCA) maps are meant to capture the most important habitat areas for a species, not all habitat areas. Interpreting the habitat concentration area models requires an understanding of how they were intended to be used in our study and how they were derived. HCAs were not intended to identify critical habitats or to prioritize areas for conservation. Instead, HCAs in our study represent habitat areas as "seeds" on the landscape separated by sufficient space to allow for modeling connectivity between them. For focal species that occur in well-defined habitat areas (Greater Sage-Grouse, Sharp-tailed Grouse, mountain goats, and bighorn sheep), we delineated HCAs based on extensive survey data. For these species, HCAs approximated currently or recently occupied habitat within the study area (Chapter 3 species summaries; Appendix A), and their patchy distribution inherently allowed room to model linkages between them.

The species that are continuously distributed but perhaps at varying density across the study area (all other species aside from the four mentioned above) presented a challenge. Defining core areas based on a range map of predicted or actual species distribution did not allow for sufficient room between HCAs to model linkages and cost-weighted distance. Instead, we delineated HCAs for these species based on a subset of their range such that core areas were restricted to only the largest concentrations of the most suitable habitat. As such, HCAs for these species do not closely match the full range of their predicted GAP distribution (Chapter 3 species summaries; Appendix A). Moreover, the species with the broadest distribution required the most stringent definition of core habitat (i.e., the proportion of habitat within the home range radius moving window was greater) in order to restrict the number and extent of HCAs to a degree suitable for our connectivity models. Because the level of stringency defining HCAs varied across species, comparison of the number and extent of HCAs between species is not appropriate.

Importantly, HCA and landscape integrity core area locations that resulted from modeling decisions like these also defined where linkages could occur. As a result, if an area within a species' GAP distribution contains no HCAs or linkages (e.g. for American black bears in much of western Washington; Fig. 3.33) that does not mean the area does not provide important local habitat or connectivity.

RELIABILITY OF LINKAGE MAPS AT DIFFERENT SCALES

Figure 4.5 illustrates scales appropriate—and inappropriate—for applying our results. The coarse data layers and broad scope of our analyses limit the resolving power of our map products, and this becomes evident upon close inspection of our mapped linkages. This is one reason why we feel the "broad-brush" appearance of our cost-weighted distance maps may best convey the level of certainty that can be ascribed to our results. Our linkage maps in many cases show modeled linkage locations that imply a higher level of precision in linkage locations than our data can support when viewed at scales that are finer than intended (e.g., Fig. 4.5, bottom row).

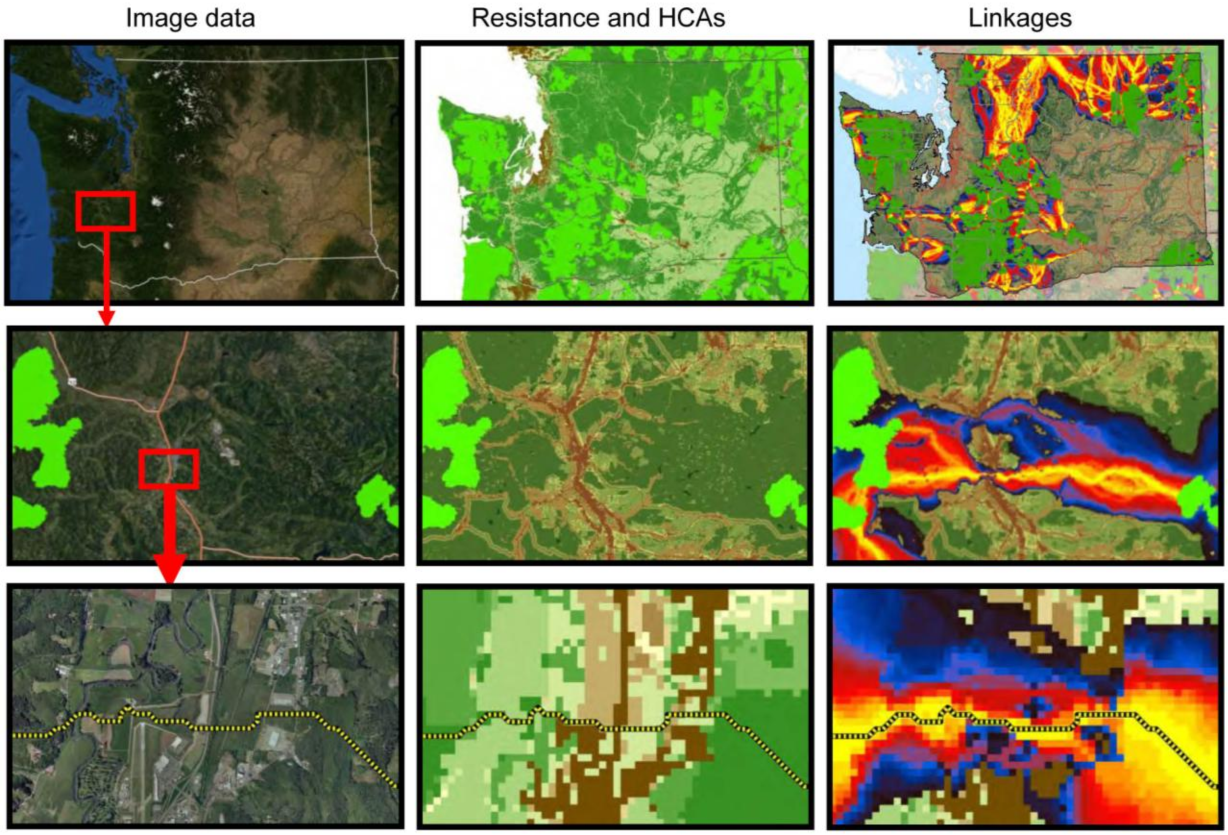


Figure 4.5. Effects of scale on reliability of linkage modeling results. Because base data layers do a good job of capturing patterns in land cover and other features at the extents shown in the top two rows, we consider our modeling results to be informative at these scales. Note the pinch point where options are constrained (I-5 crossing near Centralia, WA). However, linkage and resistance maps become unreliable at the finer scale depicted in the bottom row. The modeled location of the 'best' portion of the linkage (dashed line) actually crosses the northern tip of the Chehalis-Centralia Airport—hardly a good place for an elk to be. This illustrates the need for fine-scaled linkage analyses; a detailed linkage design would certainly reroute this linkage, assuming the linkage proved to be viable, cost-effective, and compatible with local planning goals after fine-scaled analysis.

4.4. Informing Priorities

Within the networks of connected habitats we've identified, conservation priorities can and should be established. However, while our maps provide important information to support connectivity conservation, they do not define conservation priorities on their own. Priorities and methods to set them will depend upon the missions and goals of the organizations that are using these products. For example, conservation priorities for the needs of an individual species could be different from priorities meant to conserve biodiversity or ecological processes. Similarly, priorities for investments in wildlife-friendly highways might take into account traffic volumes and highway geometry, factors that may be less important in other kinds of prioritization schemes.

We expect prioritization among linkages will typically be accomplished at ecoregional or local scales. At these scales, finer-resolution analyses that integrate regional and local information and consider local planning needs and constraints can be added, as can more detailed spatial data or field data on species movements. Information relevant to other conservation objectives, such as ecoregional assessments and salmon recovery priorities, can also be more easily integrated at these scales.

We have included corridor quality maps and data (see description in section 4.3.3; Appendix E) to assist with setting priorities. Focal species summaries (Chapter 3) provide biological interpretation for many of the linkages we've identified. In addition, we encourage users to pay particular attention when linkages coincide for multiple species and/or our landscape integrity models (Figs. 3.73–3.75).

4.5. A Foundation for Finer-Scale Analyses and Linkage Design

The WHCWG will follow this statewide analysis with ecoregional connectivity analyses that will build on this report while focusing on smaller planning areas. This has the benefit of allowing us to: (1) include spatial datasets unavailable for the statewide project area, (2) include more regional participation thus allowing the incorporation of regional knowledge, and (3) incorporate considerations that may influence connectivity unique to a regional landscape.

The ecoregional analyses are analogous to the "Regional Analysis" framework articulated in the California Essential Connectivity Report (Spencer et al. 2010); we encourage readers to refer to that report for what we consider an important resource for mapping and prioritizing linkage networks at regional scales and for completing detailed linkage designs at local scales.

Our first ecoregional connectivity analysis will be for the Columbia Plateau in eastern Washington, and an overview of how this report will inform the ecoregional analysis is given below in section 4.6.2. The result will be products that include refined habitat blocks and more detailed linkage maps to inform regional and local conservation efforts.

Local-scale linkage designs replace coarse-scale linkage maps. These linkage designs map finer linkage details and provide conservation actions needed to conserve and/or restore connectivity within identified linkages. Linkage designs will typically follow ecoregional analyses or more local level analyses that provide additional data and information useful for identifying priorities for the linkage design work.

The statewide analysis can be a useful resource before finer details are added, particularly when conservation opportunities arise or projects are proposed that may impede wildlife movement. In such cases, decisions may need to be made as to whether to proceed with a more local detailed linkage analysis before results of ecoregional analyses are available. If a proposed project, such as the widening of a stretch of highway, falls within an area identified by this report as a habitat concentration area or linkage, then this can be a trigger for further detailed analysis and potentially for a fine-scale linkage design. Although such analyses would require additional local knowledge, data, and field work, the base data and products from this report will provide valuable resources to build upon.

Such an example occurred at Stevens Pass Ski Resort in 2009. In 2009 the resort updated its Master Plan for Development, which outlines future plans for operation and growth. During the discussions surrounding this plan's update it was identified that the ski resort fell within an important habitat connectivity area for multiple montane species based on previous work (Gaines et al. unpublished; Singleton et al. 2002). These past analyses were coarse scale and did not provide the detail necessary for analyzing Master Plan impacts to connectivity. In response, the resort hired the Western Transportation Institute to conduct a detailed finer-scale analysis of connectivity in the Stevens Pass vicinity north and south of Highway 2 in Washington's Cascades Mountains. By conducting analyses at the appropriate spatial scale, the study allowed the ski resort, and the national forests upon which it operates, to better evaluate how their plans would affect habitat connectivity (Begley & Long 2009).

4.6. Example Uses of the Statewide Analysis

With attention to the caveats and the interpretive information we've provided above, the statewide connectivity analysis can be used in a variety of conservation planning contexts. For example, it can be used to inform:

- The Western Governors' Association Wildlife Corridors Initiative.
- The Washington State Department of Fish and Wildlife's Wildlife Action Plan.
- Implementation of safe wildlife passage structures and complementary measures by the Washington State Department of Transportation in accordance with Executive Order 1031 (e.g., enlarged culverts, wildlife overpasses, and fencing).
- Land management plan revisions and decisions for public lands in Washington State, including our national forests, state parks and forests, and state and federal arid lands.
- Decision making by conservation organizations.
- Local government efforts to protect habitat connectivity and initiate coordination on finer-scale analyses for comprehensive planning.
- Investments through state and federal grant programs for conservation of habitat and working lands (e.g.,Washington Wildlife and Recreation Program, Land and Water Conservation Fund, and Farm Bill incentives).

Below we provide details on two specific uses for our products. The first is by WSDOT for their wildlife-friendly highway program, and the second regards the scaling down of the statewide analysis to the ecoregional scale for the Columbia Plateau ecoregion in Washington.

4.6.1. Example use: Washington State Department of Transportation

WSDOT operates a state highway system composed of over 11,000 km of road. The agency has an expressed interest in reducing the effects of these roads on wildlife movements and reducing the risks of collision to make the highways safer for the traveling public. This statewide analysis puts WSDOT in an improved position for determining the best locations for investing in wildlife-friendly highway improvements. These maps, when integrated with other information, will enable WSDOT to make informed decisions about where to allocate limited funds available for habitat connectivity.

WSDOT's main anticipated use of these maps is to identify locations where highways intersect with connected linkage networks. What follows is a discussion of how WSDOT anticipates applying this information at the transportation corridor, project, and I4 (a highway improvement program) highway improvement levels.

Transportation corridor planning takes a long-range view of transportation needs for a specific area: planning considerations include many social and environmental factors. In this decision framework WSDOT has the greatest flexibility for considering different options to meet the needs of people and the environment. A wide range of ecological considerations might be included when establishing priorities for transportation improvements within the corridor. These could include, for example, maintaining landscape permeability for large carnivores, cultivating connectivity to provide for key ecological functions, and minimizing wildlife-vehicle collision risks for motorists. Many of the methods described in this chapter for using the data produced by this statewide analysis will be important for examining options and identifying best practices within the corridor planning framework. After all of the relevant factors have been considered, the corridor plan could indicate where to implement specific improvements such as wildlife underpasses, barrier fencing, wildlife guards on intersecting side roads, and more.

The I-90 Snoqualmie Pass East project is a good example of the application of similar information to a highway improvement project that benefitted from least-cost corridor analyses as well as extensive field work that included snow tracking, motion-triggered cameras, and other methods. The result is a highway design that includes wildlife crossing structures, extensive barrier fencing, and many subtle features intended to improve conditions for wildlife.

During the planning phases of the project, a broad coalition of public and private organizations engaged on connectivity issues in the broader I-90 corridor, including issues related to the "checkerboard" public-private land ownership pattern within the planning area. Conservation organizations from across Washington united in a campaign to address long-term conservation of habitat north and south of the I-90 Project area. Today, that campaign has conserved over 40,000 acres of land in the I-90 Project area, securing the habitat values that WSDOT's highway improvement plan also seeks to enhance.

Looking beyond the transportation corridor planning framework, highway projects usually come with a specific scope, a limited budget, and a well-defined timeline: opportunities for accommodating ecological needs are more limited. However, where linkage networks are identified as overlapping with a highway project, there are almost always opportunities to facilitate low-cost improvements. These include things like choices of median barrier types (cable barriers are generally better for wildlife than concrete barriers), improvements to passage conditions in existing bridges and culverts, and, possibly, new fencing. It will not normally be possible to create dedicated wildlife structures on most highway projects.

In another highway improvement arena, I4 projects are purposefully conceived and designed to rectify an environmental shortcoming. The categories of projects that fall under this section of WSDOT's budget are Fish Passage, Chronic Environmental Deficiencies, and Habitat

Connectivity. In each category, a method to establish priorities has been developed and is used to determine the order for project completion. The method for determining priorities within the habitat connectivity category has not been completed yet. The maps produced by this project, which provide detail on the intersection of the transportation system with linkage networks, will be among the factors used to develop I4 program priorities. Other factors, such as traffic volume, highway geometry, wildlife-vehicle collision rates, adjacent land ownership (an indication of the likely permanence of habitat values in the area), will also be used in WSDOT's prioritization.

4.6.2. Example use: Columbia Plateau Ecoregion

A review of the results from our statewide connectivity analysis in the Columbia Plateau ecoregion highlights the need for a finer scale analysis in this geography. There is a high degree of overlap in shrubsteppe species' and landscape integrity networks in our analysis, showing that potential movement routes are being limited to fewer and fewer portions of the landscape (Fig. 3.75).

At the time of publication, we are starting an ecoregional analysis in the Columbia Plateau. The results will include better-defined habitat blocks and more detailed linkage maps to inform regional and local conservation efforts. We are collaborating with the Arid Lands Initiative (ALI), a multi-partner effort working to develop and cooperatively implement a coordinated strategy for the conservation of Washington's arid lands. As part of this collaboration, the ALI core team is functioning as an ecoregional advisory committee for the WHCWG. The ALI will use the results of the Columbia Plateau connectivity analysis to identify shared priority areas for the implementation of strategic actions such as fire management, habitat restoration, and the identification of viable alternatives to development on working lands. While the ecoregional products are being developed, the statewide analysis will provide broad-scale guidance, and may be used to identify initial priority areas. It will also inform decisions on how to combine the connectivity analysis results with other analyses and knowledge to identify the full suite of shared priorities.

The ALI is already reaching out and engaging wildlife experts and stakeholders with interests in arid lands conservation. We are working with these experts and stakeholders to inform the modeling and usage decisions, including data availability and quality, best focal species, and size and habitat quality thresholds for defining core areas for both focal species and landscape integrity models. These contributors will also help define model parameters that reflect the available knowledge on species movements, determine what information is most useful for prioritizing linkage areas, and highlight what models need validation with on-the-ground data.

The statewide analysis is providing the analytical and methodological framework for the ecoregional scale analysis. At the same time, it provides coarse-scale results to guide and inform the development of ecoregional scale products. For example, the statewide analysis results highlight a north-south "backbone" of lands along the east slope of the Cascades in the Columbia Plateau that appear important for multiple species as well as for landscape integrity (Fig. 3.75). Selecting focal species that better represent the eastern areas of the ecoregion will likely provide better resolution in areas closer to the Idaho border. Incorporating information on wind development, such as has occurred around the Ellensburg area, will provide additional detail on areas to focus on for conserving connectivity. Similarly, the selection of focal species with more limited movement capacity will give more definition to the gradient of opportunities for implementing different strategies, including areas for restoration, or areas critical to protect from wildfire.

The improvements in the resolution and information we will obtain through the Columbia Plateau ecoregional analysis will, in turn, inform subsequent connectivity analyses at similar scales in other Washington ecoregions. Additionally, there will be areas or strategies where the ecoregional scale analyses do not provide sufficient detail for local decision-making. However, these intermediate scale results will again highlight priority areas where local parties or partnerships should develop fine-scale linkage designs. These designs can then be focused such that they complement the broader analyses while adding significant new information for that particular area.

4.7. Additional Resources

In addition to tools and information that we are providing, there are excellent free resources available to assist with planning, implementing, and prioritizing finer scale analyses and linkage designs. These resources include:

- California's recent statewide linkages report (Spencer et al. 2010), which includes chapters that describe how to step-down results from a broad-scale analysis to the greater detail needed for implementation.

- The Corridor Design website (www.corridordesign.org) is a valuable resource for developing an individual linkage design (Beier et al. 2010). The associated ArcMap extension includes features that allow comparison of multiple linkage designs (Jenness et al. 2010), and linkage design methods specific to climate change needs are also discussed (Beier & Brost 2010).

- The Connectivity Analysis Toolkit (www.connectivitytools.org) provides tools for linkage mapping and for centrality analysis, which focuses on the relative importance of sites for maintaining connectivity across a landscape (Carroll 2010).

We will be sharing GIS analysis tools we have developed, as well as focal species and landscape integrity models you might wish to use in more refined linkage analyses for local needs. The WHCWG is committed to supporting future connectivity work and will additionally seek to engage and provide support to others working on behalf of wildlife habitat connectivity. We encourage you to check our website at: www.waconnected.org for contact information, updated information, and new products as they become available.

Chapter 5. Lessons Learned From the Analysis Process

We learned a great deal during this project about connectivity assessments and working with diverse partnerships. Our objective in this chapter is to share these insights and lessons in the hope of increasing the efficiency of future connectivity analyses. We believe this is best accomplished through an unvarnished discussion of what worked for us and which mistakes we encourage others not to repeat.

5.1. Working Group Composition

Large-scale connectivity analyses are complex and require an organized, skilled, and diverse team to complete. One of the underlying objectives that influenced the composition of the WHCWG was to include stakeholders with high capacity to implement connectivity solutions on the ground. The intent was to share ownership in the analyses guiding conservation actions. We anticipated that stakeholders would be more likely to implement aspects of the analyses if they had been involved in their development.

A consequence of this objective was the formation of a group with diverse backgrounds representing a wide variety of organizations. This diversity both strengthened and limited team productivity. We realized many benefits of diversity in terms of dynamic exchange of ideas and sufficient depth in the team to allow simultaneous progress on multiple fronts. We were also extremely fortunate to have generous support from state agency leads and to compete successfully for external grant funding. However, a significant limitation imposed by our diverse composition was that all team members were typically squeezing connectivity analyses into already overcrowded schedules, particularly as our organizations endured budget cuts and downsizing.

The lessons we want to share about team composition are that it's important to recognize constraints on productivity, set objectives, expectations, and schedules accordingly, and realize that substantial encouragement, persuasion, and patience will be required to get the analyses done. At this point, we believe implementation benefits associated with shared ownership of the analyses will more than compensate for the associated slower pace of progress that occurs in large collaborative efforts.

Lastly, we found it useful to engage university faculty as well as students in our analyses. Doing so allowed our project to benefit from cutting-edge work in modeling and climate change research. These are efforts that will ultimately lead to new applications we otherwise would not have had time to explore. We believe there may be broader opportunities to engage students in ways that enhance efficiency and allow us to tap novel approaches, ideas, and current research in fields that support or can be adapted to wildlife conservation and connectivity.

5.2. Working Group Structure

The working group structure we developed served us well. We established subgroups to manage spatial data, select focal species and lead focal species analyses, develop a communications strategy, conduct a landscape integrity analysis, develop and automate modeling, and incorporate climate change into our connectivity analyses. We found that this array of subgroups enabled us to specialize sufficiently to make focused progress on the variety of topics relevant to meeting our objectives. A core team assisted with maintaining communication, integration and cohesion among the sub-groups. Individuals often participated in more than one subgroup which further helped communication and cohesion. As well, the working group co-leads interacted with all subgroups to support and funnel information to specific subgroups as needed.

5.3. Accomplishing the Analyses

Planning our work and keeping it on schedule proved to be a constant challenge. The nature of connectivity analyses is rapidly evolving and subject to constantly changing ideas and newly realized constraints. We attempted to address this issue by writing a detailed study plan and having this plan peer reviewed by experts in wildlife habitat connectivity. We recommend study plan development as a reliable way to save time. But we add the cautionary note that we found it impossible to anticipate many of the idiosyncratic difficulties and unintended consequences associated with decisions we made about our analyses. The most efficient way to troubleshoot our analysis sequence and overall process was to conduct pilot analyses using a small subset of focal species before initiating the full analysis.

Still, while pilot analyses and other time- and labor-saving strategies are helpful, meeting firm deadlines presumes everything is proceeding according to schedule, and this is not often the case. When our best-laid plans proved to be inadequate and needed revision, we sometimes struggled to redirect multiple team members working in parallel on similar tasks. We learned that well-organized decision processes, clearly articulated written guidance, and redundant communication are essential for enabling all team members to respond to inevitable changes in direction.

We cannot overstate the importance of clear guidance and explicit definition of key terms as a constructive means for avoiding “do-overs,” and for minimizing inconsistencies among team members due to differences in interpretation. From our experience, the sooner an explicit and detailed understanding of key terms and concepts can be achieved, the better. For example, our connectivity analyses are typical in their heavy reliance on expert opinion. In the context of attempting to address the “subjective translation” problem (Beier et al. 2008), we tried to reach a shared understanding of what “resistance” means among multiple focal-species leads. We attempted to use landscape genetic information from a study of mountain goats as a reference and to help “calibrate” resistance estimates across focal species. This proved challenging, until the author of the mountain goat study (and a member of the WHCWG) presented to the focal-species leads clear conceptual and practical guidance about how to translate resource selection information into resistance values. A similar scenario played out regarding delineation of habitat concentration areas.

5.4. Communications

We benefited greatly by using a broad array of internal communication tools to help coordinate our efforts. In particular, a shared internal website for posting documents allowed team members to track new developments and provided a clearinghouse for interim products needing review. This tool, in combination with traditional conference calls and meetings worked well to maintain effective internal communication. The ability to rapidly share GIS data and analysis results via FTP and web services proved valuable in the iterative collaboration between analysts and focal-species leads. Sharing PDF versions of GIS analyses and using Adobe Acrobat to activate layers facilitated collaboration between analysts and leads with limited GIS expertise.

5.5. Making Choices

Throughout all stages of modeling as well as map cartography, we encountered a multitude of challenges and choices. For example, should resistance values for cost-weighted distance analyses be calculated by combining factors using arithmetic, multiplicative, or geometric means? How should different factors be weighted when they are combined? We reviewed literature (e.g., Beier et al. 2008; Singleton et al. 2002), and work from other states (e.g., California, http://www.dfg.ca.gov/habcon/connectivity/) and at each step made choices we felt best incorporated species needs while being simple, transparent, and easily understood.

For instance, our linkage maps are products built in five steps: (1) GIS data layers, (2) focal species selection and model development or landscape integrity model development, (3) resistance surface development, (4) identification of habitat concentration areas or landscape integrity core areas, and (5) linkage modeling. Each step had associated choices and potential pitfalls. In addition, cartographic presentation had its own set of unique challenges.

Working collaboratively and in partnerships was of immense importance for sorting through a series of issues needing consideration. Based on these experiences we do not expect our products to remain static but instead anticipate that they will evolve to incorporate new methods, data, and planning needs.

5.5.1. GIS Data Layers

The connectivity models use GIS data layers which are the “building blocks” of the analyses. Substantial GIS staff time was devoted to developing the base layers for the project primarily because we did not anticipate the mapping inconsistencies we encountered in the U.S. vegetation layers. In particular, LANDFIRE crown-cover overestimation and data gaps along the international border were a problem. We hope these mapping issues will be mitigated in future LANDFIRE data releases.

We expected difficulties in melding the Canadian and U.S. vegetation layers. But we did not anticipate the substantial effort required to integrate the Vegetation Resource Inventory (VRI) and Baseline Thematic Mapping layers into a single base for use with the British Columbia Biogeoclimate layer. Making data development even more difficult were the large data gaps in the VRI; these areas are under tree farm license and owners are not required to publically report forest attributes. Some of the tree farm license blocks are within 50 km of the international border and are important for connectivity between Washington and Canada. Once we had the Canadian and USA 11-class map layers prepared, it required several days of effort to blend the Canadian map with wet forest, dry forest, and shrub in the U.S. portion. Overall, we found extra time must be allowed for cross-border vegetation compilation, which is especially challenging due to differences in compilation data sources, standards, and mapping purposes between the countries.

As well, data may be collected at different scales, times, and for different purposes. Care must be taken when using and/or combining such data to ensure conclusions drawn from the map results are valid. For example, we found the National Wetland Inventory maps for Washington, Oregon, and Idaho to be highly inconsistent in the application of mapping densities. Their use would likely have produced erroneous results for at least one of our focal species, the western toad.

Road networks were also challenging to represent across multiple jurisdictions. Classification systems varied and fully developed data layers for local roads, particularly forest roads associated with logging, didn't exist for some areas. Consequently, our local road category included very busy county roads connecting sizeable cities as well as narrow forest roads accessible only for administrative purposes. Although we recognized the potential value of partitioning the local road data layer into more meaningful categories, we lacked the resources to do so.

Many decisions to keep data layers "simple" were necessary to accommodate the broad extent of this statewide analysis. Nonetheless, as the project proceeded we identified compelling reasons to try to adjust or add to our base layers: as there were GIS layers that, based on hindsight and/or better availability, would have benefitted our analyses. However, such additions can be very time consuming, and expended efforts may not be fruitful. For example, given the number and scale of wind farm developments in Washington, and the extensive number of transmission line corridors, these layers could have significant impacts on HCAs and linkages of several focal species. Yet, when we examined the possibility of including these spatial data we found cohesive quality layers for our study area did not exist. The extensive work to research and piece together these layers was outside our capacity. Additionally, we did not differentiate Conservation Reserve Program (CRP) lands from agricultural lands and therefore lost resolution for this key habitat category within the Columbia Plateau where there is considerable agricultural development. One of our objectives is to address these important lands, as well as energy development and transmission layers, in our upcoming ecoregional analyses.

5.5.2. Species Choices, Resistance Surfaces and Parameters

Criticisms can be leveled against many of the focal species we selected. Some might believe that widely distributed and relatively common focal species such as mule deer and black bears provide limited insight into connectivity conservation needs relative to the effort required to complete linkage modeling. Other focal species, like badgers, may be attracted to elements of infrastructure such as highway and railway embankments that fragment habitat for many non-focal species. The current distributions of some focal species, for instance the western gray squirrel, are so disjunct and isolated that connecting existing populations may be unrealistic.

We accept that all focal species have flaws; however, we found that walking critics through our selection process mitigated concerns, and we recommend not letting such criticisms overwhelm the value of focal species analyses. The strength of the focal species approach derives from thoughtful consideration of what each focal species contributes to our understanding of connectivity at a particular scale of analysis. It is also proportional to the number of focal species analyzed. Including as many focal species as resources allow will increase chances of adequately representing biodiversity.

The amount and quality of information relevant to our modeling varied greatly among focal species. For the mountain goat, we had detailed survey information about current distribution, as well as landscape genetic information that could be used to calibrate resistance of different landscape features that subdivided the population in our analysis area. But for most species, we had a patchwork of information about habitat associations, resource selection, current distribution, and movement patterns. Based on recommendations and advice from previous connectivity modeling projects, we tried to fill in the information gaps for focal species using expert opinion. We used a workshop approach to gather species experts, educate them about our overall approach, and gain their expertise regarding information we needed about focal species to parameterize resistance surfaces and delineate HCAs. This approach worked well, and set the stage for ongoing collaboration between focal species leads and species experts throughout the remaining connectivity analysis process.

Recognizing that model parameterization using expert opinion carries a high level of uncertainty, our intention was to conduct sensitivity analyses to investigate the effects of varying parameter values based on expert opinion. We conducted informal sensitivity analyses for many species as we received expert opinion and sought best solutions to improve model outputs. However, we have not formally conducted these species sensitivity analyses and acknowledge this is an uncompleted element of our work. We continue to pursue approaches for combining focal species analyses, and this objective certainly warrants future work.

5.5.3. Habitat Concentration Areas (HCAs) and Landscape Integrity Core Areas

In delineating habitat concentration areas and landscape integrity core areas, our goal was to identify those areas of substantial size and quality to be included as targets for linkage modeling. For some species we used habitat polygons previously identified in recovery plans (e.g., Greater Sage-Grouse) or management plans (e.g., bighorn sheep). For most species, however, we used habitat modeling to identify HCAs.

There are numerous factors to be considered regarding HCAs. Combining habitat concentration area minimum size with maximum linkage values could mean losing sight of stepping stone habitats which can serve as bridges between more distant habitats. For some species the convoluted shapes of HCAs—in tandem with linkage modeling rules we used that allow one linkage per HCA pair—will identify the shortest, highest quality linkages, but could miss other important linkages. In addition, we did not include all known population locations of focal species in HCAs. For example, the American badger occurs in an area southeast of the Potholes Reservoir that was not included in our modeled HCAs. We could have adjusted the minimum HCA size parameter in our badger model to allow inclusion of this location; however, adjusting the minimum HCA size for this species would have flooded the landscape with additional HCAs, losing definition useful for identifying linkages. Another alternative was to manually include the HCA as a known important area. In the end we were reluctant to add an HCA outside of our standard protocols, and chose instead to note this discrepancy in the focal species appendix.

5.5.4. Linkages

One of the challenging aspects of the linkage modeling was determining the appropriate modeling approach for the statewide extent. We chose to use cost-weighted distance linkage modeling, and to relegate other options—such as the use of Circuitscape (McRae et al. 2008)—to ecoregional modeling, local-scale modeling, or products that might eventually be developed to provide greater detail for the statewide analysis in the future. Nonetheless, the very large numbers of linkages that would need to be run for our analyses began to loom as a daunting challenge. To address this challenge, we developed a linkage mapping tool (Appendix D). While this was an enormous and time consuming endeavor, this work ultimately made us more efficient. We believe it provides an advance for our future modeling efforts as well as for those that may be undertaken by others.

5.6. Transboundary Collaboration

Challenges with travel, budgets, and the time it takes to build working relationships all come into play when collaborating across state and federal boundaries. However, wildlife habitat connectivity analysis and effective implementation necessitates considering important issues beyond administrative borders. In this analysis, our relationships with the adjacent states of Idaho and Oregon and the province of British Columbia were particularly important. Early on, we identified the need for incorporating bordering jurisdiction datasets and obtaining their review of our model results.

To address this need, we engaged in data sharing and review discussions with wildlife experts through conference calls, and conferences (e.g., Wildlinks 2009). We also hosted a transboundary summit to increase partnering across borders (April 2010). Finally, the Western Governors' Association Wildlife Corridors Initiative and the USFWS Landscape Conservation Cooperatives continue to provide important frameworks for broad, transboundary collaboration.

Chapter 6. Conclusions and Future Work

6.1. Conclusions

We are in a new era of landscape connectivity conservation, one that goes beyond a focus on species-specific corridors to an approach that retains and restores linkages for wildlife and sustains ecological processes in the face of shifting land use and climate change. The statewide analysis of the Washington Connected Landscapes Project represents a vital, collaborative effort to describe current connectivity conditions, identify crucial wildlife habitats and habitat linkages, and set the stage for finer-scale analyses and consideration of future scenarios as part of our state's contributions to the Western Governors' Association Wildlife Corridors Initiative.

Besides the findings specific to our study area presented in previous chapters, our analysis process led us to several conclusions about conducting connectivity analyses in general. First, an analysis area that includes an ample transboundary buffer is essential for understanding broad-scale connectivity patterns for wide-ranging species and ecological processes. Focal species and landscape integrity analyses revealed many linkages across geopolitical borders that likely connect populations and processes in Washington to a broader regional network. Climate change and widespread loss of habitat call on us to explore options for conserving connectivity that transcend jurisdictional boundaries and sustain natural processes.

Second, our unique approach of combining focal species with landscape integrity-based modeling allowed us to evaluate how these methods are complementary and to contrast the strengths and weaknesses of both. The correspondence analyses we've included represent our first step in this evaluation. We intend to continue exploring the insights provided by the integration of these approaches (See Future Work, below).

Third, automating the linkage modeling helped contain the financial costs of analysis while also improving the quality of connectivity models by allowing analysis of multiple species and landscape integrity approaches at the statewide scale. Connectivity model development is inherently iterative, and automation permitted greater exploration and refinement of candidate models. We expect these automated analysis tools will also accelerate completion of subsequent, finer-scale analyses.

Lastly, we cannot overstate the importance of collaboration for: (1) providing resources and expertise necessary for completing this analysis; (2) ensuring our products meet the needs of diverse partner organizations, thus promoting broad acceptance of, and familiarity with the products; and (3) identifying shared priorities, strategies, and implementation needs. Connecting people and organizations through their shared interests in wildlife connectivity has and will continue to be of paramount importance to the work of WHCWG.

Considerable work remains to be done (See below). Our focus has been to identify broad habitat and connectivity patterns; however, refinement is necessary for smaller analysis areas and for project-scale planning. We will be sharing GIS analysis tools we have developed, as well as focal species and landscape integrity models for others to use to refine linkage analyses for more localized needs. Chapters 4 provides information to help address questions potential users of this analysis might have, such as how to interpret the analyses, how to use the information we're providing, and where to obtain additional information. Finally, WHCWG is committed to supporting future connectivity work, and will additionally seek to engage and support others working on behalf of wildlife habitat connectivity.

6.2. Future Work

This statewide analysis is the first of multiple products within the scope of the overall Washington Connected Landscapes Project. We envision the development of additional products that will contribute to our understanding of landscape connectivity and support the development of strategic plans and specific projects to conserve connectivity for Washington's wildlife. We have identified several specific efforts where we expect to focus our energy in the short-term future.

6.2.1. Climate Change

From the start, we recognized the importance of incorporating climate change into our connectivity analyses. To address this need, a WHCWG Climate Change Subgroup was formed in winter 2010. The subgroup defined two fundamental goals for integrating climate change into connectivity assessments: (1) continue to provide habitat and connectivity as climate changes, and (2) accommodate climate-driven shifts in species' ranges. They developed a comprehensive analytical framework for integrating climate change into statewide and ecoregional analyses and began pilot modeling exercises. Early analyses are likely to emphasize modeling linkages along climatic gradients, identification of climatic refugia, and investigation of the capacity of riparian networks to meet connectivity conservation goals under climate change. Subsequent analyses may include investigation of linkages and refugia that are robust to different future climate scenarios, and modeling shifts in species-specific bioclimatic envelopes.

We will begin incorporating climate change model results into the statewide analysis in 2011, preparing additional map layers identifying those habitat areas and linkages most likely to provide connectivity for animal and plant species given climate change scenarios. We also believe that the ecoregional scale may be an appropriate and manageable scale for incorporating climate change into connectivity assessments. We expect to test this idea with the Columbia Plateau ecoregional analyses.

6.2.2. Ecoregional Analyses

Our first ecoregional connectivity analysis, with products anticipated 2011–2012, will focus on the Columbia Plateau and adjacent arid lands in eastern Washington, extending into neighboring states and provinces. This ecoregional assessment will benefit from our experience completing the statewide analysis, as well as from other connectivity assessments that have provided frameworks for conducting regional analysis (e.g., Spencer et al. 2010). The Columbia Plateau analysis will serve as a template for developing methods and tools for analyses of other ecoregions within Washington. From these ecoregional analyses we intend to produce finer-resolution products that complement the statewide analysis and include considerable outreach to local wildlife and habitat experts and local communities.

We believe the ecoregional scale of analysis will offer opportunities for exploring linkage quality in more detail. This enhanced information about linkage quality can provide the basis for identifying crucial or high priority sets of linkages that comprise a foundation for ecoregional networks resistant to climate change and other impacts (Spencer et al. 2010). We also expect ecoregional analyses to be a critical intermediate scale of analysis useful for identifying locations where detailed linkage designs are needed (See Spencer et al. 2010).

6.2.3. Assessing Focal Species and Landscape Integrity Approaches

We intend to delve deeper into focal species and landscape integrity approaches to connectivity analyses by: (1) reviewing literature about focal species and integrity-based approaches and compiling performance characteristics described by others for these methods, (2) examining our results to identify where they support or differ from those found in the literature, and (3) pursuing new analysis methods that quantitatively compare our focal species and landscape integrity results. We will use the findings from these evaluations to inform future analyses.

6.2.4. Model Validation and Adaptive Management

Our models are based on imperfect spatial and biological data. Evaluating the reliability of our results and refining them is important to predicting how species may respond to infrastructure development, land-use change, climate change, and other stressors, as well as to design effective conservation and mitigation strategies. Model validation followed by an adaptive management process that integrates improved species information are necessary components of connectivity analysis.

Resistance values for mountain goats (Shirk & Rice, Appendix A) were informed by a prior analysis of genetic data (Shirk et al. 2010) that linked genetic distances with resistance values in the Washington Cascades. However, for the remaining species we lacked data that could link model parameters and results explicitly to research that measured movement patterns or gene flow for the species we analyzed.

We are working on two research projects with WHCWG collaborators to begin addressing this need. The first is the Greater Sage-Grouse Project led by WDFW. This project has three elements: (1) examination of model predictions and movements by Greater Sage-Grouse using data from a large radio-telemetry study, (2) examination of model predictions and patterns of historical lek persistence, and (3) genetic analysis of Greater Sage-Grouse populations in Washington and the application of landscape genetic analyses to relate patterns of current and historical connectivity to patterns of landscape resistance. The second project is the Cascades Carnivore Connectivity Project led by the Western Transportation Institute and the U.S. Forest Service, which is evaluating barriers to carnivore movement in the North Cascades. The study employs remote camera monitoring and non-invasive hair sampling techniques (for genetic analysis) to provide information about carnivores and identify barriers to movement as well as potential linkages throughout the North Cascades. Inferred linkages and barriers will permit an informative comparison with the statewide analysis connectivity maps. We anticipate that results from both projects will help enrich our future work.

Acronyms

ALI — Arid Lands Initiative

BCME — BC Ministry of the Environment

BCMW — BC Ministry of Water, Land and Air Protection

BGC — Biogeoclimatic Subzones/Variant

BTM — Baseline Thematic Mapping

CNW — Conservation Northwest

CRP — Conservation Reserve Program

CWD — Cost-weighted Distance (See Glossary)

DNR — Washington Department of Natural Resources

DRA — Digital Road Atlas

EOSD — Earth Observation Sustainable Development

EVT — LANDFIRE Existing Vegetation

GIS — Geographic Information Systems

GOV — Governor’s Executive Policy Office

HCA — habitat concentration area (See Glossary)

IDF — Idaho Fish and Game

IRIS — Initiative for Rural Innovation and Stewardship

KNIL — Kutenai Nature Investigations Ltd.

LCC — least-cost corridor (See Glossary)

LCD — least-cost distance (See Glossary)

LCP — least-cost path (See Glossary)

MOE — Ministry of Environment

MTFW&P — Montana Fish Wildlife & Parks

NCASI — National Council for Air and Stream Improvement

NCLD — National Landcover Database

NED — National Elevation Dataset

NGO — Non Governmental Organization

NLCC — normalized least-cost corridor, (See Glossary)

NVCS — National Vegetation Classification Standard

ODFW — Oregon Department of Fish and Wildlife

SC — Sierra Club

SCW — South Coast Wildlands

SGCN — Species of Greatest Conservation Need

SNODAS — Snow Data Assimilation System

SP — Shrubsteppe Partnership

TNC — The Nature Conservancy

TRIM — Terrain Resource Information Management

UI — University of Idaho

USFS — United States Forest Service

USFS-PNW — United States Forest Service Pacific North West

USFWS — United States Fish and Wildlife Service

UW — University of Washington

VRI — Vegetation Resource Inventory

WDFW — Washington Department of Fish and Wildlife

WF — Wilburforce Foundation

WHCWG — Washington Wildlife Habitat Connectivity Working Group

WHROW — Wildlife-Habitat Relationships in Oregon and Washington

WSDOT — Washington Department of Transportation

WTI — Washington Transportation Institute

WWU — Western Washington University

YNW — Yakama Nation Wildlife

YTC — Yakima Training Center

Glossary

Alienation — Avoidance of an area by wildlife due to factors such as noise, harassment, human activity, etc.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as “gatekeepers” of flow across a landscape (Carroll 2010).

Connectivity (also ***Landscape Connectivity*** or ***Habitat Connectivity***) — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993). Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape integrity.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g. continuous strips of riparian vegetation or transportation routes). In this document, the term “corridor” is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Cost — see ***Resistance***.

Cost-weighted Distance — Each cell in a raster map can be attributed with a relative cost or resistance reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. In our models, resistance is determined by characteristics of each cell, such as land cover, housing density, elevation, etc. Cost-weighted distance analyses produce maps of total movement resistance accumulated as animals move away from specific HCAs or core areas.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Dispersal Habitat — Habitat that is suitable for movement by wildlife; may also include conditions necessary for meeting needs such as food and shelter.

Ecoregion — Area in which climate, topography and soil types are sufficiently uniform to support major vegetation communities with similar characteristics.

Euclidean Distance — Distance between two points as measured on a plane. In our modeling and analyses, Euclidean distances are the straight-line distances between closest points on the edges of neighboring HCAs.

Focal Species — As originally defined by Lambeck (1997), taxa targeted for management through vegetation-restoration efforts because they are the ones most influenced by threatening processes. For example, focal species might be the most area-sensitive, dispersal-limited, resource-limited, and ecological-process limited in a landscape. The concept is to manage a landscape for a suite of focal species, each of which is thought to be sensitive to a particular threatening process (Lindenmayer et al. 2002). We applied this definition to the context of connectivity conservation by highlighting species sensitive to habitat modification and developing selection criteria for focal species that considered how strongly species represented different threat classes, the scale of typical dispersal movements, and the effects of habitat modification on dispersal. We also sought to select a suite of focal species that represented all major vegetation types in the analysis area, and that had complementary characteristics.

Fracture Zone — An area of reduced permeability between HCAs or core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Concentration Area (HCA) — Habitat areas that are expected or known to be important for focal species based on actual survey information or habitat association modeling. We used HCAs as locations between which linkage analyses were conducted to identify important connectivity pathways. Not to be confused with "source habitat" terminology used when modeling population dynamics (i.e., habitat in which local reproductive success exceeds local mortality).

Habitat Connectivity — See ***Connectivity***.

Landscape Connectivity — See ***Connectivity***.

Landscape Integrity — A relative measure of the level of human-caused change on a landscape that combines information on land conversion, human population density, and road use and density. We used landscape integrity-based models to map large, intact core areas and natural linkages between them. Areas that have low levels of human modification and are in relatively natural or semi-natural condition have high relative landscape integrity scores and low resistances in our models.

Landscape Permeability — The opposite of resistance or travel cost; grid cells with lower permeability have higher resistance. A perfectly permeable raster grid cell would have a resistance of 1 in our resistance maps. Also refers to the ability of an entire landscape to support movement of plants, animals, or processes.

Least-cost Corridor (LCC) — A raster map depicting modeled movement routes of varying difficulty that connect two HCAs or core areas. Least-cost corridors are produced by first mapping the cost-weighted distance (CWD) from each HCA to every grid cell. The CWD layers for a pair of HCAs are then added to identify the least-cost corridor (the path between two HCAs or core areas with the lowest possible travel cost; i.e., the easiest or most efficient path). Each grid cell in the resulting map represents the minimum possible cost accumulated by an animal moving from one HCA to the other while passing through that grid cell.

Least-cost Distance (LCD) — The minimum cost-weighted distance an animal can accumulate moving from one HCA or core area to another. This is the total resistance accumulated moving along the least-cost corridor.

Linkage — see Linkage Zone.

Linkage Design — Detailed, site-specific plan meant to conserve connectivity in a linkage zone. Typically identifies a continuous swath of land which should, if conserved, maintain or restore the ability of wildlife and ecological processes to move between HCAs or core areas.

Linkage Dweller — A species that disperses between HCAs over the course of multiple generations by living and reproducing within a linkage zone.

Linkage Mapping Cutoff — Cost-weighted distance value that allows inclusion of all movement paths that are similar, in cost-weighted distance, to the least-cost corridor connecting two HCAs.

Linkage Network — System of habitats and areas important for connecting them. For our project, linkage networks represent the area encompassed by the combination of all habitat concentration areas and modeled linkages for a focal species (or core areas and modeled linkages for landscape integrity models). Composite linkage networks for groups of focal species (e.g., connectivity guilds) can be formed as the union of all species-specific linkage networks. Similarly, for landscape integrity modeling, composite linkage networks can be formed by the union of linkage networks representing different levels of sensitivity to human modification.

Linkage Zone — Area identified as important for maintaining movement opportunities for organisms or ecological processes (e.g., for animals to move to find food, shelter, or access to mates). In our report, these are areas identified by our models as important for movement between HCAs or core areas.

Metapopulation — A group of spatially separated populations of the same species, typically linked by dispersal of individuals from one population to another (Levins 1969).

Movement Corridor *— see Corridor.*

Moving Window — Spatial analysis procedure in which a function (e.g., proportion, sum) is applied to a collection of grid cells neighboring a focus cell in a raster map. The value of the function is written to an output raster at the spatial location of the focus cell. The procedure is typically implemented across all rows and columns of a raster using a circular or square neighborhood centered on each focus cell.

Normalized least-cost corridor (NLCC) — Raster map showing modeled movement routes of varying difficulty connecting two HCAs or core areas. Similar to least-cost corridors, except that all grid cells have scores relative to the best (least-cost) path. NLCCs range in value from 0 (the least-cost corridor) on up; in our linkage maps, NLCCs are displayed according to the relative resistances of routes within each linkage, using a color ramp. The color ramp varies from yellow, representing low resistance routes (routes similar in cumulative resistance to the least-cost corridor), to blue, representing high resistance routes. Note that the color scheme provides an indication of relative cumulative resistance of different movement routes within a linkage, rather than between linkages. That is, yellow is best for that linkage, but yellow in one linkage can't be compared with yellow in another. To compare between linkages, users must refer to linkage statistics in Appendix E.

Permeability — See Landscape Permeability.

Pinch Point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Raster — GIS spatial data structure containing cells arranged in a two-dimensional array or grid with each cell containing a value.

Resistance (also ***Cost***) — Resistance of a raster grid cell represents its suitability for movement, with increasing values corresponding to increasing movement difficulty. A resistance of 1 is equivalent to optimal movement habitat for a species. Conceptually, for focal species, we defined the resistance contributed by each landscape feature as the number of additional grid cells of ideal habitat a given species would move through to avoid one grid cell of the feature being considered. For each landscape feature, we estimated the additional resistance to movement imposed by the feature relative to “ideal” habitat, ranging from zero for ideal habitat to 10,000 for complete barriers. The final resistance layer for each species was then derived by summing the resistances from each input layer and adding one (to account for Euclidean distance). In landscape integrity models, resistance represents the relative reluctance of organisms to move across human-changed landscapes. Higher resistance values represent conditions that result in higher avoidance of human-altered landscapes. Landscape integrity resistance values were scaled and calibrated to the resistance values used in focal species models. Synonyms are cost and friction. Antonym is permeability.

Resistance Surface — A raster grid of resistance values.

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Appendices